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Foreword

The Congress of Carpathian-Balkan Geological Association (CBGA) is one of the older scientific international meetings and became a tradition in the field of geosciences not only in the Carpathian-Balkan region, but also in Europe. It is the first time when the congress takes place in Albania, and it happens to be the XXth jubilee. It takes place in Tirana, from 24th to 26th of September 2014 and is organized in cooperation with the most important and traditional Albanian educational and research institutions: the Polytechnic University of Tirana, the Geological Survey of Albania and the Institute of Geosciences, Water, Energy and Environment.

Research and development are today the most important sources in improving the standards of living, culture and overall wealth of a society. It is equally true that a high economic, social and cultural level is not possible without higher education, based on a sound scientific research.

Regarding geology and related sciences, relatively little has been communicated to the international audience. Albania is famous for its spectacular geology. In particular the Jurassic ophiolites offer complete geological sections and host a wide variety of Cr, Cu and Ni ore deposits. In addition, important oil and gas fields have attracted the interest of various companies that have invested and continue to invest.

The XXth CBGA Congress offers a wide program provoking discussions among colleagues from various fields within geosciences. Bringing together a high number of scientists not only from the CBGA-countries (Albania, Austria, Bosnia and Herzegovina, Bulgaria, Czech R., FYROM, Greece, Hungary, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, Ukraine) but also from other countries, e.g., Algeria, Australia, Cyprus, Egypt, France, Georgia, Kosovo*, Iran, Italy, Canada, China, Croatia, Germany, Luxembourg, Moldava, New Zealand, Norway, Portugal, South Korea Jordan, , Spain, Sweden, Switzerland, Russia, USA, England, Turkey, the congress is an excellent opportunity for presentation of outstanding scientific achievements and for a real exchange between scientists passionate about the world of geology and related sciences.

For this event, the participation of students and young geoscientists was strongly encouraged and many of them are supported by grants covering the registration fee and/or accommodation. In the name of the organizing committee, I would like to thank all our sponsors for their kind support. The companies that have offered their support have received visibility at “CBGA 2014” according to the sponsorship. The sponsors’ names are seen in the panels throughout the conference and in the pre- and post-conference newsletters.

We wish to address thanks to the conveners of the special sessions and to all colleagues who spent their time to review the abstracts included in the Proceeding volumes. We are honored that Adolphe Nicolas, Andreas Lüttge and Minella Shallo, leading scientists in their fields, kindly accepted the invitation to present plenary talks.

Our gratitude goes to all participants who have chosen the CBGA-2014 to present their scientific results and thus to contribute to a high scientific level of this traditional geological event. In total, 470 short and extended abstracts have been accepted, of which 220 will be presented orally and 250 as posters. The abstracts are published in two Abstracts volumes, as special issues of the Albanian journal “Buletini i Shkencave Gjeologjike”. More than 550 participants coming from different countries all over the world have contributed in making this congress an event of high scientific success.

As President of the congress, I wish to express my gratitude to all members of the Organizing Committee, who worked hard and did their best to have a perfectly organized meeting. Special thanks are addressed to the Ministry of Energy and Industry, whose support was a guarantee for a successful organization of this international event in Tirana.

Prof. Arjan Beqiraj

President of the XXth CBGA Congress

"Hidden" Boninitic Magmatism In The Zagros Ophiolites. A Comparison With The Albanide-hellenide Ophiolites

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Abstract

Ophiolites cropping out along the Main Zagros Thrust Zone (MZTZ) mark the suture zone between the Arabian and Sanandaj-Sirjan continental blocks. They represent a portion of the southern Neo-Tethyan oceanic lithosphere, which originally existed between the Arabian (to the south) and Eurasian (to the north) continental margins. Several authors suggested that an intra-oceanic supra-subduction zone setting (SSZ) developed in this ocean during the Late Cretaceous.

SSZ ophiolites from the Albanide-Hellenide belt are characterized by the widespread occurrence of boninitic basalts. In contrast, in the MZTZ ophiolites, these rocks have not been found so far, with the exception of one sample from the Baft area. Nonetheless, the volumetrically most abundant rock-type within the MZTZ ophiolites consists of very depleted mantle harzburgites, which have chemical features that are typical for residual mantle after boninitic-type melt extraction. Therefore, though boninitic lava flows are lacking in the MZTZ ophiolites, the occurrence of boninitic magmatism at a regional scale can be envisaged. The aim of this contribution is therefore to review available data on the Kermanshah and Sarve-Abad ophiolites (SW Iran) in search for evidence for the existence of boninitic magmatism in the southern Neo-Tethys.

The Kermanshah ophiolites are composed of various incomplete sequences formed in different tectonic settings. Among these, the SSZ sequences consist of variably depleted mantle harzburgites and minor depleted mantle lherzolites. Harzburgites show close analogies with similar rocks from the Albanide-Hellenide SSZ ophiolites. They display a significant depletion in incompatible elements and rare earth element (REE), coupled with a marked light (L) REE enrichment with respect to medium (M) REE. REE modeling shows that they may represent a residual mantle after 25-30% removal of boninitic-type melts in an intra-oceanic arc setting. The mineral chemistry of Cr-spinels also supports this conclusion.

The Sarve-Abad ophiolites consist of cumulitic lherzolites bearing minor dunite and chromitite lenses in places. The crystallization order in ultramafic cumulates is: olivine ± Cr spinel + clinopyroxene ± orthopyroxene, which is typical for boninitic melts. The mineral chemistry of Cr-spinel and pyroxenes is compatible with a genesis from a boninitic-type melt. Indeed, the calculated TiO_2 and Al_2O_3 compositions and Mg# in the parental melt that was in equilibrium with chromian spinel and olivine are consistent with boninitic-type compositions. Whole-rock geochemistry of the ultramafic cumulates is characterized by very low incompatible element content and a general enrichment in Th with respect to Ta and Nb. Chondrite-normalized REE patterns show different trends with either $(La/Sm)_N$ <1 and $(Sm/Yb)_N$ <1 or $(La/Sm)_N$ >1 and $(Sm/Yb)_N$ <1 (U-shaped pattern). Both these patterns are compatible with boninitic-type parental melts. Accordingly, REE petrogenetic modeling indicates that the Sarve-Abad ultramafic cumulates may have formed by small degrees (5-15 %) of fractional crystallization from typical boninitic melts.

In conclusion, several lines of evidence indicate that episodes of boninitic magmatism occurred within the southern Neo-Tethys Ocean during the Late Cretaceous. This conclusion poses however more questions that should be solved. The main one concerns the lacking of boninitic lavas or dykes in the MZTZ ophiolites. To this purpose, further investigations should be made. Particularly, structural investigation and a careful comparison with the well-known Albanide-Hellenide ophiolites may be helpful.

Different Rift-drift Tectonics Associated With The Formation Of The Paleo-tethys And Neo-tethys In Iran, As Deduced From Paleozoic And Mesozoic Continental Margin Ophiolites

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Abstract

In Iran, two incomplete ophiolitic sequences, which are classifiable as "Continental Margin Ophiolite" (CMO), record the tectono-magmatic processes that may occur during the rift-drift tectonic phase preceding oceanic basin formation. They are represented by: 1) the Early Carboniferous Misho Mafic Complex (NW Iran), which is associated with the formation of the Paleo-Tethys and 2) the Triassic sequences in the Kermanshah ophiolite (Zagros Belt), which are associated with the formation of the southern Neo-Tethys. Both CMO sequences consist of gabbros, sheeted dykes and basaltic lavas. The Kermanshah CMO also includes exhumed sub-continental mantle lherzolites associated with metagabbros and metadykes. Both sequences include rocks showing variable incompatible element enrichments, ranging from normal (N) MORB to enriched (E) MORB, plume-type (P) MORB and alkaline basalt compositions. Nonetheless, geological and petrological evidence suggest that the continental break-up of the Paleo-Tethys and Neo-Tethys occurred in two quite different ways.

The Misho CMO. Petrogenetic modeling shows that all rock-types have originated from polybaric partial melting starting in the garnet-facies mantle and continuing to much larger degree in the spinel-facies mantle. N-MORBs originated from partial melting of a depleted MORB mantle source (DMM), whereas P-MORBs originated from a DMM source metasomatized by variable proportions of plume-type (OIB-type) geochemical components. The tectono-magmatic evolution of the Misho Mafic Complex indicates that the initial rift-drift tectonics of the Paleo-Tethys was triggered by a mantle plume activity and was strongly affected by plume-related magmatism and associated lithospheric weakening at a regional scale. This conclusion is consistent with the models proposed for the Paleo-Tethys margins in central-eastern Asia. Moreover, regional geological evidence (e.g., regional doming, basaltic plateaux in adjacent areas) further supports the hypothesis of existence of mantle plume activity in this area.

The Kermanshah CMO. Metagabbros and metadykes show N-MORB chemistry with either low or high Sm/Yb ratios. Pillow basalts display geochemical signatures ranging from E-MORB to P-MORB and alkaline basalts. REE petrogenetic modeling show that alkaline basalts were formed by partial melting of an enriched mantle source, whereas E-MORBs and P-MORBs were generated from partial melting of a DMM source metasomatized by variable proportions of OIB-type geochemical components. Partial melting of all rock-types occurred at shallow level (spinel-facies) mantle. The initial rift-drift tectonics of the Neo-Tethys was characterized by a type of rifted margin, which is intermediate between the amagmatic type (Ligurian Tethys type) and the magmatic, plume-influenced type. Indeed, likewise the Ligurian Tethys, rifting occurred through passive (possibly, asymmetric) extension, which led to the exhumation of the sub-continental mantle. Meanwhile, high Sm/Yb rocks formed at the continent-ocean transition zone by partial melting of a DMM source locally bearing sub-continental garnet-pyroxenite relics. However, in contrast with the Ligurian Tethys model, the Neo-Tethys rift stage was also associated with volcanism featuring a marked influence of plume-type components. Nonetheless, no geological evidence supporting the existence of a Triassic mantle plume activity in this area has been documented. Therefore, the plume-type geochemical signature observed in the Kermanshah CMO sequences can likely be explained with the re-activation of portions of enriched mantle (mantle heterogeneities) that were inherited from the Paleozoic mantle plume associated with the opening of Paleo-Tethys.

Ophiolitic magma chamber processes, an Appalachian perspective

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Abstract

Oceanic/ophiolitic magma chambers differ from continental layered mafic-ultramafic intrusions because submarine magmatism is synchronous with extensional tectonism. Because oceanic ridges continuously extend, new magma constantly arrives beneath the ridge axis, where it either ponds at the base of the crust or forms sills where favourable crustal structures such as faults, shear zones, or older sills are encountered. A sheeted sill architecture for the middle and lower oceanic crust is probably common (e.g. Bay of Islands, Annieopsquotch ophiolites). Many monomineralic facies in ophiolites form as reaction rims between newly emplaced primitive magma and host cumulates. Chromitites often form as a result of incongruent dissolution, since many pyroxenes contain levels of Cr_2O_3 above the solubility limit; whereas dissolution of plagioclase commonly forms aluminous Cr-spinels. Rims of anorthosite and pyroxenite form at gabbro dissolution fronts because of pore-scale magma mixing across phase boundaries. When deformation is broadly distributed through the crust (e.g. Bay of Islands ophiolite), rocks experience high-temperature ductile shear at near-solidus temperatures. Although cumulate layering is usually interpreted to have formed by sequential crystallization / accumulation or crystal sorting against a cooling surface or floor, where deformation overprints are strong, much layering is produced by transposition and tectonic repetition of partly-solidified intrusions, hosts and reaction facies. Syn-magmatic deformation also triggers mixing between intra-cumulate intrusions and incompletely consolidated host rocks to create a range of hybrid facies, few of which have cotectic phase proportions. Cumulates affected by penetrative deformation have lower trapped melt fractions (5-10 %) than those unaffected by shear (20-30 %), suggesting that shear pumping efficiently expels pore melt from the deforming matrix. Percolation of primitive to residual melt through a deforming cumulus framework has the potential to mobilize incompatible elements and transform chemical signatures (e.g. Annieopsquotch ophiolite). Cumulates in the Betts Cove ophiolite are not penetratively deformed, and show well-developed size-graded cumulate beds, some with basal load structures, indicating that they formed as gravity deposits. These types of cumulates may form in subsiding, fault-bounded 'trap-door' chambers. The Betts Cove graded harzburgitic cumulate beds are intercalated with bedding-parallel pyroxenite sheets that merge with discordant pyroxenite dykes, suggesting that they are bedding-parallel melt segregation veins. These would have fed residual melt into fault-guided conduits, allowing expelled pore melt to be evacuated efficiently from within the thick pile of compacting cumulates.

The Peri-Arabian ophiolites (Turkey and Syria): Mid-Oceanic Ridge (MOR) and/or Subduction Initiation Rule (SIR) Ophiolites

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Abstract

The Baër-Bassit (Syria), Kızıldağ and Koçali (Turkey) ophiolites are remnants of a late Cretaceous suprasubduction zone (SSZ) oceanic lithosphere and are parts of peri-Arabian ophiolites. All these ophiolites are nearly coeval in age, except that the late Triassic volcanics of the Koçaliophiolite. They comprise harzburgitic mantle peridotites, ultramafic to mafic cumulates, isotropic gabbros, sheeted dike complex, plagiogranite, isolated dikes and volcanic rocks. The depleted nature of mantle peridotites (generally harzburgite and minordunite), the geochemistry of gabbros, dikes and late Cretaceous extrusive rocks, as well as the presence of boninites indicate abnormally high temperature and volatile flux melting beneath a forearc tectonic setting. The late Triassic volcanics of the Koçaliophiolites represent the oceanic crust that was trapped when subduction began.

Keywords: *peri-Arabian, BaërBassit, Kızıldağ, Koçali, ophiolite*

Introduction

Ophiolites are relicts of oceanic lithosphere that have been tectonically emplaced on land. They are important markers of convergent margin processes. The origin and tectonic evolution of ophiolites provides important constraints on the evolution of orogenic belts. Ophiolites form in a variety of plate tectonic setting, however, the most of the more extensive ophiolites apparently formed above a subduction zone, a tectonic setting known as a supra-subduction zone setting (Pearce et al. 1984). The peri-Arabian region from Cyprus in the West, eastward through northwest Syria, southeast Turkey, northeast Iraq, southwest Iran marks a long convergent margin, which formed during the Late Cretaceous (Shafaii Moghadam et al. 2010). This convergent margin is marked by many ophiolitic massifs. The peri-Arabian ophiolites (Le croissant ophiolitique péri-arabe of Ricou 1971) in northwest Syria (Baër-Bassit) and southeast Turkey (Kızıldağ and Koçali) defines the western part of the peri-Arabian convergent margin.

The aim of this research is to present new geochemical data from the Koçaliophiolite and compare them to those available from Kızıldağ and Baër-Bassit ophiolites. We then present a petrogenetic and geodynamic model.

Geological setting

The Peri-Arabian ophiolites including Baër-Bassit, Kızıldağ, Koçali and other ophiolites, lie along the Bitlis-Zagros zone and were emplaced southwards onto the Arabian Platform and are overlain by upper Maastrichtian-Tertiary sedimentary sequence (Fig. 1). The Baër-Bassit ophiolite contains a metamorphic sole consisting of amphibolite and greenschist rocks between the ophiolite and Arabian Platform carbonates (Parrot 1980; Al-Riyami et al. 2002). Unlike Baër-Bassit and Kızıldağ ophiolites, the Koçali ophiolite is underlain by the Karadut Complex consisting of well-developped lithological divisions ranging from upper Triassic to upper Cretaceous (Fourcade et al. 1991), which is emplaced onto the Arabian platform. The Arabian Platform comprises Palaeozoic clastics to limestones and overlying Triassic to Cretaceous platform-type carbonates (Yılmaz 1993; Al-Riyami et al. 2002). Cover units consist of sedimentary units ranging from Upper Maastrichtian to lower Miocene. The Koçali and Baër-Bassit ophiolites are disrupted by tectonic movements, but generalized lithospheric columns can be reconstructed based on field observations (Fig. 2). All these ophiolites are nearly coeval in age. The age of these ophiolites is generally ~90 Ma (Beyarslan et al. 2009; Dilek and Thy 2009; Karaoğlan et al. 2013). But, according to the age data obtained by radiolarian faunas from the sedimentary rocks in the volcanic successions of the Koçali ophiolite, there are two agefor volcanic rocks: 1) late Triassic and b) late Cretaceous (Uzunçimen et al. 2011).

The peri-Arabian ophiolites are composed of mantle peridotites and crustal sequence. Mantle peridotites consist mainly of serpentinized harzburgite with local bands and lenses of dunite. Dunite and chromite pods and lenses become more common in the upper part of the mantle sequence. Pegmatitic pyroxenite and gabbro locally intrude mantle peridotites.

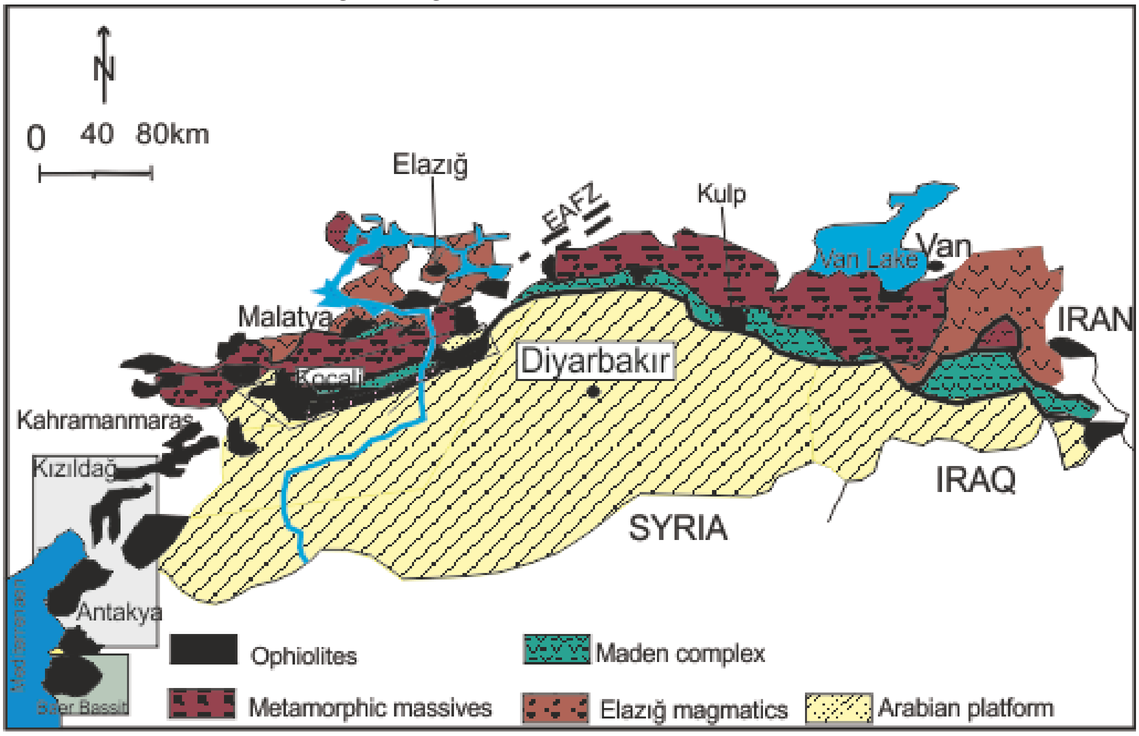

Figure 1. Map showing the distribution of the peri-Arabian ophiolites in Turkey and Syria

The crustal sequences of these ophiolites vary in thickness and lithology but are substantially similar (Fig. 2). They consist of layered and isotropic gabbro, sheeted dykes, localized high level plagiogranite, pillowed basic volcanics. The Kızıldağ ophiolite contains a thick ultramafic cumulate level overlying the mantle harzburgite, while these ultramafic cumulates are only locally preserved in the Baër-Bassit and Koçali ophiolites. The Koçali ophiolites contain also lapillistone, tuff, micritic limestone and volcaniclastic rocks at the top of the basaltic pillow and massive lava flows as an upper lava sequence.

Geochemistry

Our data came from the studies that we have done since 1990's (Bingöl 1991; Bingöl et al. 1997; Beyarslan and Bingöl 2000; Beyarslan et al. 2009), as well as from different workers (Al-Riyami et al. 2002; Dilek and Thy 2009; Varol et al. 2011).

Owing to the potential mobility of some elements during alteration, the interpretation of the analyses is generally based on the immobile elements and REE. The mantle harzburgite show the highest Cr# in spinels and the lowest proportion of cpx and whole rocks abundances of CaO and Al_2O_3, as well as very low PGE abundances. These data indicate high degree of partial melting. Except the Late Triassic volcanics of the Koçali ophiolite, the gabbros and volcanics of all these ophiolites display the same geochemical characteristics. The SiO_2 content of the relatively unaltered basaltic pillow and massive lava flows is systematically high (> 51 wt.%) compared to oceanic basalts. The Late Triassic volcanics are as rich TiO_2, as in typical MORB, which often contains > 1.4 wt.%, the Upper Cretaceous volcanics are not as rich in TiO_2 as is typical MORB.

According to the Al-Riyami et al. (2002) and Dilek and Thy (2009), there are some boninitic lavas at the high levels of the extrusive sequences of Baër-Bassit and Kızıldağ ophiolites. Boninites are lavas with high silica and magnesium coupled with low aluminium and titanium abundances. These compositional features reflect low-pressure melting of harzburgitic mantle (Fallon and Danyushevsky 2000). Boninites are enriched

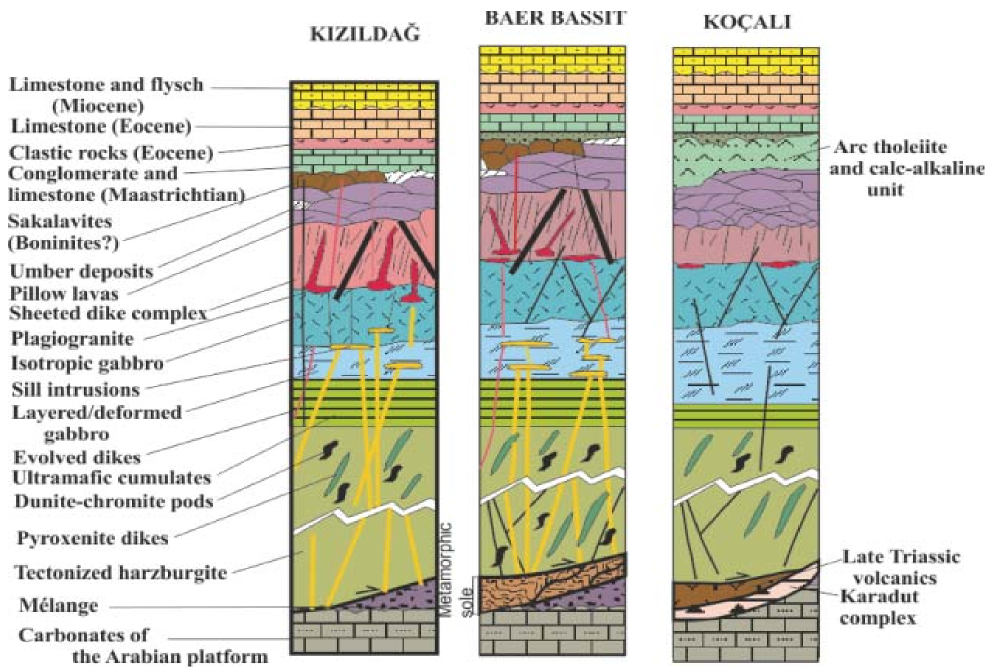

Figure 2. Composite stratigraphic columnar sections of BaërBassit, Kızıldağ and Koçaliophiolites. (Kızıldağ and BaërBassit from Dilek and Thy 2009)

in LILEs and high LREEs relative to HFSEs. Most of the Upper Cretaceous extrusive rocks of peri-Arabian ophiolites display generally flat REE patterns, although some of these rocks show LREE depletions. The upper lavas of the Koçaliophioliteshows an arc tholeiitic and calc-alkaline character. According to Stern et al. (2012), distinguishing compositions of MORB-like lavas include > 1 wt.% TiO_2, variable depletion in LREE, absence of HFSEs (e.g., Nb, Ta), depletion of spider (primitive mantle- or N-MORB-normalized) diagrams. Therefore, the Upper Cretaceous lavas are seen as a fore-arc basalts, whereas the geochemical characteristics of the Late Triassic extrusive rocks indicate a MOR setting (Bingöl and Beyarslan 2013). The geochemical characteristics of the upper lava unit of the Koçali ophiolites indicate an oceanic island arc.

Conclusion

The Baër-Bassit (Syria), Kızıldağ and Koçali (Turkey) are coeval in age and show a similar pseudo-stratigraphy. The data indicate that the peri-Arabian ophiolites include mantle and crustal sections whose geochemical characteristics can be referred to apparently contrasting tectonic settings. The most depleted ultramafic rocks indicate a forearc tectonic setting (Stern et al. 2012). The depleted nature of forearcperidotites requires unusual melting conditions: abnormally high temperature, volatile flux, or a combination of both (Stern et al. 2012). Based on the geological and geochemical data, the Late Triassic extrusive rocks display high-Ti geochemical affinity and represent a crustal portion generated in a MOR spreading center. By contrast, the late Cretaceous extrusive rocks and gabbros show low-Ti affinities and are interpreted as generated in a SSZ setting. The timing of these magmatic events indicates a general progressive evolution from MORB to SSZ magmatism. The geochemical characters of the Late Cretaceous extrusives rocks and the presence of boninites in the Baër-Bassit and Kızıldağ ophiolites suggest that the peri-Arabian ophiolites were formed in a nascent subduction zone setting. This type of ophiolites are called as “subduction initiation rule” ophiolites by (Whattam and Stern 2011; Stern et al. 2012). The arc tholeiite and calc-alkaline rocks of the Koçali ophiolite were formed in an oceanic arc developed on the oceanic crust formed by subduction processes.

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Age And Geochemistry Of Basalt-chert Associations In The Ophiolitic Complexes Of The Izmir-ankara Mélange (East Of Ankara, Turkey)

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Abstract

In this work, we present the preliminary age data of the radiolarian cherts deposited on the top of basalts related to the Eastern Ankara Mélange (part of the Izmir-Ankara Mélange). Petrological studies on basalts were carried out in order to constrain the tectonic setting of formation of the studied basalt-chert sequences.

Nine sections were sampled to the East of Ankara and twenty seven samples were collected for biostratigraphic and geochemical analyses.

The oldest radiolarian cherts documented in this work show Late Triassic age (Section 6: late Norian) and are associated with basaltic rocks with OIB character. OIB type volcanic rocks are also found in other sections and are associated with cherts of Late Jurassic (Section 3: middle-late Oxfordian to late Kimmeridgian-early Tithonian) and Early Cretaceous (Section 1: late Valanginian to latest Valanginian-earliest Hauterivian) ages.

E-MORB type rocks are associated with radiolarian cherts of Cretaceous age (Section 4: late Barremian and Section 7: Valanginian to middle Aptian-early Albian), whereas the oldest N-MORBs were found in a section of Late Jurassic age (Section 5: early-early late Tithonian). Other N-MORBs are associated with radiolarian cherts of Early Cretaceous age (Section 8: late Valanginian-early Barremian). P-MORBs type rocks were found only in a section of Middle Jurassic age (Section 2: early-middle Bajocian to late Bathonian-early Callovian age).

In this work, we document the occurrence of OIB-type rocks of Late Triassic, as well as of rocks showing different geochemical affinities (N-, E-, P-MORBs and OIB) generated during the Middle-Late Jurassic - Early Cretaceous time span. N-MORBs are compatible with composition of melts generated by partial melting of a depleted MORB mantle source. In contrast, OIBs are compatible with partial melting of enriched-type mantle source. E-MORBs may have derived from mantle source slightly enriched with respect to DMM source, whereas P-MORBs are compatible with melts generated from a mantle source significantly enriched, compared to DMM. The chemical differences shown by the distinct rock-types can be related either to differences in source composition or different tectonic settings of formation, which may have existed during the Late Jurassic - Early Cretaceous time span.

New evidence for the one-ocean model for the Balkan ophiolites: the origin and age of the metamorphic sole from the Rogozna Mts., Western Vardar Belt

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Abstract

We present new geochronological and petrochemical data from the metamorphic sole beneath the Rogozna Mts., Western Vardar ophiolite belt. The Rogozna Mts. metamorphic sole is attached to the base of the serpentinite thrust-sheet, containing MORB-type Cr-Al spinel. The sole consists of lenses of high-grade rocks at the serpentinite base, proceeding downward to medium-grade rocks of N-MORB to BAB and OIB affinity. High grade rocks are garnet-bearing metamorphic series of sedimentary precursor (andalusite–garnet–sillimanite gneisses, cordierite-bearing hornfels), grading downward to a medium-grade metamorphics of igneous precursor (gabbro amphibolites and pyroxene-amphibolites, plagioclase-amphibolites and amphibole-schists). Medium grade rocks are overprinted by a low-grade assemblage composed of (i) actinolite, epidote, clinozoisite, chlorite, sericite, or (ii) talc and chlorite, whereas high grade rocks suffered extensive listwaenitization.

The object of this study is amphibolite and various overprint assemblage. The Rogozna amphibolites are medium to fine-grained rocks with nematoblastic texture and pronounced foliation. They consist of green amphibole (~70 vol.%) with variable silica content (6.4 to 7.8 Si apfu), as well as Mg# (molar Mg/[Mg+Fe_{tot}]; 0.53 to 0.77) and variably albitized plagioclase (~30 vol.%; Ab_{24}–Ab_{98}). The amphibolites formed due to metamorphism of two basaltic suites: subalkaline/tholeiitic and alkaline. Subalkaline/tholeiitic amphibolites possess low Zr, Nb, Y, Th, Hf, TiO_2 and P_2O_5 values and a LREE-depleted pattern, typical for the N-MORB (normal mid ocean ridge basalt) to BAB (back-arc basalt) origin. Alkaline amphibolites show elevated concentrations of Zr, Nb, Y, Th, Hf, TiO_2 and P_2O_5 with a LREE-enriched pattern typically displayed by OIB (ocean island basalt). Amphibolites crystallized during intra-oceanic thrusting at temperatures between 685ºC-765ºC and at a depth of 12–17 km. Since $^{40}Ar/^{39}Ar$ cooling ages of magnesio hornblende, ranging from 164.9 ± 1.3 and 170.0 ± 1.4 Ma, and retrograde actinolite (169.7 ± 3.3 Ma) are in the same range, we can conclude that the cooling, which postdates the formation of the metamorphic sole, occurred rapidly.

The obtained Middle Jurassic age of the Rogozna Mts. metamorphic sole brings new light into the geodynamic interpretation of the Western Vardar ophiolite belt. During the past several decades only metamorphic soles from the north-western most Dinaric ophiolite belt and its extension to Hellenides have been studied radiometrically. Middle to Late Jurassic cooling ages are obtained from these soles outcropping along a 1000 km distance pointed to the age of the initial convergence and to the onset of the closure of the ocean existing between the African and Eurasian continental plates. The most important implication of this study is that there is no age difference between the Western Vardar and Dinaric ophiolite belts, and that two belts most likely share the same Middle Jurassic closing history and, therefore, we consider them to have originated from the same, single oceanic domain, namely the Vardar-Meliata Ocean.

Unraveling Protolith Ages Of Meta-gabbros From Samos And The Attic-cycladic Crystalline Belt, Greece: Results Of A U–pb Zircon And Sr–nd Whole Rock Study

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Abstract

The focus of this study is on meta-ophiolitic rocks from Samos and the Attic-Cycladic Crystalline belt, Greece. The Aegean islands are of special interest for in-depth understanding of the geodynamic history of the larger region because they represent the geographic link between the major ophiolite domains of the Eastern Mediterranean. For some of the Aegean occurrences either Jurassic (e.g. Crete, Andros) or Cretaceous (e.g. Syros, Tinos, Karpathos, Rhodos) protolith ages have been reported, but the general picture remains fragmentary, due to the scarcity of isotopic age data for such rocks.

SHRIMP U–Pb zircon geochronology, Sr–Nd isotope and bulk-rock geochemistry have been applied to meta-gabbros that occur as blocks and lenses (up to several hundred meters in size) in blueschist-facies mélanges on Samos and Evia, and in the greenschist-facies Upper Unit on Tinos. The geodynamic significance of these meta-ophiolite fragments within the overall pattern of the Eastern Mediterranean region is unclear. Regional correlations within the Cyclades archipelago and with the Jurassic meta-ophiolites of the Balkan region or the Cretaceous occurrences in Turkey are uncertain. Although field, petrological and geochemical similarities of some mélange occurrences suggest a common genetic relationship, such interpretations remain speculative if not supported by robust geochronological data.

SHRIMP U–Pb zircon dating of three meta-gabbro blocks from Samos yielded Cretaceous ages with weighted mean $^{206}Pb/^{238}U$ ages of 78.3 ± 1.3 Ma, 76.8 ± 1.4 Ma and 77.8 ± 1.4 Ma and almost identical intercept ages. Conclusive evidence linking zircon formation to regional metamorphic processes or the former existence of baddeleyite is not available. It is thus reasonable to conclude that the Cretaceous U–Pb zircon ages constrain the time of magmatic crystallization. This interpretation further substantiates models suggesting a correlative relationship with mélanges on the islands of Syros and Tinos, central Aegean Sea, where similar rocks yielded almost identical U–Pb zircon data.

Meta-gabbros from Evia and the Upper Unit of Tinos do not contain zircon. For these rocks a combination of bulk-rock Sr–Nd isotope and REE data was used in an attempt to unravel possible genetic affinities with dated occurrences. Published and new Sr–Nd isotope data of meta-gabbros from Andros, Samos, Tinos (Lower Unit) and from mainland Greece (Pindos, Othris) reveal distinctive differences among ion probe-dated samples with Jurassic and Cretaceous protolith ages. Three groups can clearly be distinguished in a $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ diagram. However, these geochemical parameters do not allow assigning tentative age estimates for yet undated meta-gabbros from southern Evia and the Upper Unit of Tinos. The situation is further complicated by the observation that the Jurassic and Cretaceous meta-gabbros do not show other discriminating geochemical characteristics that could provide plausible arguments for an approximate age assignment to undated rocks. The formation ages of the meta-gabbros from Evia and the Upper Unit of Tinos remain unresolved.

Magnetism in ultrabasic rocks and paleomagnetic data on Albanian ophiolites

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Abstract

Characteristics of the magnetization of ophiolites are presented in this paper, with particular regard to paleomagnetic investigation in Albania. In Albania, ophiolites extend from south to north along the Mirdita Tectonic Zone. Ultramafic formations represent important parts of the ophiolitic belt, though the Mirdita Tectonic zone is also characterized by different gabbros massifs, volcanic basalts and keratophyre. Integrated petrophysical investigation of the ophiolites was performed. In addition, investigation about rock magnetism was conducted for the outcrops and rock samples in six key profiles. Moreover, space orientation of the vector of the magnetic magnetization was determined. Magnetism of the ophiolites is conditioned by the presence of the ferromagnetic accessory minerals, mainly by secondary magnetite, and by the chemical and mineralogical transformations of the rocks during serpentinization, by the redistribution of mechanical stresses, as well as during the process of the dynamometamorphism and tectonic activity. Orientations of the remnant magnetization vector of the ophiolite rocks were a means to address information about formation conditions and successive changes over time.

Keywords: *Magnetization, paleomagnetism, magnetic susceptibility, remnant magnetization*

Introduction

The main features of the ophiolite magnetization in the Albanian ophiolites are reported in this paper, with particular regard to paleomagnetic studies.

Albania is rich in mineral resources, such as chrome, copper, and other ore deposits and has a long history in the field of their exploration, which is based upon integrated geological, geophysical and geochemical ground and underground surveys. These ore minerals are particularly found in ophiolites. The geophysical study consists of gravity, magnetic and IP surface mapping at different scales, and the electro-magnetic underground survey, gravitational and magnetic regional mapping at different scales and petrophysical studies, including density, magnetism, electrical resistivity, induced chargeability, and radioactivity of ores and rock formations. Geophysical information on boreholes has been obtained via well logging, which involved electric, electro-magnetic, gamma, gamma-gamma, and magnetic surveys.

Materials and methods

Investigation of rock magnetism was based on measurements of the magnetic susceptibility in outcrops together with determination of induced and remnant magnetization in samples collected in rocks of different formations throughout the Albanide ophiolite massifs. The present analysis is based on paleomagnetic studies carried out by Frashëri and Bushati in 1995, when samples were taken from ultrabasic rocks, gabbros and volcanic rocks of the Mirdita tectonic zone. In their study, space orientation of the magnetization vector was determined. In addition, for analyzing the magnetic field from AC electric current, the samples were submitted to the thermal cleaning and demagnetization. Sampling sites includ six key profiles on ophiolitic massives from south to north Albania.

Results

Ophiolites of the Mirdita tectonic zone are represented by two ultramafic massif belts. The eastern ultramafic belt consists (from bottom to top) of two different sequences: i) mantle tectonitic sequence; ii) cumulate sequence. The lower part of tectonitic sequence comprises harzburgite containing dunitic alternation, which consists of fresh rocks from the lower levels to medium serpentinized rocks in upper levels. Dunites occur as lenses of up to some meters thick stretching over hundreds of meters. Dunite with rare alternations of harzburgite and lherzolite predominates within the cumulate sequence.

Conditioned by the presence of ferromagnetic accessory minerals (mainly secondary magnetite and minor amagnetized accessory Cr-spinel), the magnetism in ultrabasic rocks is variable (Table 1, Fig. 1, photo 1). The fresh dunites and harzburgites of the tectonitic sequence do not exhibit magnetic properties (Table 1). With an average value of 2.3 and 1.9 for dunites and harzburgites, respectively, the ratio $Q_n = I_r / I_i > 1$ accounts for approximately

48% of the cases. Therefore, the impact of the thermal nature of the remnant magnetization is clear. Magnetism, especially natural remnant magnetization, increases as the activity of cataclasis increases. As the serpentinization process increases, dunites and harzburgites magnetization (in particular the remnant magnetization) increases, due to the increase in secondary magnetization is conditioned by the content of ferromagnetic mineral accessories. Basalt individualization with the remnant magnetization I_r=117.803 A/m have been encountered in south-east Albania. Gabbros from different massifs show different magnetizations. The Kurbneshi massif (northeast Albania) is characterized by gabbros with a low level of magnetization (on

Table 1. The magnetic properties of Cr-spinel ore and ultrabasic rocks (Frashëri 2008).
* Samples quantity of I_i measurement;
** Samples quantity of I_r measurement

Kind of ore or rock	Quantity of samples	Induced magnetization I_i, *10-5 units (SI)			Remnant magnetization I_r, *10-5 units (SI)			Qn=Ir/Ii		
		Min.	*Max.*	*Mode*	*Min.*	*Max.*	*Mode*	*Min/Max*	*Aver.*	*% of samp with Qn>1*
Dunite	85* 32**	0	700	10±10 50±30 200±80	10	1800	300±70	1.2/5	2.3	0.5
Serpentinized dunite	20	38	1000	350						
Harzburgite	109*56*	0	700	15±15 300±100	20	1000	300±100	1.2/13.8	1.9	0.3
Serpentinized harzburgites	87*14**	40	1000	300	20	1300	350±150	1.0/2.4	1.77	0.6
Serpentinites from dunites	82	0	3700	150±70	5	70000	300±90	1.0/31.0	1.8	0.6
Serpentinite from harzbur-gites	68	0	1100	250±50	5	9500	150±60	1.0/23.0	2.1	0.5
Pyroxenites	102	10	720	350±60	10	71000	150±90	1.0/114	4.0	0.7
Gabbro pegmatites	21	0	270	50	170	250		1.2/4.5	1.3	

magnetite and thermoremnant magnetization. Depending on the degree of serpentization, serpentine magnetism values are from unmagnetic to strongly magnetic (Table 1). In addition, the amount of serpentine in rocks does not always determine the quality of secondary magnetite. Consequently, ultrabasic rocks can be classified into: i) non-magnetic, ii) weakly magnetic, and iii) strongly magnetic rocks. These great changes in remnant magnetization, induced magnetization and Q_n ratio for Cr-spinel ores, ultrabasic rocks, in general, and for serpentinites in particular, occur due to secondary magnetite, chemical and mineralogical transformations of the rocks during serpentinization, and redistribution of mechanical stresses. The effect of dislocations is observed under the action of mechanical stresses during the serpentinization, dynamic metamorphism and tectonic process.

Pyroxenite magnetism exhibits quite high differences. However, most of the pyroxenite is weakly magnetic. (Table 1). The ratio Q_n has an average value of 4.0, but some samples extend to 114. Here, we have thermal remnant magnetization, due to the magnetic field of earth and surrounding rocks. Even though magnetic susceptibility is higher, up to 102,500 x 10^{-6} SI units, volcanic basalts and keratophyres in the northern massifs of the Mirdita have a remnant magnetization varying between 0.061 and 3.716 A/m. Their average I_r=0.007 A/m) and magnetic susceptibility 535.10^{-6}SI units. Gabbros from the Qafzezi village (southeast Albania) show comparatively stronger magnetization: I_r=52.825 A/m.

Results of stereographic projections of the remnant magnetization vector show that in parallel with common orientations nearby samples are observed with positive and inverse negative orientation. Such a phenomenon helps addressing the superposition of isothermal and chemical and thermal magnetization on remnant thermal magnetization.

Figure 2 depicts massifs preserving the approximate orientation of the remnant magnetization vectors, regardless of differences in ophiolite magnetization. The predominant orientation of the remnant magnetization vector has an azimuth of D=284° for pillow lavas, and D=297° for volcanic basalts in the central part of Mirdita zone. Azimuth D=267° of the magnetization vector have gabbros of Kurbneshi massif in this area.

In contrast with volcanic rocks and gabbros of the central Mirdita zone, harzburgites show a large dispersion of the azimuth of magnetization vectors as seen in the Bulqiza ultrabasic massif, were D=60°–300° (Fig. 2), as well as preserve the positive sense of the vectors. Such a variability of the azimuth of the magnetization direction vectors

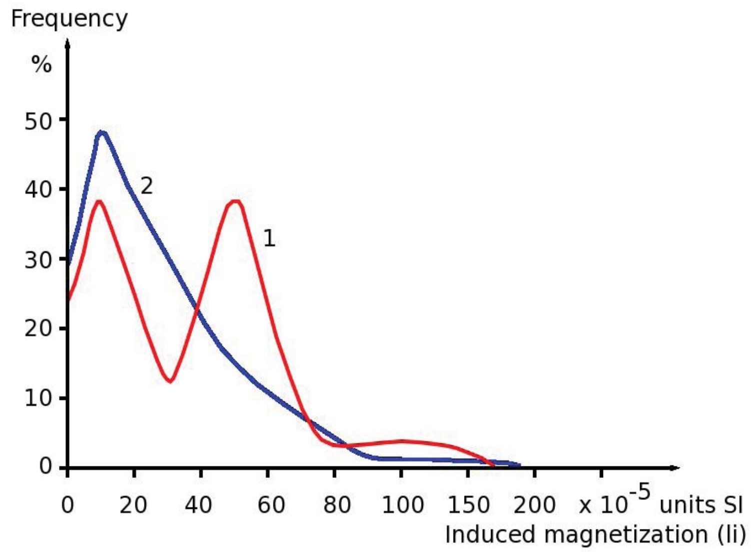

Figure 1.
The variation curves of induced (I_i) magnetization of the dunites (1) and harzburgites (2), Ragami deposit, Tropoja Massif (Frashëri et al. 2008).

Photo 1.
Serpentinite from dunite, with fissures of different ages, chrysotile-asbestos and magnetite, Kam deposits. Magnetic susceptibility $\chi > 3000 \times 10^{-5}$ units SI. Thin section, enlargement 35x, Plane polarized light (Frashëri et al. 2008).

is conditioned by the serpentinization process of the ultrabasic rocks, even in presence of low degrees of serpentinization. In the northeastern edge of the ophiolitic belt of Albanides, in the Komani area, the volcanic rocks have a clockwise rotation, analogous with the external Albanides (Fig. 2). The magnetization orientation of the gabbros in the massif of Qafzez in southeast Albania has a useful magnetic signal after cleaning and demagnization, represented by a vector of I_2=60.9° and azimuth D_2=282°. This direction is approximate with the orientation of the magnetism vector of the gabbros massif in Chalkidiki, Greece, D_2=312° and I=68°. The ophiolitic belt of the Chalkidiki underwent two tectonic phases: i) a counter clockwise rotation during the later Jurassic–lower Cretaceous, and ii) a clockwise rotation during the Tertiary (Edel et al. 1991).

Conclusions

A number of conclusions can be drawn from the present study. (1) The magnetism of serpentinites changes within wide limits, although usually magnetic sometimes they are strongly magnetic. (2) Magnetism of ophiolites is conditioned by the presence of ferromagnetic mineral accessories, mainly by secondary magnetite, chemical and mineralogical transformations of the rocks during serpentinization, and redistribution of mechanical stresses, during the dynamic metamorphism and tectonic process. (3) Results of stereographic projections of the remnant magnetization vector show that together with common orientations nearby samples are observed with positive and inverse negative orientation. Such a phenomenon

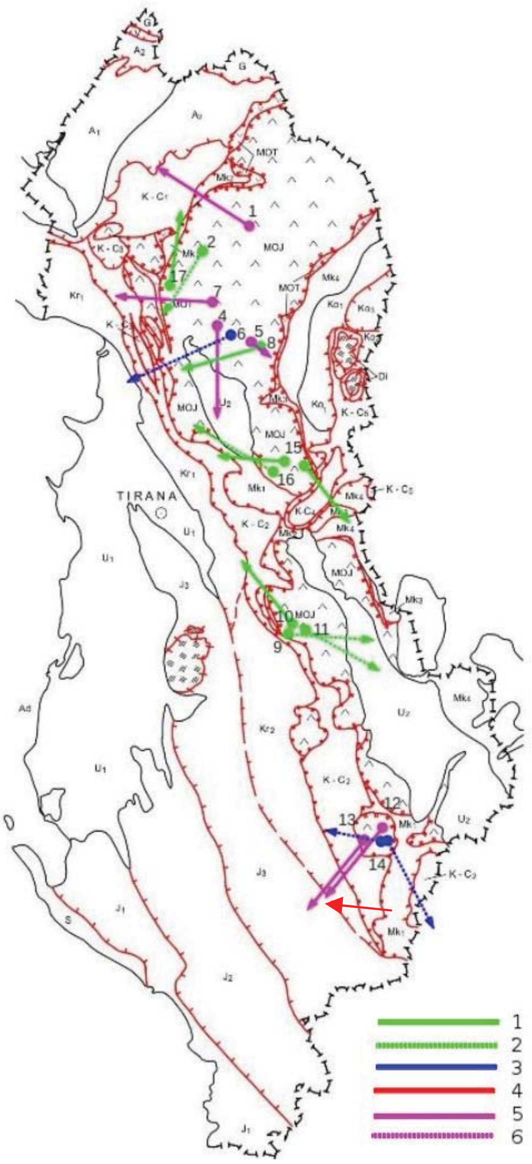

Figure 2. Declination of the magnetization vectors of the ophiolite belt in the Mirdita tectonic zone of the Albanides.

Tectonic zones:
Internal Albanides:
M- Mirdita zone
G- Gashi zone
Ko- Korabi zone

External Albanides:
A- Albanian Alps
K-C- Krasta-Cukali zone
Kr- Kruja zone
J- Ionian zone
S-Sazani zone
U- PeriAdriatic Depression

Magnetic declinations:
1- J > 0 Ultrabasic rocks
2- J < 0 Ultrabasic rocks
3- J < 0 Gabbro
4- J > 0 Gabbro, remnant magnetization after demagnetization
5- J > 0 Volcanic rocks
6- J < 0 Volcanic rocks

helps addressing the superposition of isothermal and chemical and thermal magnetization on remnant thermal magnetization. (4) Approximate orientation of the remnant magnetization vectors, regardless of differences in ophiolite magnetization. Here, studies on orientation of the remnant magnetization vector of the ores and the surrounding rocks are a means to address formation conditions and changes over time.

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Origin Of The Sheeted Dykes From The Kızıldağ (Hatay) Ophiolite, Turkey

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Abstract

The Kızıldağ ophiolite in the Eastern Mediterranean region (Fig. 1) is characterized by a complete oceanic lithospheric remnants of the Southern Neotethys. A well-preserved ophiolite pseudostratigraphy and the lack of evidence for any significant emplacement-related tectonic deformation in the Kızıldağ ophiolite suggest that it did not experience any large-scale tectonic transport from its original igneous environment (Robertson 1986; Dilek and Delaloye 1992; Dilek and Thy 1998). Therefore, the Kızıldağ ophiolite is one of the best examples in which to observe structural evidence of sea-floor spreading tectonics and structural processes. It displays a complete ophiolite assemblage that comprises, from bottom to top, depleted mantle tectonites, ultramafic to mafic cumulates, isotropic gabbro, sheeted dykes, plagiogranites and a volcanic complex (Selçuk 1981). The Kızıldağ (Hatay) ophiolite formed in a suprasubduction zone setting during late Cretaceous (Bağcı et al. 2005, 2008; Dilek and Thy 2009; Karaoğlan et al. 2013a,b).

Keywords: *Kızıldağ, ophiolite, sheeted dyke, chilled margin, geochemistry*

Detailed field and laboratory studies were carried out on the sheeted dyke complex along Mediterranean coastline in Çevlik-Samandağ (Hatay) region. Twelve stations were defined in order to better understand internal structure, cross-cutting relations and geochemical groups of sheeted dykes that are interpreted as evidence of sea-floor spreading. Individual dykes in the sheeted dyke complex range in thickness from 0.5 cm to 100 cm and includes number of gabbroic screens. The orientations of the sheeted dykes in

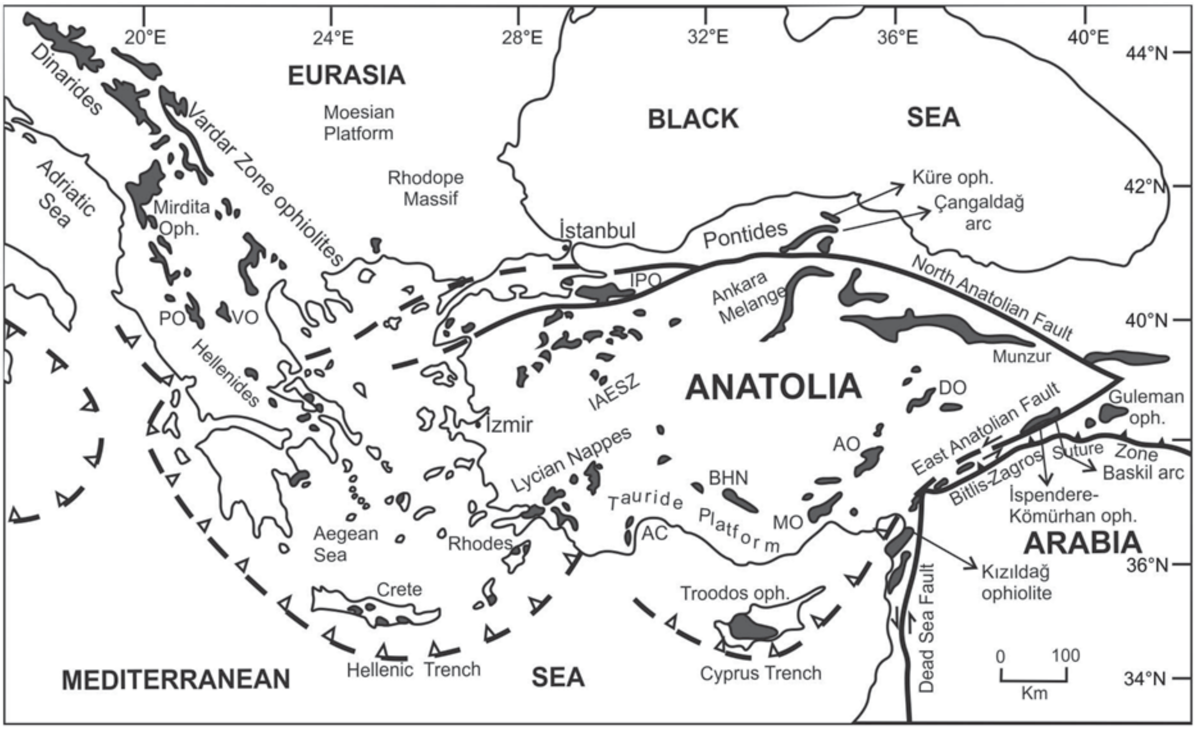

Figure 1. Distribution of the Neotethyan ophiolites in the eastern Mediterranean region (from Robertson, 2002).

first eight stations are generally N75-85W/60-75NE and locally N85E/75NW. For the last four stations they display N69-77W/78SW and N35-60E/65-80SE due to local neotectonic effects. The dykes are petrographically represented by diabase, microdiorite and quartz microdiorite whereas the gabbroic screens are represented by gabbro and diorite. At least three different dyke generations are observed on the basis of the cross-cutting relations (Fig. 2).

The geochemistry of dykes suggests that they were derived from a tholeiitic magma. Four different geochemical groups were defined based on their TiO_2 (0.26 to 1.23 wt.%) and Zr (16 to 49 ppm) contents (Fig. 3). Chilling margin statistics in the sheeted dykes show mainly north-directed chilled margins althought south-directed and

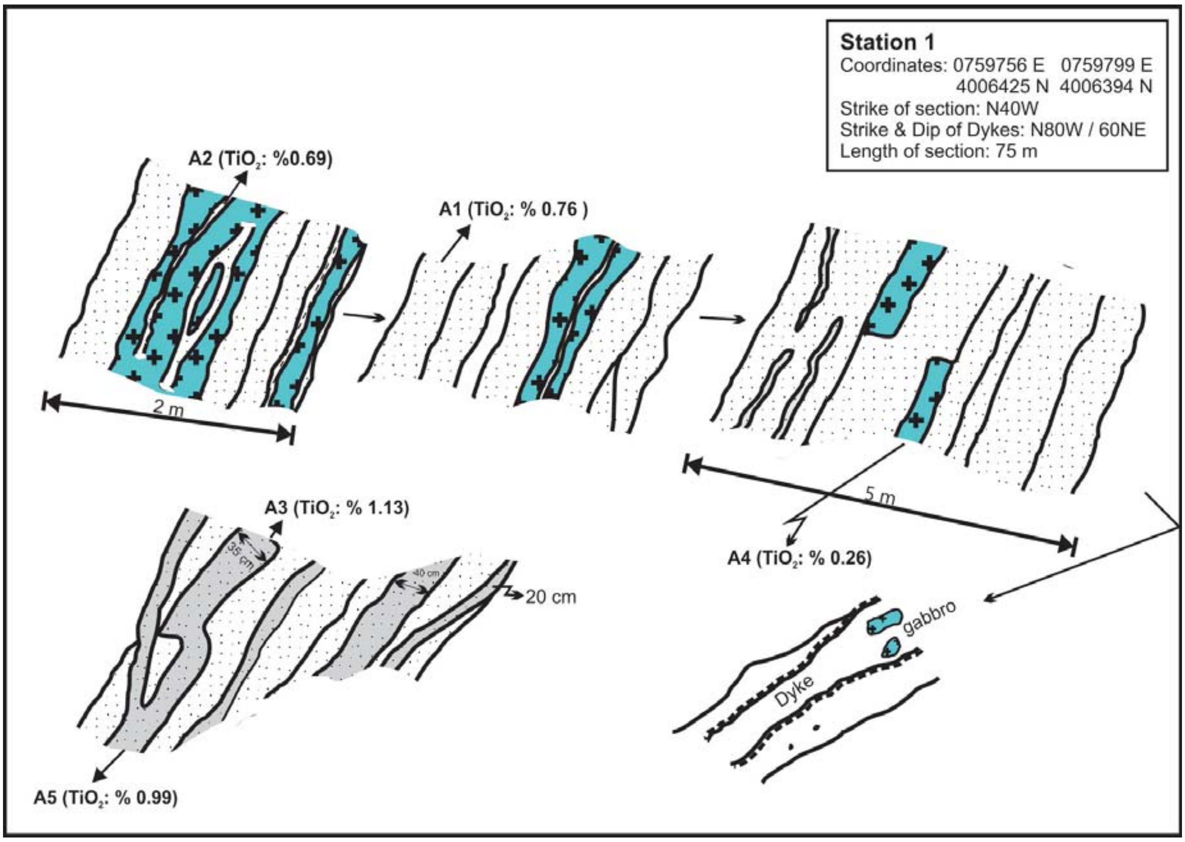

Figure 2. Representative sketch for the field relations of underlying isotropic gabbro and sheeted dykes.

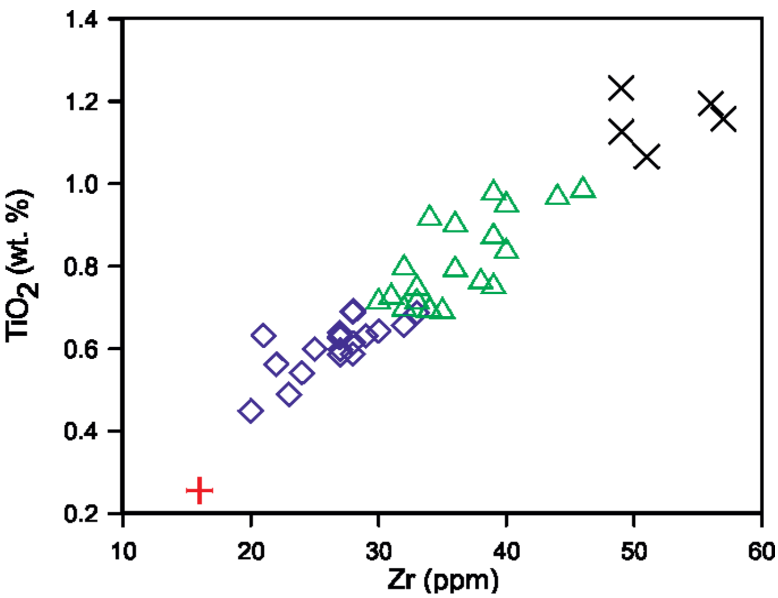

Figure 3. Zr vs TiO_2 diagram showing distinct dyke generations in the sheeted dykes of the Kızıldağ (Hatay) ophiolite.

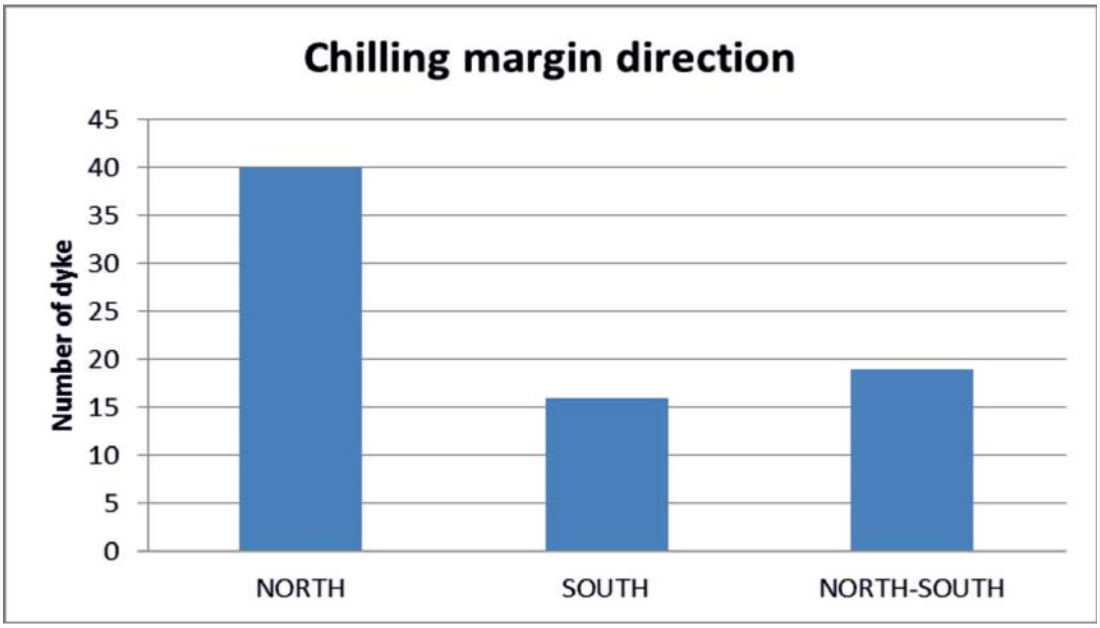

Figure 4. Chilling margin directions of the dykes studied in the Kızıldağ (Hatay) ophiolites.

Figure 5. (a) relations of sheeted dykes and the underlying gabbro, (b) well-developed sheeted dykes, (c) gabbro screens in sheeted dykes and (d) well-developed chilling margins of a dyke in sheeted dykes.

north/south-directed chilled margins are also seen (Figs. 4 and 5). This may suggest that the Kızıldağ (Hatay) ophiolite was formed in the northern part of an approximately E-W trending Neotethyan spreading ridge on the basis of present day geographic position. According to paleomagnetic studies, the initial orientation of Kızıldağ (Hatay) sheeted dykes and hence the associated spreading axis are suggested as 020^{o} (Inwood et al. 2009). When the chilling margins are restored it is clearly seen that the oceanic crust of the Kızıldağ (Hatay) ophiolite was derived from the E-SE part of an approximately 020^{o} trending Neotethyan spreading ridge. All the evidence suggest complex spreading geometries and different magma generations contemporaneously occured in a fore-arc tectonic setting in the Southern Neotethys during the late Cretaceous, similar to present-day marginal basins.

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New data on middle jurassic radiolarians from the sedimentary cover of the ophiolites in the northern Albania (Mirdita nappe)

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Abstract

The ophiolites cropping out in Albania (Mirdita Ophiolitic Nappe) represent the remnants of the lithosphere of the ocean (Maliac-Vardar Ocean) located between the Adria and the Eurasian Plates. The closure of this ocean, due to an eastward subduction (present-day coordinates), and the collision of the Adria Plate with the Eurasian Plate, caused the formation of the Dinaric-Hellenic Belt.

The Mirdita Ophiolitic Nappe overlies the units of the deformed Adria Zone and includes, from the bottom upwards, a Sub-ophiolitic Mélange (Rubik Complex), the Triassic Ophiolite Unit (Porava Unit) and two ophiolitic units (Western and Eastern Belts). The Ophiolitic Nappe is overlain by the Simoni Mélange and the Firza Flysch. The ophiolitic units of the Western Belt represent an oceanic lithosphere generated at a mid-oceanic ridge (MOR ophiolites), while the units belonging to the Eastern Belt represent an oceanic basin developed over a subduction zone (SSZ ophiolites). The Eastern Belt overthrusts westwards the Western Belt. The Sub-ophiolitic Mélange with the overlying Porava Unit were previously called "volcano-sedimentary formation" and, successively "Rubik Complex".

This paper concerns the study of the radiolarian cherts (Kalur Cherts) of the sedimentary cover of the ophiolitic units in six sections: Gurthi, Gurth 2, Gurth 4 in the Eastern Belt, as well as Gomsiqe, Karma and Koman in the Sub-ophiolitic Mélange. The examined radiolarian cherts gave the following ages:

Gurthi section, sample GU 7 (intercalated in the basalts), latest Bajocian-early Bathonian to middle Bathonian (UAZ 5-6) on the basis of the occurrence of *Eucyrtidiellum semifactum* Nagai & Mizutani and *Japonocapsa* sp. aff. *J. fusiformis* (Yao).

Gurth 2 section, sample G2-1 (collected 20 cm above the base of the basalts), middle Bathonian to late Bathonian-early Callovian (UAZ 6-7) on the basis of the co-occurrence of *Eucyrtidiellum unumanese dentatum* Baumgartner with *Theocapsomella cucurbiformis* (Baumgartner) and *Theocapsomella medvednicensis* (Goričan).

Gurth 4 section, sample G4-3 (collected about 2 metres from the basalts), latest Bajocian-early Bathonian (UAZ 5) on the basis of the occurrence of *Eucyrtidiellum semifactum* Nagai & Mizutani and *Unuma latusicostatus* (Aita).

Gomsiqe section, sample AL 1205b (intercalated in the basalts), late Bajocian to latest Bajocian-early Bathonian (UAZ 4-5) on the basis of the co-occurrence of *Archaeodictyomitra* (?) amabilis (Aita), *Unuma gordus* Hull and *Unuma latusicostatus* (Aita).

Karma section, sample AL 372 (intercalated in the basalts), middle Bathonian (UAZ 6) on the basis of the presence of *Striatojaponocapsa synconexa* O'Dogherty, Goričan & Dumitrica and *Kilinora (?) oblongula* (Kocher).

Koman section, sample AL 374 (intercalated in the basalts), late Bajocian to middle Bathonian (UAZ 4-6) on the basis of the occurrence of *Unuma gordus* Hull and *Striatojaponocapsa synconexa* O'Dogherty, Goričan & Dumitrica.

Our data confirm that the ages of the Kalur Cherts of the Eastern Belt are comparable with those of the radiolarian cherts belonging to the Western Belt.

Geochemical Characteristics And Ages Of Ophiolitic Bodies Within The East Anatolian Accretionary Complex, Ne Van Area, E Turkey

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Abstract

The East Anatolian Accretionary Complex covering vast areas in E Turkey and W Iran is made of several packages of mélange complexes formed during successive phases of the still ongoing convergence between the Arabian and the Tauride-Anatolide plates. It involves dismembered blocks/thrust slices of the Neotethys oceanic lithosphere that was generated between the Triassic and Late Cretaceous and reworked into flysch-basins during the Tertiary. These oceanic lithosphere units include variably serpentinized harzburgites, dunite and cumulate gabbros, cut by parallel diabase dyke-swarms. Another type of oceanic rocks, also found as allochthonous bodies, are basaltic lavas and associated oceanic sediments. Geochemistry of the diabases reveals three distinct groups, including a) supra-subduction zone (SSZ) type, b) enriched MORB (E-MORB) type and c) oceanic-island basalt (OIB) type. The Ar/Ar ages of the the diabase dikes range from 105 to 92 Ma. The volcanic rocks studied in this paper are alkali-basalts, basanites and trachyandesites. The new geochemical data suggests that the samples may have been derived from mixing between an OIB-like source and a source showing a weak subduction signal. Associated micritic limestones yielded late Maastrichtian foraminifers, the youngest ages obtained yet from oceanic sediments of S Neotethys.

The petrological features and the ages provided from the southern Neotethys oceanic lithosphere is indicative for an intra-oceanic subduction that produced arc and back arc type units that accreted at the end of the Cretaceous. There is no indication for younger oceanic lithosphere generation spreading but accretion has continued until mid Tertiary.

Keywords: *East Anatolian Accretion Complex, ophiolite, petrology, Van, SE Turkey*

Introduction

The East Anatolian Accretionary Complex (EAAC, Sengör and Yilmaz 1981) is one of the critical units in the Eastern Mediterranean, where remnants of oceanic branches of disputed number and locations are located (e.g. Robertson et al. 2007; Parlak et al. 2009). The ophiolitic outcrops and metamorphic assemblages between Malatya–Elazig ophiolites in the West and the western Persian/southern Armenian ophiolites in the East (Fig. 1) have been attributed to the Ankara-Erzincan Ocean (for discussion see Robertson 2002) or to the Mus branch of the southern Neotethys of Sengör et al. (2008) or, alternatively, to the Amanos–Elazig–Van Suture Belt of Göncüoglu et al. (1997).

To obtain reliable evidences for the tectono-magmatic evolution of the oceanic lithosphere along this belt, a detailed study of ophiolitic bodies has been performed. This paper presents new geochemical, geochronological and paleontological data from the mélanges between Lake Van and the Persian border.

Geology

In the studied area the EAAC comprises the Eocene-Oligocene Kırkgecit flysch with olistoliths and/or tectonic lenses of an ophiolitic assemblage (Yüksekova Complex) mantle and crustal lithologies. The para-autochtonous cover of the Yüksekova Complex is the Late Paleocene-Eocene Seske Formation, represented mainly by neritic limestones, also found as blocks within the Kırkgecit flysch. The flysch unit includes olistostromal sequences with ophiolitic blocks, ranging from pebble to megablock (> 1 km) sizes, embedded in a clastic matrix. The tectonic package of flysch-type deposits become younger from north to south and the age ranges from Middle Eocene to the Late Oligocene-Early Miocene. All these formations were affected by thrusting and overturned folding with southern vergence. Neogene and Quaternary volcanics seal the thrust slices.

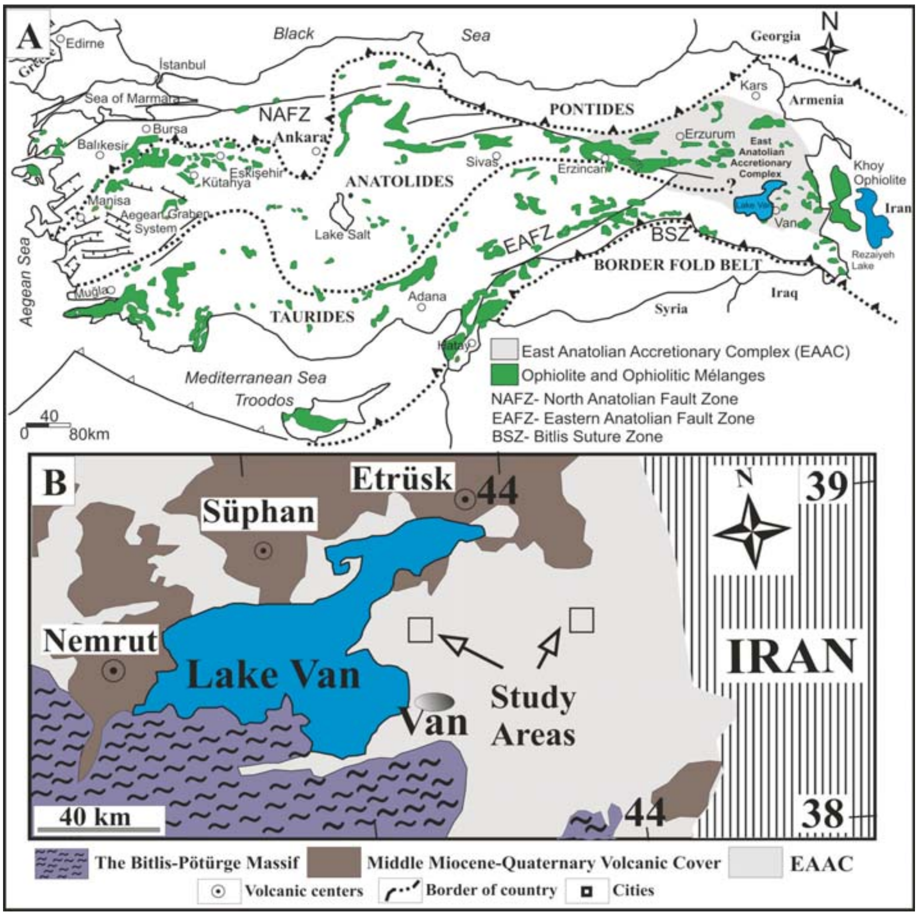

Figure 1. a. Distribution of ophiolites in Anatolia; b-Locations of the study areas on the East Anatolian Accretional Complex (EAAC).

Figure 2. Field occurrence of ophiolitic rocks in Van area: a- Diabase dyke cutting peridotites, b- basaltic lava-micritic limestone association including late Maastrichtian fossils.

The studied Mehmetalan, Mollatopuz and Alabayır ophiolitic units float in the Kırkgeçit unit (Colakoglu et al. 2012). The ophiolitic bodies include ultramafic tectonites with rare mafic cumulates and pegmatitic gabbro, cut by isolated diabase dykes (Fig. 2a) with Ar/Ar ages between Albian-Cenomanian.

The blocks of volcanic rocks within the flysch comprise massive and pillow lavas intercalated with reddish, pelagic, fossiliferous limestone, mudstone, and radiolarian chert. The radiolarian chert occurs as thin bands within the basalt and pelagic limestone. Patches of micritic limestone within pillow basalts (Fig. 2b) indicate that the basaltic extrusions were contemporaneous with the deposition of lime mud near the carbonate compensation depth in a deep oceanic basin. The entire volcano-sedimentary assemblage is intruded by lamprophyre dykes of unknown age.

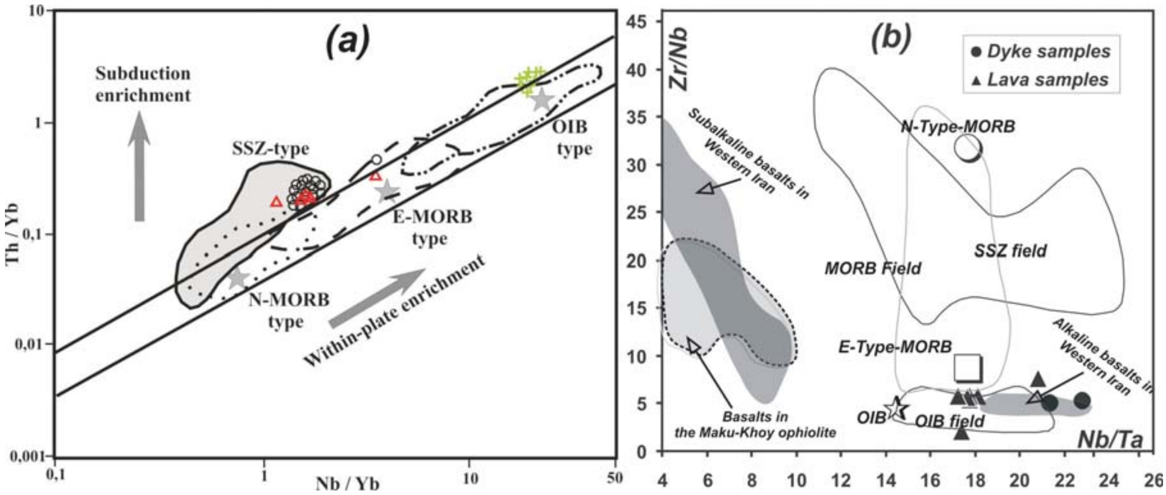

Figure 3. Trace element ratio plots of: a- Group I and II (o, Δ) and Group III (+) diabase dykes, b- lavas with micritic limestone (triangles)

The micritic limestones are rich in foraminifers, including:

Racewiguembelina fructicosa (Egger),
Racewiguembelina fructicosa (Egger),
Contusotruncana contusa (Cushman),
Globotruncanita stuarti (De Lapparent),
Globotruncanita stuarti (De Lapparent),
Globotruncanella havanensis (Voorwijek),
Globotruncanella contusa (Cushman) and
Globotruncanita stuarti (De Lapparent).

This assemblage is indicative of a late Maastrichtian depositional age of the micritic sediments and concomitant volcanism.

Petrology

The early Late Cretaceous diabase dykes display characteristic features of a- supra-subduction zone (SSZ) type rocks from intra-oceanic environments which are characterized by HFSE patterns largely subparallel to normal mid-ocean ridge basalt (N-MORB) coupled with relative enrichment in Th and LREE relative to Nb (Group I) (Fig. 3a); b- enriched MORB (E-MORB) -type showing some degree of enrichment relative to N-MORB (Group II) and c- oceanic-island basalt (OIB) type with characteristic humped trace element patterns, coupled with fractionated LREE/HREE profiles (Colakoglu et al. 2012). By this, all groups were interpreted to have been generated by partial melting of different source regions of the same arc-basin system (Colakoglu et al. 2012).

The late Late Cretaceous volcanic rocks, on the other hand, exhibit enriched trace element signatures (Fig. 3b). Considering also the isotope data (Colakoglu et al. in review), these samples appear to reflect mixing between an enriched source (similar to those of OIBs) and a depleted source less with a weak subduction component. Hence, they can be generated in a back arc setting by upwelling of asthenospheric mantle due to retreat of the subducting slab.

Regional Geological Implications and Conclusions

The new data from the ophiolitic units in the Van area indicate the presence of SSZ-type volcanic rocks in the EAAC. The presence of SSZ-type ophiolitic assemblages within the Yüksekova Complex was already known in the western and central parts of the SE Anatolian Suture (e.g. Robertson et al. 2007). However, our new findings shed light on the details of the chronological and tectono-magmatic evolution of Neotethys. First of all, the age and the tectono-magmatic features of the oceanic lithosphere in Van are very similar to a number of ophiolitic bodies along the Amanos-Elazıg-Van belt. This fact provides a clue on the derivation of these ophiolites from the southern branch of Neotethys rather than the northerly located Ankara-Erzincan-Sevan-Akera belt. Moreover, to the east, across the Turkish-Iranian boundary, SSZ-type basalts associated with sediments occur in the same tectonic setting as those in the study area. From these the Nain, Dehshir, Shahr-e-Babak, and Baft ophiolites of the Inner Zagros Ophiolite Belt include Cenomanian to Campanian pelagic limestones that are found as thin layers between the SSZ-type lavas or laying on top of ophiolites (Moghadam and Stern 2011).

Another implication of our new finding is that the age of the SSZ-type oceanic lithosphere generation and hence the initiation of the intra-oceanic subduction must have started during the late Early Cretaceous (Albian), earlier than previously known. Likewise, the new late Maastrichtian age data indicates that the formation of the intra-oceanic subduction lasted longer than previously known.

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Subduction Initiation Recordin Suprasubduction Zone Ophiolites in the Tethyan Realm and in the Phanerozoic – Precambrian Record

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Abstract

The internal structure - stratigraphy and geochemical characteristics of suprasubduction zone (SSZ) ophiolites in different orogenic belts indicate a seafloor spreading origin in forearc-incipient arc settings during the initial stages of subduction. In general, there is a well-developed magmatic stratigraphy in the extrusive sequences of these ophiolites from older MORB-like lavas at the bottom towards younger island arc tholeiite (IAT) and boninitic lavas in the upper parts (Figures 1 and 2). A similar progression of the lava chemistry also occurs in crosscutting dike swarms and sheeted dikes, indicating increased subduction influence in the evolution of ophiolitic magmas through time. Lherzolitic peridotites in structurally lower parts of the upper mantle sequences of these ophiolites represent the residue after MORB melt extraction. Harzburgite and harzburgite-dunite associations higher up in the mantle sequences and below the mafic-ultramafic cumulates (transitional Moho) are crosscut by networks of orthopyroxenite (opxt) veins, which include hydrous minerals (amphibole). These orthopyroxenite veins represent a reaction product between the host harzburgite (depleted, residual peridotite) and the migrating Si-rich (boninitic) melt. The harzburgite-dunite-opxt suites characterize melt-residue relationships and melt migration patterns in the mantle wedge during the initial stages of subduction and incipient arc construction. Thus, most SSZ ophiolites display a lateral and vertical progression of melt evolution in their crustal and upper mantle components that traces different stages of subduction initiation-related magmatism, reminiscent of the forearc magmatism in some of the modern arc-trench rollback systems as in the Izu-Bonin-Mariana and Tonga-Kermadec subduction factories. The along-strike continuity for more than 1500 km of this well-documented chemostratigraphy and geochemical progression in different ophiolite belts is strong evidence for

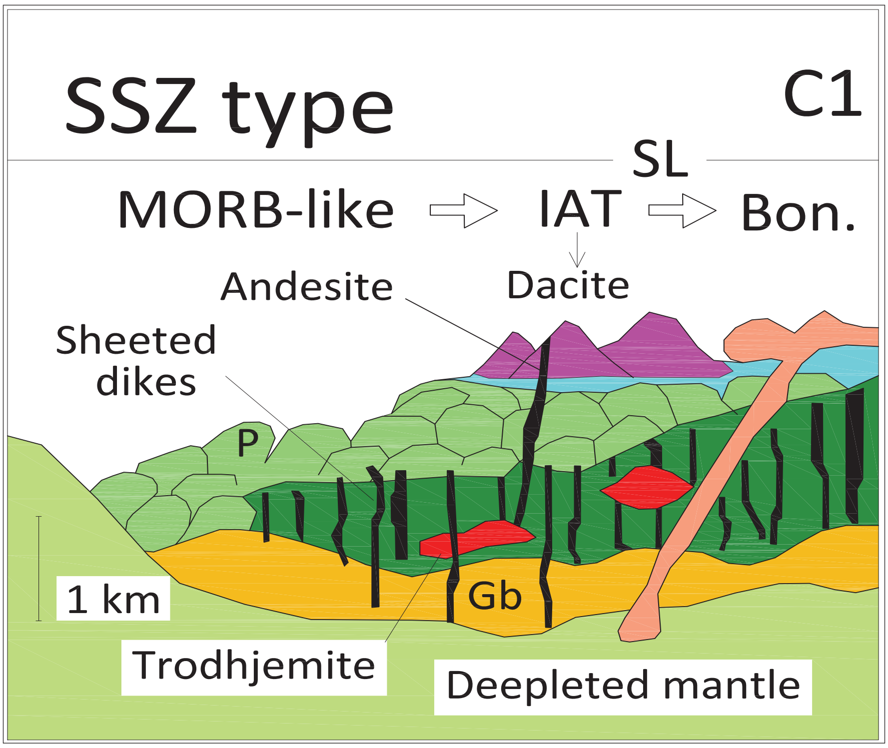

Figure 1. Internal structure and lithological units of a SSZ ophiolite produced during subduction initiation magmatism. Bon.- Boninite, Gb - Gabbro, IAT- Island arc tholeiite, P- Pillow lava, SSZ type - Suprasubduction zone type.

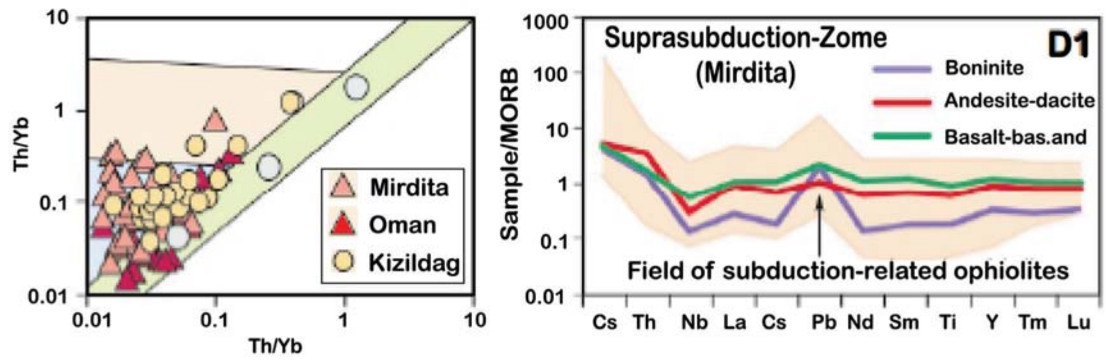

Figure 2. Th/Yb – Ta/Yb and multi-element diagrams (from Dilek and Furnes 2011, and the data sources therein) displaying the characteristic features of SSZ Tethyan ophiolites.

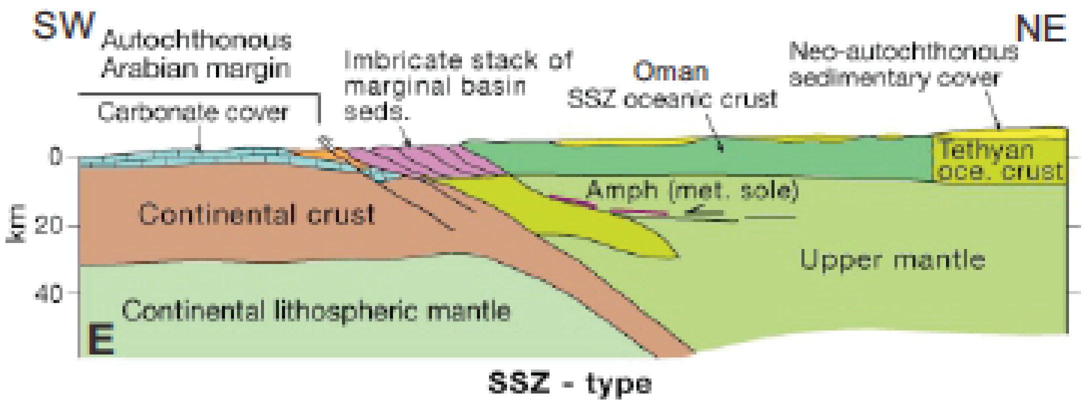

Figure 3. Tectonic emplacement of the SSZ Oman ophiolite and its metamorphic sole onto the rifted margin of the Arabian plate via continent – trench collision (from Dilek and Furnes 2014).

spontaneous subduction initiation followed by rapid slab rollback in ancient ocean basins. SSZ ophiolites in the Tethyan and other orogenic belts were emplaced into continental margins by continent – trench collisions within 7-10 m.y. of their magmatic construction (Figure 3). I will discuss the global SSZ ophiolite record in light of our new ophiolite classification and evaluate the secular trends in SSZ ophiolite evolution in Earth history through time.

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Yarlung Zangbo ophiolite: a critical updated view

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Abstract

The Yarlung Zangbo ophiolite belt is located in southern Tibet, China. Distributed in east-west direction with a distance of ~2000 km, this ophiolite had been used as an important petrological indicator to constrain the suture zone between India and Asia, and represents the vanished Neo-Tethyan ocean between them. According to previous studies and our recent field investigations, however, this ophiolite belt is characterized by the following features: (1) Mantle peridotites predominate over mafic rocks; mantle peridotites mainly consist of harzburgites, but with a significant proportion of lherzolites; (2) Cumulative gabbro is usually absent although it was identified in three localities with a maximum thickness less than 1000 m; (3) Sheeted dykes are absent, but there are gabbroic-doleritic sills intruding into the peridotites. In some cases, dolerites occur as dykes in basalts; (4) Generally, basalts directly overly the peridotites, although the interface between them is mostly occupied by doleritic sills; (5) Peridotites and mafic rocks are significant different in terms of Sr-Nd isotopic compositions; (6) Gabbros and dolerites were emplaced during the ~120-130 Ma period with a limited temporal interval across the whole belt, and were derived from depleted asthenospheric mantle. These lines of evidence suggest that the ultramafic and mafic rocks formed separately without any genetic connection. Therefore, we suggest that some of the mantle peridotites outcropping in the Yarlung Zangbo ophiolite belt might be sub-continental lithospheric mantle that originated beneath the Asian plate. We suggest that during the Early Cretaceous, extension of the leading edge of the Asian continent resulted in the exhumation of the subcontinental lithospheric mantle, and the formation of an oceanic basin. Exhumation and thinning of the lithosphere resulted in upwelling and melting of the asthenosphere, which led to the eruption of basalt and intrusion of gabbro and dolerite. During the maximum extension phase, partial melting of the metasomatized refractory lithsopheric mantle gave rise to high-Mg melts. Therefore, the Yarlung Zangbo ophiolite is much different from the ideal ophiolite section defined by the Penrose conference, and should not be considered as a remnant of the Neo-Tethyan ocean between the Indian and Asian continents. Considering that the mafic rocks are only sparsely developed in the area, we propose that the Yarlung Zangbo ophiolites represent oceanic crust formed at an ultraslow spreading center with a spreading rate much lower than that in western Alps, and hence it can be defined as an end-member ophiolite formed in the ultraslow spreading setting.

Variscan Ophiolites In The Western Carpathians: Lithology, Geochemistry, Metamorphic Evolution And Geotectonic Significance

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Abstract

Relics of the Variscan (Upper Devonian/Lower Carboniferous) ophiolite suture have been found in the Western Carpathians. Original single suture representing a fossil boundary between two lithospheric paleoplates with various Variscan histories was reactivated and scattered during the Alpine orogeny. Ophiolite relics in the form of tectonic slices or blocks in mélanges are components of three individual lithostratigraphic units – the Pernek, Zlatník and Ochtiná Groups – differing in original location in the former oceanic basin. Geochemical type of ophiolite basalts point to P-type of ophiolites mostly related to the rifted plate margins.

Keywords: *Ophiolites, Variscan, lithology, geochemistry, Western Carpathians*

Introduction

The Alpine-Carpathian section of Alpine-Himalayan mountain belt seems to belong to a specific category of orogenic belts produced by several repeating Wilson cycles. Its geological structure has been formed in at least three overprinted orogenic events: (1) Caledonian (s.l.), (2) Variscan and (3) Alpine orogeny. Every cycle was related with opening and closure one ocean basin, so minimally three oceanic sutures could be traceable in this realm. Hitherto relics of the tectonically dismembered Alpine oceanic suture ascribed to the former Triassic-Jurassic Meliata Ocean in the form of several small ophiolitic units has been known. Nevertheless during the last decade mostly due to geochemical studies also significant vestiges of the ocean responsible for the Variscan orogeny have been identified in the Western Carpathian realm. Following three lithostratigraphic units representing relics of the Variscan oceanic crust have been found: (1) Pernek, (2) Zlatník and (3) Ochtiná Groups.

Variscan ophiolite units in the Western Carpathians

Pernek Group builds up a part of the Palaeozoic crystalline complexes on the NW edge of the Tatric Superunit. The Pernek Group is most widespread in the Malé Karpaty Mts. (Ivan, et al. 2003) but small occurrences are also in the Považský Inovec Mts. and Strážovské vrchy Mts. The Pernek Group comprises the complex of metamorphosed basic igneous rocks originally formed mostly by basaltic lava flows and, in lesser amounts, also by isotropic gabbros, both penetrated by doleritic or gabbroic veins. Due to multistage metamorphic alteration they were transformed to greenstones or amphibolites. In its uppermost part the complex is built up by alternated layers of black shales, metacherts and actinolitic schists representing a cover, sedimentary in origin, layered on basaltic flows. Distribution of trace elements relatively immobile in metamorphic processes and Nd isotope ratios indicate that composition of metabasalts originally varied between N-MORB and E-MORB types. They display characteristic flat to mildly-steeped chondrite normalised REE patterns (La_N/Yb_N = 0.87-1.86) and typical LREE depletion (La_N/Sm_N = 0.32-1.10; La_N = 5.06-36.29) Oceanic rift setting and generation by partial melting of depleted (εNd_{370}= ca. + 9) to mildly enriched mantle source are typical for such rocks. Fractionation of olivine, clinopyroxene and/or plagioclase participated on the formation of some basalts and gabbroic rocks. Sporadically also metabasalts with BABB geochemical signature have been found here. Rocks of sedimentary cover were formed in deep-water oceanic environment from fine-grained protolith, which was probably created by mixing of oceanic and terrigenous sedimentary components with altered and disintegrated basaltic material. They display Ce-anomaly and those with higher content of the organic matter are enriched in V and Cr. Lenses of the Cyprus-type pyrite ores are embedded in the rocks of the sedimentary cover. The Pernek Group was preliminarily dated as ca. 370 My old (Putiš et al. 2009) and it can be interpreted as an incomplete dismembered Variscan ophiolite sequence, which originated as upper part of an ancient oceanic crust. Because the Pernek and neighbouring Pezinok Groups, both Devonian in age, were formed in quite different tectonic settings (abyssal oceanic basin vs. rift-related basin adjacent to continent) and subsequently intruded by ca. 350 My old granitoid plutons, they might have been in tectonic position already in pre-Visean time. This is the evidence for the existence of plate convergence, space shortening and nappe stacking directly related to Variscan orogeny.

Zlatník Group is located nearby northern boundary of the Gemeric Megaunit. It can be divided into two formations: (1) Grajnár Fm. and (2) Závistlivec Fm. The Grajnár Fm. is composed of lava flows of aphyric or plagioclase-phyric metabasalts with the metamorphosed banded redeposited acidic volcaniclastics, black to dark grey in colour, in their upper part. The Závistlivec Fm. is represented by the sedimentary mélange with enclaves of metabasalts, metadolerites and metagabbros, rarely also acidic differentiates and epidosites, variable in size (tens metres to psammitic fraction) embedded in the metamorphosed and strongly deformed sedimentary matrix originally derived from igneous rocks (Ivan and Méres 2012).

Relic ophitic or subophitic textures changing into porphyric or cumulate ones, are still discernible in most metabasalts from the Grajnár Fm. Igneous clinopyroxene partly replaced by actinolite and chlorite, zoisite/clinozoisite/epidote, albite and variable amount of white mica, carbonate or pumpellyite, leucoxenized ilmenite and pyrite is typical mineral association in metabasalts. Metamorphosed sedimentary rocks in the Grajnár Fm. are represented by: (1) greenschists, (2) phyllites and (3) fine-grained albitites. They are composed mainly of fine-grained sericite, albite, quartz, chlorite, carbonate, and Fe-oxides pigment. Quartz grains, volcanogenic in origin, are locally also present.

Primary igneous textures are partly preserved also in metabasalts, metadolerites and metagabbros from the Závistlivec Fm. Metamorphic mineral association is represented by amphiboles, albite, chlorite, clinozoisite/epidote, pumpellyite, carbonate, axinite, titanite, Fe-oxides and sulphides. Amphiboles are usually zoned and very variable in composition (pargasite, edenite, megnesiohornblende, actinolite, riebeckite, winchite). Relic igneous clinopyroxene has been found in metagabbros only. Metamorphosed intermediate to acid differentiates contain mostly of sodic plagioclase, in lesser amount of quartz, chlorite, epidote and Fe-oxides. Metamorphosed sedimentary rocks are represented by: (1) metamorphosed sedimentary breccias, (2) metapsammites and (3) phyllites. Chlorite, amphibole, epidote and albite together with lesser amounts of sericite, leucoxenized ilmenite and Fe-oxides or sulphides dominate in mineral composition of these rocks. Breccias contain angular clasts of the metamorphosed basalts, dolerites, gabbros and acid igneous rocks highly prevailing over fine-grained albite matrix with disseminated small grains volcanogenic quartz. In metapsammites moreover ultramafic clasts with chromian spinels and relics of the sodic and sodic-calcic amphiboles have been found.

Metabasalts of the Zlatník Group display transitional geochemical signature among the N-MORB, E-MORB and BABB types (La_N/Yb_N = 0.70-1.72; La_N/Sm_N = 0.50-1.67; La_N = 10.54-48.84). Only a part of them is compositionally close to basaltic liquids, others represent cumulates or differentiates of Fe-Ti-basalt type. REE distribution in the acid differentiates is similar to that in plagiogranites from ophiolite complexes. Metagabbros correspond to the identical geochemical type as metabasalts and metadolerites but display lower concentrations of total REE and other incompatible elements. Chemical composition of the metamorphosed sedimentary rocks reflects their petrographic variability. Metamorphosed sediments from the top of the Zlatník Group (Grajnár Fm.), relatively homogenous in composition, display low mineralogical and chemical maturity typical for rocks derived from less altered and unsorted acid to intermediate arc magmatic rocks. Trace element distribution and REE patterns are very similar to calc-alkaline dacites. Chemical composition of the metamorphosed sediments from the lower part of the Zlatník Group vary in wide interval - phyllites and metapsamites are mostly close to dacites, whereas greenschists of sedimentary origin chemically remain of metabasalts. Basic source rocks influenced also composition of chlorite-rich phyllites. Major and trace element distribution in all these rocks indicate immature and unsorted character of the original sediments as well as no sign of the weathering trend.

The Zlatník Group underwent a polymetamorphic evolution. Rocks of the Grajnár Fm. were metamorphosed in very low-grade metamorphic conditions locally overprinted by the greenschist facies event of variable intensity. Metamorphic evolution of the Závistlivec Fm. is much more complex. An ocean-ridge metamorphic event preceded the very low-grade stage in metagabbros and metadolerites and was followed by high-pressure subduction metamorphism and retrogression in the greenschist facies conditions. The Zlatník Fm. is probably the Upper Devonian/ Lower Carboniferous in age, metabasalt from the Grajnár Fm. was preliminary dated as ca. 385 My old (Putiš et al. 2007). Continual sequence of basaltic lava flows of the Grajnár Fm. was probably created as an uppermost part of the oceanic crust floored relatively narrow basin. The Závistlivec Fm. represent an ophiolite mélange resembles of subduction mélanges frequently forming the basal part of some ophiolite complexes. Blocks in this mélange were derived from the deeper part of the oceanic crust than is present in the Grajnár Fm. and contains also ultramafic detritus coming from the rocks of the upper mantle origin.

Ochtiná Group displays lithologies similar in petrography and geochemistry to the Závistlivec Fm. of the Zlatník Group and is also represented by ophiolite mélange with blocks of ophiolitic rocks (metabasalts, metadolerites, metagabbros and metaultramafites) together with blocks of carbonate rocks in its upper part. The Ochtiná Group is located directly in the northernmost margin of the Gemeric Superunit and is divided into two subunits: (1) Hrádok/Črmeľ Fms and Ľubeník Fm (Ebner et al. 2008). Basic igneous rocks of the Ochtiná Group are intensively metamorphosed into greenstones with poorly preserved original textures. Ultramafic rocks are fully serpentinized. The matrix of mélange is composed of grey to black metamorphosed sedimentary rocks (metaconglomerates, metasandstones, phyllites) locally rich in organic matter. Great majority of metabasalts from the Ochtiná Group displays transitional geochemical signature between N- and E-MORB (La_N/Yb_N = 0.55-1.96; La_N/Sm_N = 0.50-1.41; La_N = 10.42-33.93) but types similar to BABB have also been found. The age of ophiolitic rocks is not known, but carbonates from the uppermost part of the Ľubeník Fm. were biostratigraphically dated as the Late Visean to Serpukhovian.

Geotectonic significance of the Variscan ophiolite units in the Western Carpathians

Ophiolitic rocks located in the three lithostratigraphic units – the Pernek, Zlatník and Ochtiná Groups, are very similar in age, petrographic and geochemical features, so could be related to one common Variscan oceanic basin. Dominated geochemical type of metabasalts-transitional between N-MORB and E-MORB-point to similarity with the P-type ophiolites in the classification by Pearce (2008). Volcanic rifted plate margin is the frequent geodynamic setting for this ophiolite type. Riftogeneous sequences Devonian in age with the OIB type volcanic rocks adjacent to ophiolitic units in the present-day geological structure support this assumption. Differences between individual lithostratigraphic groups reflect their various original setting in the original oceanic basin. The Pernek Group represents a most distal relict of the oceanic floor formed just in the mid-ocean ridge, whereas mélanges of the Ochtiná Group and Závistlivec Fm. of the Zlatník Group were created in the accretionary wedge during active subduction of the oceanic crust at the basinal margin. The Grajnár Fm. was originally formed probably as the uppermost part of the oceanic crust in the marginal area of an oceanic basin not too remote from the ensialic magmatic arc what is indicates by a cover of the dacitic pyroclastic rocks of the arc provenance (Ivan and Méres 2012).

The Pernek, Ochtinná and Zlatník Groups represent in current geological structure of the Western Carpathians relics of a single Variscan ophiolite suture reactivated in Alpine era. This suture would be actually a record of the last evolution stage of the Upper Devonian/Lower Carboniferous oceanic basin, which was termed as the Pernek Ocean. The suture could be interpreted as a fossil boundary separated two lithospheric paleoplates with different Variscan tectono-thermal evolution where southern plate (in present day coordinates) was spared extensive plutonic activities and metamorphic reworking. On the other hand the northern plate display quite different history – magmatic activity related to the subduction of the Pernek Ocean and formation of the magmatic arc led also to the intensive metamorphic alteration in the upper crust mainly due to increased thermal flow related to granitoid plutonism. Lower Carboniferous (360-350 My) I- and S-type granitoids in the Veporic and Tatric

Superunits of the Western Carpathians could be products of this plutonism.

Correlations with global tectonic schemes and other Variscan ophiolites

If the global tectonic schemes are taken into consideration then interpretation of the Pernek Ocean as a small intraterrane basin in the framework of the Hun Terrane seems to be most possible. Also assumption that the Pernek Ocean could be originally an embayment of the Paleotethys Ocean scissor-like widened to the east cannot be excluded (cf. Frisch et al. 2011). In the Variscan Europe are the ophiolite relics thought to be almost exclusively the Cambrian or Devonian in age. Devonian ophiolites have been described from the NW Spain, Cornwall (Great Britain), Giessen (Germany), Vosges (France) or from the French Massif Central (Ivan and Méres 2012 and citations herein).

Conclusions

In the Western Carpathians the Variscan (Upper Devonian/Lower Carboniferous) dismembered incomplete metamorphosed ophiolites have been found. They form three lithostratigraphic units: (1) the Pernek Group (in the Tatric Superunit), (2) Zlatník and (3) Ochtiná Groups (both in the Gemeric Superunit) and are represented by the ophiolitic P-type with transitional geochemical type of basalts between N- and E-MORB. These three groups originally form a single ophiolite suture - a final stage of the evolution of a Variscan oceanic basin termed as the Pernek Ocean. Ophiolite suture of the Pernek Ocean is a fossil boundary between two lithospheric paleoplates with the different Variscan tectono-thermal evolution.

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Heterogeneus Mantle Section In Albanian Ophiolites: Evidences From Mineral And Bulk Rock Chemistry

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Abstract

In the classical view, the Albanian ophiolites are divided in an eastern SSZ-, and a western MORB-belt, respectively. This view is reflected in the mantle section by the predominance of harzburgites in the eastern belt and lherzolites in the western belt. Nevertheless, recent investigation mainly carried out in the western belt revealed a different picture. It shows a wide compositional variation within the peridotitic massifs, depending on their geographical position within the belt.

The Albanian western ophiolite belt extends for more than 140 km in N-S direction. The southernmost massifs of Voskopoja, Rehove as well as Morava are dominated by lherzolites. They contain, only minor harzburgite bodies. By contrast, the next two massifs further in the north, Devolli and Vallamara, consist almost exclusively of highly depleted harzburgites. In turn, the massifs situated in the central area of Albania, such as Shpati, Kuterman and Skenderbeu are built up of almost equal proportions of harzburgites and lherzolites. In these three massifs, generally harzburgites are dominating in the western parts, while lherzolites prevail in the eastern parts. The Puka and Gomsique massifs situated in the northern part of Albania are similar to those in the southernmost part, i.e. dominated by highly fertile lherzolites. By contrast the eastern belt is more uniform and contains only massifs dominated by harzburgites, such for example the Shebenik and Bitincka massifs in Southern Albania.

The chemical composition of peridotites shows a high variability. For example, Al_2O_3 and CaO range from almost zero up to approximately 4 wt.%. This is consistent with fertile peridotites on one hand, and extremely depleted peridotites, on the other hand. The composition of typical ultramafic minerals such as olivine, chromian spinels and pyroxenes reflects this lithological variability as well.

Among the massifs in the western belt, the mantle composition changes several times, from lherzolitic, close to primitive mantle, to highly depleted harzburgitic. Each massif has an individual petrographic and geochemical trend. In all massiffs mantle rocks prevail, only few, e.g. Shpati and Voskopoja and Puka are associated with crustal sections. These contain mafic and ultramafic cumulates, various gabbros, tiny remants of sheeted dikes as well as massive or pillowed lavas, often brecciated.

By contrast, the eastern belt has been formed by a more homogeneous harzburgitic mantle. Also here, crustal sections are rare.

Proterozoic zircons in the Rubiku granite of the Jurassic Albanian ophiolite: a challenge for geodynamic models

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Abstract

The ultramafic and mafic members of the Mid-Jurassic Albanian ophiolites are associated with fairly common felsic rocks, represented mostly by plagiogranites. The aim of our reconnaissance SHRIMP study of zircons in the Rubiku granite (~ 60 km NE of Tirana) was to highlight its origin and, possibly, the timing of the ophiolite obduction and collision.

Based on mineralogical and geochemical data, an oceanic lithosphere affinity and supra-subduction emplacement setting for the Rubiku granite seems most likely. A probable mantle source is supported by: low K, trace-element pattern similar to MORB (except for Th and U), the absence of a Nb-Ta anomaly and low $(^{87}Sr/^{86}Sr)_i$ ratio. However, a contribution of continental crust material to the granite, during or shortly after its emplacement, cannot be excluded, which is evidenced by its peraluminous characteristics, presence in it of Al-rich minerals (micas) and Th-U enrichment.

The Rubiku granite appears to comprise two distinct zircon populations. Older Group 1 (~ 1.83 Ga) comprises large crystals short prismatic in habit, with magmatic-type zoning. The high proportion of these exogenic zircons and their homogeneity strongly suggest that they crystallized during a single Palaeoproterozoic event. The younger Group 2 zircons, 169±2 Ma in age, are interpreted as a product of crystallization from magma broadly contemporaneous with the ophiolite formation.

The discovery of the old zircons in the Rubiku granite is not, in fact, a complete surprise, as similarly old zircons have been reported elsewhere from rocks of oceanic lithosphere provenance, e.g. from the Mid-Atlantic Ridge and similar environments. The presence of such old zircons in rocks from intra-oceanic environments, typically located far from continental lithosphere plates, inspired new ideas about geodynamic processes and mutual inter-reaction between the lithosphere and sub-lithospheric mantle, including the question of continental-crust growth and destruction processes.

The petrogenetic processes inferred from the zircon age spectra in the Rubiku granite may help refine geodynamic models of the evolution of the Albanian ophiolites. Based on rather limited data from one granite dyke, we tentatively review possible palaeotectonic scenarios.

Scenario 1: Old zircons in rocks of oceanic-lithosphere provenance assumes that the Rubiku granite is a plagiogranite genetically connected with the basic magmas of the ophiolite. In the *Mid-Ocean Ridge setting*, the old Palaeoproterozoic zircons could have come from the asthenosphere that possibly comprised materials of continental lithosphere provenance; alternatively, they crystallized in magmatic conduits of melt migration to shallow levels of the lithosphere. In the *Intra-oceanic supra-subduction zone setting*, the primary magma source (and source for old zircons?), could be placed within the supra-subduction mantle wedge underlying the extension system producing the SSZ-type magmas (and possibly comprising domains “contaminated” by old continental-crust materials).

Scenario 2: Old zircons from continental-crust sources in an obduction/collision setting refers to ealier concepts suggesting a continental-crust origin (or contamination) of the K-rich granites in the ophiolites. A difficult problem is that no rocks of continental crust affinity of the age of 1.83 Ga (analogous to zircons in the Rubiku granite) have been reported from this part of the Mediterranean.

The results of our reconnaissance study at Rubiku confirm that these intriguing problems of the presence of old zircons in much younger rocks of oceanic lithosphere affinity are worth more systematic studying, both in ancient ophiolitic successions and in rocks of recent oceanic settings.

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Nw-mirdita Ophiolite, Analogue To Oceanic Core Complex. Some Consequence On The Emplacement Of The Ophiolite Belt.

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Abstract

The continuous section of Middle Jurassic oceanic crust, exposed in the central part of Mirdita along a N-S-trending synform, limited by western and eastern lineaments of ultramafic exposures is assigned to successive episodes of magmatic and amagmatic spreading in a slow to moderate spreading environment. Both mantle rocks lineaments are composed of harzburgite that record asthenospheric mantle flow parallel to the N-S paleo-ridge, and rotates into a transverse direction in the northern domain. The north-western massifs present in addition a high strain deformation localized in the dome-shaped envelopes of these massifs, interpreted as representing the detachment surface of an oceanic core complex (OCC), rooting at 5 km depth, in a thick Moho transition zone composed of melt-impregnated dunites, and responsible for the exhumation of the mantle rocks. In this model, the amphibolitic rocks bordering both mantle lineaments, dated 160-170 Ma, express spreading-related exhumation in the western domain, whereas they record initiation of the closure of the Jurassic oceanic basin in the eastern massifs. The shift from spreading to convergence occurs during this short time laps of ~10Ma, and militates for in situ closure of an oceanic basin. A model of the Mirdita basin closure is presented, accounting for the westward location of the paleo-ridge of origin.

Key words: *Mirdita ophiolite, slow spreading, oceanic core complex, Dinaride ophiolite belt*

The Jurassic Mirdita ophiolite crops out in the western branch of the Hellenide-Dinaride ophiolite belt in the Balkan Peninsula; it represents a remnant of the Tethyan oceanic lithosphere developed between the Apulian and Pelagonian microcontinents. It escaped most Alpine and Cenozoic deformation, possibly due to a thick and rigid ophiolitic basement. A continuous section of Middle Jurassic oceanic crust, including thin gabbros, a sheeted dike complex and extrusive rocks, is exposed in the central part of the ophiolite along a N-S-trending synform, limited by western and eastern lineaments of mantle rocks exposures. The sheeted dyke complex strikes N-S and is steeply dipping, indicating that the paleo-ridge was oriented parallel to the N-S corridor and that the ophiolite has not been significantly tilted, as marked by also by nearly horizontal Cretaceous limestone deposits overlying the ophiolite. Classically, the western massifs, Gomsiqe, Puka and Krabbi, have been considered ‘lherzolitic’, and the eastern massifs, Kukes, Lura and Bulqiza, ‘harzburgitic’. Detailed structural mapping (Nicolas et al. 1999; Meshi et al. 2010) (Fig. 1) reveals that the deep mantle section was harzburgitic in both and that the major differences are restricted to the uppermost mantle and crustal section. The eastern ultramafic domain has a typical harzburgitic mantle exhibiting a high-temperature asthenospheric foliation dipping steeply to moderately to the west to southwest, overlain by a thick clinopyroxene and plagioclase-rich dunites, belonging to a Moho transition zone (MTZ) rich in basaltic impregnations and chromite deposits, and by a lower crust of layered gabbros (1-2 km thick). In contrast, the western ultramafic domain has a zoned mantle, with asthenospheric harzburgite exposed at its western margin, progressively replaced eastward by plagioclase-peridotites that were highly strained in lithospheric conditions, and that are bounded by amphibole-peridotite mylonites along with crustal rocks. The “lherzolites” are in fact mylonitic MTZ formations. The occurrence of plagioclase is ascribed to melt impregnation processes that occurred immediately before or during intense lithospheric deformation. Mantle peridotites of the western massifs locally are in direct contact with the overlying diabase and volcanic rocks along ductile shear zones. The high strain deformation of the western massifs localized in the dome-shaped envelopes of these massifs is interpreted as representing the detachment surface of an oceanic core complex (OCC), rooting at 5 km depth, in a thick MTZ, and responsible for the exhumation of the mantle rocks (Fig. 2). Successive episodes of magmatic and amagmatic spreading in a slow to moderate spreading environment explains the contrast between eastern and western massifs.

Figure 1. Geological and structural map of the North-Mirdita ophiolite, depicting high-T (asthenospheric) and low-T (lithospheric) foliation trajectories and major shear zones with their sense of motion.

Recent detailed studies in western massifs, mainly Puka and Krabbi (Nicolas et al. 2014), complement previous structural mapping of the northern Mirdita ophiolite and confirm the ridge parallel high-T, asthenospheric mantle flow that characterize slow to moderate oceanic spreading rates as recorded in other ophiolites. In the western massifs the transition from asthenospheric mantle

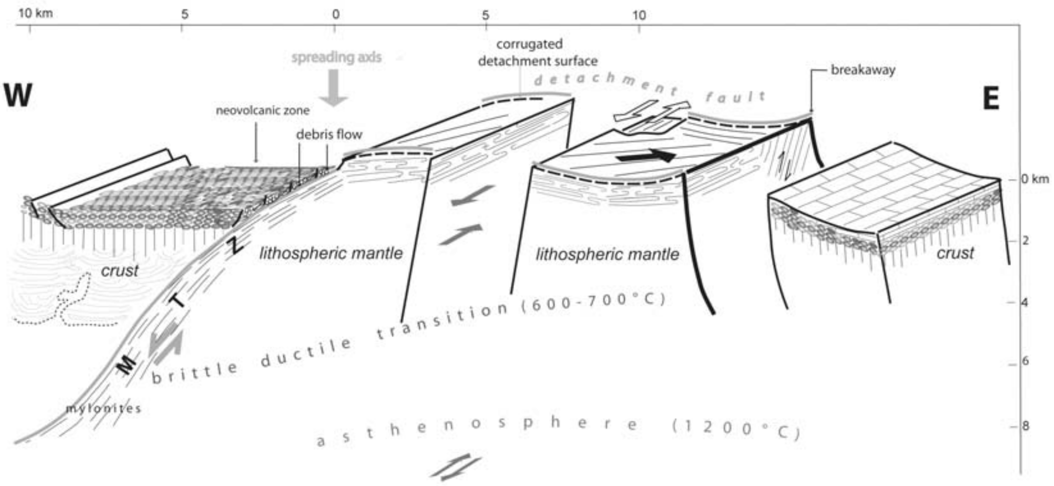

Figure 2. Exhumation of Mirdita western massifs (Krabbi-Puka) based on oceanic core complex model. The mylonitic half-dome is developed partly at the expense of the Moho transition zone (MTZ). Dominant shear senses, and structural dissymmetry of the massifs favour rooting of the detachment fault along a ridge axis located west of Mirdita. Red arrow corresponds to high-T flow in asthenospheric mantle; orange arrow, to medium-T mantle detachment flow; black arrow, to detachment flow recorded in the mylonites.

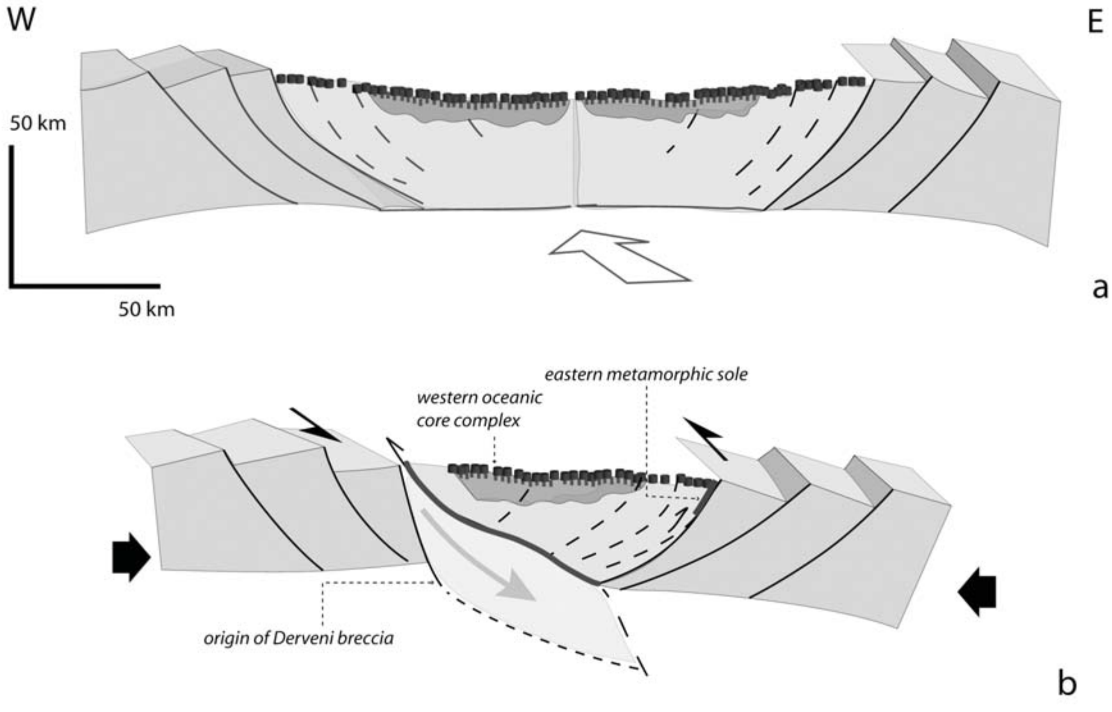

Figure 3. Model of Mirdita ophiolite exhumation. a) Kinematics recorded in mantle peridotite: ridge parallel mantle flow during spreading of a Middle Jurassic basin (amphibolite dating). b) Followed by compression as recorded in the metamorphic sole of the eastern ophiolite. Eastward subduction of the western oceanic lithosphere accounts for fluids contamination during the exhumation of the eastern mantle wedge. Eastern metamorphic sole formed possibly at the expense of Late Triassic - Early Jurassic rift basins.

flow to detachment mylonites operates across a porphyroclastic domain, accompanying a rotation of the flow directions as described in oceanic OCCs. Kinematic and petrological results suggest that the paleo-ridge of origin was located west of Puka and Krabbi massifs. In the eastern massifs, the N-S ridge parallel asthenospheric mantle flow recorded in the most southern massifs rotates into a transverse direction in the northern domain, and maintains similar orientations when evolving to porphyroclastic texture towards the eastern margin of massifs.

In the western massifs studied, most amphibolites belong to the mylonitic OCC detachment shear zones, although in the eastern massif, metamorphics form discontinuous lineaments at the eastern contact between mantle peridotites and the Triassic formations of the Korabi platform, presenting the inverted metamorphic gradient from garnet pyroxenite to greenschist, characteristic of a "metamorphic sole". The kinematics recorded in the basal harzburgite and their contact metamorphic sole are not systematically coupled; both foliations are parallel to the paleo-ridge and the Korabi platform margin, steeply dipping west, whereas lineations are dispersed in the metamorphic soles around a down-the-dip trend. This steep geometry departs from the model of oceanic detachment as documented in the fast spreading situation represented by the Oman ophiolite for instance, and better militates for the record of an in-situ basin closure.

Both western and eastern metamorphic formations converge in the same range of $^{40}Ar/^{39}Ar$ dating, 160-170 Ma, Bajocian-Bathonian (Dimo-Lahitte et al. 2001). The western mylonitic detachment shear zones record spreading in a OCC whereas the eastern are metamorphic soles that record the initiation of closure of the basin, the shift from spreading to convergence occurs during this short time laps ~10 Ma.

The detailed study of the Puka-Krabbi area and its interpretation as an OCC exhuming the north-western mantle of Mirdita, and merging from a ridge located westward, has implications on the proposed models of Mirdita basin closure. The resulting polarity could explain the Mirdita ophiolite dissymmetry as shown in scheme of figure 3. We suggest that a subduction has been initiated along the western ridge, subducting the half-west part of the basin. This may be responsible for fluid contamination and "SSZ" signature in the Kukes massif of eastern Mirdita. Such polarity could account for the existence of a metamorphic sole along the eastern margin of the ophiolite, and for the type of Derveni breccia, 45 km depth exhumed from the western subduction surface at 166 Ma (Giata et al. 1992).

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Ophiolite diversity (Oman and North-Mirdita), reflects of fast- and slow-spreading ridges

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Abstract

This is a review on ophiolites, based on a former classification of fast versus slow spreading ophiolites (Nicolas and Boudier 2003) based on the nature of the underlying mantle (LOT:lherzolite ophiolite type; LHOT: harzburgite-lherzolite ophiolite type; HOT: harzburgite type) and comparing Oman a typical HOT to North-Mirdita ophiolites, a LHOT ophiolite that developed a core complex.

Key words: *Oceanic Core Complex, chromite, mantle flow below ridges*

Oman ophiolites are very similar, including their size, to the East Pacific Rise (EPR) at 9°N, the most studied ridge segment by marine geophysicists. They are both representing fast spreading ridges (~10km/Ma.). Working in Oman, we favor studies in fast-spreading ridges because their activity is time-independent, meaning that no parameter varies with time, the best situation to understand seafloor accretion. The contrast with slow spreading ridges is illustrated by figure1 showing how their activity, such as Mirditaophiolites, is time dependent. Typically, the volume of melt surge from the mantle varies with time. Following periods of continuous activity, exemplified by continuous sheeted diabase dikes, there are periods where the ridge is starving. Seafloor spreading remains a necessity imposed by lithospheric plates motion and during such periods, creation of new crust is replaced by tectonic extension, typically exhumation of the spectacular oceanic core complexes (OCC) (Fig. 2). Discovered nearly 20 years ago along the Mid-Atlantic Ridge, the OCCs have been studied with limited seafloor geological exploration (submersibles, drilling and dredging, complemented deeper by geophysical profiles). However, Nicolas et al. (1999) described in the western Mirdita ophiolitic massifs, what is so far the best OCC in ophiolites. For the first time, it was possible to observe how these exhumation thrusts are rooting in the mantle and force their way to emerge as large domes thrust upon the seafloor.

Another striking feature that distinguishes fast and slow spreading ridges is their relation with the uprising mantle below the ridge axis and how it delivers melt to build the accreting crust (Fig. 1). Basically, the rising mantle isnearly 3D at the scale of a single mantle diapir that is ~10 km in diameter, as measured in Oman. This is due to the shape of the overlying lithosphere that, being nearly horizontal, favors 3D divergence. It has been shown at EPR that at the scale of ridge segments the thin lithosphere at the ridge may have its own tectonic segmentation, fairly independent from the large-scale uprising mantle flow structures under it. This is in sharp contrast with slow spreading ridges, where the cooling of lithosphere defines below the ridge axis a conduit parallel to the ridge with symmetrical ~30° slopes that controls the asthenospheric mantle flow as illustrated in figures 1 and 2.

A remarkable feature and valuable resource of eastern Mirdita ophiolites is their chromite deposits, possibly the second in the world with over 3Mt, after the Kempirsay ophiolite in Southern Urals with 10 Mt (review in Boudier and Al-Rajhi 2014). The main mines are in Buldiza massif (Meshi et al. 2005). The chromite pods are clustering within the mantle transition zone (MTZ), a dunitic layer between residual mantle and Moho. The largest chromite deposits are in slow spreading ophiolites, where the MTZ is also thickest, another consequence of the mantle flow channeling (Fig. 1). In fast spreading ridges as Oman, MTZ is thinner and chromite pods are small. We account for these seemingly paradoxes by the depth of melt crystallization and by the mantle fertility. The exceptional 3 Mt chromite districts are tentatively explained by the grand mantle convection recycling former local chromite enrichments in the uprising mantle.

Turning now to fast spreading ridges, figure 3 is a model of crustal accretion above a mantle diapir illustrating the role of MTZ as a physical and chemical relay between primitive melt injected

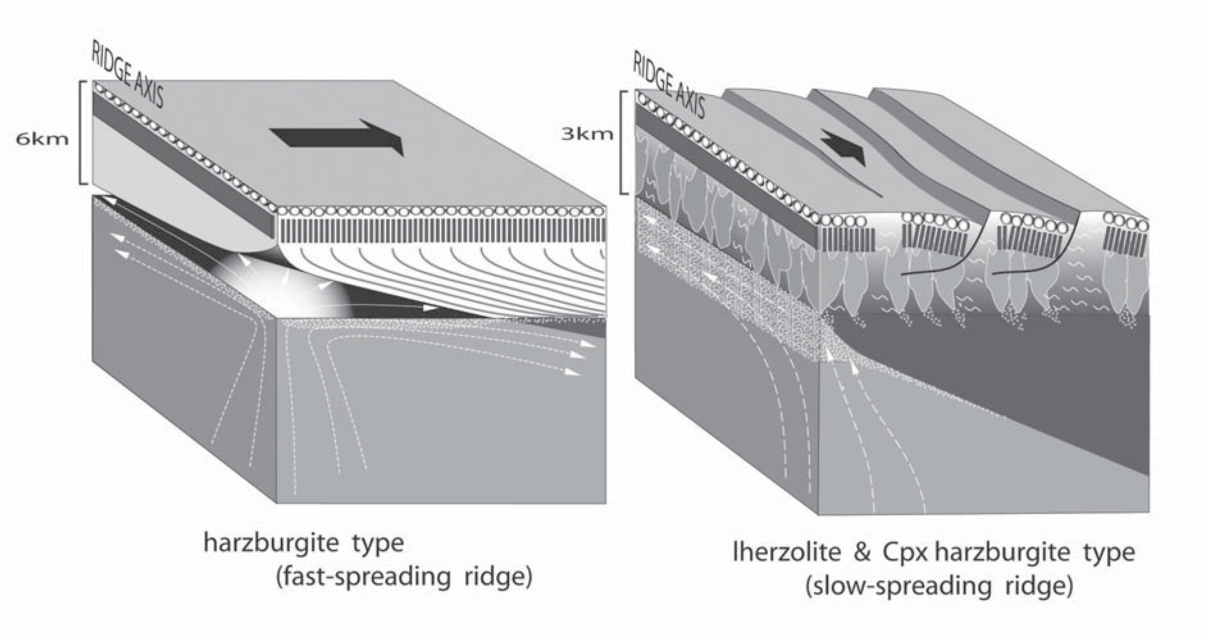

Figure 1. Sketches illustrating the main differences between fast- and slow- spreading ridges, deduced from structural studies in ophiolites. (Nicolas and Boudier 2003).

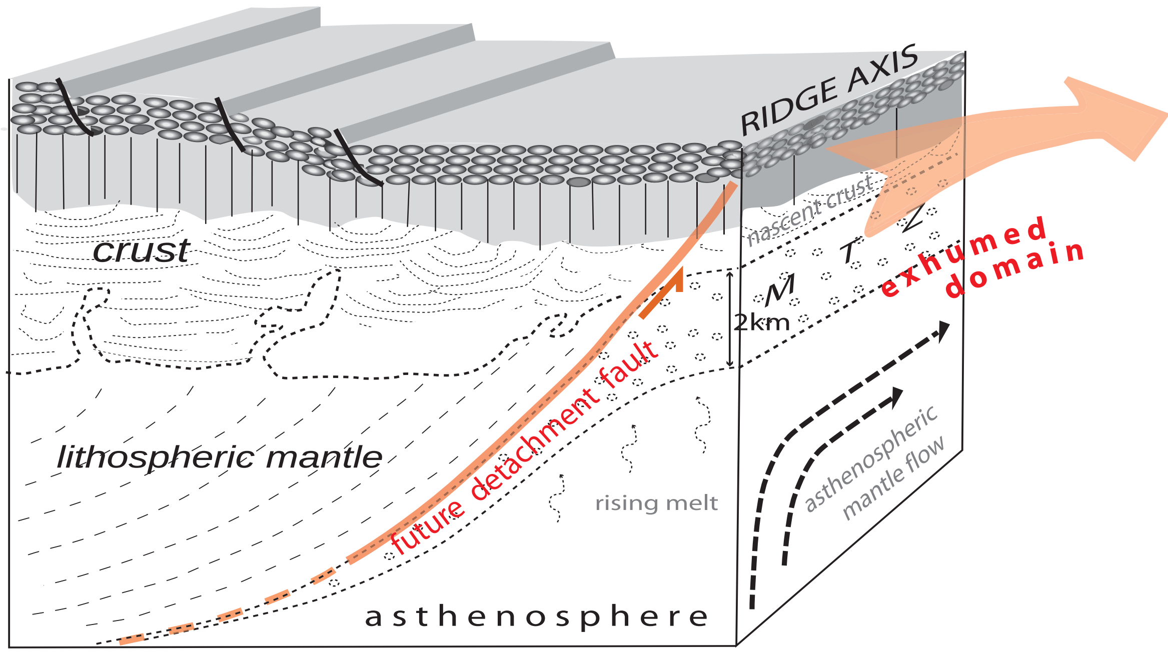

Figure 2. Sketch of the rooting of a OCC in a slow spreading ridge, inspired from the west Mirdita massifs. The lithospheric channel in the uppermost mantle drives the ridge-parallel asthenospheric flow and plates a km-thick MTZ below ridge axis. the OCC is rooting in the soft MTZ (Nicolas et al. submitted).

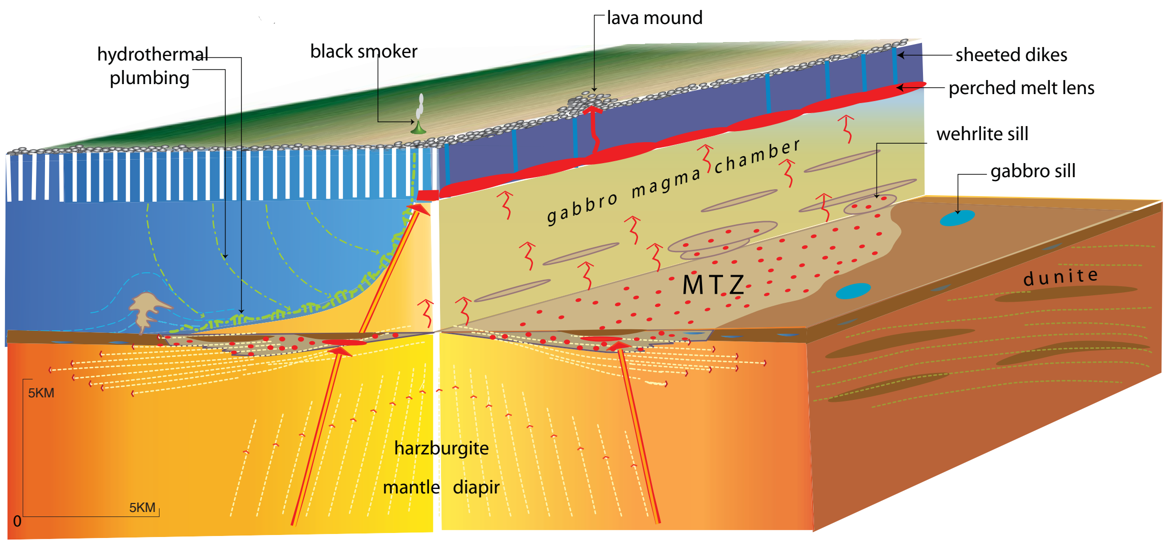

Figure 3. Sketch of crustal accretion of a fast spreading ridges above a mantle diapir, insisting on the diverse interactions and the central role of the MTZ: a physical transition 1)stocking melt issued from mantle and episodically being injected into the perched melt lens and 2) coupling the horizontal mantle flow issued from the diapir to the magmatic flow into the magma chamber thanks to intermediate viscosities. To the left of the sketch, the hydrothermal cooling (unconventional convective model).

from the mantle and evolved melt re-injected into the melt lens perched beneath the sheeted dike complex. The MTZ is a melt reservoir feeding the lens with a centennial frequency whereas, injections from this lens melt to seafloor creating the overlying dikes is decadal. Subsidence from the lens floor into the magma chamber creates most of the gabbro unit. On the left of figure 3, seawater hydrothermal cooling constrains the upper magma chamber to a steep and comparatively narrow chimney.

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The Voskopoja ophiolitic Complex

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Abstract

The Voskopoja ophiolite (VO) is one of the larger ophiolitic massifs in Southern Albania. It extends over ~30 km from N of the Devolli river (village of Strelca) to the southern tip of the Korca graben southwest of Korca. It dips generally eastwards. The massif has a slightly arcuate shape, trending NE-SW in the northern part, N-S in the central part and NW-SE at the southern end. Towards north it is either fault bounded or thrust onto the subophiolitic mélange. The latter consists of a sandy-silty matrix with serpentinite and Triassic to Jurassic limestone blocks ranging in size from few meters to several km. In the south, the mélange zone is several hundred meters wide but becomes significantly thinner towards north. In the south the mélange is in turn thrust towards the west over the Rehove massif. The latter was thrust onto Palaeogene sediments of the Krasta zone.

The VO is divided in two 'slices', separated by elongate lenses of amphibolites, micaschists and marbles. They possibly represent a metamorphic sole at the base of the higher unit which includes ultramafics and remnants of a crustal section. The lower tectonic unit contains only highly serpentinized peridotites. They originated from lherzolites and plagioclase-lherzolites, which build up approximately 90% of the ultramafics, the rest being harzburgites. Due to the high degree of serpentinization, the assignment of the serpentinites to their protoliths is difficult. The higher tectonic slab shows, at its southern part, relatively thick zone of HT ultramafic mylonites, possibly indicating a former transform fault. Both peridotite bodies are cut by gabbro bodies and dolerite dikes.

Fagments of the crustal section are only preserved in the southern and central part of the VO. They are mostly fault bounded and contain small slices of wehrlites, troctolites and clinopyroxene gabbros. A continuous sheeted dike section is missing, but some basalt clasts in the overlaying volcanic breccia containing remnants of chilled margins could be an indication of a prior sheeted dike body. A coherent volcanic sequence with pillow lavas and massive lava flows is only exceptionally preserved. Instead, volcanic breccias are deposited onto the gabbroic section or directly onto ultramafics. In some places the breccias and other sediments are up to several hundred meters thick. They start with a more than one hundred metres thick poorly sorted breccia with clasts up to several meters in size. Most clasts are basalts resembling a MORB composition, but gabbro and serpentinite components occur as well. Higher up in the sequence the sediments become finer grained and better stratified. In the uppermost parts the sediments contain fossiliferous limestones indicating an age interval ranging from latest Jurassic to Berriasian and even earliest Aptian.

The VO is the only ophiolitic massif in Southern Albania made up predominantly from lherzolite and plagioclase bearing lherzolite with only little harzburgite. The ultramafic section is similar to the Gomsiqe massive from the so called Western belt in Northern Albania.

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The Arkot Dağ Mélange, Central Turkey: Evidence For The Geodynamic Evolution Of The Intra-pontide Suture Zone

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Abstract

The geological setting of Turkey can be described as an assemblage of continental terranes separated by ophiolite-bearing suture zones that mark the areas where the PaleoTethyan and NeoTehyan oceanic basins were destroyed. In northern Turkey, one of the most important suture zones is represented by the Intra-Pontide one consisting of an east-west trending belt of deformed and/or metamorphic units located at the boundary between the Istanbul-Zonguldak terrane to the north and the Sakarya terrane to the south. These units can be regarded as issued from the Intra-Pontide domain, whose geodynamic history is still a matter of debate. Along the Akpinar-Araç-Bayramoren geotraverse, located in central Turkey, an ophiolite-bearing mélange, known as the Arkot Dağ Mélange, is well-exposed along the Intra-Pontide suture zone. The Arkot Dağ Mélange can be described as an Upper Santonian chaotic sedimentary deposit consisting of an up to 1000-m-thick succession of slide-blocks of different sizes and lithologies enclosed in a sedimentary matrix consisting of shales, coarse-grained arenites, pebbly mudstones and pebbly sandstones. The slide-blocks, from a few meters to hectometers in size, are represented by metamorphic rocks (mainly micaschists and gneisses), by ophiolites (peridotites, gabbros, IAT and BAB basalts and cherts) and by sedimentary rocks (cherts, neritic and pelagic limestone, marly limestone and ophiolite-bearing turbidites). The youngest age among the slide-blocks has been provided by the ophiolite-bearing turbidites where a late Coniacian nannofossil assemblage has been found. The cherts have provided a wide range of ages from the Middle Triassic to Late Cretaceous, whereas the fossils found in the limestone indicate Late Jurassic to Early Cretaceous ages. The matrix of the Arkot Dağ Mélange, even if unaffected by metamorphism, shows deformations represented by multiple meters-thick cataclastic shear zones at the boundaries of the mélange slices or inside them. According to its features, the source area of the Arkot Dağ Mélange was most likely a stack of continental and oceanic thrust sheets emplaced in the Late Cretaceous onto a continental margin. The data collected from the different slide-blocks suggest that the Intra-Pontide domain was characterised by an oceanic basin that opened at the latest in the Early Jurassic. The opening of the Intra-Pontide oceanic basin was followed by the development of a subduction zone with a subsequent opening of suprasubduction oceanic basin in the Middle Jurassic – Early Cretaceous. The convergence in this suprasubduction oceanic basin started at the Early/Late Cretaceous boundary by an obduction process, whereas its final closure can be regarded as Late Paleocene.

Timing Of Tectonic Events During South Neotethyan Convergence, SE Anatolia

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Abstract

Geothermochronological methods were used in this study to find out (i) formation age of SSZ-type crust along the Southern branch of the Neotethys, (ii) timing of the initiation of the closure of the ocean, (iii) timing of the continent-continent collision and (iv) velocity of the collision by measuring the formation, cooling and exhumation ages of the magmatic/metamorphic units along the Southeast Anatolian orogen.

Southeast Anatolian orogen is one of the best places where mountain building processes can be well observed. The evolution of the belt comprises the closure of the southern branch of the Neotethys during late Cretaceous-Miocene time span and formation of high plato as a result of continent-continent collision. The peri-Arabian ophiolites such as the Troodos (Cyprus), Kızıldağ (Hatay), Koçali (Adıyaman) and Semail (Oman) formed around 95-90 Ma, whereas the Tauride belt ophiolites namely the Göksun (Kahramanmaraş), İspendere (Malatya), Kömürhan and Guleman (Elazığ) formed around 84-87 Ma. There is an age difference of ~5-7 Ma between the two ophiolite belts in SE Anatolia. The peri-Arabian belt ophiolites emplaced onto the Arabian platform towards south while the Tauride belt ophiolites emplaced beneath the Tauride active margin and were intruded by arc granitoids (Esence-Baskil) between 82 and 84 Ma. During Early-Middle Eocene period, a back-arc basin opened in the north and the Berit metaophiolite had its maximum metamorphism (HP-HT). Exhumation of the HP/HT metamorphics occured during 52-50 Ma. As a result of continuous subduction to the south of Pütürge continent, the Berit metaophiolite and the overlying nappes were episodically intruded by the Doğanşehir granitoid during Middle Eocene. The uplift of the granitoids along the belt were triggered by the back-arc spreading, the final exhumation occurred as a result of collision of the Tauride and Arabian platforms during Miocene (Burdigalian-Messinian).

Gravity model of Eastern Vardar zone ophiolites in Kuršumlija area

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Abstract

The Eastern Vardar zone (EVZ) includes relics of former oceanic crust and it is placed in the central part of Serbia. On the north, it extends to the Apuseni Mountains in Romania, and to south through the central part of F.Y.R.O.M., and Peonias subzone of the Vardar zone in North Greece. The EVZ is placed eastern of continental fragment i.e. Kopaonik Unit and western of the Serbian-Macedonian Massif (SMM). It formed during convergence and collision processes in the Mesozoic. The larger outcrop of Eastern Vardar ophiolites in Serbia is located in the Kuršumlija area, where ophiolites are represented by 20 km-long bodies composed of gabbro, gabbro-dolerite, and dolerite dykes, which are associated with volcanic rocks and are overlain by limestones. Basaltic pillow lavas are rarely present. On eastern and western margins of the EVZ, small isolated outcrops of serpentinized harzburgites occur. Ophiolites are mainly associated with intermediate and calc-alkaline granitic rocks. According to earlier research, on the west, the EVZ was thrusted on the SMM during Upper Cretaceous. Since the EVZ is in tectonic contact with the SMM, determination of tectonic fabric was very significant to determine ruptures on surface that represent boundaries between these two tectonic units. For determination of tectonic fabric Landsat 7 satellite images were used, as well as field data, second derivatives of gravity acceleration have been also calculated in order to define zones of vertical contact of different units. In this paper two approaches are presented: qualitative and quantitative analysis. Four groups of ruptures have been determined: regional ruptures with NNE-SSW and NW-SE direction and local ruptures with directions: NE-SW and W-E. Qualitative analysis was preformed to determine the contact between the EVZ and SMM according to lateral changes along profile and to the horizontal distribution of ophiolite beneath the surface. For Bouguer anomaly map, average density value is set on 2.67 g/cm^3. Upward continuation of gravity acceleration was used to determine the causes of anomaly and to obtain information about distributions of bodies under surface. Normalized standard deviation has been applied in this paper in order to define boundaries (edges) of anomaly (i.e. ophiolites). Quantitative analysis was conducted in order to obtain the vertical distribution of EVZ ophiolites. Density values of represented rocks are obtained from rock samples taken on the field and from literature. As the causes of anomalies in the investigated area have expressed extension along one direction NNW-SSE, 2.5 D inversion was applied along profile placed perpendicular to position of EVZ ophiolites in the Kuršumlija area. The purpose of modeling was to create a model of ophiolites that have high density, so adjacent rocks that have similar density are unified. Model of 9 different blocks is created regard to lithology and density of different units. Modeled ophiolites of the EVZ have very sharp and steep contact with adjacent units. Ophiolites are modeled to a depth of 5 km, and extension of the ophiolites was estimated to be between 1.5 to 5 km. Cretaceous sediments are modeled with average thickness of 1 km, and the Jurassic mélange is 1.5 km. Granitoids are modeled as intra-ophiolitic intrusions. Obtained model of EVZ ophiolites suggest that the EVZ is lying below the SMM. EVZ ophiolites are represented as a single body, tectonically disturbed and in specific tectonic contact with adjacent units.

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Jurassic radiolarian assemblages from continental successions in the surrounding areas of Mirdita ophiolites

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Abstract

The Jurassic radiolarian cherts of Albania are included in both the ophiolitic successions of the Mirdita zone (Kalur Cherts), interpreted as remains of the Tethyan oceanic lithosphere, and in the carbonate successions, deposited on the continental margin of the Tethys Ocean.

In this paper we examine the radiolarian assemblages of 7 sections of radiolarian cherts pertaining to the carbonate successions of the continental margin: Porava, Plani i Bardhe, Derstila, situated west of the Western Ophiolite belt and Draja, Selishta, Skenderbej 1, Luniku, located east of the Eastern Ophiolite belt.

The examined radiolarian assemblages gave the following ages:

Porava section, sample PM-4 (collected 3 meters above the pelagic cherty limestone), latest Bajocian-early Bathonian to middle Bathonian (UAZ 5-6) on the basis of the presence of Eucyrtidiellum semifactum Nagai & Mizutani and Striatojaponocapsa synconexa O'Dogherty, Gorican & Dumitrica.

Plani i Bardhe section, sample B-2 (collected 10 meters above the red nodular limestone), late Bajocian to middle Bathonian (UAZ 4-6) on the basis of the presence of Striatojaponocapsa synconexa O'Dogherty, Gorican & Dumitrica and Hexasaturnalis tetraspinus (Yao).

Derstila section, sample 0-44 (collected about 0.2 meter above the platform limestone), middle Bathonian (UAZ 6) on the basis of the occurrence of Striatojaponocapsa synconexa O'Dogherty, Gorican & Dumitrica and Zhamoidellum ventricosum Dumitrica.

Draja section, sample 0-27 (collected 1,5 m above the pelagic cherty limestone), latest Bajocian-early Bathonian (UAZ 5) on the basis of the occurrence of Williriedellum tetragona (Matsuoka).

Selishta section, sample 338 (collected 0.5 m above the pelagic cherty limestone), middle Bathonian to late Bathonian-Early Callovian (UAZ 6-7) on the basis of the presence of Eucyrtidiellum (?) circumperforatum Chiari, Marcucci & Prela and Zhamoidellum ventricosum Dumitrica.

Luniku section, sample 166 (collected 1.2 m above the pelagic nodular limestone), late Bajocian to latest Bajocian-early Bathonian (UAZ 4-5) on the basis of the presence of Saitoum pagei Pessagno, Williriedellum marcucciae Cortese and Unuma latusicostatus (Aita).

Skenderbej 1 section, sample Sk-3 (collected 0.1 meter above the stromatolitic limestone), late Bajocian to middle Bathonian (UAZ 4-6) on the basis of the presence of Striatojaponocapsa synconexa O'Dogherty, Gorican & Dumitrica.

The data from the radiolarian chert of continental margin successions are compared with those from the radiolarian chert belonging to the ophiolite-bearing successions.

The ages of the basal (lower) parts of radiolarian chert belonging to carbonate successions are largely equivalent to those of the radiolarian chert on top of the Albanian ophiolites.

A New Method Of Discriminating Between Different Types Of Ophiolitic Basalts And Their Tectonic Significance Using Th-nb And Ce-dy-yb Systematics

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Abstract

A new discrimination diagram using absolute measures of Th and Nb is applied to ancient ophiolites to best discriminate a large number of different ophiolitic basalts. This diagram was obtained using >2000 ophiolitic basalts and was tested using ~560 modern rocks from known tectonic settings. Data consist of ten different basaltic varieties, including two types that have never been considered before, which are: a) medium-Ti basalts (MTB) generated at nascent forearc settings; b) a type of mid-ocean ridge basalts showing garnet signature (G-MORB) that characterizes Alpine-type (i.e., non volcanic) rifted margins and ocean-continent transition zones (OCTZ). In this diagram, basalts generated in subduction-unrelated settings can be distinguished from subduction-related basalts with a misclassification rate <1%. This diagram highlights the chemical variation of oceanic and OCTZ basalts from depleted compositions to progressively more enriched compositions reflecting, in turn, the variance of source composition. Chemical contributions of enriched components (plume-type components) to mantle sources can therefore be identified. Enrichment of Th relative to Nb is effective for highlighting crustal input via subduction or crustal contamination. Basalts formed at continental margin volcanic arcs can be distinguished from those generated in intra-oceanic arcs in supra-subduction zones (SSZ) with a misclassification rate <1%. Within the SSZ group, two sub-settings can be recognized. They are: a) SSZ characterized by chemical contribution from subduction-derived components (forearc and intra-arc) characterized by island arc tholeiitic (IAT) and boninitic basalts; b) SSZ with no contribution from subduction-derived components (nascent forearc) characterized by MTBs and depleted-MORBs. Two additional discrimination diagrams are proposed: a) boninite and IAT basalts can be discriminated with a confidence level >99.5% using a Dy-Yb diagram; b) G-MORBs and N-MORBs can be discriminated using a Ce/Yb-Dy/Yb diagram.

Keywords: *Basalts; Ophiolite; Discrimination diagram; Trace elements; Plate tectonics*

Introduction

Different rocks or rock associations found in ophiolitic complexes preserve records of tectono-magmatic events that occurred during distinct phases of oceanic development, from continental rifting to oceanic spreading, subduction, accretion and continental collision (e.g., Dilek and Furnes 2011). Recognition of the tectonic affinity of ancient ophiolites is therefore a fundamental problem for all scientists working on this topic. In addition to field data, basalt geochemistry is commonly used for recognizing a variety of different tectonic settings, as well as the nature of mantle sources. To this purpose, tectonic discrimination diagrams based on major and/or trace elements have been a common technique for addressing this problem since the early 70s. However, the most common tectonic discrimination diagrams are not fully satisfactory in correctly classifying data (see Vermeesch 2006 for a detailed discussion). This fact may be related to several potential issues, such as: a) use of arithmetic means of multiple samples; b) use of samples not statistically representative (either limited number of samples or limited number of places); c) use of a limited number of the various basaltic types that can be found in ophiolites; d) implications of the constant-sum constraint of geochemical data; e) implications of the spurious correlations associated with the use of element ratios (Chayes 1949).

Pearce (2008) has demonstrated the importance of the Th–Nb proxy for highlighting crustal input and hence distinguishing oceanic, non-subduction setting from subduction-related settings. However, in his schemes, he uses Yb as a normalizing value for Nb and Th abundances, which may result in severe spurious correlations (Chayes

1949) that may lead, in turn, to significant rates of misinterpretation of data. Therefore, this work intends to develop the method of Pearce (2008) by proposing a new discrimination diagram based on absolute measures of Th and Nb that can discriminate the largest possible number of tectonic settings of formation of ophiolitic basalts.

Database and methods

A database comprising >2000 geochemical analyses of basaltic rocks of known tectonic affinity from worldwide ophiolitic complexes was compiled from the literature in order to be used as training data. The database includes samples from both intact volcanic sequences and mélange terranes, which span in age from Proterozoic to Cenozoic. Ten different varieties of ophiolitic basalts are taken into account in this work, including two basaltic varieties that have never been considered in any discrimination diagram so far presented in literature. They are: a) basalts showing a marked garnet signature (G-MORB) that are generated at Alpine Tethys-type (Iberian-type) ocean-continent transition zones (OCTZ) (e.g., Montanini et al. 2008); b) Medium-Ti basalts (MTB) with geochemical features that are intermediate between those of normal-type mid-ocean ridge basalts (N-MORB) and those of island arc tholeiites (IAT). MTBs are interpreted to be generated at nascent intra-oceanic arcs (e.g., Bortolotti et al. 2002).

A spurious correlation arises when one variable, A is correlated with a second variable, B and the two parameters are ratios with a common denominator (i.e. A=x/z; B=y/z). Chayes (1949) is one of the few authors that brought to the attention of geologists the unwelcome effects that may arise when dealing with these ratios. From the equations in Chayes (1949) it can be demonstrated that the two parameters A and B become strongly mutually correlated even if the original variables x, y, z were totally uncorrelated from each other. It results that the passage from ratio correlation (e.g., x/z vs. y/z) to inference about relations between absolute measures (i.e., x vs. y) is ambiguous at best and often misleading. For this reason a simple discrimination diagram based on absolute measures of Th and Nb (Fig. 1a) is used for plotting the training data. Moreover, two additional discrimination diagrams are also proposed: a) a Ce/Yb-Dy/Yb diagram (Fig. 2a) for distinguishing G-MORB from N-MORB; b) a Dy-Yb diagram (Fig. 2b) for discriminating boninitic and IAT basaltic types. The use of element ratios in the first case is fully justified by preliminary tests showing that no spurious correlations are generated for these rock types. The boundary lines in the diagrams obtained using training data have been tested using a second set of data including ~560 basaltic rocks from modern tectonic settings.

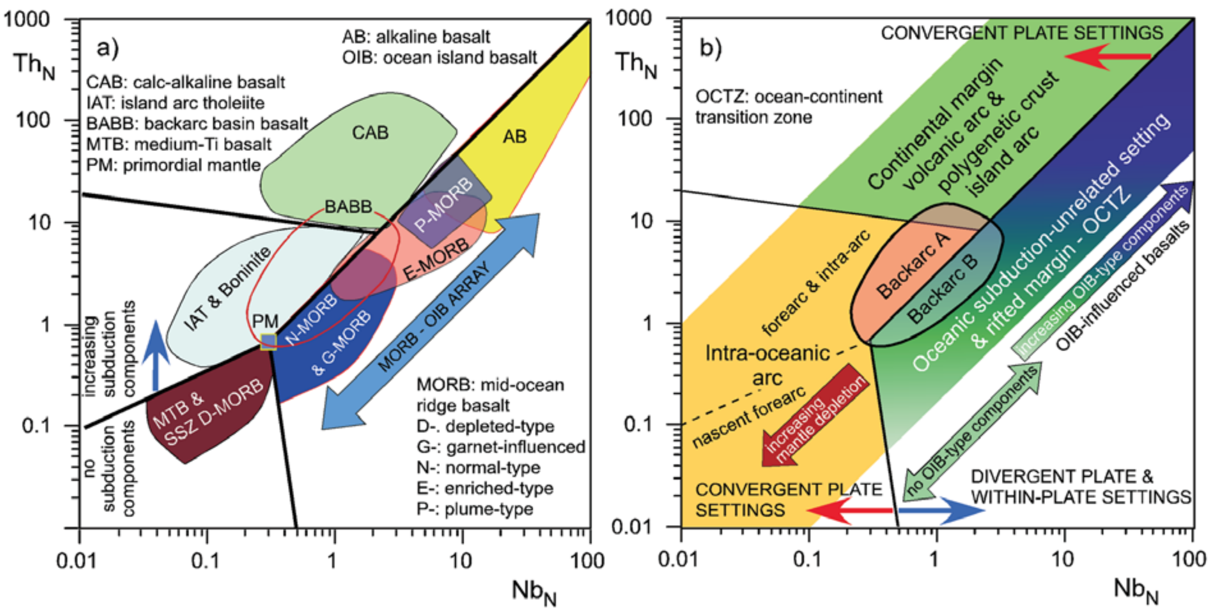

Figure 1. (a) Compositional variations of different ophiolitic basalts on the Th_N-Nb_N diagram; (b) Tectonic interpretation of ophiolitic basalts based on Th_N-Nb_N systematics. Backarc A: BABBs characterized by input of subduction or crustal components (e.g., immature intra-oceanic or ensialic backarcs); Backarc B: BABBs showing no input of subduction or crustal components (e.g., mature intra-oceanic backarcs). In both panels, Nb and Th are normalized to the N-MORB composition (Sun and McDonough 1989).

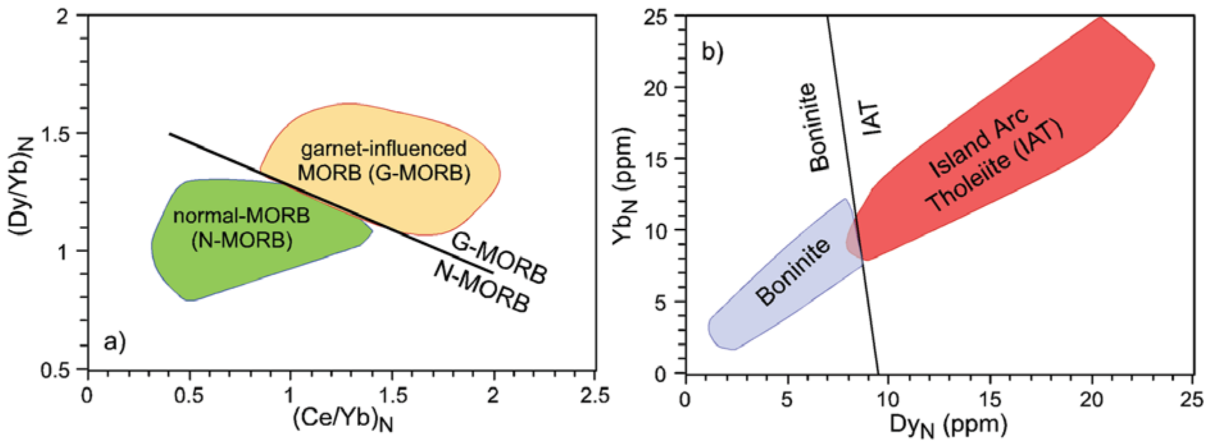

Figure 2. (a) Chondrite-normalized Dy/Yb-Ce/Yb diagram used for discriminating between G-MORB and N-MORB. (b) Chondrite-normalized Dy-Yb diagram used for discriminating between boninitic and IAT basalts. Normalizing values are from (Sun and McDonough 1989).

Discussion and Conclusions

In the Th_N-Nb_N diagram in Fig.1a, >99% of the basaltic rocks from subduction-unrelated settings plot below the segment between the primordial mantle (PM) composition (Sun and McDonough 1989) and the point with co-ordinates $Nb_N = 100$; $Th_N = 1000$ thus defining the N-MORB–OIB array (definition of acronyms is given in Fig.1a). In contrast, >99% of subduction-related basaltic rocks plot above this segment. In this diagram, G-MORBs and N-MORBs occupy the same field and therefore they cannot be discriminated from each other simply using Th-Nb systematics. Nonetheless, these rock-types can be easily discriminated with a confidence level >96% using a chondrite-normalized $(Ce/Yb)_N$ vs $(Dy/Yb)_N$ diagram (Fig. 2a).

E-MORBs and P-MORBs have Nb and Th contents higher than those of N-MORBs and typically form trends extending along the MORB–OIB array away from the N-MORB composition. AB samples plot at the higher Nb-Th part of the N-MORB-OIB array. From Fig.1a it results that there is large overlap between different types of rocks within the MORB-OIB array. However, the Th_N-Nb_N diagram highlights the chemical variance of subduction-unrelated basalts from depleted compositions (N-MORB) to progressively more enriched compositions (E-MORB and P-MORB) and highly enriched compositions (AB), which reflects the variance of source composition and degree of melting. It also highlights the chemical contributions of enriched (OIB-type) components to mantle sources. In this work, the term "OIB-influenced basalts" (OIB-influenced ophiolites) instead of plume-proximal basalts (or ophiolites) is preferred. In fact, based only on the geochemistry of basalts, the concepts of "plume-proximal" and "plume-distal" (e.g. Pearce 2008; Dilek and Furnes 2011) cannot be unambiguously applied to ancient ophiolites. Indeed, enriched basalts generated at plume-proximal settings are hard to be distinguished from similar rocks generated at plume-distal settings, where the plume-type signature may be associated with complex mantle heterogeities, or chemical features inherited from previous tectonic events, or very low partial melting degree of a depleted mantle source (or, eventually, a combination of these).

Within the subduction-related group, IATs and boninites plot in the same field (Fig. 1a). These rock-types can however be discriminated with a confidence level >99.5% using a chondrite-normalized Dy_N-Yb_N diagram (Fig. 2b). In contrast, CABs can be easily distinguished from IATs and boninites as they plot at the higher Nb-Th part of the volcanic arc array. The misclassification rate for these rocks is <0.5%. Medium-Ti basalts and supra-subduction zone (SSZ) D-MORBs can be readily distinguished from all other ophiolitic rock-types as they plot at the lower Nb-Th part of the diagram (Fig. 1a). Th and Nb contents in these rocks are lower than those of PM (Sun and McDonough 1989) and, in some cases significantly lower than those of the depleted MORB mantle.

Backarc basin basalts plot almost symmetrically across the N-MORB-OIB array and extend from the PM composition to the lower Th-Nb part of the CAB composition (Fig. 1a). They mainly overlap the Nb-Th compositions of N-MORB, and IAT +

boninite. It is therefore clear that a discrimination among these rock-types using Nb-Th systematics is impossible.

The test of the proposed discrimination diagrams by using basalts from modern tectonic settings gave very good results. All the basaltic varieties, but BABB are perfectly classified. Nonetheless, for BABBs, the misclassification rate is quite limited (~6%).

The tectonic interpretation of ophiolitic basalts based on Th-Nb systematics is shown in Fig.1b. Basalts generated at divergent plate and within-plate settings can effectively be distinguished from basalts generated at convergent plate settings. The divergent plate and within-plate settings include oceanic, subduction-unrelated environments, such as mid-ocean ridge spreading centres, oceanic plateaux, and seamounts, as well as incipient oceans at volcanic, non-volcanic (Alpine-type), and transitional rifted margins and/or OCTZ.

Using this diagram, three different types of convergent plate settings can be discriminated. Continental margin arcs and island arcs with complex polygenetic crustal nature can be distinguished from intra-oceanic arcs (Volcanic Arc ophiolites and SSZ ophiolites of Dilek and Furnes 2011, respectively). Within the SSZ setting, two sub-settings can be recognized. They are: a) SSZ influenced by chemical contribution from subduction-derived components (forearc and intra-arc sub-settings) characterized by IAT and boninitic basalts; b) SSZ with no contribution from subduction-derived components (nascent forearc sub-settings) characterized by MTBs and D-MORBs.

Basalts formed in backarc basin settings cannot be straightforwardly identified using Th_N-Nb_N systematics. For these rocks there remains considerable ambiguity since they show the highest variability in terms of incompatible elements and REE, as they may form in a variety of tectonic environments ranging from embryonic to mature backarc and from oceanic to continental (ensialic) settings (Dilek and Furnes 2011). Additional geochemical and, especially, geological constraints need to be used. Nonetheless, the Th_N vs. Nb_N diagram (Fig. 1b) may assist in the recognition of backarc settings characterized by a variable contribution from crustal chemical components (i.e., immature intra-oceanic or ensialic backarcs) and backarcs showing no input of crustal components (e.g., mature intra-oceanic backarcs).

Finally, it is not the intention of this paper to discredit previously proposed discrimination diagrams or previous ophiolite classifications (e.g., Dilek and Furnes 2011), which still remain valid. Rather, this paper merely intends to provide an improved method for discriminating the largest possible number of different basalts that can be found in ophiolites with the maximum confidence level. To this purpose, the large number of samples used in this paper as both training and testing data is statistically fundamental.

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New Evidence Of The Youngest Oceanic Crust In The Zagorje - Mid-transdanubian Zone Based On The Example Of Lower Cretaceous Metamorphic Sole From The Kalnik Mt. (North Croatia)

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Abstract

Amphibolite beneath mantle lherzolite in tectonic slices is found inserted in the upper Lower to Upper Cretaceous sedimentary succession from Kalnik Mt. in north Croatia (Šegvić et al. 2005, 2014, Ignjatić 2007). The Kalnik Mt. is a southwestern part of the narrow Zagorje – Mid-Transdanubian Zone (ZMTDZ) bounded by Zagreb-Zemplin lineament at the south and Periadriatic-Balaton lineament at the north (Pamić and Tomljenović 1998). Amphibolites provide the petrological, geochemical and chronological data necessary to constrain the late history of Repno Oceanic Domain (ROD) that connects Meliata-Maliac and Dinaric-Vardar oceanic systems. Primary amphibolite parageneses consists of pargasite-magnesio-hornblende and oligoclase-bytownite (common amphibolite) ± almandine-grossulare rich garnet ± clinopyroxene (garnet-clinopyroxene amphibolite and clinopyroxene amphibolite, respectively). Minimum equilibration temperature for amphibole-plagioclase pairs was estimated to 520 °C at pressure of 0.53 GPa; the highest metamorphic grade of 670 °C at 0.71 GPa was recorded in garnet-clinopyroxene amphibolite. Mineral compositions and thermobarometric studies of the amphibolites reflect metamorphic conditions typical of metamorphic sole formation. Retrograde paragenesis consists of albite, actinolite, epidote-coisite-clinocoisite, titanite and chlorite, and corresponds to greenshist facies. Protolith REE patterns match modern ocean ridge basalts [(La/Lu)cn = 0.51-0.82], whilst the normalised multielement diagram shows slight negative HFSE anomalies [(Nb/La)pmn = 0.44-0.90], diagnostic for magmatic rocks from suprasubduction zones.

Overall geochemical data suggest back-arc basin (BAB) tholeiitic mafic extrusives (lack of Eu anomaly) and IAT-like cumulates (Eu positive anomaly) to be amphibolite precursors. It is suggested that protoliths of Kalnik Mt. metamorphic sole represent an oceanic crust formed at the ridge of a back-arc marginal basin. K-Ar dating on amphibole separate yielded the Lower Cretaceous age (118 ± 8 Ma) that reflects the isotopic equilibration related to the dynamothermal metamorphism caused by near ridge tectonic displacement. The existence of one or more back-arc basins placed westwards of the Tiszia-Dacia continental Mega-Unit that have been producing oceanic crust during Upper Cretaceous to Early Palaeocene is, thus, put forward. This defines the analysed amphibolites as the youngest oceanic crust of ROD, nowadays structured within the Zagorje-Mid-Transdanubian Zone, the triple junction area of the European continental margin, Tisza-Dacia Mega-Unit and the Internal Dinarides.

Structural Analysis Of The Korabi Zone, Northern Albania: Implications For The Root Zone Of The Mirdita Ophiolite.

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Abstract

The Dinaro-Hellenic foldbelt is the result of Mesozoic–Tertiary convergence and continental collision between the Eurasian and Adriatic plates after the closure of the Tethys ocean. In Albania, it is made up of three major terranes: (1) a Western zone of Early Oligocene–Middle Miocene fold-and-thrust nappes of sedimentary rocks derived from Adria; (2) a Central belt made up of an ophiolitic nappe, the Mirdita ophiolite, and underlying thrust slices of both continental and oceanic origin; and (3) an Eastern zone, the Korabi Zone, of Hercynian basement of low-grade rocks unconformably overlain by Permian–Lower Triassic rift-related deposits followed by Middle Triassic–Upper Jurassic carbonates. The Korabi Zone and correlative rocks of former Yugoslavia are currently interpreted either as a micro-continent originally located between two separate oceanic basins, the Mirdita–Pindos oceanic basin to the west and the Vardar Zone oceanic basin to the east, or as a tectonic window below a single ophiolitic thrust sheet in which the most distal paleogeographic domains of Adria are exposed. The age of the Mirdita ophiolite is 165-160 Ma; it has been thrusted over a metamorphic assemblage of thrust slices derived from both continental and oceanic domains, termed here the Gjejane subzone, which includes an infraophiolitic metamorphic sole that yielded 40Ar/39Ar ages varying from 171 to ca. 162 Ma, interpreted as the timing of obduction of the Mirdita ophiolite. The root zone of the ophiolite and correlative terranes of the Dinarides still is a source of debate: some argue that it is a far-travelled thrust sheet that roots eastward into the Vardar Zone, whereas others believe that Albanian and Greek ophiolites of the Pindos Zone are doubly-verging (West- and East-directed) terranes forming the remnants of a small Jurassic oceanic basin between a Pelagonian block to the east and Apulia to the west. In Albania, structural analysis conducted in both the Korabi and Gjejane subzones supports the rooting of the Mirdita ophiolite nappe into the Vardar Zone. Field observations and structural measurements have been acquired along two subparallel transects, (1) the Kukes-Luma River transect which exposes both the Korabi and Gjejane subzones, as well as a well-developed normal faults system marking their boundary, and (2) the Bushtrica-Caja River transect, located approximately 20 km south of Kukes, that exposes a rock sequence belonging exclusively to the Korabi subzone, and which has been mapped in order to document the nature of structural variations in that Korabi subzone, the Gjejane subzone being poorly-exposed along that transect. The metamorphic grade in both the Hercynian basement and overlying Permian-Triassic cover sequence of the Korabi subzone is at greenschist facies. The Permian to Jurassic cover sequence records two phases of regional deformation, D1 and D2. D1 is associated with a NE-trending, SE-dipping regional schistosity axial-planar to NW-verging F1 folds and related SE-dipping thrust/reverse faults. D2 is marked by a NNE-trending crenulation cleavage and upright F2 folds. There are no isotopic age constraints for deformation and metamorphism in the Albanian Korabi Zone but zircon fission-tracks analyses yielded 150-125 Ma, suggesting that these rocks were at temperatures below ca. 240°C at that time, and that regional metamorphism is therefore Early Cretaceous or older. K-Ar micas ages from correlative rocks of the adjacent Republic of Macedonia vary between 148 and 130 Ma, suggesting that D1 is Late Jurassic or older, which is consistent with Middle Jurassic ages preserved in the metamorphic sole of the Mirdita ophiolite. It is thus suggested that a continent-ocean suture located east of the Mirdita ophiolite (in the Vardar Zone) is favored by a top-to-West structural polarity of regional deformation (the «Eohellenic orogeny») in the Korabi Zone, which is in agreement with east-dipping subduction and west-directed obduction; and by the occurrence of a major Mio-Pliocene west-dipping normal faults at the western boundary of the Korabi Zone, which indicates that the Mirdita ophiolite was located higher in the crust and structurally above the Korabi Zone in pre-Miocene times.

Petrological and paleontological evidence for generation of an arc - back-arc system within the closing southern branch of Neotethys during Late Cretaceous

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Abstract

The Yüksekova Complex between Elazig and Malatya in SE Turkey comprises representatives of the Southern Neotethys oceanic lithosphere. The dominating rock unit is grayish to red colored massive and pillowed basic volcanic rocks associated with radiolarian cherts and micritic limestones.

Geochemically, the incompatible element diagrams of pillow-lavas point out two different compositional rock groups, transitional between IAT and N-MORB, and E-MORB. This grouping is also confirmed by morphological and mineralogical-petrographical data. Tectono-magmatic discrimination diagrams suggest the presence of an intra- arc and back-arc pair. Melting modeling based on REE shows that parental magmas of the basalts were formed by partial melting of a spinel lherzolithic mantle source. This shows also that the source deepened from intra-arc to back-arc and the melting degree decreased, by the change of the source.

Radiolarian cherts within the pillow-basalt successions of the Yüksekova Complex as well yielded two groups of ages; the Group I pillow-lavas are Cenomanian - early Turonian and the Group II lavas are Santonian-early Campanian in age.

All geological and petrological features prove that the studied Yüksekova volcanics were successively formed in intra-arc and back arc settings related to intra-oceanic subduction within the Southern Branch of Neotethys during the Late Cretaceous.

Keywords: *intra-arc, back arc, Late Cretaceous, Yükseova Complex, SE Turkey.*

Introduction

In Eastern Mediterranean, remnants of the Southern Neotethyan oceanic lithosphere are found mainly as dismembered ophiolitic bodies and subduction accretion complexes and/or mélanges

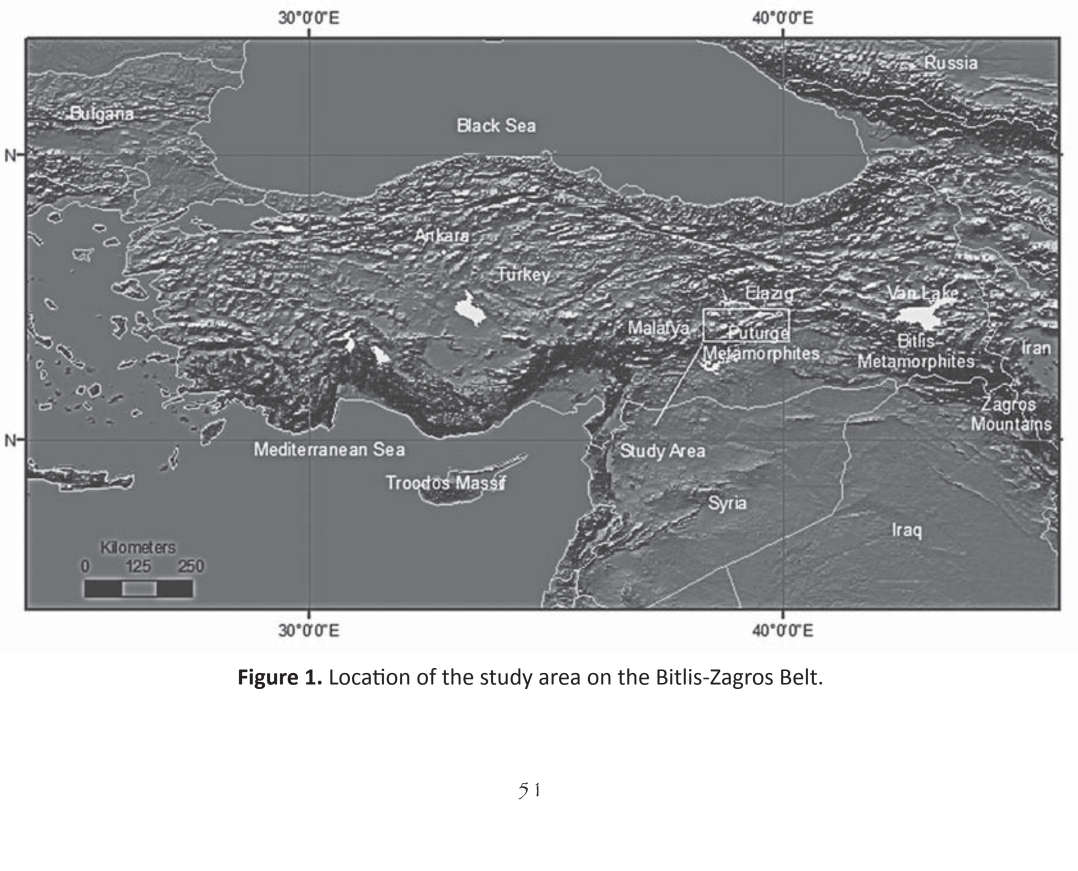

Figure 1. Location of the study area on the Bitlis-Zagros Belt.

(e.g. Robertson et al. 2007; Parlak et al. 2009). In SE Anatolia these mélange complexes outcrop as allochthonous bodies along two distinct belts from Cyprus to the Amanos Mountains on the eastern Mediterranean coast, to the Turkish-Iranian border and along the Zagros suture belt to Oman and Makran (Fig. 1). In the Turkish segment of this suture the northerly located belt is known as the Amanos-Elazıg-Van suture belt (Göncüoglu et al. 1997) and the southern one is called by a number of different names including the Bitlis suture (e.g. Sengör and Yılmaz 1981). The former one is bounded in the north by Paleozoic-Mesozoic platform rocks of the Tauride-Anatolide Terrane and in the south by the Bitlis-Pütürge Massif (Göncüoglu and Turhan 1984) representing the platform-margin sediments of the Arabian plate. The mélange complexes on the central part of this belt between Elazıg and Malatya are considered as a part of the Yüksekova Complex and comprise blocks and/or slices of variably serpentinized mantle rocks, together with red and pink mudstones, radiolarian cherts, massive and pillow-lavas (e.g. Ural et al. 2012, 2013). To understand the tectono-magmatic evolution of the volcanism within the Southern Neotethyan Ocean the crustal rocks were sampled in detail. This paper presents new geochemical data on the ophiolitic pillow basalts together with paleontological data from the associated (as interlayers and intra-pillow fillings) radiolarian mudstones and - cherts.

Field relations

Yüksekova Complex and numerous ophiolitic bodies are found as more than several hundred m thick thrust slices (Fig. 2) within an imbricated zone. The Yüksekova Complex or Elazıg Volcanics (e.g. Bingöl and Beyarslan 1996) is intruded by the Late Cretaceous-Early Tertiary Baskil magmatics, representing arc-type assemblages formed within the subducting Neotethys.

The earliest cover of the Yüksekova Complex is represented by the flyschoidal sediments of the Hazar Group of Late Cretaceous-Early Eocene age. Middle Eocene Maden Complex units stand for the oldest overstep sequence disconformably covering all pre-Eocene tectonic units and characterizing the remains of an extensional basin. Renewed compression during post-Eocene along the belt resulted in imbrication of Maden Complex together with the oceanic and metamorphosed continental margin units of the Arabian Microplate (Bitlis-Pütürge Metamorphics) and the Tauride-Anatolides (Malatya-Keban Metamorphics). Yüksekova Complex is made of massive/pillowed lavas and dykes associated with volcanoclastics, green and red mudstones and radiolarian cherts.

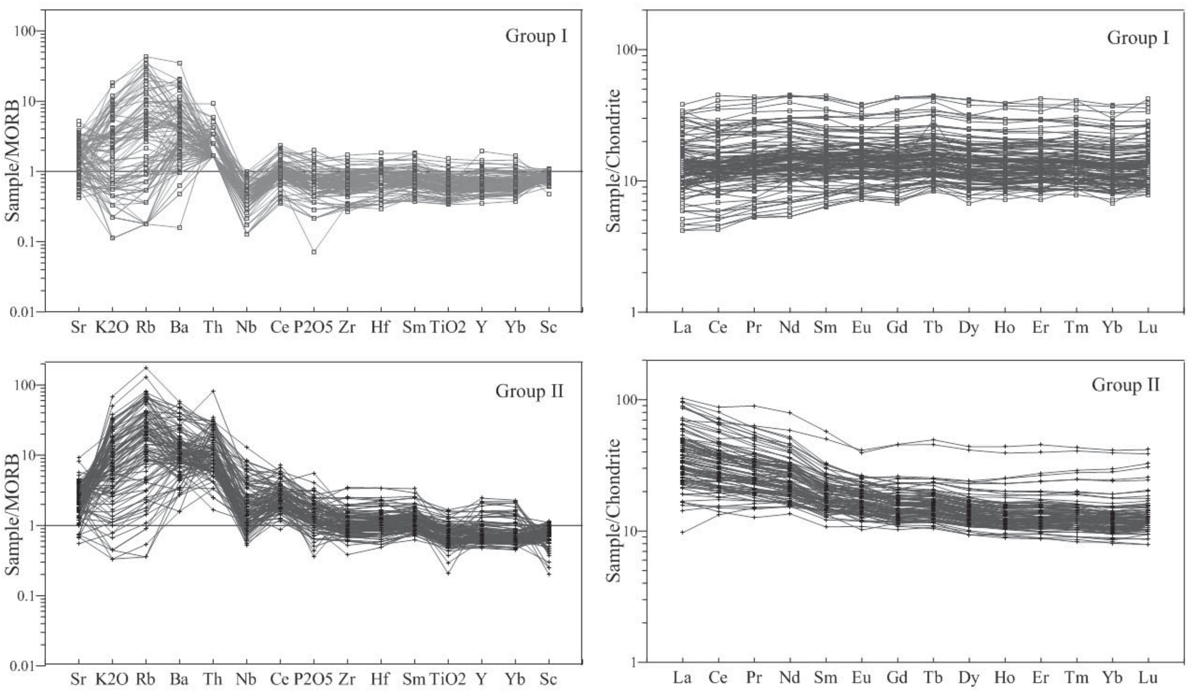

Figure 2. The trace and rare earth element diagrams of Group I and Group II of Yüksekova pillow basalts.(MORB: Mid-ocean ridge basalt, Normalization values are from Sun and Mc Donough 1989).

It locally shows several hundred meters thick continuous and undisturbed successions. More commonly, however, the volcanic and sedimentary lithologies are blocks, embedded in a chaotic mélange, displaying both tectonic and depositionary contacts. Individual chert and/or micritic limestone sequences within the volcanic-volcanoclastic units are up to 3m thick, brick red-violet in color and may comprise dm-thick radiolarian cherts alternating with micritic limestones and green-red mudstones. The most common block types are the pillow lavas with intra-pillow radiolarian cherts and mudstones, which were sampled to study their geochemical characteristics. The pillow lavas are variably altered and cut by diabase dykes. They include calcite- and zeolite-filled vesicules at the rim of the pillows.

Geochemistry

The studied pillow-lavas show tholeiitic to tholeiitic calc-alkaline transitional character. Petrographical features and the whole-rock trace element and REE variations reveal two different compositional groups (Fig. 2); Group I, being transitional between island arc tholeiite and normal-mid-ocean ridge basalt, and Group II represents enriched-mid ocean ridge basalt. The Sr, Nd and Pb isotope data reveal that the studied volcanic rocks were derived

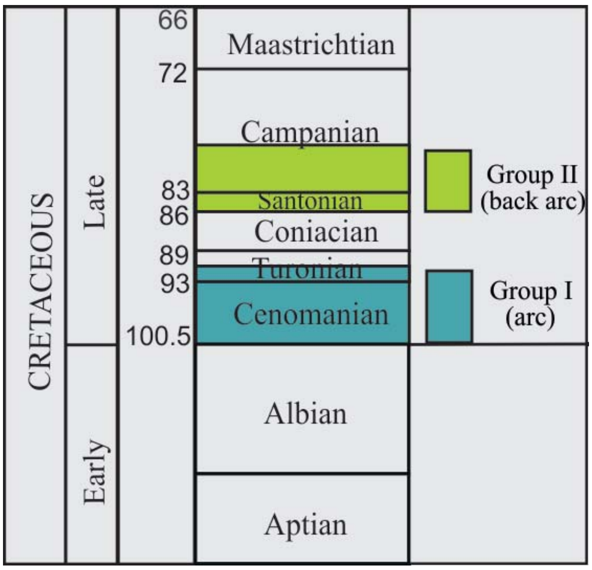

Figure 3. Distribution of radiolarian ages from Group I and Group II pillow-lavas.

from a depleted mantle source, possibly from a remnant oceanic crust.

Plotted on the multidimensional tectonic discrimination diagrams, refer rifting in an arc environment (Group I basalts), and back arc basin (Group II basalts) developed by maturation of the rifted arc in later stages.

New Radiolarian age data

Radiolarian faunas were described for the first time from cherts in primary depositional contact with the basaltic rocks in this belt. Two dictinct age groups are recognized as early Cenomanian –early Turonian and early Santonian-early Campanian (Fig. 3). Radiolarian taxa (*Pseudoaulophacus putahensis Pessagno, Dactyliosphaera* sp., *Pseudodictyomitra pseudomacrocephala* (Squinabol), *P. tiara* (Holmes), *Thanarla veneta* (Squinabol), *Dictyomitra formosa* Squinabol, *Crolanium* sp., *Stichomitra* spp.) revealing the early Cenomanian- early Turonian age have been determined from the chert samples, associated with the Group I basic volcanics.

Radiolarian cherts associated with Group II basic volcanics include diverse radiolarian taxa (*Alievium gallowayi* (White), *A. superbum* (Squinabol), *Archaeospongoprunum bipartitum* Pessagno, *Crucella espartoensis* Pessagno, *Spongodiscus multus* Kozlova, *Patellula verteroensis* (Pessagno), *Pseudoaulophacus floresensis* Pessagno, *P. lenticulatus* (White), *P. pargueraensis* Pessagno, *Dictyomitra formosa* Squinabol, *D. koslovae* Foreman, *Stichomitra* spp, *Rhopalosyringium* spp.) indicating the early Santonian - early Campanian age.

Conclusions

The supra-subduction character of the volcanic rocks within the Yüksekova Complex was commonly accepted (e.g. Robertson et al. 2007). However, the details of the tectono-magmatic evolution as well as the timing of the events during the subduction were a matter of debate. The new geochemical and isotopic data obtained in this study are in favour of a new model, involving an arc-back arc pair. This interpretation is supported by ages obtained from pillow lava-radiolarian chert associations indicating that the arc-rifting stage was realized during the Cenomanian-early Turonian, followed by Santonian-early Campanian spreading in a back arc basin within the closing southern branch of Neotethys.

Acknowledgment: This study is partly based on TUBITAK Project Number 108Y201.

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Selection of lithic raw materials at Neolithic and Chalcolithic sites in southern Romania

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Abstract

This presentation examines the lithic raw materials used to produce the knapped stone artefacts (e.g. blades, scrapers, projectile points) found at 12 sites throughout southern Romania, specifically Liubcova-La Orniţa, Ipoteşti-La Conac, Radovanu-Gorgana I, Vărăşti-Grindul Grădiştea Ulmilor (Boian), Glina (Bobeşti)-Via lui Poleaşcă, Călăraşi-Grădiştea, Bogata-Lac Gălăţui, Dudeşti-Malul Roşu, Izvoarele-Fântânele, Garvăn-Mlăjitul Florilor, Garvăn-Dinogeţia, and Luncavişa-Cetăţuia Tell. These sites range from the Neolithic (Starčevo-Criş, and Dudeşti, Boian and Vinča A & B cultures) to the Copper Age (Vinča C and Gumelniţa A & A2 cultures). The artefacts were compared with geological samples collected along the Lower Danube, where numerous sources of knappable raw materials suitable for producing tools were found. Such raw materials are in particular Cretaceous flint (from chalk outcrops, for example, in Romania at Hârşova, Ovidiu, Peştera, and Murfatlar and in Bulgaria at Nikopol, Ravno, and Chakmaka) and Cretaceous chert (from limestone outcrops, for example, in Romania at Hârşova, Cheia and Remus Oprean, and in Bulgaria at Tetovo, Kriva Reka, and Kiukato). In addition to in situ sources of raw material, pebbles and cobbles were observed along the Lower Danube in the alluvial sediments of the Danube.

Both the artefacts and the geological samples were investigated by means of polarized light microscopy in order to identify possible raw materials used in prehistoric times. All of these materials are composed primarily of microcrystalline quartz. The majority of the quartz is granular but a fibrous variety occurs occasionally. The other components are calcite (often associated with microfossils) and Fe-oxihydroxides, in various amounts. In general, the cherts appear to have more calcium carbonate and a larger and more varied quartz grain size than the flints. Smooth surfaces, more predictable conchoidal fractures and generally higher translucency are more common in flint samples. The chert samples are difficult to distinguish by macroscopic and microscopic means from chert found elsewhere, e.g., in the Carpathian Mts., but the flint is more easily distinguished. Both are distinguishable from flint of the Moldavian Plateau. The results of the artefact analyses indicate that the populations at the settlements studied almost exclusively used locally available materials and imported very little in the way of lithic materials. They were also using a large amount of lower quality local material, suggesting that they were not being highly selective in terms of the quality of the materials.

Acknowledgements: Financial support from the Romanian Ministry of Education and Research (PN-II-ID-PCE-2011-3-0881 project) is acknowledged. The artefacts analysed in this study were from excavations conducted by Dr. Eugen Comşa, and are now housed at the Romanian Academy of Sciences in Bucharest. Access to the artefact collections was obtained with help from Dr. Alexandra Comşa.

Understanding bitumen provenance in Apulian Bronze Age settlements through pottery (15th - 11th century B.C.)

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Abstract

Evidence of bitumen use has been found in several Apulian Bronze Age coastal sites such as Otranto, Roca, Le Pazze (LE), Scoglio del Tonno (TA), Monopoli (BA) and Torre Santa Sabina (BR), but there are no archaeometric data on its geological source or specific use.
Bitumen remains on Apulian Bronze Age pottery from Monopoli and Torre Santa Sabina were investigated by pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS) and gas chromatography-tandem mass spectrometry (GC-MS/MS). The first method was selected because of its sensitivity and its ability to identify the presence of bituminous material.
Archaeological literature points to the Majella deposit (Abruzzo, Italy) and the Selenicë bitumen lake (Albania) as possible sources of bitumen. The depositional environment of the former is marine whereas the latter has lacustrine and deltaic inputs. Tandem mass spectrometry, by permitting us to gather information on the possible geological input by comparing the amounts of terpanes (hopanes) and steranes, and the TPP ratio (C30 tetracyclic polyprenoid isomers (C30TPP)/C30TPP plus C26 27-norcholestanes), has demonstrated its usefulness. 27-norcholestanes were found to be in low amount in both the Selenicë samples and archaeological samples. Moreover, the profiles of terpanes (hopanes) and steranes of the Selenicë samples and those of ceramic samples from Monopoli and Torre Santa Sabina were compared in order to obtain further information on the origin of the archaeological samples. According to chemical indices, the only bitumen deposit matching the archaeological samples is the Selenicë bitumen lake. These arguments are supported by the silt inclusions in the bitumen remains found in the pots and by archaeological evidence at the Monopoli and Torre Santa Sabina sites, such us Aegean pottery finds. They attest to trade links between the two Adriatic coasts in the Middle and Late Bronze Age.
Gas chromatography-mass spectrometry (GC-MS) was also employed to indicate whether there was any deliberate addition of fats to the archaeological bitumen. Such an addition would lower the softening point (about 120 °C) of the Selenicë bitumen. The presence of benzothiophene in the archaeological samples suggests the use at temperatures below 220 °C (the boiling point of benzothiophene). A vessel use in a temperature range up to about 220 °C also excludes its direct contact with flame and points to an indirect heating system (e.g. water-bath).
Taking into account its occurrence in Apulian coastal sites, it is presumed that main utilization of bitumen was for caulking. Only in a few cases, was bitumen used as an adhesive to repair pottery.

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Multidisciplinary studies of glyptic objects from Constantine Schmidt-Ciążyński collection (the National Museum in Kraków, Poland)

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Abstract

Archaeological observations supported by mineralogical data (i.e. gemmological and Raman microspectroscopy, scanning electron microscopy, X-ray diffraction) were conducted to characterize both ancient and modern glyptics objects. These works of art were assembled by Constantine Schmidt-Ciażyński (1818-1889), the famous Polish gems collector in the nineteenth century, and now housed at the National Museum in Kraków (Poland). The collection includes 2517 specimens made of a variety of materials and coming from different periods of time. Within this extensive group, there are more than 2300 cameos and intaglios – engraved gemstones. The set was only partially elaborated and published (a group of gems with signatures of modern artists, Egyptian scarabs and magical gems, a group of Mesopotamian and Iranian cylinders as well as Sasanian seals and some of the Byzantine specimens). Hence, no extensive studies of the whole collection have been carried out, yet.

Since 2012, a new project on Italic, Hellenistic and Roman gems, which involve 800 objects from this collection, has been commenced. The first aim of it was to characterize the material used by ancient gem-engravers. This large group consists of objects made of various stones. The most representative are silica group minerals and rocks. The minerals are mostly represented by colour varieties of quartz (rock crystal, amethyst, smoky quartz) and chalcedony (chrysoprase, cornelian, sard, agate, onyx, sardonyx) and opal. Garnets (pyrope, almandine), and other rare stones (e.g. diamonds, emeralds and amazonite) were also identified. Among rocks, jasper seems to be the most frequently used. Lapis lazuli and marble belong rather to the rarity. Only in one case, artificial material, i.e. glass-paste, has been detected. The results obtained with mineralogical methods were helpful for further studies, i.e. describing, interpreting and finally dating ancient engraved gems.

The project includes also a small group of post-classical intaglios and cameos bearing portraits of Roman emperors and members of their families. Some of these gems are engraved in gemstone doublets (a sort of composite), which seem to be more frequently used in the Classical and Post-classical periods (eighteenth and nineteenth centuries) rather than in the Renaissance and Baroque (sixteenth and seventeenth centuries). This might be due to the use of new sources of stones or the rise of demand for engraved gems in the eighteenth and especially nineteenth century.

Mineralogical data obtained only with non-destructive methods can be treated as supportive for archaeological studies. It seems that only using interdisciplinary methods allows obtaining reliable conclusions in dating engraved gems.

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Copper Age pottery from the Southern Carpathians (Romania): An archaeometric study

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Abstract

One of the main Copper Age cultures within the territory of modern day Romania was the Coțofeni culture. It existed from 5500 to 4500 BP throughout Transylvania, the Southern Carpathians, and the western part of the area between the Southern Carpathians and the Danube. Coțofeni sites are located on river terraces, hill slopes and in caves. The settlement at the Cerişor Cave in the Poiana Ruscă Mountains (Southern Carpathians) provided a large number of artefacts, including ceramic sherds. Our study focuses on compositional and fabric features of 14 pottery shards in order to unveil the technological conditions of firing (temperature) and raw material provenance. The ceramic samples were studied by polarized light optical microscopy and X-ray powder diffraction (XRPD).

Based on the colour of the ceramic body as seen in fresh cuts, the sherds can be classified into two groups: orange ceramics (4 sherds) and gray ceramics (10 sherds). Microscopically, the ceramic body consists of matrix and coarse non-plastic components. The ceramic wall has a mixed texture, with both oriented and chaotic zones, marked by the arrangement of mica lamellae. Optically, the clayey matrix varies from birefringent (4 samples) and birefringent-partly isotropic (8 samples) to isotropic (2 samples). It contains variously-sized clasts, mostly quartz, muscovite and feldspars. Subordinately, small epidote-clinozoisite, staurolite, garnet and chlorite occur. Quartz grains are fissured due to thermal shock or display glassy rims pigmented with iron derived from the matrix. Microcline and plagioclase feldspars show cross-hatched twinning and polysynthetic twinning, respectively. Lithoclasts (quartzites, micaschists, quartzo-feldspathic fragments) and ceramoclasts are frequent.

The XRPD data indicate a fairly uniform mineralogical composition for most of the sherds, with illite-muscovite, quartz and feldspar as the main mineral phases. The intensity of illite-muscovite lines is diminished to various degrees. The samples with isotropic matrix produced diffraction spectra with no muscovite and illite peaks.

Firing atmosphere is suggested by the sherd color: gray for a reducing atmosphere and orange for an oxidizing one. The firing temperatures range between ~800ºC and ~950ºC as indicated by the thermal changes of the minerals and by the modified XRPD patterns.

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Mineralogical characteristics of ancient ceramics from Daute Hill (Albania)

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Abstract

In spring 1970, during the archaeological excavation of a Hellenistic necropolis located at the Hills of Daute, an exceptional sanctuary dedicated to Aphrodite was discovered. The necropolis belonged to the Epidamne-Dyrrhachion (nowadays, the city of Durrës) - one of the most important ancient settlements within the territory of recent Albania. The necropolis was dated to 4th to 2nd century B.C., a period known as the "Greek period". The area has a relief dominated by low hills with gentle slopes and large valleys. Various Miocene and Pliocene sands and shales crop out along the valleys. The riverbeds contain recent alluvial sandy sediments.

The ceramics finds are of particular importance, due to the high number of terracotta figurines, many well-preserved. A number of 45 shards of figurines were studied by means of optical microscopy in polarized light (OM), X-ray diffraction (XRD) and electron microprobe analysis (EMPA), in order to identify the mineral composition and finally to characterize the raw materials and to infer the firing conditions.

Stylistically, the figurines were assigned to two time periods: a) an earlier period, with influence of Greece, i.e. Corfu and Athens, and b) a later period, with influence of southern Italy (Tarent). Despite they generally show a low porous and orange-red-brownish coloured ceramic body, the detailed investigation revealed a large variety of compositions and fabrics. Three main groups were separated based on mineralogical and textural-structural features. All groups show basically an Fe-rich clayey material. The first group is characterized by a carbonate-rich illitic matrix, with mostly quartz and plagioclase, subordinately muscovite and chloritized biotite. Carbonates show signs of partial decomposition. The second group includes ceramic with an illitic matrix embedding quartz, K-feldspar, chloritized biotite and argillaceous clasts. The third group is characterized by a ceramic body showing a much more complex composition, with carbonate-rich illitic matrix and various clasts. The latter consist of quartz, K-feldspar, plagioclase, muscovite, chloritized biotite, various heavy minerals, and lithoclasts (quartzite and basalt). Calcareous foraminiferids, partly decomposed and sometimes replaced by framboidal pyrite, are frequent.

The firing phases are restricted to variable amount of glass. A Ca-rich silicate phase is found in the first and third groups. The results indicate a firing temperature below 900 ºC. Research focused on raw clayey materials in the neighbourhood of the site is ongoing. Even if some of the figurines might have been produced locally, imports from Greek workshops cannot be ruled out.

Ceramic potsherds from Dacian Sarmizegetusa Regia (1st century A.D.): composition, chemistry and provenance

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Abstract

The Sarmizegetusa Regia (Grădiştea de Munte) site is located in the Sebeş Mountains (Southern Carpathians, Romania). It functioned as the capital of Dacia till the Roman conquest in 106 C.E. The settlement consisted of a fortress, a religious area and several residential districts. Within the fortification, pits containing ceramic and glass fragments, coins, iron artefacts, iron slag, charcoal as well as charred seeds were found. Thirty potsherds were studied by polarized light microscopy (OM), X-ray powder diffraction (XRPD) and electron microprobe analysis (EMPA). The major, minor, trace and rare earth elements chemistry was determined for twenty one samples by inductively coupled plasma emission spectroscopy (ICP-ES) and inductively coupled plasma mass spectroscopy (ICP-MS).

The sherds have either a grey or an orange-brown colour. The ceramic body consists of a sintered or partly vitrified groundmass of clay minerals and various fine clasts. Among the latter are quartz, feldspar (mostly alkali-feldspar, less frequently plagioclase), muscovite, biotite, as well as chlorite. Epidote-clinozoisite, amphibole, garnet, titanite, staurolite, rutile, zircon, apatite and an Fe-rich compound occur as accessory phases. Lithoclasts are restricted to quartzite, micaschist, chlorite schist, biotite schist, gneiss and occasionally acidic volcanic rock fragments. The XRPD data indicates the predominance of quartz and feldspar.

EMPA shows an illitic groundmass. Mostly alkali-feldspar was identified, plagioclase being rare. Among the alkali-feldspars, K-feldspar predominates. Overgrowth of albite by alkali-feldspar is common. In most of the samples, there are Fe-rich phases, having significant amounts of SiO_2, Al_2O_3, MgO, CaO and, occasionally, P_2O_5. 'Intergranular bridges' connect clay minerals, lamellae and non-plastic grains. Muscovite, chlorite and biotite do not show much thermal transformation, except for exfoliation or partial melting.

Geochemical data show that all samples are poor in CaO. Based on Al_2O_3 content, a low-Al (LAL) and a high-Al (HAL) group, respectively, were separated. The HAL samples show higher Al, Fe and Mg contents, compared with the LAL group. Si, Ca, Na and P are higher in the LAL sherds.

The overall composition of both, the grey and the orange-brown sherds, points to similar illitic clays as raw materials. The most likely candidates for quarrying potter's clay would be outcrops of a Badenian age north of the site, in the Transylvanian Basin. As it could be inferred from the pot surface marks and the oriented texture of micas within the ceramic wall, the vessels were produced using a potter's wheel. The firing was variable in regards to both temperature and atmosphere. Some of the vessels were produced at temperatures <800ºC. Most of the pottery, showing advanced vitrification and frequent K-feldspar overgrowth, was fired at higher temperatures, ranging from 850ºC to almost 1050ºC. The atmosphere was reducing for the grey pots and oxidizing for the orange-brown ones, respectively.

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Moulds for terra sigillata ceramics produced at Micăsasa, in Roman Dacia (2^{nd}-3^{rd} c. A.D.)

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Abstract

At a settlement in Roman Dacia, dated to the 2^{nd}-3^{rd} c. AD and located at Micăsasa in the middle of modern-day Romania, a large number of ceramic shards were discovered. Twenty six pottery kilns, clay extraction and waster pits, a large quantity of pottery fragments and in particular the ceramic moulds, point to the existence of large pottery workshops. Of special interest are the fired clay-based moulds used to obtain the famous Roman luxury pottery known as terra sigillata. North-west, north and north-east of the archaeological site, there are large outcrops of light yellow Neogene calcareous silty mudstone which were supposedly used as sources for ceramic raw material. The aim of the study was to compositionally investigate twenty five mould shards, by means of optical microscopy in polarized light, X-ray powder diffraction and electron microprobe analysis (EMPA).

The shards are around 1 cm in thickness and have light colours, mostly pink to light brown. In all samples, the outer surfaces of the ceramic walls are relatively rough, but the inner ones, with various intaglio motifs, are smoothed. Microscopically, the ceramic body consists of a microcrystalline matrix with scarce isotropic areas, embedding quartz, feldspars, muscovite and biotite grains, and a dispersed Fe-rich phase. Carbonate (calcite) clusters, as well as isolated grains are characteristic. Heavy minerals, quartzite, micaschist and quartzo-feldspathic fragments are rare.

The EMPA data, combined with back scattered electron (BSE) images, provided information on mineral chemistry and thermal changes. The character of the groundmass, based on the results of EMPA, is illitic. Some of the calcite grains show spherical bubbles, others have a ‘decomposition’ aureole. Micas are either partly melted or exfoliated. Feldspars show also some weak signs of melting. There is a depletion of K in potassium feldspars. The illitic groundmass shows a trend towards Ca-rich and Al-poor compositions, compared to muscovite. Quartz grains incorporate foreign elements, e.g., Al, Ca and K.

The Roman settlement of Micăsasa produced, among other types of pottery, imitations of the one of the highest quality pottery types in Antiquity, terra sigillata. The moulds were obtained from a fine, calcareous illitic clay. Contradictory features, such as the coexistence of unchanged calcite grains - calcite with decomposition signs, exfoliation - untransformed micas and the partial melting of some minerals, are characteristic. These prove high thermal difference within the same pot, which might range up to more than 100 ºC, as well as a short firing time. On average, the moulds were obtained by firing at a temperature higher than 800 °C but not exceeding 850-900 °C.

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Mineralogy of Late Upper Palaeolithic red ochre from Lovas, Hungary

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Abstract

Palaeolithic mining pits for painting material were discovered near Lovas, Hungary in the course of quarrying dolomite. The paint extracted is 'ochre' – a weathering product of Fe-rich dolomite. Ochre is the colloquial term used by archaeologists to describe soil or rock containing red or yellow Fe oxides or hydroxides. During Upper Palaeolithic red ochre has been used in cave paintings and ritual burial contexts. Ochre was widely used by Middle and Upper Stone Age hunter-gatherers in Europe, Africa and North America, as both internal and external medications, food or wood preservatives, insect repellents, tanning for hides, and other purposes. In Hungary, the earliest remain of red pigment was found on a polished mammoth tooth plate recovered at the Middle Palaeolithic site of Tata, dated to the Last Interglacial (125–90 kyr). Apart of this exceptional occurrence, ochre is found at sites of Ságvárian and Epigravettian (ca. between 20 and 10 ka BP).

The Lovas ochre mine operated between 35 and 11 ka BP. The excavations exposed a series of well-preserved bone artefacts (elk bones, fragments of antler) and stone tools, deposited in a mountain slope during the very Late Pleistocene interglacial period.

This work analyses the compositional signature of red ochre samples using the basic analytical methods for mineralogy: polarized light optical microscopy, X-ray powder diffraction and scanning electron microscopy with energy-dispersive spectrometer (SEM-EDS). The quantitative evaluation of the XRD patterns revealed that the prevailing mineral is dolomite (~80 %) accompanied by some quartz (~10 %), kaolinite (~5 %) and muscovite (~1 %). The rest (4 %) is hematite, which gives the red colour of the ochre. SEM-EDS shows that red ochre contains Ca (52.1 wt.%) and Mg (4.2 wt.%) indicating the dolomite; and Fe (22.7 wt.%) as hematite.

This is a local material that possibly was exported from the site, but no evidence has found yet. The results obtained permit the identification and characterization of this ochre type and, furthermore, allow the establishment of mineralogical proxies for the study of questions related to ochre characterization, formation processes and provenance. Future studies can be expected to yield comparable finds from Upper Palaeolithic settings, either during fieldwork or as the result of the reanalysis of old finds.

Local and exotic building and decorative stones in historical castles of SW Poland: Results of reconnaissance field inspection

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Abstract

Our joint Austrian-Polish research project aims at investigation on material-cultural heritage connected with exploitation and usage of natural building and decorative stones in Central Europe, based on case studies from Western Austria and SW Poland. Special attention is given to the usage of local rocks, as well as exotic decorative stone materials traded across Europe in different historical periods. The results are expected to highlight historical and social aspects of natural stone usage through centuries: stone-mining heritage, inter-regional trade links, as well as social customs, preferences and relationships. The recognized state of preservation of architectural stone elements in the castles should be useful in case of renovation. Educational and tourist potential of historical stony castles and palaces is also addressed in our project.

We have started our joint research with the inventory of historical stony castles in SW Poland and with selecting unique objects for detailed interdisciplinary studies (combining historical aspects, petrographic investigations and weathering/biodeterioration issues), aiming first at determination of the rock types and their provenance. It should be noted that this part of Poland is well known for its building stone deposits and that the most famous Silesian sandstones, granites, and marbles have been intensely used, both locally and also exported to other countries. Vice-versa, exotic stone materials were imported to embellish the architectural decoration of palaces and castles in this area.

Out of the total number of ca. 100 historical castles and palaces in SW Poland, many are in ruins or in very bad condition, mostly because of the damage and plundering during and after the Second World War. Based on the available data, we have selected 30 of them for preliminary inspection and documentation. However, in most of them, the original architectural decoration and endowment has not been saved, due to damage, dismounting and theft, and/or major re-building. Fortunately, still a few castles have preserved some of their original values of stone architecture.

Ten of the largest and best preserved castles are excellent examples of common usage of local stones as construction and decorative materials, e.g.: Czocha (early XIV c., rebuilt in 1909-14) – mainly local gneiss and micaschist; Grodziec (XIV c., rebuilt 1906-08) – Neogene black basalt ashlars combined with yellowish Cretaceous sandstone blocks and red bricks; Świny (XIII/XIV c.) – Permian rhyolites with addition of Neogene basalt and Cretaceous sandstone; Książ (late XIII c., renovated in late XX c.) – Devonian/Carboniferous graywacke plus some sandstone, granite and basalt; Kamieniec Ząbkowicki (XIX c., under renovation) – outstanding 'mosaic' of red bricks and several local stones – micaschist, granite, sandstone and basalt); Otmuchów (early XIII c., rebuilt in 1820?) – erratic cobblestone, granite and sandstone; Moszna (XVIII c.,; renovated 1912-14) - Triassic limestone, granite, sandstone and marble.

Only three of these castles, i.e. Czocha, Książ and Moszna, have preserved significant amount of the original stone decoration, including a range of exotic materials, such as colourful limestones and marbles, serpentinites, imported sandstones etc. The sources of the exotic decorative stones can be determined either from historical documents or detailed comparative petrographic studies which are in progress.

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Agates from Kerrouchen (the Atlas Mountains, Morocco)

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Abstract

In recent years, Moroccan agates from the Atlas Mountains have drawn the interest of worldwide gems collectors. These unique gems occurring within basic volcanic rocks make a variety of forms. The most frequently are nodules, but veins are also found. Each agate-bearing region has specific gems, characteristic only to one locality and differing from others found in Morocco. Their colour and internal structure are diagnostic. Some of the solid inclusions, e.g. copper sulphides, Fe-compounds, found in the agates are probably related with of the ore deposits in the area.

The agate nodules from Kerrouchen (Khénifra Province, Maknés-Tafilalet Region) occur in Triassic basalts. The nodules may reach up to 30 cm in diameter and are monocentrically zoned. The bands are coloured in pastel pink, grey, white and yellow, extremely rare in more intense colours. Infiltration canals ('osculum') are present. 'Plume' and 'dendritic' agates, coloured in brown and red, are very characteristic of Kerrouchen area. All agates have heterogenic structure, built of a microcrystalline variety of silica, generally defined as low alpha quartz, but also contain some amounts of moganite. Due to their size, colour and zoning patterns, the agates from this locality are valuable museum pieces.

Agates from Kerrouchen were investigated with polarizing microscopy, scanning electron microscopy with EDS detector, supported by Raman microspectroscopy.

Monocentric agates having white and grey bands consist mainly of low alpha quartz and subordinately moganite, with distinctive 460 cm^{-1} and 501 cm^{-1} marker Raman bands, respectively. Linear profile of agates (traverse across banding) indicates that moganite concentrates in the grey zones.

'Plume' agates, with characteristic brown and red bands, contain a high amount of Fe oxides and oxihydroxides, as observed at SEM. The Fe-rich phases form both regular and irregular patterns, as well as veinlets, spherical concretions and lenses within the nodule. Occasionally, irregularly-shaped aggregates of copper sulphide are observed. Raman microspectroscopy revealed that Fe-compounds are mainly represented by hematite and goethite. The presence of hematite is marked by bands at 225, 247, 293, 410, 498 and 605 cm^{-1}. The intensive bands at 293, 410 and 605$cm^{-1}$are assigned to Fe-O symmetric bending vibrations (E_g mode), whereas the weaker bands at 225 and 498 cm^{-1} are related to symmetric stretching vibrations of Fe-O (A_{1g}). Goethite is evidenced by marker bands at 299, 400 and 550 cm^{-1}. The most intensive band at 400 cm^{-1} is related to Fe-O-Fe/-OH symmetric stretching vibrations. The others bands are attributed to Fe-OH symmetric bending and Fe-OH asymmetric stretching vibrations, respectively. Rutile was also identified within the agates with characteristic bands at 140 (B_{1g}), 436 (E_g) and 603 cm^{-1} (A_{1g}). These mineral inclusions are sometimes accompanied by carbonaceous material marked by 1297 and 1560 cm^{-1} bands.

The hydrothermal Si-rich and Fe-moderate post magmatic fluids infiltrating the volcanic mafic rocks initiated the formation of agates in Kerrouchen. Copper sulphides and titanium oxides originally present in host rocks were then incorporated into the crystallization of agates zones. The origin of carbonaceous matter present in 'plume' and 'dendritic' agates may be both of hydrothermal or hypergenic activities.

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Alabaster from the Ukrainian Carpathian Foredeep in the architecture of Cracow

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Abstract

Alabaster, a rock with low hardness, high coherence, fine-crystalline structure and the property to achieve an optically "warm" surface when polished, was used since Antiquity as a sculpting, decorative and architectonic stone. Alabaster applied in the architecture of Cracow (Poland) is mainly of the Middle Miocene age (Middle Badenian) and comes from the deposits located within the Ukrainian Carpathian Foredeep, chiefly along its northern margin, the so-called "Podolia rim". Usually, it forms layers with the thickness of 10 to 40 cm. This alabaster has shades of white, yellowish, willow green, brownish, usually with differing spots or veins. Often the rock is brecciated and partly semi-transparent. It was called the Ruthenian-, Polish-, or Lwów "marble" and was quarried in Polish Crown's Rus' (part of the former Polish-Lithuanian 'Commonwealth') starting with the 16th century. It was quarried in the region of the middle course of the Dnister River and its tributaries, from the vicinity of Lwów (Lviv) as far as Chocim (Khotyn), with the most known site of its exploitation at Żurawno (Zhuravno). Another quarry were located at Wasiuczyn (Vasiuchyn), Czerniejów (Cherniiv), Kąkolniki (Kukilnyky), Kołokolin (Kolokolyn), Brzozdowice (Berezdivtsi), Kałusz (Kalush) and Buchaczów (Bukhachivtsi). The exploitation finally ceased in the second half of of the 17th century as a result of devastating riots during the Cossacks' Chmielnicki Insurrection. Further raids of Tatars and long-lasting wars with the Ottoman Empire made impossible quarrying till the end of the 17th century.

Quarrying and working of alabaster at Zhurawno began again in Poland after the First World War, being supported by the family of Duke Czartoryski. In a workshop called 'Alabastrownia', the rocks extracted were cut, shaped and finally polished. Not only professional artisans such as master Bertini of Volterra (a center of alabaster processing in the Apennines), but also eminent architects and sculptors, e.g. Józef Szostakiewicz, an architecture engineer, and Jadwiga Horodyska, a sculptresswere employed here. These artists created a unique "Żurawno style", represented by sophisticated fancy artefacts as well as high-class decorations for churches and private buildings. After the Second World War, between 1960 and 1990, the alabaster deposit at Zhuravno was quarried for producing façade tiles. Currently, this historic site for alabaster quarrying is abandoned and faces total degradation.

Alabasters have been used since Middle Ages in the monumental architecture of Cracow. It was applied mainly as a sculpting material, in architectonic details and sepulchral art by Italian (e.g. Gian Maria Padovano, Girolamo Canavesi, Santi Gucci Florentine, Giovanni de Simon, Andrea and Antonio Castelli, Bartholomeo Stopano, Sebastiano Sala), Dutch (Herman Hutte, Heinrich Horst, Thomas Nikel), German (Andreas Bemer, Hans Pfister, Johann Georg Lehner), Danish (Martin Christian Peterson) and Polish (Jan Michałowicz of Urzędów, Jan Biały, Jakub Trwały, Marcin Bielawski) artists, particularly throughout the Renaissance period. The contribution of alabaster and the ways of its using are much diversified in time, while its provenance is, generally, unknown. The most representative sculptures of the Miocene alabaster are present in Cracow as sacral objects, e.g. in the Wawel Cathedral, St. Mary's Church, the churches of Dominican and Missionary Fathers and Discalced Carmelites. Alabaster was used there to produce bas-relief and epitaph plaques, as the material of tombs, ciborium, altars, statues and as many other architectonic details. This rock is also present as decorative polished slabs in some lay buildings, e.g. of the Jagiellonian Library.

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Without Mount Olympos, would there be a Meteora? Early Cenozoic Crustal Exhumation and Rapid Sedimentation across Thessaly, Greece

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Abstract

Mount Olympos and Meteora are two of the most famous and popular heritage sites of Greece: Olympos is, of course, the home of the ancient Gods, and Meteora is a UNESCO World Heritage site. Both sites owe their cultural legacy to extraordinary geological origins. Olympos, the highest mountain of Greece at 2917 m, is now recognized as an exhumed remnant of the Apulian ribbon continent (fragment of Africa), subducted beneath the Pelagonian outlier of the Pangaean supercontinent during plate collision dating from the mid-Jurassic to early Tertiary. Meteora consists of a sedimentary geomorphic paradise of Oligocene-Miocene conglomerates sculpted during the recent ice ages into rock spires, many of which host Byzantine Monasteries. Olympos is situated jutting above the Aegean coast along the eastern margin of Thessaly; Meteora is found in western-central Thessaly, nearly 100 km west of Olympos. It would seem that these two heritage sites, so diverse in geological origin, would be unrelated phenomena. Our recent observations, however, indicate an immediate cause/effect relation between the two sites.

Meteora is located within the Mesohellenic Trough (MHT), a compressional sedimentary basin of late Eocene to middle Miocene age. The majority of sediments are deltaic, including flyschoid deposits hosting both deep-water foraminifera and abundant fresh-water plant fossils in the same outcrops. Coral-bearing units persist into the youngest MHT sediments (upper to mid-Miocene). The provenance of the MHT sediments was to the East, derived from rivers crossing the emerging Pelagonian continent. Syn-tectonic deformation within the MHT attests to an uplifting eastern continental margin.

The exhumation of the Pelagonian Margin dates to the Eocene based on ages of zircon and apatites found within MHT sediments. Core complex migmatites within Pelagonian gneiss are also Eocene in age. Blueschists are absent along the Pelagonian margin with the MHT, and most Tr-Jr platform carbonates are not highly deformed. Early exhumation in the Eocene was characterized by rapid cooling, which was significantly subdued in the Oligocene. However, the doming and exhumation of the Olympos-Ossa subducted Apulian carbonate platform likely occurred around 18-15 Ma based on the apatite data, and this process appears to have been an abrupt event. The exhumed Olympos rocks are enveloped by blueschist facies rocks, and the Apulian carbonates are mylonitic in texture.

At about the Oligocene-Miocene boundary an advent of coarse conglomerates and turbidite slurries occur over the MHT terrain: the thickness of these units ranges from tens of meters to over 400 m in the Meteora area. The cobbles within the Meteora sediments are largely core complex gneiss, some of boulder scale, though the nearest outcrops of similar Pelagonian outcrops are at least 25 km distant. We have located several fragments of blueschist-facies rocks that could only have come from Olympos. These sediments represent a rapid outpouring of high-energy deposition: cobble rounding must have occurred in rivers, but these were then redeposited as matrix supported turbidites pouring through possible submarine canyons into the mid-late Miocene sea.

The timing of this influx coincides with the doming and exhumation of Olympos; its rugged mountains essential for the high-energy fluvial and marine environment represented in the Meteora conglomerates. In short, had there been no Mt Olympos and its rapid uplift, there would be no Meteora.

Phase and chemical composition of ancient Thracian pigments from Bulgaria: the cases from tumulus no. 21, Eastern Necropolis of Sboryanovo National Reserve and from Shushmanets tomb-temple

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Abstract

Pigments from two Thracian tombs from different geographic and historical regions of Bulgaria – from the Royal Necropolis of the Getae in northeast Bulgaria (Sboryanovo National Reserve, tumulus no. 21) and from the necropolis of the Odrysian Kingdom in the Kazanlak valley (Shushmanets tomb), are studied and compared. It is found that, besides similarities in the used materials like hematite as red pigment and lime as binding material, the two tombs show some differences. In the Sboryanovo (tumulus no. 21), the blue pigmentation results from mixing of lime and fine grained dark-coloured minerals as rutile, ilmenite, magnetite, chrome-spinel, jacobsite, pyrite, cerussite and manganese-oxides. In the Shushmanets tomb, the blue colour is achieved via mixing of lime material and ground charcoal. All pigments in the Sboryanovo tomb no. 21 are used as paint applied in a thin layer, while in the Shushmanets tomb, the pigments are used mainly for colouring the initial mortars.

Keywords: *red-, light-blue-, dark-blue-, white pigments, Thracian tombs*

Introduction

The ancient Thracian tribes that inhabited the territory of the Balkan Peninsula left a rich archaeological heritage, evidenced by numerous ground tombs. Their appropriate restoration and preservation need information on the mineral and chemical composition and provenance of the used raw materials, as well as on the techniques applied for building, plastering and painting. The present study aims at clarifying the phase and chemical composition of the pigments used in the decoration of two Thracian tombs of IV-III B.C. situated in two different geographic and historical regions of Bulgaria (Fig. 1a): (i) the ground tomb under tumulus no. 21 of the Eastern Royal Necropolis of the Getae in the Sboryanovo National Reserve, northeast Bulgaria (Gergova 2008); and (ii) the tomb-temple under Shushmanets tumulus, a part of vast necropolis of the Odrysian Kingdom in the Kazanlak valley. For the present study, all samples of the aforementioned tombs were provided by the Center for Restoration of Art Work (Sofia, Bulgaria).

Information on the archaeological objects

The ground tomb under tumulus no. 21 of the Sboryanovo National Reserve is set within Quaternary loess – widely spread sediments in the region (Filipov 1994). The tomb consists of two premises: in the first one, remains of ritual funeral of horse and dog are found; in the second, interior premise on white floor, there is a decorated eschara (altar) (Fig. 1b) representing truncated pyramid with incised geometric ornaments coloured in red and dark-blue. The substrate below the pigmented layer of both, the eschara and floor, is beige-yellowish, fine-grained, porous, weakly cemented clayey loess (Tarassova et al. 2013).

The tomb-temple under the Shushmanets tumulus is an example of architecture style typical for the South Thracian areas. It consists of a wide corridor, antechamber with a semi-cylindrical vault supported by Ionic column, and a circular main chamber (tholos) with vault pillared by Doric column. The entrance into the chamber was closed in ancient time with a decorated stone door. All premises (their walls, floors and ceilings), the columns and the door are built up of manually worked biotite granite and covered by two or one coat plaster (Tarassova et al. 2012). At present time, the plaster is well preserved on the Doric column, on a part of the walls and the floor of the antechamber and the tholos, and on the stone door. The plaster is white, except several places of the frieze in the antechamber where it is light-blue (Fig. 1c) and on the stone door where is red (Fig. 1d).

Experimental

Three samples from the eschara (Sboryanovo National Reserve) – the white, dark-blue and red

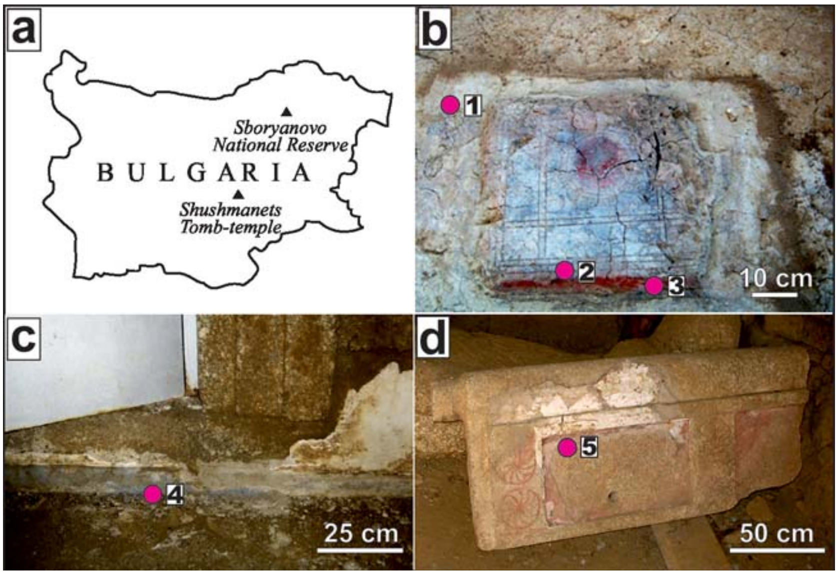

Figure 1. (a) Location of the two archaeological sites studied, on the map of Bulgaria; (b) eschara (altar) from the Sboryanovo National Reserve; (c) antechamber, and (d) rock door of the Shushmanets tomb-temple. Rings and numbers on figures indicate the places of sampling.

pigmented materials (Fig. 1b), and two samples from the Shushmanets tomb – the light-blue and red coloured materials (Fig. 1c,d) have been studied in the present work. Small pieces (0.1-0.05 mm) of the pigmented materials were carefully extracted from the samples using binocular optical microscope, then mounted on specimen stubs and coated with carbon or gold for investigation of their micro-morphology and chemical composition on a ZEISS EVO 25LS scanning electron microscope (SEM) equipped with an EDAX Trident analytical system. Secondary electrons (SE) and backscattered electrons (BSE) images and energy dispersive (EDX) electron probe microanalyses were obtained at 20 kV acceleration voltage. Petrographic analysis of thin sections of coloured plasters was completed on a Leitz Orthoplan-Pol optical microscope. A part of the materials was examined with X-ray powder diffraction (XRPD) using a D2 Phaser Bruker AXS diffractometer (CuKα radiation, 2θ range 4-40^o, scan step of 0.05^o sec^{-1}). All investigations were performed in the Institute of Mineralogy and Crystallography, Bulgarian Academy of Sciences (Sofia).

Results and discussion

Pigments of eschara *(ground tomb no. 21, Sboryanovo National Reserve)*

1. White pigment

The white layer is formed via whitewashing. SEM and EDX examinations reveal that the material consists of lime binder and filling material (30-40 vol.%). The lime consists of micrometer-sized (3-8 μm) scalenohedral calcite crystals, while filling material is a mixture of quartz, potassium feldspar and non-burned chalk including pieces of coccolith debris (Fig. 2a). Chalk of Late Cretaceous age is widespread in northeastern Bulgaria (Filipov 1994). In EDX spectra of the lime binder, besides the X-ray lines of Ca, weak peaks of Si and Al are identified being related to terrigenic constituents of the used raw lime material.

2. Dark-blue pigment

The dark-blue decoration was obtained by applying a mixture of hydrated lime as binder and fine-grained (5-15 μm) blend of dark-coloured minerals as filling material (Fig. 2b). The following phases have been identified: rutile, ilmenite, magnetite, chrome-spinel, jacobsite, fromboidal pyrite, cerussite, manganese-oxide gels. Most of these are typical of heavy fractions of the river sediments in territories with geology dominated by basic and ultrabasic rocks. Cerussite is a common secondary supergene mineral formed on galena. Framboidal pyrite is found in coastal sediments, marsh soils, beach sands and coals.

3. Red pigment

Although the red coloration affects a layer with thickness of 0.1-0.5 mm, the most intense red colour is observed on the surface of the samples as a very thin (10-20 μm) and dense coat that is well recognizable in BSE images as bright areas (Fig. 2c). According to EDX analysis, the pigment is an iron oxide – most likely hematite. The traces of arsenic detected in hematite indicate its provenance in the oxidation zone of an iron sulphide deposit. The substrate of clayey loess below the dense hematite layer consists of quartz, montmorilonite, K-feldspar, mica, dolomite, calcite, dolomite, chlorite, manganese gels and coals.

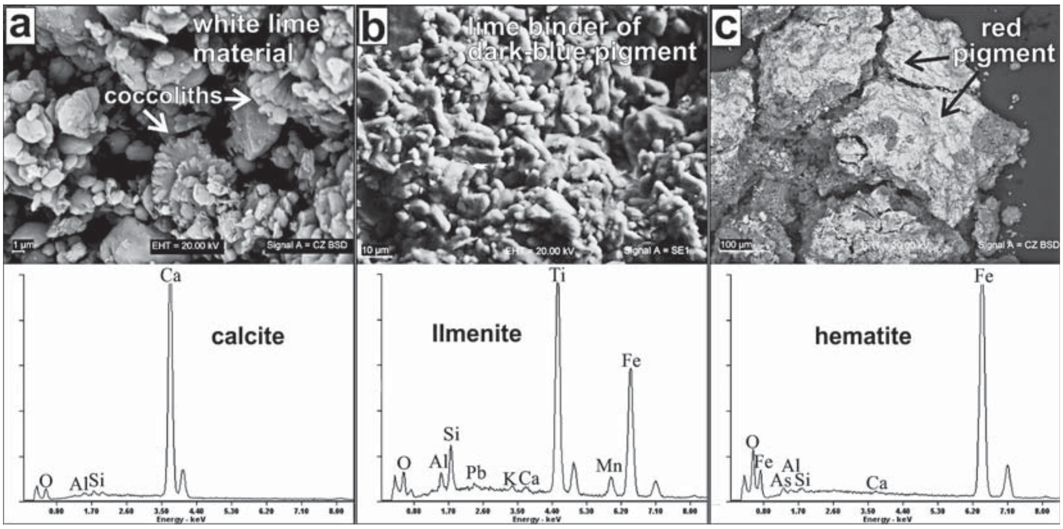

Figure 2. (a) BSE image and EDX spectrum of white lime material (white pigment); (b) SE image of lime binder for dark-blue pigment and EDX spectrum of ilmenite as a constituent of dark-blue pigment; (c) BSE image and EDX spectrum of red pigment (hematite). Eschara, ground tomb № 21, Sboryanovo National Reserve.

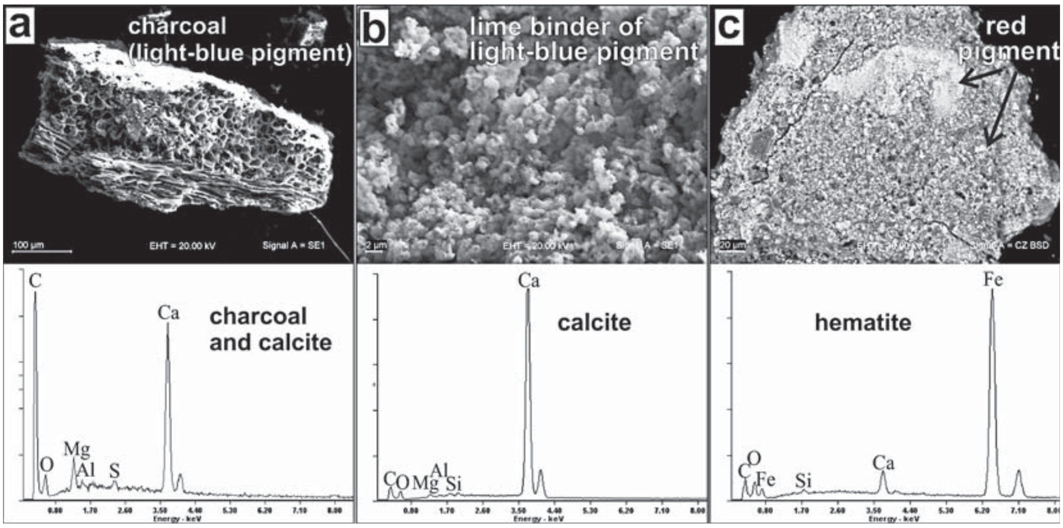

Figure 3. (a) SE image and EDX spectrum of charcoal and calcite in the light-blue pigment (plaster in the antechamber frieze); (b) SE image and EDX spectrum of lime binder for light-blue pigment in plaster of the antechamber frieze; (c) BSE image and EDX spectrum of red pigment (hematite) on the stone door. Shushmanets tomb-temple.

Pigments of Shushmanets tomb-temple

4. Light-blue pigment of antechamber frieze

The light-blue pigmentation is not restricted to a thin upper layer but affects the whole coat of the plaster in the antechamber frieze. Such a distribution suggests that the pigmenting material have been added directly into primary mortar used for the coat. The mortar consists of lime as binder and grains of calcite, dolomite and limestone as aggregates. The only coloured material found in the plaster studied is ground charcoal (Fig. 3a). In combination with the prevailing white lime material i.e. calcite (Fig. 3b), the fragments of charcoal gives a bluish colouring effect to the plaster.

5. Red pigment of the stone door

The red pigment is found in the upper compact and intense red layer with a thickness of about 0.1 mm, as well as in the underlying coat of the plaster with light reddish to pink nuances (Fig. 3c). The plaster is mainly composed of lime binder and grains of calcite, dolomite and limestone. The red and reddish colour correlates with the content of Fe_2O_3 which is up to 4.5 wt.% in the plaster layer, and up to 73 wt.% in the intense red layer. It suggests the presence of hematite (Fig. 3c), which is further confirmed by XRPD. Besides hematite, the upper red layer contains also calcite as lime binder material. Due to micrometric inclusions of magnetite within hematite, the whole material is fairly magnetic. This peculiarity of hematite supports the identification of Precambrian chlorite-sericite schists of the Berkovitsa unit with non-economic magnetite-hematite ore deposits cropping out in the neighbourhoods as source of the red pigment (Kostov 1949).

Conclusion

Except of the ground charcoal used in the Shushmanets tomb, all other pigments applied in the two Thracian tombs are natural minerals ('earth pigments'). Based on the mineralogical features of the materials, it seems that mainly local raw materials have been extracted and used as pigments in the Shushmanets tomb. Nevertheless, except of the white pigment, most of the pigments from the Sboryanovo tomb no. 21 were imported from other regions in the area of the Royal Necropolis where there are no suitable ore/rock sources for hematite and other dark coloured minerals. There are some similarities and differences in the phase and chemical composition of pigments used in the two tombs, as well as in the techniques applied by the ancient Thracians. For example, the hematite, although being of different origin, is the only red pigment used in both tombs. The blue pigments in the two tombs are essentially different. In the Sboryanovo tomb no. 21, the blue pigmentation results from mixing of lime and fine grained blend of different dark-coloured minerals, as rutile, ilmenite, magnetite, chrome-spinel, jacobsite, pyrite, cerussite and manganese-oxides. In the Shushmanets tomb, the blue tint is achieved by mixing of lime and ground charcoal. Two distinct ways of application of pigments are observed in the two tombs. All pigments in the Sboryanovo tomb no. 21 are used as a part of paint applied in a thin layer. In the Shushmanets tomb, the pigments are used mainly for colouring the initial mortars and only for the upper red layer a dye consisting of hematite and binding lime was used.

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Insights in the technology of manufacture and provenance of ceramic vessels from the necropolis of Hellenistic Issa (Middle Adriatic, Croatia)

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Abstract

Archaeometric analyses were carried out on 42 ceramic sherds originating from Issa, an ancient Greek settlement in the East Adriatic area, established on the island of Vis in the Late Classical times. All sampled ceramic material is associated with the funeral context of Issa, and formerly belonged to vases that as grave goods accompanied the tombs on the locality of Vlaškanjiva (Eastern Issean necropolis). Given their functional context, the selected vases comprise various types of tableware used for drinking or pouring and dipping, cosmetic boxes as well as small containers for oil. According to the stylistic, morphological and pottery fabric criteria, the recovered ware was classified as red-figured, black-slipped, grey-slipped, red-slipped, plain painted, plain, and relief ware, as well as Alto Adriatico and Gnathia pottery. The samples of presumed local manufacture or of imported origin were selected to cover all the mentioned classes, dating from the 4th-1st c. BC. The aim of this study is to characterise the ceramic material both mineralogically and geochemically in order to inferr the local manufacture technology and artefacts' provenance. Wefurther aim to describe the socially embedded context of ceramic production and seaborne pottery trade in Issa during the Hellenistic period. Polarized light optical microscopy (OM), X-ray diffraction (XRD), scanning electron microscopy (SEM) and X-Ray fluorescence (XRF) were used for the study.

The XRD identified quartz, Al-rich diopside, plagioclase, K-feldspar, 10 Å mica-like phyllosilicate and hematite in the ceramic body. Minor pigeonite, gehlenite as well as 14 Å and 15 Åclay minerals also occur. Optical microscopy and SEM analyses show that all the samples consistof an optically isotropic groundmass, yellow to dark in colour, embedding various amounts of non-plastic grains. Two artefacts are featured by large amount of fossil fragments, made of either micritic to palisade calcite (bivals, bryozoan, and various foraminiferas) orsilica (radiolarians). The non-plastic inclusions show obvious signs of firing such as exfoliation, melting bubbles, or chemical depletion. For instance quartz is frequently featured by the decrease of Si toward its rims and the incorporation of elements, like Al, K, Ca, and Fe, whereas calcite underwent a complete thermal obliteration. Most striking thermal alterations are shown by mica whereby post to the exfoliation and enlargement of its 001 planes, whereas the Fe-rich phase starts to emerge along the exfoliation margins. Firing temperatures for specimens containing calcite are inferred to be moderate, reaching 700 °C, whereas for those showing newly-formed clinpyroxene, gehlenite, and metastable mica, temperatures might have exceeded 900 °C.

Statistical treatment of XRF chemical data using the principal component and linear discriminant analyses show two discrete groups of artefacts defined by the correlation patterns of trace elements, mostly of those related to magmatic processes (Cr, Ni, Nb). Corroborated by stylistic analyses we interpret both groups to have had a local origin, being produced from essentially two types of raw material – the illite rich terra rossa and the clays formed at the expense of magmatic rocks emerging near the city of Komiža. The rest of analysed potsherds that do not correspond to established groups of local potteryis classified as imported Gnathia and Alto Adriatico wares. They must have provenanced from south and north of Italy respectively, as our preliminary archaeometric results indicate. For two potsherds marked by (1) the large amount of fossil fragments, (2) the unusually high CaO (~30 wt.%) and low SiO_2 (9 wt.%) and Fe_2O_3 (5 wt.%) contents, as well as (3) the peculiar mineralogy featured by smectite presence and lack of feldspar, the first analyses show a possible import from Levant, which in the future needs to be further investigated.

Integrated foraminiferal and radiolarian biostratigraphy of the youngest (Late Albian through Late Cenomanian) sediments of the Tatra Massif, Central Western Carpathians

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Abstract

The foraminiferal and radiolarian biostratigraphy of the youngest sediments in the Tatra Massif (Central Western Carpathains), have been studied in selected sections containing marly and clayey sediments of the Zabijak Formation (Polish part of the Tatra Mountains). Benthic foraminifers, dominated by agglutinated species, occur abundantly throughout the studied succession, while planktonic foraminifers are generally sparce. Five planktic and two benthic foraminiferal zones have been recognized. The marly part of the Zabijak Formation (Zadnie Kamienne Member and lower part of the Pisana Member) comprises the *Pseudothalmanninella ticinensis* (Upper Albian) through the *Rotalipora cushmani* planktic foraminifera zones, and the *Haplophragmoides nonioninoides* and *Bulbobaculites problematicus* benthic foraminifera zones. The uppermost part of the Zabijak Fm. consisting of numerous clayey turbiditic layers with hemipelagic clays does not contain stratigraphic markers. The radiolarian species were recognized exclusively in the Lower Cenomanian part of the Zabijak Fm. Radiolarian assemblages represent *Holocryptocanium barbui-Holocryptocanium tuberculatum* radiolarian Zone.

Key words: *Albian–Cenomanian, Tatra Massif, biostratigraphy, foraminifera, radiolaria*

Introduction

The Tatra Massif is the highest part in the Central Western Carpathians (up to 2655 m a.s.l.; Fig. 1A,B), built of two main rock systems: Paleozoic crystalline core and Early Triassic–Late Cretaceous sedimentary sequences which belong to several tectonic units, including the High-Tatric autochtonous cover and overthrusted High-Tatric and Sub-Tatric nappes. The youngest part of the sedimentary strata is referred to the Zabijak Formation (Krajewski 2003), which contains marls, marly shales and silty/sandy turbidites in its upper part. Although the biostratigraphy of the Zabijak Formation has been studied intensively, most of the published reports are devoted to its Lower–Upper Albian basinal units, represented by basinal conglomerates and various types of limestones (summary in Bąk and Bąk 2013).

The age of the youngest sediments of the Zabijak Formation is still poorly constrained. The available biostratigraphical data, published so far, suggest its Albian through the Middle Turonian age (see disscusion in Bąk and Bąk 2013), although the only Albian age is well documented. The main reason is that these deposits are tectonically arranged, especially their uppermost part which consists of soft marls and shales. The present study provides foraminiferal and radiolarian data from the middle and upper parts of the Zabijak Formation, with the aim of opening a discussion on the age of the youngest deposits of the Tatra Massif.

Material and methods

Fourty-seven samples have been collected from four sections (Fig. 1B,D). Three sections, located in the Dolina Chochołowska valley, on the Ku Stawku pass (between Stoły Hill and Raptawicka Turnia Mt), and in the Dolina Kościeliska valley (Hala Pisana alp), represent the autochtonous unit. The section in the Dolina Miętusia valley (Żleb Kobylarz gully) belongs to the allochtonous unit (Czerwone Wierchy nappe). The youngest deposits consist of pelagic succession of marls (Zadnie Kamienne Mb.), passing upward to marly shales intercalated with thin-bedded silty/sandy turbidites (Pisana Mb.). Deposition of these sediments took place on a submarine Tatric Ridge and its southern slopes to the Križna Basin (Fig. 1C), under neritic–bathyal depths, above the CCD.

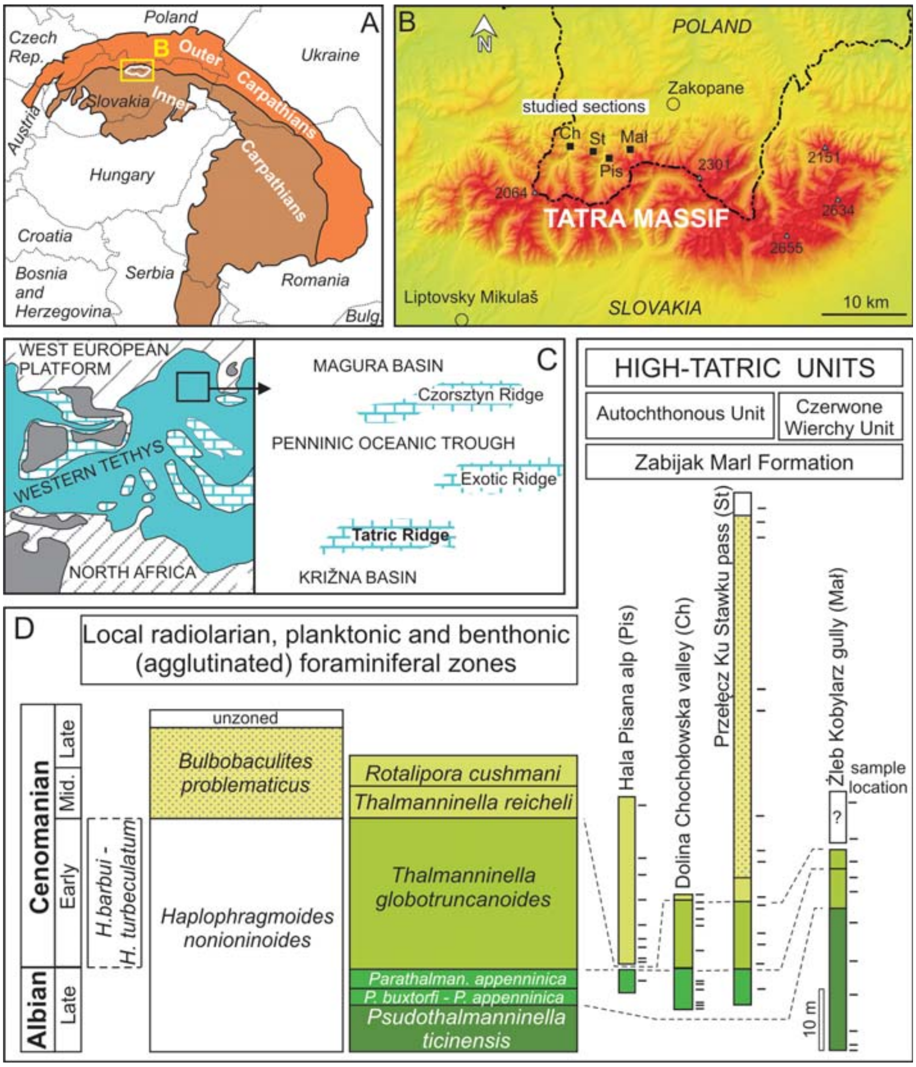

Figure 1.

A. Tatra Massif (inside of rectangle "B") against the background of a simplified geological map of the Carpathians.
B. Location of the studied sections in the Tatra Massif with contour map of this area (Bryndal 2014); for abbreviations of sections – see figure D.
C. Late Albian–Cenomanian palaeogeographic reconstruction showing the studied area in the Western Tethys domain and the Carpathian Basin (compiled in Bąk and Bąk 2013).
D. Local planktonic and benthic (agglutinated) foraminiferal and radiolarian zones with correlation of the Upper Albian–Upper Cenomanian sections studied (Bąk and Bąk 2013).

Foraminiferal assemblages

Agglutinated foraminifers with varying admixtures of calcareous benthic and planktonic forms predominate. A total of 78 species-level taxa were recognised, 43 of which are agglutinated, 18 calcareous benthic, and 17 planktonic (for details see Bąk and Bąk 2013).

Agglutinated foraminifers are dominated by siliceous-walled forms, with *Glomospira*, *Ammodiscus*, *Recurvoides*, *Trochammina* and tubular forms such as *Rhizammina* and *Rhabdammina* among the main genera. The content of agglutinated foraminifers increases significantly upward the sections.

Calcareous benthic foraminifers are dominated by epistominids, and associated with forms of genera *Gavelinella* and *Gyroidinoides*. All benthic forms represent up to 25 % of the whole assemblages.

Planktonic foraminifers are generally poorly-preserved, with diagenetic phosphatic transformation. Their number is higher in the lower part of the succession. They are dominated by *Pseudothalmanninella subticinensis* (Gandolfi) and *Pt. ticinensis* (Gandolfi) with rare *Planomalina buxtorfii* (Gandolfi). The planktonic foraminifera are also rich in the middle part of the Kamienne Member, where rotaliporids, with abundant *Parathalmanninella appenninica* (Renz) dominate, composing with other planktonic forms almost 100 % of the foraminiferal assemblages. Moreover, these deposits include other stratigraphically siginificant planktonic forms such as, *Thalmanninella globotruncanoides* (Sigal) and *Th. reicheli* (Mornod). The highest part of the Kamienne Member yielded *Rotalipora cushmani* (Morrow).

Foraminiferal biostratigraphy

Seven biostratigraphical zones are distinguished based on the succession of planktonic (mainly) and agglutinated benthic foraminifers (Fig. 1D). The distinguished zones are: *Pseudothalmanninella* *ticinensis* Interval Range Zone, *Planomalina buxtorfii Parathalmanninella appenninica* Concurrent Range Zone, *Parathalmanninella appenninica* Interval Zone (Upper Albian), *Thalmanninella globotruncanoides* Interval Range Zone (Lower Cenomanian), *Thalmanninella reicheli* Interval Range Zone, *Rotalipora cushmani* Taxon Range Zone, and *Bulbobaculites problematicus* agglutinated foraminiferal Interval Range Zone (Middle–Upper Cenomanian).

The local planktonic biozonation is compared with the chronostratigraphic standard and integrated microfossil zonation from the Western Tehys area of Robaszynski and Caron (1995).

Among potentially stratigraphically useful forms of deep-water agglutinated foraminifers are: *Haplophragmoides nonioninoides* (Reuss), *Plectorecurvoides alternans* Noth, *Bulbobaculites problematicus* (Neagu) and *Haplophragmoides cf. walteri* (Grzybowski). Two benthic zones have been distinguished here which cover the whole section (Fig. 1D): *H. nonioninoides* Zone and *B. problematicus* Zone, corresponding to the Albian–Lower Cenomanian and Middle–Upper Cenomanian, respectively.

Radiolarian assemblages and biostratigraphy

Radiolarians are scarce in the studied sediments, however, well preserved specimens have been found in several Upper Albian and Cenomanian samples (summary in Bąk and Bąk 2013).

Among the radiolarians, an occurrence of *Dictyomitra montisserei*, *Holocryptocanium tuberculatum*, *Mallanites triquetrus*, and *Archaeocenosphaera mellifera* was used for stratigraphy of the marls representing the upper part of the Zadnie Kamienne Member. Following the discussion on radiolarian stratigraphy by Bąk (2011), the studied assemblages have been classified to *Holocryptocanium barbui-Holocryptocanium tuberculatum* Zone that corresponds to the Lower Cenomanian.

Conclusions

The oldest marly sediments of the Zabijak Formation occur in the allochtonous ic units (Żleb Kobylarz gully section), and correspond to the *Pseudothalmanninella ticinensis* Zone (Upper Albian). Marly sedimentation within the autochtonous area of the Tatra Massif started later, in the *Planomalina buxtorfii – Parathalmanninella appenninica* Zone, age of the latest Late Albian.

The youngest, documented planktonic foraminiferal zone, *Rotalipora cushmani* Zone, of the Middle–Late Cenomanian age, was recognized in the upper part of the marl succession (Zadnie Kamienne Member). The uppermost part of the studied succession, containing the muddy turbidites is represented by *Bulbobaculites problematicus* Zone, which corresponds to the Middle–Upper Cenomanian, and ranges possibly up to the Cenomanian–Turonian boundary.

Radiolarians from the studied sediments are well documented in the lower and middle parts of the Zabijak Formation, corresponding to the Lower Cenomanian.

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Bacteriogenic iron oxides as an evidence of hydrothermal vent activity - case study from the Polish part of the Silesian Nappe and Tatra Massif

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Abstract

Ferruginous (i.e. ferrous oxides/hydroxides) coatings occurring in the Upper Albian–Cenomanian marine sediments of the Carpathians, represent the occurrence of Iron Related Bacteria. The singular grain coatings consist of densely packed elongated capsules of 5 µm width, with a wall thickness of 0.1 µm. These structures are remnants of the original bacterial sheath. The chemical composition of the capsules and their morphology show that they may be representatives of the Sphaerotilus–Leptothrix group, living recently around low-temperature hydrothermal vents. Such vents are interpreted as the source of metals for bottom sediments in the Silesian Basin (Outer Carpathians) and most probably in the Tatric Basin (Inner Carpathians), too.

Keywords: *Iron related bacteria, hydrothermal vents, Upper Albian–Cenomanian, Silesian Nappe of Outer Carpathians, Tatra Massif*

Introduction

Iron occurs widely in various geological environments. Ferrous minerals can be formed either by inorganic precipitation or as a result of bacterial processes. Bacterial mediated Fe (II)-oxidation seems to be the most important component of the Fe redox cycle under aquatic oxygen-depleted conditions. Iron oxidation by bacteria may be even 60 times faster than the abiotic reactions (Soggard et al. 2000). Bacteria known from modern environments, which can catalyze the oxidation of Fe (II) and Mn (II), are called Iron Related Bacteria (IRB). These bacteria are able to accumulate metallic ions, either in special structures outside their cells or in the surrounding extracellular polymeric matrices. The fossilization of bacteria is the most possible, if they have precipitated extracellular inorganic coatings. Thus, this provides the only information to bacterial type recognition in the fossil record. The modern IRB can live in variable land and marine habitats, e.g. they can be associated with marine hydrothermal environments, too (e.g., Noike et al. 1983; Schrenk et al. 1998; Kirby et al. 1999). In the present study, we report morphological and chemical evidences of IRB from the Cenomanian marine sediments in the Polish part of the Carpathians, which has been recognized by the authors in turbidite layers of the Silesian Nappe and marls of the Tatra Massif. Moreover, we discuss the possible source of Fe for the bottom sediments.

Material and methods

This paper presents data collected in two sections (Fig. 1A,B). The first one is located in the central part of the Silesian Nappe (Outer Carpathians), where the Albian–Turonian sediments are cropping out in a 75 m thick sequence in the quarry at the Barnasiówka Ridge (Wieliczka Foothills). The section comprises of deep-water hemipelagic non-calcareous clayey shale with siliciclastic and biogenic turbidite. Fe coatings are frequent in the whole Cenomanian part of the section.

The second section is located in the Polish part of the Tatra Massif (Inner Carpathians), where the Albian–Cenomanian sediments are cropping out in a 60 m thick sequence in the Żleb Żeleźniak gully, which is a left tributary of the Dolina Kościeliska valley. The section comprises of Upper Albian echinoderm limestone with stromatolites at the top and Upper Albian–Lower Cenomanian marl with calcareous shale. Fe coatings are frequent at the contact of the limestone and the marl successions.

The analyses of Fe coatings were performed on thin sections, however, SEM micrographs of microfacies and electron microprobe point analyses of selected mineral constituents were also done.

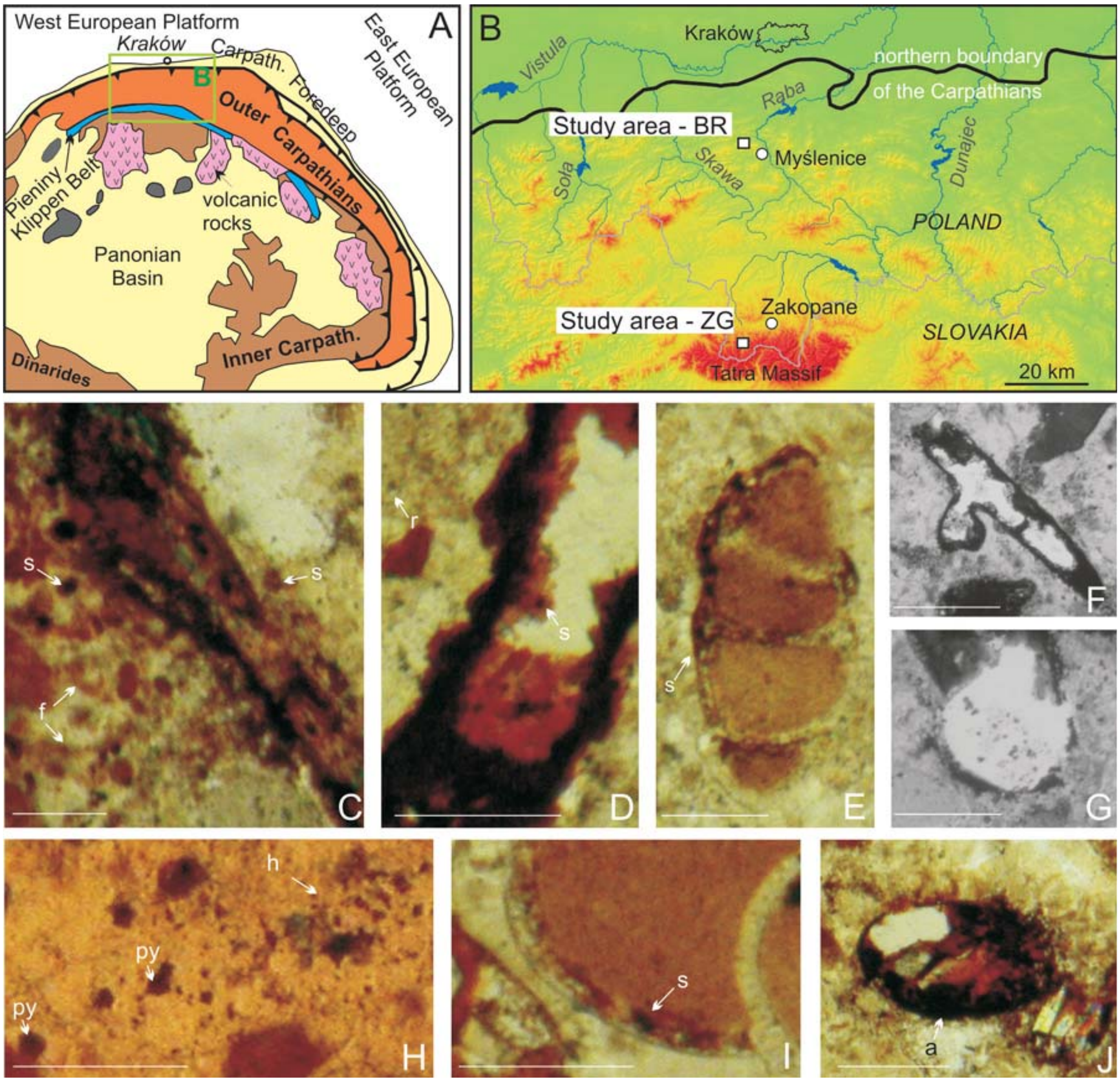

Figure 1.
A. Carpathians against the background of a simplified geological map of the Alpine orogens and their foreland.
B. Location of the studied sections (white rectangle) with contour map of this area (Bryndal 2014); BR – Barnasiówka Ridge in the Wieliczka Foothils, ŻG – Żleb Żeleźniak gully in the Tatra Mountains.
C. Brown amorphous iron oxide and hydroxide forming elongate structures (8–10 µm of diameter) as remnants of filament (f) and sheathed iron-fixing bacteria (s) from Sphaerotilus – Leptothrix group.
D. Benthic foraminiferal test completely replaced by bacterial felts. Donut morphology with common remnants of bacterial holdfasts, where bacteria attach to surfaces; brown bacterial rods (r).
E, I. Benthic calcareous foraminiferal test that was partly dissolved and replaced by Fe oxides/hydroxides due to biochemical dissolution by IRB; bacterial sheaths (s) replaced the wall.
F. Calcitized sponge spicule destructed and coated by amorphous iron.
G. Microbial colonization of the calcite, visible as pits and bacteria-size holes on surface of calcite grain.
H. Remnants after bacterial filaments (f) and holdfasts (h) similar to those made by Sphaerotilus – Leptothrix group. Pyrite crystals (py) was formed in association with reminiscent of bacteria.
J. Fe mineralization after bacterial felts which fill in foraminiferal test.
Scale bars: 20 µm for C; 50 µm for D, F–J; 100 µm for E.

Results

In the turbidites of the Silesian Nappe deposits, brown Fe coatings have been formed on each type of calcareous and siliceous bioclasts, as foraminiferal tests (Fig. 1D,E,I,J), spicules of siliceous sponges (Fig. 1F) and fragmented echinoderm skeletons. The calcareous skeletons are partly or completely replaced by Fe oxides/ hydroxides. Coatings are accompanied by singular microcrystals or aggregates (Fig. 1C). Fe coatings occur also on calcified sponge spicules which surfaces were corroded in µm size borings and covered by micro laminated brown encrustations (Fig. 1F). This process took place also inside the spicule, after the inner canal earlier calcification. Pigment is also spread in the intergranular pore space filled by blocky or isopachous bladed calcite cement.

In the deposits of the High-Tatric units, the main bioclast-types, which are covered or replaced by Fe oxides/hydroxides, are fragmented echinoderm skeletons. In some cases, calcareous bioclasts possess micro-borings or micro-cavities, which are filled by Fe oxides/hydroxides (Fig. 1G). There are also layers inside stromatolite which are composed of small crystals of magnetite.

The thin-section view of microfacies, at magnifications of 1000 times achieved under light microscope, shows that singular grain coatings and those one formed the mats consist of densely packed elongated capsules of approximately 5 μm width, which resemble bacteria-like structure (Fig. 1C). SEM observations revealed singular bacterial-like capsules comprising hollow inside, generally uniform size and oval outer shape. The wall of the individual capsules is 0.1 μm thick and may be a remnant of the original bacterial sheath, created outside of the cell membrane (see details in Bąk M. et al., in press). EDS analysis showed that the capsules contain large amount of iron and manganese, therefore may be representatives of the IRB (Bąk M. et al., in press).

Further evidences of bacterial origin of Fe staining and coatings are the fuzzy, brown to black, disk-like stains of pigment, which are usually surrounded by thin, moderately long and transparent fibres (Fig. 1C,D,J). These structures resemble to the bacterial holdfasts and their general outline and shape might be characteristic for bacteria from the Sphaerotilus–Leptothrix group. Structure consisting of black to brown flocks, surrounded by radiating filaments resembles to the present-day species of Leptothrix lopholea. In turn, filaments radiating from more massive rounded and dark colonies arranged in the form of isolated clusters resemble to the Leptothrix cholodnii. Another sign of the bacterial occurrence in the studied sediments and their life activity is the pitting corrosion of siliceous and calcareous grains (Fig. 1G).

Discussion

Modern species of the IRB can live and precipitate oxidized Fe or Mn in specific conditions. Present day Leptothrix species are widely distributed in the aquatic environments, which are characterized by low oxygen gradient, temperatures between 10-35 ^{o}C and a source of high iron and manganese ions content (e.g., Spring 2002). Such habitats may occur worldwide today both on land and in marine environments. However, the most probable analogue for the IRB occurrence in the Silesian and High-Tatric sediments can be found in marine and oceanic water settings. In such environments, the recent bacteria are known as associated with volcanic springs or hydrothermal venting areas (Dymond et al. 1989), where they form communities including numerous taxa.

According to Bennet et al. (2008), modern submarine venting may provide even 12–22 % of the global deep-ocean dissolved Fe budget. The IRB are numerous groups of organisms, which occur characteristically at deep-sea vents and areas related to a significant export flux of dissolved Fe from hydrothermal venting. They include mainly the Sphaerotilus–Leptothrix group and can get incrusted by ferrous hydroxides (Sphaerolitus) or ferromanganese oxides (Leptothrix).

The occurrence of hydrothermal vents (source of Fe and other elements) during Late Cenomanian–Early Turonian times was earlier suggested for the Outer Carpathian basins (Bąk, 2006, 2007). Study of the geochemical indices around the C–T boundary sediments for association of Fe, Mn and microelements in two Fe-Mn layers, including (Ni+Cu+Co) content, Co/Zn ratio, REE distribution pattern suggest that they may derive from hydrothermal fluids. The occurrence of deep-sea vents also during the Early and Middle Cenomanian in this area is very probable, because it was the period of maximum rate of continental crust extension under the Carpathian basins with the lowest accumulation rate at the basin floor during the whole Cretaceous (Golonka et al. 2002).

Conclusions

The Cenomanian deep-water turbidites of the Outer Carpathians, deposited below the CCD, contain Fe- and Fe-Mn oxides and hydroxides, visible macroscopically as brown staining. The SEM observations and electron microprobe point (EDS) analyses of their mineral constituents show that most of them consist of densely packed elongated, approximately 5 μm width capsules, which are interpreted as bacteria-like structures. The capsules contain large amount of iron and therefore may be representatives of the Iron-Related Bacteria (IRB) from the Sphaerotilus–Leptothrix group.

The most possible sources of metals for bottom sediments, where the IRB could live and precipitate oxidized iron, were submarine hydrothermal vents. The occurrence of hydrothermal vents during Cenomanian–Turonian times in the Outer Carpathian basins was earlier documented using the geochemical indices of the sediments around the C–T boundary.

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Correlation of the Middle and Upper Triassic formations between the Slovenian Southern Alps and the Transdanubian Range (Hungary)

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Abstract

According to the Triassic palaeogeographic reconstructions, the Transdanubian Range (TR) were positioned between the Northern Calcareous Alps and the Southern Alps, and they all formed part of the continental margin of the Neotethys. During the lateral extrusion, the TR was translated far to the east along the Periadriatic - Balaton Lineament, which represents a first-order structural element, separating South Alpine from the Austroalpine and Penninic units. The Triassic successions of the western and central Southern Alps have very similar characteristics with the TR, particularly in the Upper Triassic with well-developed facies belts of the Main Dolomite – Dachstein Limestone system. Recently, there has been significant improvement in the knowledge of the Middle and Upper Triassic stratigraphic successions in the Slovenian part of the Southern Alps (Julian Alps, Kamnik-Savinja Alps and South Karavanke Mts.). In the Middle Anisian, shallow, small anoxic intraplatform basins within a vast carbonate platform were recognized particularly in the Kamnik-Savinja Alps. Late Anisian (Illyrian) was characterized by rifting processes and partial drowning of the Contrin carbonate platform, with formation of small half-grabens filled either with volcanic material (rhyolites) or with the Uggowitz Breccia. The half-grabens were finally filled with the Buchenstein Fm and the prograding platform (Schlern Fm). In the TR, the half-graben Felsöörs Basin was formed between the island-type Tagyon Platform; however this basin was significantly greater than the half-grabens in the Julian and Kamnik-Savinja Alps. The Buchenstein Formation shows the same depositional trend in both areas. The Ladinian - ?Lower Carnian Schlern Fm is equivalent to the Budaörs Dolomite Fm. Both of them are informally called as"Diplopora Dolomite". On the relatively stand-still blocks, platform carbonate deposition continued uninterruptedly from the Late Anisian till the Early Carnian, whereas in the Slovenian Basin to the south, deeper water successions were characteristic from the Late Anisian till the end of the Triassic period. In the Southern Alps in Italy, the former interplatform basins were definitively filled only during the Late Julian, but in the Slovenian part platform sedimentation occurred from the Late Ladinian till the Late Carnian and could be compared with the Ederics/Sédvölgy Formation of the TR. Only in the western part of the Julian Alps and the South Karavanke Mts., the mixed carbonate – terrigenous Tor Fm (part of the Raibl Group) deposited and clastic influence obviously did not reach areas more to the east. The Tor Fm could be compared with the Sándorhegy Fm of the TR, a transitional unit between the Veszprem Marl Fm and the Fodolomit (Hauptdolomite). During middle – late Tuvalian, a strong increase in subsidence and following highstand allowed a re-establishment of the rimmed carbonate platform in the Slovenian Southern Alps. The drowning triggered deposition of the basinal Carnitza Fm and coeval progradation of the Main Dolomite platform in NE direction. Above the Main Dolomite, the Dachstein Limestone is positioned and its thickness increases and totally prevails in NE direction. In the more distal parts (NW Julian Alps, W Karavanke Mts.) the basinal sedimentation continued with cherty dolomites (Bača Dolomite) and dark platy limestones (Frauenkogel Fm) until the end of the Triassic and beyond. These basinal sediments could be well correlated with the Matyashegy Formation and the Csovar Limestone Fm, respectively, from the intraplatform basins at the NE part of the TR. The Triassic/Jurassic boundary is proved within the Csovar Limestone by ammonites.

In the eastern part of the Julian Alps, Upper Tuvalian – Lower Norian red pelagic platy limestones (Martuljek Limestone) are positioned above the drowned Razor carbonate platform with cyclic oncoidic peritidal succession and below the Dachstein Limestone. The Dachstein platform with a well-developed coral reef margin and slope with clinoforms prograded into the basin in NE direction, presumably towards the open shelf on the ocean ward margin of the platform. The top of the pelagic sequence is younger (Sevatian) in the Kamnik - Savinja Alps, where limestones with chert nodules are positioned above the Martuljek Limestone. This red limestone and limestones with chert nodules above could be compared with the Hallstatt or Pötschen Limestone, but their equivalents are missing in the TR.

An attempt for the correlation of the Jurassic and Cretaceous formations of the Southern Alps, Slovenian Alps, the Drauzug Zone and the South Bakony

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Abstract

In spite of the fact that recently the South Bakony and the entire Transdanubian Range (TR) are in direct contact with the Southern Alps, the successions of these two geographic/tectonic units have several lithostratigraphic units of similar or the same character. The peculiarity of MT the situation is that the Southern Alps are locatedon the southern side of the Periadriatic Line, which is one of the largest tectonic lines of the region, whereas the TR, the Northern Karawanks and the Drauzug are found on its northern side. In spite of this, the successions of the latter two tectonic units also closely relate to the Southern Alps. The areal extent of the Mesozoic successions of the Southern Alps is much larger than those in the South Bakony, the Drauzug and the Karawanks.

The uniform carbonate platform of the eastern part of the Southern Alps started to disintegrate in the Early Jurassic owing to the rifting process and the Belluno Basin developed between the Trento and the Friuli Platforms. The former Calcari Grigi Fm of the Trento Platform is renamed as Calcari Grigi Group distinguishing several formation rank units within it, whereasin certain parts of the platform the succession became highly condensed. In the Belluno Basin, cherty limestone developed in the Hettangian-Pliensbachian ages and it was replaced by black shales and manganese carbonates in the Toarcian. A new succession started to develop on the Trento Plateau in the Middle Jurassic and was characterised by Rosso Ammonitico facies. In the Belluno Basin, the basinal facies continued by oolitic and bioclastic limestone the material of which derived from the western side of the Friuli Platform where a long hiatus in the Toarcian was also typical. In the Belluno Basin the oolitic and bioclastic limestone was followedby cherty mudstone, skeletal turbidites and debris flows, and then the Rosso Ammonitico facies of Kimmeridgian to Early Tithonian age returned gradually again. From the Friuli Platform the Ellipsactinia-bearing platform limestone prograded northward and inter-fingered with the basinal succession of the Belluno Basin.

In the eastern continuation of the Southern Alps, the platform and basin development can be also found in the Julian Alps and in the Southern Karawanks. The Friuli Platfom spread over to Slovenia, while the Belluno Basin continued in the Slovenian Trough. The varied Triassic platform carbonates (oolitic, calcarenitic or massive) continued in the Jurassic. In the late Early Jurassic it is replaced by basinal cherty limestone with manganese intercalations. In other places, the platform carbonate continued until the middle Late Jurassic, when it was replaced by breccia or cherty limestone.

The general trend of the Jurassic and Cretaceous succession of the South Bakony area is adequate to that of the Trento Platform. The only important difference is, that the platform drowned in the Early Liassic and the basin was dissected by submarine highs. The basal beds are equal to the Calcari Grigi but they are confined to the Hettangian and overlain by varied bioclastic rocks including cherty limestones. At several places, the Liassic terminated with manganese-bearing rocks (manganese limestone, even carbonate or oxide ore). Large part of the Middle Jurassic is composed of the Rosso Ammonitico with intercalations of Bositra and cherty limestone beds. These beds are followed by radiolarite indicating the deepest part of the Jurassic succession. The “Oxfordian breccia” is a typical basal element of the Upper Jurassic. The Ammonitico Rosso repeated again in the Upper Jurassic. The overlying platy limestone is a transitional formation towards the Berriasian - Hauterivian Maiolica limestone. The lateral facies changes are less striking than in the Southern Alps. The south-westward deepening was the general tendency in the South Bakony already in the Jurassic but became stronger during the Cretaceous. Some South-Alpine facies names have already been used in the Bakony during the last century but we expect that the joint usage of common lithostratigraphic names will also be achieved.

The Jurassic and Cretaceous formations of the Drauzug Zone are restricted to a narrow belt but the majority of the formations can be correlated with those of the TR and the Southern Alps as well.

Similar or identical Mesozoic lithostratigraphic units in the northern part of the Transdanubian Range and in the Eastern Alps

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Abstract

The Transdanubian Range (TR) is the only tectonic unit which has preserved the original transitional connection between the Southern and the Eastern Alps (SA, EA) in the Mesozoic. This is the reason why we start the correlation with this unit while emphasizing their common facies or lithologies. The Triassic successions have similar characteristics in the Northern Calcareous Alps (Tirolic and Bajuvaric nappes) and in the western and central Southern Alps. In the Triassic times all areas belonged to the lagoonal or reefal facies belt of the carbonatic passive margin of the Tethyan Realm facing to the southeast. Some of these specialities can also be recognised in the TR albeit not as clearly as they occur since the Early Jurassic till the Early Cretaceous. The basic significance of the Triassic succession in the TR is the predominance of the platform carbonate which was interrupted by shallow bathyal basinsin the Middle and the Late Triassic represented by marls and pelagic limestones. There are a few lithostratigraphic units the names of which derives from the EA or from the SA. The Jurassic successions of the Gerecse and the BakonyMts. are similar in their major characters, except their basal beds. The Upper Hettangian red, fossiliferous limestone was deposited on the tilted and erosional surface of the Dachstein Limestone Fm in the Gerecse Mts. Hettangian rifting and Toarcian break-up in the Penninic Realm led to a completely new palaeotopography: a horst-and graben morphology was formed in broad areas of the rift valleyes. It is well developed in the Gerecsepart of the TR. This is expressed in the deposition of their identical sedimentary successions showing a general deepening trend: deep-water grey or red cherty limestones in the basins and red nodular limestones on the morphological highs. The deepening culminated in the late Middle Jurassic to the Oxfordian with the deposition of radiolarian cherts. The Kimmeridgian-Tithonian is characterized by deposition of red and greydeep-water carbonates, except a few areas where shallow-waterplatforms were established. The deep-water sedimentation continued in the earliest Cretaceous. The Gorba High is an exceptional block in the Gerecse because it was elevated above the sea level in the Early Jurassic and it became flooded in the late Middle Jurassic. The Oxfordian breccia composed of white limestone fragments is a product of a significant compressional event in the EA. It can be found in deeper (radiolarite) and shallower(upper Ammonitico Rosso) environment as well. The radical change started in the Gerecse already in the Berriasian while it happened in the Tirolic nappes in the Valanginian only. The coarsening upwards flysch type succession occurred in the Gerecse in the Valanginian with marl, continued by sandstone and finished by breccia-conglomerate in the Albian. It is an evidenceof a fundamental tectonic activatyof the broader area to which the Gerecse must have belonged (Salzburg area, Dinarides). The large size rudistid limestone cobbles, black radiolarite and basic volcanic rocks derived from the north are clear evidence for the nearby existence of a carbonate platform and a nearby source of an obducted oceanic crust. The other striking phenomenon of the Gerecse flysch sequenceis that it was replaced within a few tens of km by a less sandy, but silty and marly succession to the southwest direction where a ridge separated the South-Alpine and the North-East-Alpine developments. In this transitional basin rudistid facies also developed. These kinds of rocks are found in the Northern Calcareous Alps in the late Early Cretaceous, as well.

All successions show a break in sedimentation between the Lower and Upper Cretaceous. Upper Cretaceous transgressed and rests unconformably above faulted and folded older rocks. The Gosau Group, defined in the NCA, applies for these successions which include a terrestrial to shallow-water interval (Lower Gosau Subgroup) and a deep-water interval (Upper Gosau Subgroup) which ranges into the Eocene.

The subjects and aims of the special session SS3

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Abstract

The geological build–up of the CBGA territory is a product of a varied sedimentary and fairly complicated Variscan and Alpine tectonic history within a relatively small area which is subdivided among small countries. The connection between the countries and their geologists may be good or even very good but the principles of the International Stratigraphic Guide are accepted not on the same level, and often differently used by the experts of sedimentary, magmatic and metamorphic rocks even within the national stratigraphic commissions. The consequence is that there are hundreds or even thousands of lithostratigaphic names in several countries. These are too many already not only for the mapping geologists but also for hydrogeologists and stratigraphers. The situation is more problematic for students because the understanding of the geological build-up of their own country where they live can't be achieved without the basic knowledge of the geology of the neighbouring countries. As the fundamental information is written within the rocks, the students and also we haveto be acquainted with the rocks. Similar type of rocks can be developed in different sedimentary environments e.g. limestone in shallow marine or lacustrine environments. The situation is the same with the clastic sediments or even with the magmatic rocks as well. Often detailed information is required for distinguishing or correlating the rocks, often multilateral and detailed description for an acceptable correlation or for lock–out from correlation are needed.

Historically, there were some nests at the early stages of geological activity from where geological knowledge has been exported for other areas. This is the case of Hungary where geologists came from the Eastern Alps. They recognised that there are several similar or identical rocks to those they found in the Alps, therefore they used alpine names in many cases. Famous among those is the Triassic Dachstein Limestone or the Hauptdolomit. Later on, when the independent geological research started in Hungary, there were not so tight contacts between the geologist of the two countries, local names were given that time when the stratigraphic concept was not yet born.

Nowadays, there are several attempts for the correlation of stratigraphic successions of varied North-Alpine tectonic units with the North-Eastern and the South Western Transdanubian Range, and with other tectonic units, we had so far only a few miscarry attempt. The situation is more or less the same in the case of Hungary and other neighbouring countries such as Slovakia, Romania, Serbia, Croatia and Slovenia.

At first glance the correlation of lithostratographic units seems to be relatively easy in case the succession can be followed over the national border. This is the situation in the Villány - Bihor Zone of the Tisza Unit. In spite of a very good correlation we could not draw conclusion todecreas the number of names of lithostratigraphic units. The situation is more complicated in case when one of the former palaeogeographic units was cut by major tectonic lines or even zones and the continuation of the unit was moved far away from its original position and large part of the succession eroded. The Transdanubian Range and the Eastern Alps are good examples for this situation. The first one was pushed out from among the Eastern and Southern Alps. In spite of theircomplicated tectonic situation they still have many similar or even same lithostratigraphic units but with different names. The major aim is to simplify the lithostratigraphic chart of these and other regions (entire Carpathians and even Dinarides) via selecting the most adequate sections and using their names for all occurrances.

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Where Trento and Plassen type topographic highs meet (Jurassic-Cretaceous stratigraphy of the Julian Alps, NW Slovenia)

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Abstract

Two genetically different structural highs characterized the Late Jurassic Tethyan continental margins. The first group of highs resulted from differential subsidence during Early Jurassic rifting and remained deeply submerged well into the Cretaceous. Their stratigraphic record consists of pre-rift platform carbonates (or quartz sandstone) overlain by condensed pelagic deposits ranging in age from the Early or Middle Jurassic to the middle or Late Cretaceous. One of the best known and the most extensively studied examples of this group is the Trento Plateau in the Southern Alps. Numerous other examples from the Betic Cordillera to the Carpatho-Balkanides, are distributed along the former margins of the Piemont-Liguria Ocean continuing as far as the Ceahlau-Severin rift. Such intrabasinal highs are also common along the Neotethyan margin in Turkey, Iran and Oman. The Plassen type structural highs, on the other hand, record a considerable uplift to neritic environment in the Late Jurassic. Upper Oxfordian to Berriasian platform carbonates overlie Middle Jurassic and older deep-water sediments or ophiolites. These structural highs formed in a contractional regime and their spatial distribution is much more limited, restricted to the closing Meliata-Maliac-Vardar branch of the Neotethys. In addition to the classical Plassen carbonate platforms s.l. of the Northern Calcareous Alps, such carbonate platforms are known from the Apuseni Mountains and the Vardar/Axios Zone, and their erosional remnants have been reported from Slovakia, Hungary, Serbia, Albania and Greece. Stratigraphic correlations in areas where both types of structural highs were located relatively close to each other can help to restore the evolution of the continental margin between the Piemont-Liguria and the Neotethys oceans.

In the Julian Alps, the uppermost nappe (the Pokljuka Nappe) consists of deep-water Upper Triassic to Lower Cretaceous deposits of the Bled Basin. Berriasian carbonate breccias contain shallow-water limestone clasts that originated from a Plassen type carbonate platform. The directly underlying nappe (the Krn Nappe), which constitutes the major part of the Julian Alps, preserves a nice example of a Trento type pelagic plateau, named the Julian High.

The succession of the Bled Basin is composed of Norian–Rhaetian relatively thick-bedded limestone with chert nodules (the Zatrnik limestone), Lower Jurassic cherty limestone with echinoderms, Pliensbachian carbonate breccia (the Ribnica breccia), Upper Bajocian to Lower Tithonian bedded radiolarian cherts and shales, Upper Tithonian–Berriasian Biancone limestone ending with carbonate breccia and calcarenite (the Bohinj Formation), marly limestone, and finally Valanginian–Hauterivian mixed carbonate-siliciclastic turbidites with ophiolite debris. The upper part (above the Toarcian to Lower Bajocian gap) is almost identical to the succession of the Lower Tirolic units (Ruhpolding Radiolarite, Oberalm Formation including the Barmstein Limestone, Schrambach Formation and Rossfeld Formation in stratigraphic order). The lower part correlates better to the Pötschen and Dürrnberg formations of the Upper Tirolic units.

The sediments of the Julian High rest upon a thick pile of Upper Triassic to Lower Pliensbachian platform limestones. The major part is characterized by Bathonian to Lower Tithonian Rosso Ammonitico limestone (the Prehodavci Formation), Upper Tithonian to Neocomian Biancone limestone, Albian to Cenomanian Scaglia variegata, Turonian to Campanian Scaglia rossa and Upper Campanian to Maastrichtian flysch. This succession correlates well with that of the Trento Plateau but the Cretaceous part is apparently extremely condensed. The Biancone limestone and the Valanginian to Albian Puez Formation of the Trento Plateau are over 120 m thick, whereas the coeval formations of the Julian High are estimated to not more than 20 m. Another distinguishing feature of the Julian High is local occurrence of several hundred meters deep neptunian dykes filled with carbonate blocky breccias and sealed with the Lower Albian Scaglia variegata. The submarine highs of the Bavaric units in the Northern Calcareous Alps show a similar general stratigraphy. The main difference between the two areas is the age of syn-orogenic turbidites. The oldest siliciclastic deposits of the Bavaric units (the Lech Formation) are dated to the Aptian-Albian boundary. They are considerably older than the flysch of the Julian High but correlate well to the formation of deep neptunian dykes.

A trial correlation of some Mesozoic lithostratigraphic units of the Western Carpathians and the Pannonian Basin

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Abstract

In the Hronicum the Triassic and the Lower Jurassic formations preserved their original Alpine names, while the rests of the Jurassic ones have no lithostratigraphic names. In the Gemericum there are preserved only a few Triassic formations and their names are mainly Alpine ones. For all subunits of the Triassic successions in the Tatricum and Veporicum their original Alpine names are used. The majority of the Jurassic units here have no lithostratigraphic names, while the rests are either Slovak or Alpine ones. Among the Cretaceous units there are just Slovak names although several of them have onlylithologic names yet.

In the one third of the Outer Alps and Carpathians and of the Klippen Belt subunits have some Jurassic formations either with Slovakian or Alpine names, not always official ones. The only difference between the Cretaceous and the Jurassic tectonic units is that almost all of them have Cretaceous formations mainly with local names except the Austrian Klippen Zone where the names are of Alpine origin.

In the TR the great majority of the Triassic formations has local Hungarian names and just three have East Alpine ones (Kössen Fm, Dachstein Limestone Fm, Hauptdolomite Fm), but the third one in translated form. One formation name (Buchenstein Fm) derives from the Southern Alps. It means that they are the only common Triassic names in the TR, which are used in the Eastern Alps and in the Western Carpathians albeit there are more common lithological units. In the Mid-Transdanubian part of the zone and the Bükk Mts there are only local names. In the Gerecse Hills there is only one lithostratigraphic name imported from the Eastern Alps and it is also used in the Hronicum. Even if names of the formations are different, but there are very similar or even the same lithology in the Jurassic and Cretaceous of the Tatricum, Veporicum and the TransdanubianRange as well.

On the Hungarian part of the Tisza Unit and the Tatricum and Veporicum in Slovakia the basal beds of the Triassic and the Upper Triassic and also the Lower Jurassic has very similar lithology, but it is not reflected in the nomination, and their proper correlation needs joint comparative studies.

Component analysis in the Vardar/Axios Zone of Northern Greece reveal an eroded Late Jurassic carbonate platform comparable to those of the Eastern Alps/Western Carpathians, Dinarides, Albanides and Hellenides

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Abstract

Microfacies and biostratigraphic analysis of components in polymictic mass-flow deposits on top of ophiolites in the eastern Vardar/Axios Zone in Northern Greece prove the onset of a Late Jurassic shallow-water carbonate platform on top of the obducted nappe stack.

The succession with the redeposited components akin to those known west of the Pelagonian Zone, e.g. the Zyghosti Platform in Northern Greece and the eroded Kurbnesh Carbonate Platform in Albania, and therefore indicate a palaeogeographically similar provenance area.

Similar Late Jurassic carbonate platforms on top of the Middle to early Late Jurassic nappe stack were also formed in the Dinarides, the eastern Southern Alps, the Eastern Alps and the Western Carpathians. This allow to follow the formation of a carbonate platform pattern along the suture zone of the “Neotethys” in Jurassic times from the Eastern Alps/Western Carpathians in the north, along the eastern Southern Alps and the Dinarides/Albanides towards the Hellenides. The original palaeogeography of this Jurassic orogeny was disrupted by younger tectonic motions and today forms a puzzle in the Alpine orogens of the eastern Mediterranean. In places, this puzzle can be reconstructed only from redeposited components in younger mass flows. The platform pattern is best preserved in the Northern Calcareous Alps, named there the Plassen Carbonate Platform that formed on top of a Middle to early Late Jurassic nappe stack.

Keywords: *Vardar/Axios Zone, Late Jurassic, Early Cretaceous, carbonate platform, Neotethys.*

Introduction

Component analysis can be used as a tool to reconstruct an eroded hinterland and can provide detailed insights into the palaeogeography. In addition, correlation between microfacies of redeposited carbonate sequences and carbonate platforms with better preserved successions in other areas may also contribute to the palaeogeographic reconstruction. It is possible to recognise common trends in different areas or compare the tectonostratigraphic trends.

The detailed component analysis carried out in the Lower Cretaceous sedimentary succession containing several polymictic mass-flow deposits on top of the Vardar/Axios ophiolites in the Neochorouda area of Northern Greece provides the opportunity to contribute to the still controversial opinions on palaeogeography of the Hellenide realm (for a detailed review see Robertson 2012). In addition, the litho- and microfacies of the components representing remnants of a formerly huge Late Jurassic carbonate platform on top of obducted ophiolites allow a correlation with other Late Jurassic platforms in the Eastern Alps/Western Carpathians, Dinarides, Albanides and Hellenides (Kostaki et al. 2013). Similar Upper Jurassic shallow-water carbonate components from mass-flow deposits were described by Schlagintweit et al. (2008) from the Kurbnesh area of central Albania. The components are interpreted to derive from an eroded Kimmeridgian?-Tithonian shallow-water carbonate platform which was deposited on top of the Mirdita Ophiolite Zone nappe stack. The Zyghosti Platform on top of the Vourinos ophiolites occurs in a similar position (e.g., Carras et al. 2004; Fazzuoli and Carras 2007). This situation resembles the Late Jurassic Plassen Carbonate Platform evolution on top of the Middle to early Late Jurassic nappe stack in the Northern Calcareous Alps, which was subjected to partial erosion from the Jurassic Cretaceous boundary onwards (Gawlick and Schlagintweit 2006).

Results and Discussion

In the study area on top of the Vardar/Axios ophiolites the sedimentation started with the deposition of a series of turbidites/mass flows containing reworked ophiolite material and shallow-water clasts. Resedimented bioclasts of reef builders, shells, brachiopods, crinoids and foraminifera as well as a fragment of *Griphoporella jurassica* (Endo) occur (Fig. 1.2). Some fragments are coated and encrusted. *Microencruster Crescentiella morronensis* (Crescenti) is common. Benthic foraminifer *Labyrinthina mirabilis* Weynschenk was also encountered (Fig. 1.1). These taxa are referred mainly to the Kimmeridgian.

Deposition continued with mass-flow deposits (about 6 m in thickness) with components of shallow-water origin and ophiolitic material. The shallow-water components are derived from fore-reef, reef, back-reef and open lagoonal areas; corals, sponges, calcareous algae, benthic foraminifera such as *Pseudocyclammina lituus* (Yokoyama) and a considerable number of encrusting microorganisms were found. From among the microencrusters *Crescentiella morronensis* (Crescenti), *Radiomura cautica Senowbari-Daryan* and Schäfer, *Labes atramentosa Eliasova* and *Perturbatacrusta leini* Schlagintweit and Gawlick were encountered (Fig. 1.5). *Thaumatoporella* sp. (Fig. 1.4), *Griphoporella jurassica* (Endo) and *Neoteutloporella socialis* (Praturlon) are common (Fig. 1.3). The latter is common in Tithonian shallow-water carbonates. Above the mass-flows, a siliciclastic turbiditic sequence follows, based on ammonoids it can be assigned to the Berriasian (Mussalam and Jung 1986).

The reefal components of different facies are interpreted as redeposited from a Kimmeridgian?-Tithonian carbonate platform which was formed in a way identical to the Zyghosti and the Kurbnesh Carbonate Platforms with the onset of shallow-water carbonate production originally on top of the ophiolitic nappes (Gawlick and Schlagintweit 2006; Schlagintweit et al. 2008). Erosion of these platforms commenced soon after sedimentation, as it can be expected in a mobile tectonic environment and were redeposited until the Early Cretaceous.

The Berriasian evolution is characterized by an increasing influx of siliciclastic and ophiolitic debris as documented in the study area by a 20 m thick turbiditic sequence of immature sandstones with coarse-grained mass flows and within the sequence. In the mass flow mainly grainstones and rudstones composed of different bioclasts and coated grains in addition to sandstone clasts occur. The bioclasts are debris of different reef builders such as corals and sponges as well as foraminifera and algae such as *Salpingoporella pygmaea* (Gümbel) (Fig. 1.7) and *Dissocladella? bakalovae* Dragastan. Common microencrusters are *Labes atramentosa* Eliasova, *Crescentiella morronensis* (Crescenti) and *Radiomura cautica* Senowbari-Daryan and Schäfer. Some of the benthic foraminifera are *Nautiloculina cf. oolithica* Mohler, *Anchispirocyclina lusitanica* (Egger) (Fig. 1.6), *Mohlerina basiliensis* (Mohler) and *Pseudocyclammina lituus* (Yokoyama).

Sedimentation continued with the deposition of a polymictic conglomerate (>250 m thick), containing a great amount of metamorphosed carbonate components, derived from the Triassic of the "Pelagonian". The components in the conglomerate are a mixture of older carbonates as well as siliciclastic-crystalline rocks. The components vary in size, with blocks larger than 10 cm often occurring. In different metamorphosed shallow-water clasts of most probably Middle Triassic age foraminifera dominate (Fig. 1.8). Also in some clasts recrystallized radiolarians occur.

In the study area the carbonate production started with the built up of a Late Berriasian?-Valanginian shallow-water carbonate platform most probably in the course of sea-level rise. These shallow-water carbonates reach a thickness of about 40 m and contain besides the dasycladales *Griphoporella cretacea* (Dragastan) (Fig. 1.9), *Furcoporella? vasilijesimic*i Radoicic (Fig. 1.12), *Linoporella aff. capriotica* (Oppenheim) (Fig. 1.11), *Suppiluliumaella aff. methana* Dragastan and Richter, debris of *Selliporella neocomiensis* (Radoicic) (Fig. 1.10), different microencrusters associations such as *Radiomura cautica* Senowbari-Daryan and Schäfer and *Crescentiella morronensis* (Crescenti), as well as the foraminifera *Coscinophragma* sp. and *Andersenolina* sp.

Conclusions

The Late Jurassic carbonate platform components in the Early Cretaceous sedimentary succession on top the Vardar/Axios ophiolites reveal the existence of a carbonate platform pattern as known e.g. in the Eastern Alps or the Dinarides/Albanides/Hellenides. The litho- and microfacies

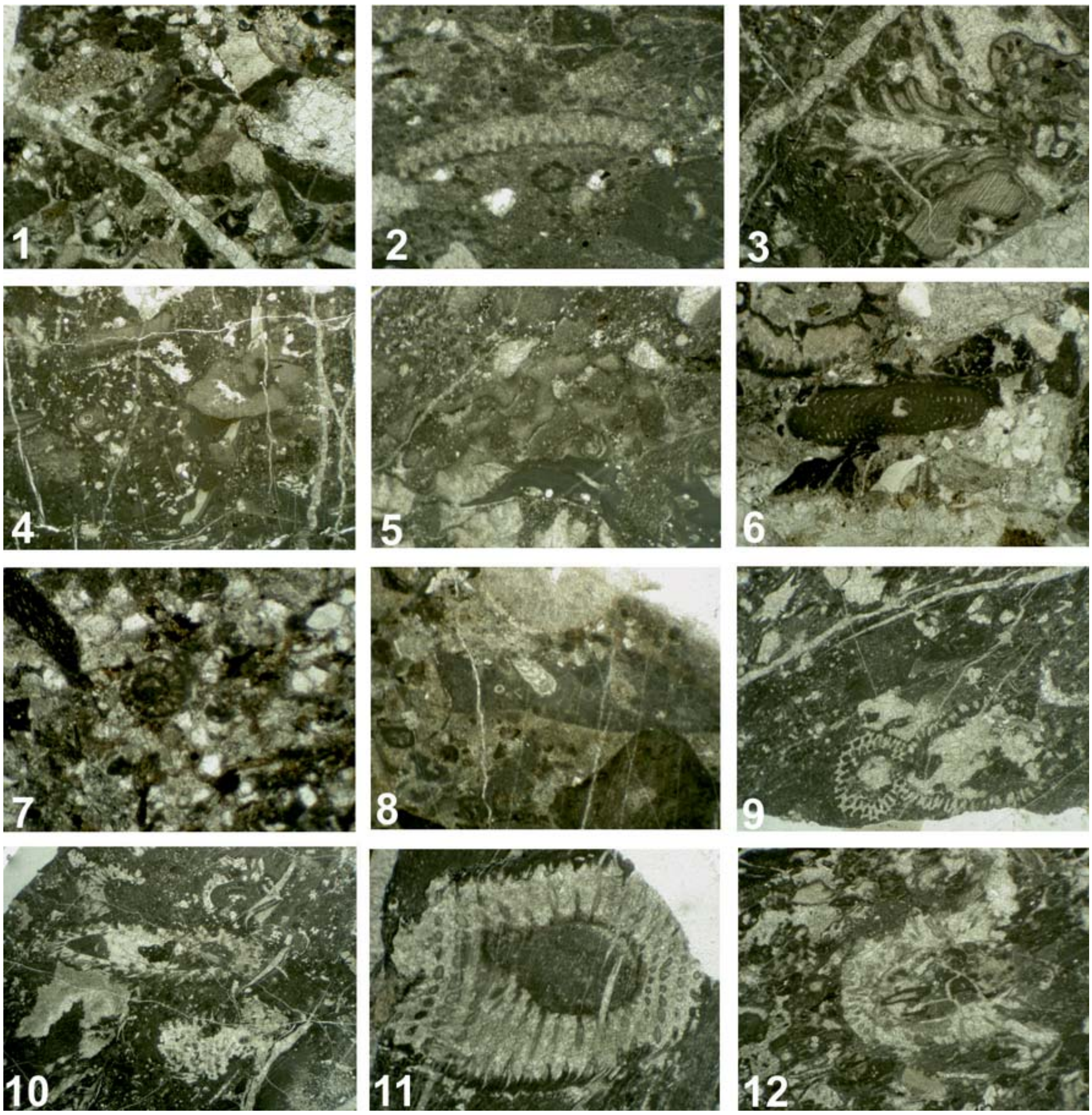

Figure 1 Components of the polymictic mass-flows:

1. Rudstone with different clasts and *Labyrinthina mirabilis* Weynschenk (width: 0.5 cm)
2. A fragment of *Griphoporella jurassica* (Endo) (width: 0.25 cm)
3. *Neoteutloporella socialis* (Praturlon) (width: 0.5 cm)
4. Boundstone with *Thaumatoporella sp* (width: 0.5 cm)
5. Boundstone with *Perturbatacrusta leini* Schlagintweit and Gawlick (above) and *Labes atramentosa* Eliasova (below) (width: 0.5 cm). Components from the turbiditic sequence of sandstones with intercalated coarse-grained mass flows:
6. *Anchispirocyclina lusitanica* (Egger) (width: 0.5 cm)
7. Grainstone with different clasts and *Salpingoporella pygmaea* (Gümbel) (width: 0.5 cm). Components from the polymictic conglomerate:
8. Metamorphosed shallow-water clasts of most probably Middle Triassic age containing foraminifera (width: 0.5 cm). Microfossils from the shallow-water carbonates:
9. *Griphoporella cretacea* (Dragastan) (width: 0.5 cm)
10. Boundstone with *Suppiluliumaella aff. methana* Dragastan and Richter and debris of *Selliporella neocomiensis* (Radoicic) (width: 0.5 cm)
11. *Linoporella aff. capriotica* (Oppenheim) (width: 0.25 cm)
12. *Furcoporella? vasilijesimici* Radoicic (width: 0.25 cm).

characteristics of all platforms are very similar. Also the faunal and floral content is known in all areas, whereas it differs from that known e.g. from the European-Asian margin.

This situation confirms that the Eastern Alps/ Western Carpathians, Dinarides, Albanides and Hellenides underwent the same geodynamic history as synthesized bellow. Intra-oceanic subduction in late Middle to early Late Jurassic triggered the WNW to NW directed nappe stacking and ophiolite obduction (e.g. Kilias et al. 2010; Missoni and Gawlick 2011). This process was followed by the onset of evolution of Late Jurassic shallow-water carbonate platforms on top of the obducted ophiolites or on the complete nappe stack. Early Cretaceous extension and erosion due to mountain uplifting resulted in a reconfiguration of the nappe stack. The erosional products including ophiolitic debris were transported into the newly formed adjacent basins. The uplifting was followed by extensional collapse and exhumation of the metamorphic basement that triggered the infilling of the basins with its erosional products.

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Needs for a modern lithostratigraphic division in the Western Carpathians

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Abstract

Lithostratigraphy is one of the main pillars of any interregional correlation of geological units. Any cross-border geo-scientific correlation can hardly work without precise definition of the lithostratigraphical terms and the categorization of rock bodies. Paradoxically, the problem of the Alpine-Carpathian lithostratigraphy follows from the fact that it belonged to the best known systems of rock column division in the world. The majority of Meso-and Cenozoic lithostratigraphical units were defined one and half centuries ago just here (Puchov Marl, Gutenstein-, Wetterstein-, Adnet-Limestone, Lunz Beds, etc.). Although, the time is running, geoscience is prograding and new stratigraphic rules are evolving. Stratigraphical knowledge accumulated, many areas in the world became more instructive and they served as more progressive patterns and models for newer divisions. On the other hand, former Austrohungarian models remained untouched. This is because we need revision study and modern redefining of sedimentary units which could enable wider and more detailed correlations.

Despite several top- specialized studies of Upper Paleozoic complexes, only rough sedimentary petrology studies have been completed here. Our knowledge of Lower Triassic clastic wedge is far from complete, too. We learned that the old division of Mid-Triassic carbonate ramps and platforms are too schematic. Detailed knowledge of lithostratigraphy can help in the interpretation of the “Ladinian Aborted Rifting” and/or the “Lower Carnian Pluvial Event”, as well. An archive of palaeoclimate and palaeotectonic data is hidden in the Upper Triassic Carpathian Keuper and in the Hauptdolomit sequence, still. The history of separation of the Alpine-Carpathian microcontinent from the European shelf could be reconstructed by the analysis of Lower Jurassic lithostratigraphic record. Process of Middle Jurassic basins deepening and of the Czorstyn Ridge elevation could be also interpreted by a detailed study of particular rock sequences. Wide distribution of the Rosso Ammonitico facies belongs to the old mysteries of the Jurassic paleogeography: however, evolution and correlation of numerous formations composed of Jurassic condensed red nodular limestones has never been described. There are lots of uncertainties in the correlation of both Lower Cretaceous planktogenic pelagic limestone (Neocomian) carbonates and neritic (Urgonian) carbonate platforms. The interpretation of Mid Cretaceous collapse of carbonate sedimentation and onset of fine detrital sedimentary formations are even more disputable. We know very little about the start and the correlation of the Gosau sedimentary basins and their evolution, but the correlation of the Palaeogene basins and their termination (as late as during earliest Miocene) is just enigmatic. The Miocene sedimentary basins and their connection with moving orogenic wedge have been subject to numerous studies, but the interpretation of their evolution is far from being final still.

Final stages of the Magura Basin development: the Krynica and Bystica facies zones in Poland and Slovakia (Western Outer Carpathians)

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Abstract

Recently in several sections in Poland and Slovakia have been found flysch deposits younger than the Magura Sandstone Formation. These deposits were located sometime at the front of the Pieniny Klippen Belt (PKB) and still reveal deep-water character, as it is documented by rich flysch-type agglutinants, occurrence of radiolarians and turbidite-flow sedimentation.

The studied sections are located inthe lower reaches of the Veselianka Creek, Oravska Jasenica quarry and the Hruštinka stream in Babin, SW of Námestovo. These deposits belong to the Oravska Magura (Krynica) lithofacies zone, and are represented by the Magura Sandstone (Cergov Fm.), Racibor and Malcov formations. Based on previous studies age of these formations was determined respectively as: the Paleocene-Middle Eocene, Middle Eocene-Lower Oligocene and Upper Eocene to Oligocene. The Magura Sandstone has been sampled in the Veselianka stream section and Oravska Jasenica quarry, the Racibor Fm. in the Veselianka section and the "Malcov Fm". in the Hruštinka stream section.

These deposits contain foraminifers, which represent the index species of the Late Chattian and Aquitanian-Burdigalian biozones, like *Paragloborotalia pseudokugleri* (FO – P22, LO – M1), *Globorotalia peripheroronda* (FO – M2), *Globigerineloides trilobus* (FO – P22/M1), *Globoquadrina praedehiscens* (FO – P22, LO - M2), *Globigerinoides aff. sicanus* (FO – Burdigalian).

The autochthonous assemblages are characterized by the presence of *Calcidiscus premacintyrei, Sphenolithus conicus, Sphenolithus disbelemnos, Sphenolithus dissimilis, Reticulofenestra pseudoumbilica* and *Triquetrorhabdulus carinatus*. At the same time *Dictyococcites bisectus, Cyclicargolithus abisectus and Zygrhablithus bijugatus* are absent from this association. According to the FO of S. disbelemnos and/or *Umbilicosphaera rotula* are reliable biostratigraphical events, characteristic for the lower limit of NN2 Zone. In such case the age of all samples can be determined as not older than NN2 zone which is Early Miocene. The nannofosil assemblages from all localities are highly dominated by reworked species. The percentage of allochthonous assemblages oscillates between 30 and 40 % and could be even higher due to long-ranging taxa such *Braarudosphaera bigelowii, Coccolithus pelagicus* and *Sphenolithus moriformis*. The abundance of Cretaceous species is rather low and range from 4 % to a maximum 10 %. Paleogene species account for 26 % to 36 % of the reworked assemblage.

Examined sedimentary formations from the Horna Orava sections display the facies and age similarity with the youngest deposits from the Magura Succession in Poland and Eastern Slovakia. These deposits still reveal deep-water character, as it is documented by the rich flysch-type agglutinants, occurrence of radiolarians and turbidite-flow sedimentation. This suggest that during the Oligo-Miocene along the front of the PKB developed the residual piggy-back basin separated by partially uplifted part of the Outer Carpathians

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The Gosau Group: syntectonic Upper Cretaceous to Paleogene in the CBGA region

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Abstract

The lithostratigraphic subdivision of Cretaceous to Paleogene strata of the CBGA region is characterized by a large variety of formations and higher-rank lithostratigraphic units within individual member countries. This fact is due to the large variety of facies, from continental to deep-marine, especially as a consequence of Alpine orogeny, resulting in a high number of different Alpine tectonic zones and thrust units. However, some facies assemblages and successions can be recognized in a wider area, and possibly correlated over several countries.

A special case is established by the Gosau Group and equivalent Gosau-type sediments within the Alps-Carpathians-Balcanides area. The term "Gosauschichten" or Gosau-type sediments or Gosau-facies was used loosely for transgressive Upper Cretaceous successions within an area from the Eastern Alps of Austria up to the Carpathians of Romania. At its type locality in the Northern Calcareous Alps (NCA) of Austria, the Gosau Group is defined by a basal angular unconformity above Permian to Lower Cretaceous rocks, thus marking a new sedimentary cycle starting in Late Turonian times. These deposits follow a phase of Lower Cretaceous to Cenomanian deformation, which was attributed to the Austrian phase.

The Lower Gosau Subgroup (Upper Turonian -Campanian) at the type locality and other Gosau basins in Austria starts with terrestrial deposits. Widespread (karst) bauxites indicate weathering in subtropical-tropical climate and give evidence for subaerial exposure of wide areas for the first time in the Mesozoic. Alluvial and fluvial conglomerates indicate syntectonic sedimentation and considerably tectonic relief, including source areas mainly from the NCA, but also from "exotic" sources both to the north and to the south of the NCA. Alluvial sediments pass gradationally into shallow-marine successions with a mixture of various facies types, from fan-delta conglomerates to coastal strata and small rudist and coral bioherms and lagoons. Abundant fossils like rudists, solitary corals, molluscs (gastropods like Trochacteon, Actaeonella, Nerinea, etc.; bivalves like inoceramids) and ammonites mark these "Gosau-type" facies. Individual basins show strong intrabasinal and interbasinal facies changes within a few kilometers, and a rugged topography. Basins of the NCA were interpreted as relatively small, strike-slip related basins due to extension after contractional deformation and thrusting, including piggy-back basins on thrusts. Strong, short-lived tectonic subsidence pulses characterize this phase of basin formation.

Above an unconformity, the Upper Gosau Subgroup (UGS) in Austria comprises deep-water deposits such as marls and a broad variety of deepwater clastics up to the Eocene. Turbidites dominate some parts of the basins. A major subsidence pulse is present at the base of the UGS which deepens the whole NCA area step-by-step in bathyal to abyssal depths, with some of the northern basins showing deposition below the CCD.

In principle, this characteristic "transgressive" succession is characteristic not only for the NCA, but also for central Alpine complexes in Styria and Carinthia.

Very similar deposits in the continuation of the Austrian basins are known from Slovakia (Brezová Group, Myjava Group) and Hungary (Transdanubian Range). Largely similar transgressive successions with slightly different stratigraphic ages are also reported from Romania (Apuseni Mountains) and Serbia (e.g., Mokra Gora, Western Serbia). Although geotectonic positions and basins may have been different, the largely similar basin development points to a common evolution of the area after a mid-Cretaceous tectonism followed by renewed marine transgressions and a deepening of the depositional areas. A common, high-rank lithostratigraphic unit (Gosau Group or Gosau Super-Group) seems appropriate, despite different formations (and subgroups) in different basins. Interestingly, some more features are in common along the area, e.g. the occurrence of ophiolitic detritus including chrome spinel in heavy mineral assemblages. Thispoints to a common mechanism of tectonic basin formation related also to Late Jurassic to Early Cretaceous ophiolite obduction and suturing in the Neotethys realm, largely to the south of these basins.

A GIS approach to the identification of individual neotectonic blocks; preliminary application to Heraklion basin, Crete Island, Greece

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Abstract

This paper presents a novel methodology for identifying neotectonic blocks based solely on geomorphological features of the study area. The main idea behind this methodology is that individual crustal blocks are being deformed more or less uniformly in successive deformation phases. This uniformity in deformation is reflected on the morphological characteristics of the block. The older the deformation, the subtler its morphotectonic signature will be, all other parameters (e.g. lithology, erosion pattern, etc.) being the same. In order to estimate the overall effect of neotectonic deformation on individual crustal blocks, we propose a multivariate analysis of various morphometric features associated with this deformation.

The first stage of this methodology is the critical reviewing and harmonization of geological features. We propose the classification of all mapped geological units into three classes: loose sediments, compact sediments and bedrock. This classification is not a strict one, as it takes into account the physical characteristics of each unit, rather than its exact litho- and chrono- stratigraphic characterization.

The second stage consists of block definition, using mapped faults and fault zones. As crustal blocks are being deformed, their boundaries should consist of rather large-scale faults. The existing faults in this case are not examined on the basis of their individual geometrical and kinematic features, but rather on their position as bounding faults of those pre-defined blocks.

The third stage is the calculation of specific indices and morphotectonic features for each of the blocks. One of the most important and effective indices is the Topographic Ruggedness Index (TRI), which describes the topography in terms of its ruggedness. TRI reflects the effect of erosion on the Earth's surface for a specific block, which in turn may be associated with the vertical movements of areas with recent tectonic activity. Other morphological variables that are been taken into account in the proposed methodology are the maximum and minimum altitudes of an individual block, the local and regional base levels, etc., as well as various other values that derive from those variables.

Finally, the evaluation of all previous stages leads to the characterization of each block based on the results of the previous stage. Differences between the same variables in different blocks signify a different neotectonic behavior. The result is a semi-quantitative evaluation of various levels of tectonic activity, which in turn can be applied into individual faults within the blocks for assessing their possible seismic potential.

In order to test this methodology, we performed a geomorphological analysis in a GIS environment of Heraklion basin in Crete Island, Greece. It is a fault-bounded Neogene basin that is also criss-crossed by neotectonic faults of various strikes. Crete was selected because it is located on the accretionary wedge of the Hellenic Arc and is characterized by intense neotectonic uplift due to its geotectonic position. Heraklion basin has been divided into several blocks, based on geological and structural information of published maps, which were digitized in a 1:10,000 scale. For each of those blocks several morphotectonic parameters have been calculated. Preliminary results show that there is a clear differentiation between blocks of various sizes, indicating that their uplift has not been uniform in the neotectonic period. The application and refinement of the proposed methodology is expected to yield more detailed results regarding recent deformation patterns in areas of neotectonic activity.

The Cephalonia, Greece, 2014 earthquake sequence: surface effects and structural model

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Abstract

The Cephalonia, Greece, 2014 earthquake sequence consists of a series of earthquakes, the strongest of which are the Mw 6.1 of January 26 and the Mw 6.0 of February 3, 2014. Their focal mechanisms indicate that they have been generated through the activation of a right-lateral strike-slip fault, with reverse component. These mechanisms are consistent with the general geometrical characteristics offshore Cephalonia Transfer Zone (CTZ), a dextral structure that interrupts the continuity and displaces the western part of Hellenic Arc. Nevertheless, the location of their epicentres, as well as the ones of the entire sequence, show that it was not the main CTZ that was activated, but rather faults that are kinematically linked to it.

The broader area is probably the most seismically active one of eastern Mediterranean, as indicated by a large number of strong, destructive earthquakes (e.g. AD1469 M7.2, 1636 M7.1, 1743 M7.0, 1759 M6.3, 1766 M7, 1767 M7.2, 1862 M6.6, 1867 M7.4, 1912 M6.8, 1915 M6.6, 1939 M6.3, 1953 M6.4, M6.8 and M7.2, 1972 M6.3, 1983 M7.0). The smaller earthquakes of the sequence conform to the general active tectonic fabric of the area, i.e. they were associated with strike-slip and reverse faults, indicating a transpressional regime.

The two strong earthquakes created a variety of environmental effects, such as landslides, rockfalls and liquefaction, while surface ruptures were limited and of secondary nature. Rockfalls were largely controlled by the geomorphology, as they happened in areas of steep slopes, regardless of the geological structure. Large rockfalls were observed in several areas along the western shoreline of the island, mainly at beaches such as Mirtos, Petani, Platia Ammos, AghiaEleni, Xi and several more unnamed coastal localities with similar steep slopes. Several rockfalls were also observed in non-coastal areas, such as Kipourei, Atheras, Angonas, Farsa, Kourouklata and many more. Finally, a lot of smaller rockfallsoccurred along the western slopes of AenosMountain, the tallest peak of the Ionian Islands. Rotational landslides were observed in fine-grained Neogene sediments that cover the largest part of Paliki Peninsula (SW part of the island), the largest one being at Sullari. These Neogene sediments caused significant amplification of the seismic waves, resulting in heavy damages in areas such as Havriata village. Rather limited liquefaction happened in low-lying coastal areas, most notably at Lixouri harbor, which suffered severe damage and became nonoperational.

Since the earthquakes did not produce surface ruptures, we carried out fieldwork onPaliki Peninsula in order to understand the tectonic structure of the area and to compare its structural fabric with the information from focal mechanisms. Several faults of various kinematics and strikes were identified:

- Right-lateral strike-slip faults of NNE-SSW strike.
- High-angle reverse faults of NW-SE strike.
- Normal faults of NE-SW strike.

The location of the faults and the angular relations between them indicate that they are compatible with a typical strike-slip deformation pattern, i.e. the normal and reverse faults are not primary ones, but rather transfer faults that link the large dextral faults. The distribution of aftershocks and the strike of the mapped faults show that the sequence did not take place on the main CTZ, but on faults that are linked to it and act as Riedel shears of the principal displacement zone. This is also reflected in the internal fabric of the carbonate bedrock, where micro- and mesostructures show a similar pattern of deformation. Therefore, the current active status of the area is in good accordance with the structural fabric of the western part of Cephalonia, which therefore has been shaped by the proximity to the CTZ, at least since Late Pliocene.

Neotectonic incision rates in the western Pannonian Basin (Hungary) based on complex geochronological, volcanological, GPS studies and sediment balance calculations

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Abstract

The Pannonian Basin system is a result of lithospheric extension in the late Early to Middle Miocene times. After the Late Miocene thermal subsidence phase, the Pannonian Basin started to be inverted by newly established compressional to strike-slip regime. The basin inversion started gradually from the southern to central basin parts, in the ca. 7–4 Ma time span. The investigated area incorporates the Transdanubian Range (TR), a SW–NE trending hilly area across the western Pannonian Basin, and its forelands. Dated landforms mainly occur above Late Miocene sediments of the Pannonian Basin.

One important consequence of basin inversion was the uplift and subsequent erosion of the Pannonian Basin. The rate of uplift or the lowering of the surfacewas investigated by diverse geochronological data, GPS measurements and reconstruction of Pliocene volcanic edifices.

In the southern TR we have two data sets which constraint the gradual lowering of landforms: base levels of Pliocene basaltic volcanoes and maars demonstrate a maximum rate of 0.1 mm/a surface lowering if denudation has started just after volcanism. Cosmogenic in situ ^{10}Be concentrations suggest 0.04 to 0.08 mm/a surface lowering in wind-eroded small depressions.

In the central part of the TR, pediment surfaces and alluvial fans were dated by luminescence method. Maximum incision rate of a major river could reach 1mm/a, and this relatively high value can be interpreted as a result of local footwall uplift of an active fault.

In the northern TR several data can be arranged in a ca. W-E cross section. In the western foreland of the northern TR, terraces of the Danube river were dated by combined cosmogenic and luminescence dating techniques. Minimum ages of landforms correspond to increasing maximum incision rates (0.06 to 0.12 mm/a) from west to east, toward the range. In the axial part of the TR published cosmogenic ^{3}He minimum exposure ages from strath terraces yielded a much higher maximum incision rate around 1.6 mm/a although this rate can be questioned by luminescence dates of valley-filling loess deposits. On the south-eastern side of the TR, published U/Th series dating of cave minerals, suggest 0.15 to 0.32 mm/a lowering of karst water level, which reflect uplift rate of this area. It is in agreement with U/Th series dating of travertines, which indicate a maximum uplift rate of 0.2-0.4 mm/a. The variable uplift rates were attributed to local fault-related deformation.All these data are in agreement with the assumption of the much larger uplift rate in the axial part of the TR than in its foreland, due to its differential deformation (folding or faulting).

Repeated GPS measurements of several sites in and aroundthe region can also provide constraintsfor vertical motion during the last 20 years. Preliminary data indicate that vertical motions do not exceed 0.5 mm/a in the TR. The incision of major and local valleys resulted in denudation of considerable amount of sediments from the TR. Deposition occurred in nearby locations, in forms of fans and river terraces while other part was transported into basins of ongoing subsidence. Preliminary calculations of this material balance show that the above model is feasible.

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Neotectonics and geodynamic of Albanian

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Abstract

Present the geological situation of Albanian territory in the frame of regional geology as well as an overview of neotectonic structure that build up this country. The geological structure of Albania is multifold and complicated and has some tectonical structures of different regimes and generations. In the regional tectonic frameworkd we have elaborated elaborated the relationships between Adriatic microplate as a tectonic unit that has played and continue to play a major role in geodynamics and in the central Mediterranean and as a result in Albania. Special attention has been paid on the interpretation and colleraltion of data registered by the permanent GPS geodynamic network in Albania and neighboring countries.

At the same time, based on geodynamic data presented, the displacements and deformation of the outer and inner Albanide's tectonic units in relation to the stable euroasian Plate and the apulian block.

Geological structure of Albania

The geological structures of Albania are part of the Dinarides-Albania-Hellenic belt, which represents the southern extension of the Alpine Mediterranean fold and thrust belt (Suess 1983). This orogen is located in southern extension of Alps, along the eastern coasts of the Adriatic and the Ionian seas and from here passing the Aegean Sea stretching towardsto Taurides in Turkey.

In the framework of Mediterranean tectonics the Albanian orogen is placed to the opposite of the of the Adriatic microplate. The movements of the Adriatic microplate hare a consequences of the convergence between the African and Eurasian Plates (Mantovani et al. 2006). The tectonic relationships of the Albanian orogen with the Adriatic microplate, differentiating from the Aegean or Hellenic Arc, appears to be relations of a continental collision, which is associated with compressional feauters like thrusts and nappes in Albania.

The geological formations in Albania are made up build of different types of rocks that includes a wide range of stratigraphic ages. The ages ranges from Paleozoic up to Quaternary times.

Based on characteristics of magmatism, structural criterias and the relations between units, the Albanian geological units are divided in inner and outer zones, where the Inner ones are located east and north-east in the country, while the outer Albanides are found in the west and south west.

From the tectonic point of view, the geological structure of Albania is part of teh Alpine fold and thrust belt.

During the Alpine evolution, pre-neotectonic, in inner zones a huge pile of tectonic nappes formed, while in outer zones still compression caused overthrusting. The convergene of geological structure of Albania is oriented south-west, from the inner zones towards outer ones, with massive displacements towards south-west (Aliaj 1996; Koçi 2012). Based on the geological studies in the field, microtectonic, geophysical ones as well as studying the focal mechanisms of some earthquakes are compiled the Neotectonic and Seismotectonic Maps of Albania, with different stress regimes during the Plio-Pleistocene to Holocene (present-day).

Results of Albanian GPS geodynamic network

Nowadays there is gained important data from the GPS Geodynamic Network of Albania and neighbor countries related to present geodynamic situation of Albania. Figure 1 gives an overview of the displacements of the outer and inner Albanides, in relation to the Eurasian Plate and the Apulian block.

The data derived from GPS Network for a period of 10 years in Albanian in relation to the Eurasian and Apulian Plates shows that outer Albanides including hte Sazani, Ionian and Kruja areas, have been affected by an important pre-Pliocenecompression and later a major shortening post-Pliocene occurred in the nearby Adriatic Valley. The outer Albanides have been

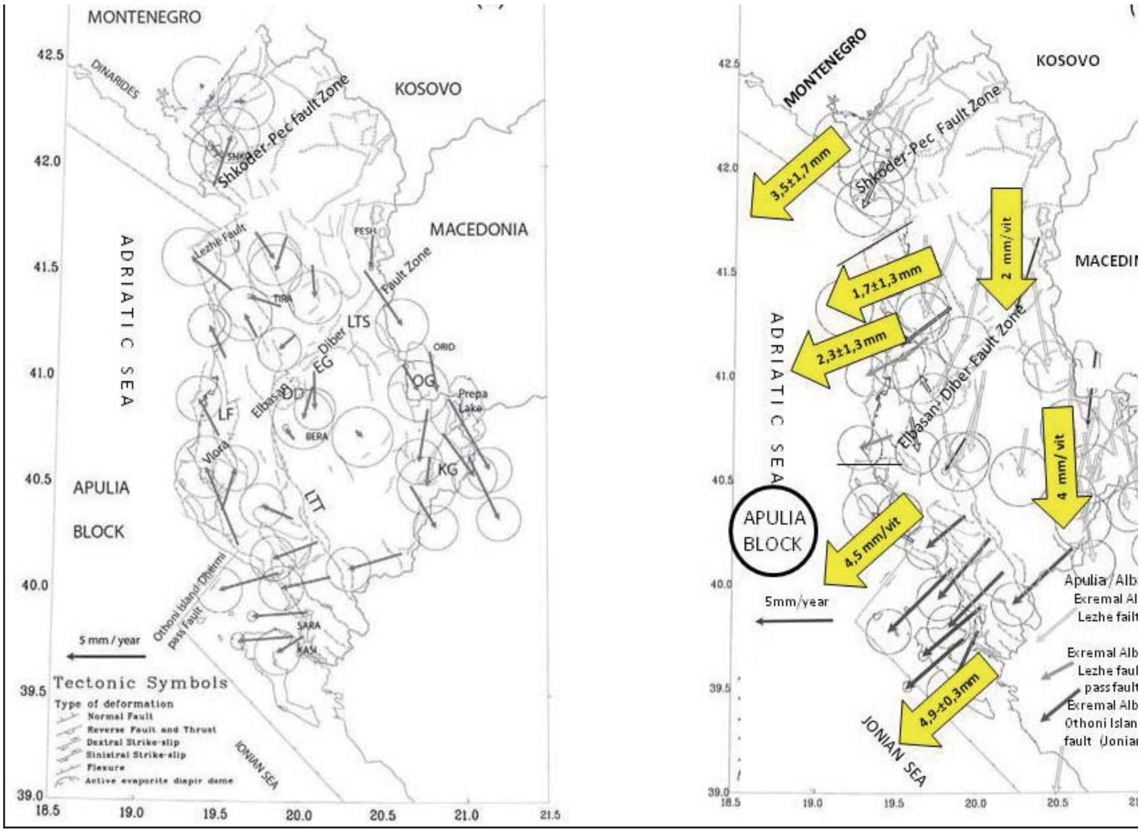

Figure 1. Map of displacements of Albania in relation to the Euroasian plate (Figure a) and Apulian block (Figure b). (Jouanne F. et al. 2012)

formed with infringements of overthrust, reverse faultingand with folds trending NNW-SSE and in some cases of a cross-linked displacement of NE-SW up to E-W orientation. The many solutions of focal mechanisms of shallow earthquakes show a horizontal compression direction that dominates along the area of Adriatic collision (Fig. 2). This tectonic situation is reflected in historical and instrumental earthquakes of a large magnitude.

The results of GPS network for the points that are located in outer Albanides shows that they are displaced towards west and north-west in relation to Eurasia and south-west in relation to the Apulian block (Fig. 1 A,B). In the meantime there can be detected an average deformation in the continental part of nearby Adriatic Valley (2 mm/year between Tirana and Kryevidh) and an important shortening in Adriatic Sea that increases from North to South in Albania (Jouanne et al. 2012) (Fig. 1). This shortening is observed from overthrust and reverse faultsas well as focal mechanisms of many earthquakes.

In relation to Eurasia, the speed of displacements of points outer of Albanides change in direction and value. In northern Albanides (north of cross section Shkoder-Peje), can be seen that the displacements are perpendicular to the axes of the folds and show a shortening of 3 mm/year ± 1.7 mm/year. Meanwhile in the area that is located between cross-section Shkoder-Peje and Vlore-Tepelene, the velocity of displacement are different. In the marine section where this shortage is 2.3 ±1.3 mm/year and for the land areas this shortage is 1.7±1.3 mm/year. In the southern section of outer Albanides the displacements are 4.9±0.3 mm/year (Fig. 1/B) (shortening) and can be observed in naval area, based on the permanent station of Saranda there.

The overview of displacements for the inner areas (those in the east part of area Krasta-Cukali) shows differences in relation to outer zones. The obtained results from the albanian GPS network and neighbor countries show that the direction of movements is towards south and south-east in relation to Euroasia and towards south and south-west in relation to Apulian block with 2 mm/year for the sections that are located in north part of cross section Elbasan-Diber and with 4 mm/year in its south (Fig. 1 A/B).

In Albania the nowadays deformations are linked to Adriatic collision: the oppression in the outer area become normal with the boundary of Adriatic

Figure 2. The overview of extertions field in Albanian territory (A/1 dhe A/2 for the outer parts and B/1, b/2 for the inner parts)

collision or based on the displacement direction of orogen towards west. This phenomena is clearly shown by the tensor of exortions in compression which in Shkodra-North Vlora area the direction of exortions forms an angle which decreases in the sections that are located north Vlora (over the infringements of north Sazani) (Fig. 2-A/1). In the meantime the situation for the southern part of Albanian territory shows that the tensor of compression is almost perpendicular with the axeis of structures (Fig. 2-A/2), (Koçi 2008, 2013).

In relation to the inner Albanides can be observed that: sections of Peshkopi – Ohrid lake and Ohrid-Korce are under the influence of pull out regime (extension). In the section of Peshkopi-Ohrid Lake this expansion is made towards NW-SE direction, which is shown from the direction of extension tensor (Fig 2-B/1). The same situation can be observed even for the section Oher-Korce but with the direction of extension is E-W in the center and changes towards south to SSE-NNW (Fig 2-B/2).

Conclusions

The overview of displacements of outer Albanides is linked to the continuous collision between the eastern border of Adriatic microplate and Albania, just like south-west part of Eurasian Plate. The amount of displacements in western border of Albanides increase from north towards south. In the north-western part the magnitude of displacements is about 3 mm/year, in the central part (Tirana station) this displacement is about 3.2 mm/year and in the southern part (Saranda station) this displacement is 4.9 mm/year in relation to Apulian block. The increase of displacement values from north towards south for the Albanian orogen in relation to Apulia block shows for an counter-clockwise rotation of Apulian block and a possible clockwise rotation of Albania and its mountain belts.

In relation to the extension, it is observed that in the outer zones of the Albanides the compressive forces are dominant and these observations is also supported from the focal mechanism of the earthquakes. While in the inner zones are currently under extension.

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Cenozoic stress/deformation field of the eastern East European platform as related to the Late Alpine collision deformation of the Greater Caucasus

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Abstract

In the south-eastern East European platform and Urals, as well as the young Scythyan platform, the Cenozoic collision deformation is widely spread. First of all, these are crumbled aulacogen covers (the Dnieper-Donets, Viatka-Kazhim, and Pachelma aulacogens). The covers were dislocated conformably on platform basements in some places, but commonly they were partly detached from it with formation of inversion foldbelts (such as the Donets Herzinian one in the Alpine stage, Saratov and Kerensk-Chembar deformation). Basements of some anteclises (the Voronezh, Tokmovo, and Volga-Urals ones) dividing the aulacogens were also involved into deformations. The greatest upthrusting of basement onto cover can be observed there (e.g., the Zhigouli upthrust). In general, the thrusting and folding occurred during the Early Miocene-Quaternary, with its periodicity strictly corresponding to that of the Late Alpine tectonic phases in the Greater Caucasus: Early Miocene (the H. Stille›s Styrian phase), terminal Miocene-initial Pliocene (the Attic and Rhodanian phases), and Earliest Pleistocene (the Valachian phase). The sole exception is provided by the Dnieper-Donets aulacogen deformation crumbled before the Eocene (the Laramic phase). Beside the synchronous occurrences, there are some other evidences of relation of intraplate deformations to the Arabia-Eurasa collision in its Caucasian region: (i) the W–E (up to WNW-ESE strike) orientation of the intraplate upthrusts and folds, (ii) wide distribution of strike-slip zones as well as similarity in orientation and location between the right and left strike-slips considered with those in the Greater Caucasus: domains of the formers are built up to the north the domains of the latters, (iii) directed southward increasing basement involvement into the Cenozoic deformations. For example, in the Donets-Azov region, a basement neotectonic megafold was imposed not only onto Donets Herzinian foldbelt, but also on the Precambrian basement of the Rostov high of the Ukrainian shield. To some extent, this basement fold resembles a northern flank of the Greater Caucasian orogen built by an actived basement of the Scythyan plate.

Signs of influence of collisional pressure onto intraplate deformations are also demonstrated by the Cenozoic stress/deformation field studied by the authors by means of mesotectonic measurements of tectonic striation, slickensides and veins in the Upper Mesozoic-Quaternary rocks. As a result, a series of maps of the Cenozoic stress field of the area studied has been first computered. The maps show an orientation and dip of general normal and tangential tectonic stresses as well as a character of the stress regime type (compression, extension, or horizontal shear) determined with the Lode-Nadai coefficient. A combination of the macrotectonic and mesotectonic data allows the following conclusions on dynamics of the platform Cenozoic structures formation. (1) In the southern part of the studied platform area (the Zhigouli, Saratov and Kerensk-Chembar dislocations, and Donets foldbelt in the Alpine stage), formation of the structures was greatly affected by increasing toward the Greater Caucasus compression in the thrust and strike-slip stress regimes. Horizontal projections of a compression axis in all these areas are oriented to the N–S (up to NE-SW) whereas horizontal projections of an extension axis are oriented to the W–E (up to WSW-ESE). (2) The compression is also growing eastward, to the Uralian-Mougodjary recent orogeny, but its axis is directed there to the W–E, with the extension axis orienting to the N–S. (3) In the right angle between mutually perpendicular domains: the southern (adjacent to the Caucasus) and eastern (“the Uralian”) ones, a domain of horizontal extension is present; an extension axis was oriented both to the N–S and to the W–E. In topography this area represents a vast depression, with its centre approximately marked by the point of a confluence of Kama with Volga, the greatest rivers

of the Russian plain. In this domain, the collision (?) compression also took place, but it was only slightly pronounced in the surface (for example, deep-seated folds of the Vyatka dislocations) and, besides, had a stronger disperse in axis orientation. Some prevalence of the NW-SE axis orientation allows conclusion that such compression strike was a result of a geometric composition of two mutually perpendicular vectors of pressure directed from the Greater Caucasus and the Urals, correspondingly. (4) All the results listed above indicate to an essential role of far collision stresses in the formation of the Cenozoic structure of the studied platform territory. The collision pressure came predominantly from the Greater Caucasus belonged to the Peri-Arabian collision area as well as from the recent Urals representing presumably the north-eastern “outpost” of the Peri-Indian collision area. (5) Several discrepancies in the macro- and mesotectonic data in relation of role of the compression and extension on formation of every platform neostructure (the formers point to more compression setting) are consistent with the idea that these far collision stresses being passed at the depth through the consolidated crust upwards (to the earth surface) were partially scattered in the platform cover.

New insights on the seismic hazard in the Balkans inferred from GPS

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Abstract

The Balkans region sits at the transition between stable Eurasia and highly straining continental Eastern Mediterranean, resulting in a widespread seismicity and high seismic hazard. Because of intensive human and economic development over the last decades, the vulnerability has increased in the region faster than the progress in seismic hazard assessments. Opposite to the relatively good understanding of the seismicity in plate boundaries contexts, the seismic hazard is poorly known in the regions of distributed continental deformation like the Balkan region and is often underestimated (England and Jackson 2011). Current seismic hazard assessments are based on the historical and instrumental catalogues. However, the completeness interval of the historical data bases may be below the average recurrence of individual seismogenic structures. In addition, relatively sparse seismological networks in the region and limited cross-border seismic data exchanges cast doubts in seismotectonic interpretation and challenge our understanding of seismic and geodynamic processes. This results in a inhomogeneous knowledge of the seismic hazard of the region to date. Geodetic measurements have the capability to contribute to seismic hazard by mapping the field of current active deformation and translating it into estimates of the seismogenic potential. With simple assumptions, measurements of crustal deformation can be translated in estimates of the average frequency and magnitude of the largest events and assessments of the aseismic deformation. GPS networks in the Balkans have been growing during the last few years mainly for civilian application (e.g. Cadastral plan, telecommunications), but opening new opportunities to quantify the present-day rates of crustal deformation.

Here we present the initial results of GEOSAB (Geodetic Estimate of Strain Accumulation over Balkans), an AXA-Research-Fund supported project devoted to the estimation of crustal deformation and the associated seismic hazard of the Balkan region. We processed all the currently available data acquired on these new networks using the precise point positioning strategy of the Gipsy-Oasis software (Bertiger et al. 2010, version 6) and the daily ITF 2008 transformation parameters (x-files) from JPL. Daily coordinates are obtained in a Eurasia-fix reference frame created using the strategy developed by Blewitt et al. (2012). We present this new velocity field combined with previously published data sets covering the Balkan Peninsula. This unusually dense picture of the current deformation, in particular in Slovenia, Serbia and northern Greece, is combined together with tensor moments from RCMT and CMT to derive a continuous map of the strain rate over the region using the approach of Haines and Holt (1993). These maps bring new insights on areas of significant strain accumulation over the Balkan Peninsula and are a first step to better assess seismic hazard there. In particular we demonstrate that significant strain is accommodated in the Balkans peninsula from northern Greece to the Carpathian belt. The location of strain is an important indication for identifying active faults in the region.

New data on the Pieniny Klippen Belt evolution a case study of the Małe Pieniny Mts (Western Outer Carpathians, Poland)

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Abstract

The Małe Pieniny Mts of Polish Western Carpathians, are located between the Dunajec River Valley on the west and Polish/Slovak state boundary on the east. These mountains are up to 12 km long and 5 km belongs to the Pieniny Klippen Belt (PKB), a suture zone, that separates the Central Carpathians from the Outer Carpathian accretionary wedge. Along the northern boundary the PKB is separated from the Paleogene to Early Miocene flysch deposits of the Magura Nappe by a narrow, strongly deformed belt belonging to the Grajcarek Unit.This Unit is composed of the Jurassic, Cretaceous and Paleocene pelagic and flysch formations. The klippen units of the PKB are represented by the Jurassic-Lower Cretaceous carbonate formations overlain by the Upper Cretaceous variegated marls and flysch deposits. After the Middle Paleocene the klippen units were initially pushed over the Grajcarek sub-basin and finally refolded all together. At the turn of the Early Miocene the PKB nappes were thrust over the Magura Nappe. This was followed by the Middle Miocene compression, strike-slip deformation along the northern and southern boundaries of the PKB and development of its its present-day flower structure and then, by the Late Miocene andesite intrusions and finally transverse faults developed.

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The Cephalonia, Greece, 2014 earthquake sequence: implications of earthquake triggering

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Abstract

On January 26, 2014, the island of Cephalonia was struck by a strong (M_w 6.0) earthquake. The epicentral area was located on the Paliki Peninsula, at the western part of the island, where widespread environmental effects and damages to buildings and infrastructure occurred. The mainshock was followed by several aftershocks, the two strongest of which occurred from few hours after the mainshock (M_w 5.3) up to few days (February 3, M_w 5.9). Preliminary published seismological results reveal a transcurrent fault system: the two strongest shocks demonstrate almost pure right-lateral strike-slip faulting striking approximately NNE-SSW, whereas the M_w5.3 shock was produced by a reverse dip-slip fault of NW-SE direction. At the same time, preliminary relocated aftershock spatial distributions and epicentral locations of the Institute of Geodynamics (National Observatory of Athens) imply the activation of a transpressional bend near and parallel to the well-known offshore Cephalonia Transfer dextral strike slip Zone (CTZ). This transpressional bend is expressed as a series of blind thrust faults, causing uplift and bending of the overlying Eocene to Miocene sediments, as shown in geological maps of the area.

Taking into consideration the aforementioned preliminary seismological data, we modelled the faults that were responsible for the three strongest shocks (including the mainshock) of the earthquake sequence and calculated the stress change pattern after the first, second and third shock respectively, using the Coulomb failure criterion. Our model is based on the relocated aftershock spatial distribution, epicentral locations and focal mechanisms of the Institute of Geodynamics (National Observatory of Athens). It includes three blind fault planes with locations estimated from the focal mechanisms and aftershock distribution, geometric and kinematic parameters adopted from the focal mechanisms and dimensions estimated from magnitude scaling empirical relationships and aftershock distribution. Stress change pattern is calculated according to the next event, considering stress prior to the mainshock equal to zero, for a wide range of depths, from 4 down to 20 km, in order to cover the depth range of the aftershock sequence as well as the thickness of the seismogenic layer of the area. For this reason, several vertical profiles were also produced. Stress change pattern after the latest event is calculated according for both strike-slip and reverse faults that can be found in the study area.

Our first results show that i) the reverse fault responsible for the first strong aftershock should be blind, with a minimum depth of ca. 12 km, given that stress load is observed approximately between 10 and 18 km depth, and ii) stress accumulation on the respective fault planes before each aftershock, imply a triggering effect. However, Coulomb stress changes for earthquake triggering scenarios of strong instrumental earthquakes before the 2014 sequence (since 1953) show poor or no triggering effect at all for most of the past events except the 1983 sequence. Our models and results will be updated according to the latest upcoming data, while the Okada dislocation model will be applied in order to compare the surface deformation with preliminary published InSAR and GPS results.

Geological data on the source of the 2012 Mw 5.6 Pernik earthquake, SW Bulgaria

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Abstract

The earthquake of M_W 5.6 on 22 May 2012 in SW Bulgaria is a shallow normal-faulting earthquake. Coseismic ground cracks along a fault-line scarp, focal mechanisms and hypocentre allocations suppose that the seismogenic source is a normal fault segment from the NW boundary fault of Pernik basin, named Meshtitsa fault, which has not been considered as an active fault previously. A paleoseismological trench was excavated in 2013 across the middle of the fault segment. Scarp morphology, trench data, and electrical resistivity profiles provide evidence that the fault displacements near surface are distributed along a main fault positioned between Upper Cretaceous agglomerate tuff and Paleogene sediment and along adjacent bedding planes within the Paleogene. Bedding-plane fault slip occurs preferably on contacts between conglomerate and argillite. The trench data confirm that the Meshtitsa fault experiences repeating medium-sized earthquakes during the Holocene. The relatively small displacement and dispersed pattern of fault slip distribution near and on the surface result in subtle tectonic morphology of a pre-existing fault-line scarp and adjacent landscape. Weak morphotectonic features similar to those of the Meshtitsa fault have to be considered when earthquake potential of a region is evaluated.

Keywords: *2102 Pernik earthquake, intraplate active faults*

Introduction

A shallow normal-faulting earthquake of M_W 5.6 hit the SW Bulgaria on 22 May 2012. Hundreds of constructions have been affected in the vicinity of Pernik town. Damages have been reported even in the capital Sofia about 25 km away. Estimates on epicentre (EMSC 2012, USGS 2012) have located the earthquake in a Tertiary basin called Pernik basin. Observed coseismic ground cracks along a fault-line scarp (Radulov et al. 2012) considered together with focal mechanisms and hypocentre allocations (EMSC 2012, USGS 2012) suppose that the seismogenic source is a normal fault segments from the NW boundary fault of Pernik basin. The fault has not been considered as an active fault previously. A combined study on triangulation and GPS data has recorded increased extension assigned to a suggested NW-SE striking fault along the Pernik basin (Kotzev et al. 2005). Quoted authors have alarmed the importance of fault identification and allocation at that region. However, relevant studies have not been undertaken before the 2012 earthquake.

We studied in details the Meshtitsa fault, which is considered to be the 2012 earthquake source. Surface geology, geomorphology, shallow electrical resistivity imaging and trench data are presented and discussed.

Geological and Geomorphological Background

The Pernik basin is a continental basin filled with conglomerate, sandstone, shale, and coal of prevailing Oligocene age positioned in the Srednogorie tectonic zone (Fig. 1). The Srednogorie is a regional Upper Cretaceous-Tertiary zone that hosts main extensional loci of the northernmost area of Northern Aegean extensional province.

The Tertiary strata of Pernik basin form a syncline. Many small-scale normal faults in the basin (Kamenov 1964) evidence post-sedimentary extensional tectonics. Bounding faults are arranged in a segmented pattern with changing strikes (Fig. 1). Reverse, normal and strike-slip kinematics have been attributed to the faults (Bončev et al. 1960; Kamenov 1964; Kostadinov 1971). Traditional concept that the basin is an autochthonous syncline compressed between two reverse faults (Bončev et al. 1960) is not likely because it requires fault plane rotation along the vertical accompanied inversion from syn-sedimentary extensional faults dipping toward the center to compressional faults dipping in the opposite sides. Kostadinov (1971) has described dextral transpression on sub-vertical fault planes along the SW basin boundary nominated as Pernik fault zone. The simplest explanation is that recent extension takes place along optimally oriented already existing wall. The middle segment from the NE bounding fault system that shifts strike almost 90° is known as Lyulin reverse fault (Fig. 1). The Lyulin reverse fault has recently been extended toward NW along the Meshtitsa fault segment (Marinova et al. 2010) in contradiction with field observations on

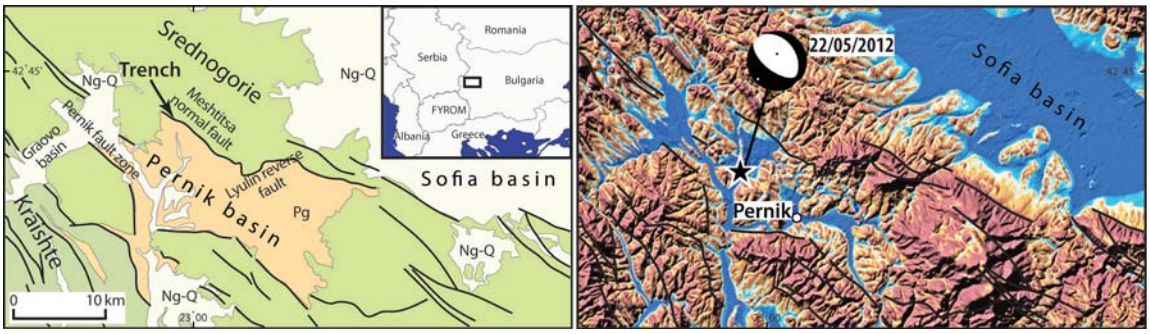

Figure 1. Tectonics (left) and geomorphology (right) of the 2012 Pernik earthquake region. On tectonic map: Pg – Paleogene; Ng-Q – Neogene-Quaternary. Geomorphology presented by shaded relief map from SRTM 3 arc second data (USGS) and colour overlap of Multi-resolutional river bottom index (Gallant and Dowling 2003) indicative for present-day depocenters. Blue colours show increased aggradation, and reddish colours outline area of increased degradation. Geomorphic index calculated by SAGA software. Epicenter and focal mechanism from USGS (2012).

fault segments originated in or underwent strike-slip tectonics. Zagorchev (2009) has emphasized the importance of strike-slip tectonics for the neotectonic period in SW Bulgaria.

The Pernik basin and the Graovo basin shape a hilly intramountain depression consisted of three Late Pleistocene - Holocene depocenters (Fig. 1). Depocenters are relatively flatter and lower-relief areas well outlined by means of multi-resolutional river bottom index (Gallant and Dowling 2003). Recent aggradation is confined to channel and flood alluvium, rare alluvial fans, and landslides along the mountain foothills. Limited sediment indicates prevalent erosion, which tends to mask fault-related landforms. In adjacent normal-fault hanging-wall basins, e.g. the Sofia basin, the Quaternary thicknesses commonly reach tens of meters over fault-scale areas, which is not typical for sub-basins in the Pernik region. Subtle morphotectonics of the Pernik basin and weak instrumental seismicity have been reasons seismogenic potential to be underestimated before the 2012 earthquake.

The Meshtitsa Fault

We refer the north-western section of the NE bounding fault to Meshtitsa fault. The fault generally separates an Upper Cretaceous volcano-sedimentary sequence in the footwall from Oligocene terrigenous sediment in the hanging normal fault at that place (Kamenov 1964). The 2012 earthquake hypocenter is positioned on a normal fault plane that intersects terrain along the Meshtitsa fault trace. Coseismic ground cracks are documented along the same fault trace (Radulov et al. 2012). It is a normal fault dipping to SW, and cannot be considered as prolongation of the Lyulin reverse fault that dips toward the mountain.

The Meshtitsa fault has been mapped over a distance of approximately 9 km. Geomorphic features that mark the fault trace are scarps, regular changes in valley width and depth, beheaded streams, linear valleys, water springs, temporary sag ponds and small landslides. The fault scarp is discontinuous and very gentle. Terrain slope along the scarp usually does not exceed 8°. Upper Cretaceous agglomerate tuff, which is bare or covered by very thin soil, is commonly observed at interfluves in elevated fault block. Thick soil is formed at the scarp base. Grid-based geomorphic indices also indicate different rates of aggradation and degradation in areas separated by fault trace (Radulov 2013).

Electrical resistivity survey along the entire fault length shows a zone of steeply inclined to SW structures. The zone width usually is a few tens of meters. Higher resistivity marks footwall volcanic sediments. Extremely low resistivity characterizes the medium close to the main sub-vertical structure.

Trench

In 2013, we excavated a paleoseismological trench at the middle of the fault segment, on an interfluve, close to a bank of an alluvial river crossing the scarp. The closest coseismic ground cracks related to the 2012 earthquake have been observed at 350 m from the site in NNW direction. Discontinuous sub-parallel color lines on the topsoil parallel to the fault strike are observed. Precise topographic profiles across color lines show steady slope with local concavities; but any small-scale fault scarp cannot be recognized. Electrical resistivity profiles at the site image sharp sub-vertical limits reaching almost to the land surface. Trench is 60-m-long. The trench depth changes, and reaches maximum depth of 2.5 m.

The deposits in the trench are divided into Holocene deposits of units A, B, and C; and basement units D, E, and F (Fig. 2). Unit A is a plough zone. Unit B is dark, massive, with prismatic partition, built of clayey-sandy material with rare angular and semi-rounded pebbles and sandy lenses, rare calcite enrichments, and a lot of ceramics and charcoal in the base. The age of ceramic fragments is Late Bronze (1200-800 BC). Unit C is built of clayey-sandy material, with angular pebbles, and rare charcoals. Units D and E are Paleogene deposits. Unit D represents an alternation of variegated sandstone and pebbly conglomerate. Sandstone is unsorted and with massive structure. Conglomerate is composed of well-rounded rock fragments in sandy-clayey matrix. Bedding plane of unit D steeply dips to SW at angles of 69-75°. Unit E is argillite, which is water saturated. Unit F represents trachyte-andesite agglomerate tuff of Campanian age.

Two distinct faults are recognized (Fig. 2). The front fault separates units D and E. The basement units and the fault are eroded by a Holocene alluvial channel of unit C. The base of Holocene channels is not affected by fault displacement. The rear fault is positioned between Paleogene conglomerate (unit D) and Upper Cretaceous agglomerate tuff (unit F), and offsets the lowermost erosional surface of the Holocene alluvial channels (base of unit C). Displacement along fault dip-direction is 15 cm. The fault transforms in several cracks upward into the unit C, and does not penetrate above into the unit B. Open fissures on top of unit C filled in with material of unit B are common in the trench. We did not identify any open fissures that terminate at the base of layer ploughed after the 2012 event (unit A).

Discussion

The Meshtitsa fault is a normal fault that inherited a pre-existing planar fault of high dip angle (close to 60° from the 2012 earthquake focal mechanism). We suggest that the main fault close to the surface is positioned between Upper Cretaceous agglomerate tuff and Paleogene sediment. Sub-vertical limits on electrical resistivity profiles south-westward the main fault correspond to Paleogene bedding planes. Bedding-plane fault slip related to branches diverged from the main fault occurs within the Paleogene, especially on contacts between conglomerate and argillite. Most probably, displacement of a single faulting event is distributed along main fault and/or adjacent

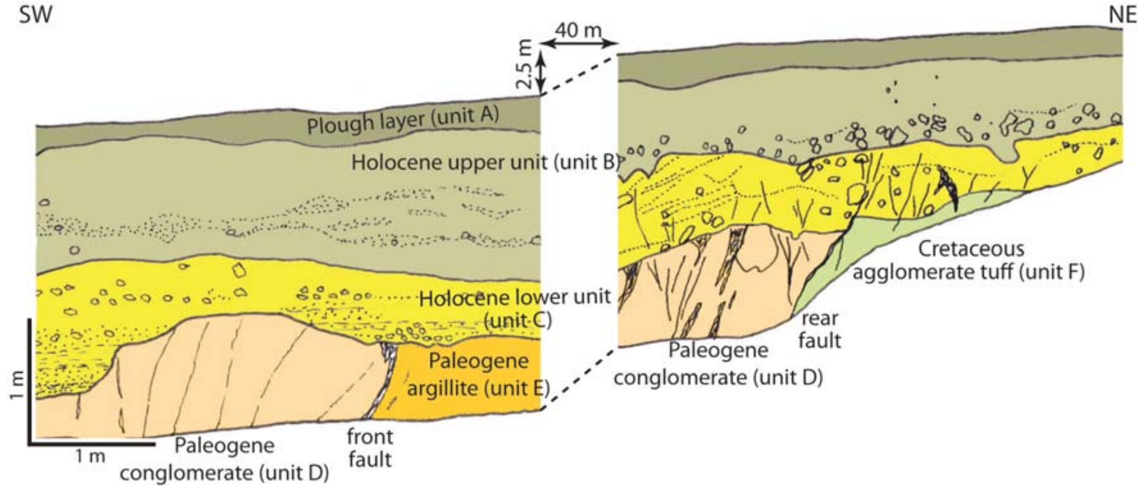

Figure 2. Logs of fault zones at SE trench wall.

bedding planes near surface. Distribution of the total fault displacement along more branches is in agreement with configuration the 2012 coseismic ground cracks that have been arranged along two sub-parallel lines. Fault slip distribution for single and multiple events over a few tens of meters wide fault zone result in very long and flat scarp. Moreover, displacement associated with 5.6-6.0 magnitude range is relatively small; and even events larger than 2012 earthquake would create small scarp that would be quickly removed.

Conclusion

The Meshtitsa fault experiences repeating medium-sized earthquakes during the Holocene. The relatively small displacement and pattern of fault slip distribution near and on the surface result in subtle tectonic morphology of a pre-existing fault-line scarp and adjacent landscape. Weak morphotectonic features similar to those of the Meshtitsa fault have to be considered when earthquake potential of a region is evaluated.

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Variations of seismicity and rates of deformation in major active strike-slip zones

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Abstract

Active strike-slip fault zones: the El Ghab segment of the Dead Sea Transform zone (Eastern Mediterranean) and the central Talas-Fergana fault zone (Central Asia) are studied. The both zones are characterized by temporal variations of rates of accumulation of strike-slip deformation. These variations are expressed in the both fault zones, first of all, by the fact that, according to the GPS data, the strike-slip deformation is not accumulated now or its rate is many times less, than the average rate during the Holocene and Quaternary or Pliocene-Quaternary. At the same time, weak transverse shortening is measured in the both zones by the GPS technique. No strong earthquake is registered in these zones in the XX century, but epochs of intensification of seismicity (strong earthquakes) took place in the both zones in the historical time. In the southern and central parts of the El Ghab zone, 30 strong historical earthquakes and no instrumental earthquake with $Ms \geq 5$ were identified. The temporal distribution of seismic energy, released by these earthquakes demonstrates the 350 ± 50-year cyclicity. Values of seismic energy, released during the peak phases of the cycles are approximated by a sinusoid that gives a possibility to suppose the ~1800-year hyper-cycle. It began in ~3rd century, reached maximum in 12th century and continued till now. Combination of geological, archaeoseismological and geodetic data shows that the rate of sinistral strike-slip deformation varied in the fault zone probably in conformity with variation of seismicity during the hyper-cycle. In the Talas-Fergana fault zone, trenching and ^{14}C dating, correlated with right lateral offsets proved that the average rates of the Late Holocene strike slip increase to the NW from ~5 up to ~15 mm/a. The studies showed also that the slip was realized mainly during strong earthquakes. New trenching and ^{14}C dating of paleo-earthquake records identified the epoch of intensification of seismicity in XIV–XVII centuries. These paleoearthquakes could produce the total dextral slip to several meters. So, several such epochs were necessary to give the calculated average slip rate during the Late Holocene. In the both studied zones, the strike-slip deformation was expressed only or mainly during strong earthquakes. The rate of its accumulation reduced in other time and transverse shortening dominated in the fault zones. These variations are caused by tectonic peculiarities. Not only the sinistral deformation component, related to shift of the Arabian Plate relative to the African one, but also the transverse component that is related to the continental slope and is expressed by the Coastal Range shortening exist in the El Ghab zone. Not only dextral deformation component, but also the transverse component, expressed by shortening of the Fergana and Talas Ranges exist in the Talas-Fergana fault zone. In both zones, the component of shortening became appreciable or dominant, when the strike-slip deformation rate reduced.

Neotectonics and seismicity of a slowly deforming segment of the Adria-Europe convergence zone - the northern Dinarides fold-and-thrust belt (Croatia, Bosnia and Hercegovina)

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Abstract

With GPS-derived shortening rates of c. 3 to 5 mm/a, the Adria-Europe convergence zone across the fold-and-thrust belt of the Dinarides (Balkan Peninsula) is a slowly deforming plate boundary by global standards. We have analysed the active tectonics and instrumental seismicity of the northernmost segment of this fold-and-thrust belt at its border to the Pannonian Basin. This area hosts a Maastrichtian collisional suture formed by closure of Mesozoic fragments of the Neotethys, overprinted by Miocene back-arc extension, which led to the exhumation of greenschist- to amphibolite-grade rocks in several core complexes. Geological, geomorphological and reflection seismic data provide evidence for a contractional reactivation of extensional faults after about 5 Ma at fault slip rates ranging between c. 0.03 and 0.09 mm/a. The study area represents the seismically most active region of the Dinarides apart from the Adriatic Sea coast and the area around Zagreb. The strongest instrumentally recorded earthquake (27 October 1969) affected the city of Banja Luka (northern Bosnia and Herzegovina). Fault plane solutions for the main shock (M_L 6.4) and its largest foreshock (M_L 6.0) indicate reverse faulting along ESE–WNW-striking nodal planes and generally N–S trending pressure axes. The spatial distribution of epicentres and focal depths, analyses of the macroseismic field and fault-plane solutions for several smaller events suggest ongoing contraction in the internal Dinarides. Our results therefore imply that current Adria-Europe convergence is widely distributed across c. 300 km, rendering the entire Dinarides fold-and-thrust belt a slowly deforming plate boundary.

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Rates and styles of active deformation at the Alps-Dinarides transition: geodetic vs. geologic data

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Abstract

At the Alps-Dinarides transition (easternmost Italy and Slovenia), the trend of Tertiary circum-Adriatic orogenic belts changes from NW-SE-oriented Dinaric structures to E-W-striking South Alpine thrusts and folds, which override the Dinaric belt. Influenced by the ongoing Adria-Eurasia convergence, this large-scale tectonic transition is currently undergoing active N-S to NNW-SSE directed shortening at the rate of 2-3 mm/yr, well-established with GNSS measurements. Map-scale geological and geomorphological features, as well as the distribution and focal mechanisms of recent earthquakes clearly indicate that the style of active deformation in the region changes from S-directed thrusting in the South-Alpine thrustbelt in the west to predominately strike-slip dominated deformation in the Dinaric domain. Deformation in the Dinaric domain appears to be mainly resolved on the prominent Dinaric NW-SE-striking dextral faults, which are associated with strike-slip basins of Pliocene-Quaternary age.

Velocity vectors derived from a regional network of ~60 GNSS stations confirm ongoing N-S shortening in the South-Alpine domain, which is comparable in magnitude to the total Adria-Eurasia convergence rate, but surprisingly do not show any coherent dextral deformation in the Dinaric domain. Active dextral displacement at ~1 mm/yr is instead indicated on the Periadriatic fault system in Dinaric hinterland, which does not exhibit any significant seismicity. Geomorphological observations confirm relatively rapid neotectonic uplift in the Periadriatic zone, probably transpressional in origin, and match well the GNSS-derived dextral slip rate of ~1 mm/yr on the Sava fault, the major segment of the Periadriatic fault system. On the other hand, the newest geomorphological data for the regional-scale Dinaric Idrija fault suggest a similar slip rate, which is not seen in the GNSS velocity field.

In the rectangular Ljubljana depression in central Slovenia, which we interpret as a neotectonic pull-apart basin, both the GNSS data and tectonic geomorphology demonstrate N-S shortening and S-directed thrusting in Quaternary sediments instead of strike-slip deformation. Similar inversion is evident also in the strike-slip Velenje basin, where a 1000 m thick Pliocene-Quaternary sedimentary succession is uplifted and eroded for several 100s of m, and where GNSS data also indicate basin-perpendicular shortening. This suggests a young, perhaps Early Quaternary change in style of deformation, which is not yet fully expressed in map-scale geological structure, but is already manifested in smaller-scale geomorphological features and in geodetic measurements of modern displacements. Another potentially controversial data source are measurements of active vertical displacements derived from precise levelling and PsInSAR surveys. Whereas velocity anomalies in those datasets are consistent with the general model of active tectonic deformation in the region, they apparently exhibit an order-of-magnitude larger vertical rates than expected from the GNSS-constrained regional shortening rate. Finally, seismic reflection and high-resolution sonar surveying in the Gulf of Trieste offshore of Slovenia and Italy shows evidence for Quaternary to recent thrusting and faulting in the largely aseismic foreland of NW Dinarides, where ongoing deformation is also not resolvable from the GNSS velocity field.

This overview demonstrates many of the problems we face in interpreting active tectonic processes when integrating highly heterogeneous datasets, which may be partly instrumental and partly (semi) qualitative in origin, and may cover vastly different time scales, from decade-long to Ma-long. These problems are particularly amplified in regions of low deformation rates, such as the northern Adriatic region, where long time series of instrumental data are required to obtain geologically significant and representative results.

From intermediate to small scale heterogeneity of compound mantle xenoliths from Cima Volcanic Field (Western U.S.A.): implications for metasomatic processes in the deep mantle

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Abstract

The mantle is the major geochemical reservoir of most rock-forming elements in the Earth. Convection and plate-tectonic driven processes act to generate local and regional heterogeneity within the mantle, which in turn through thermal and chemical interactions modulates ongoing geophysical processes; this feedback shapes the dynamics of the deep interior. Consequently, these processes contribute to the evolution of the Earth throughout its geological history.

In the current study we focus on multi-layered xenoliths like lherzolites with amphibole-rich veins and lherzolites with websterite/clinopyroxenite/dunite contacts from Cima Volcanic Field (western U.S.A.). The Cima Volcanic Field represents an isolated late Cenozoic basaltic field, part of the southern Basin and Range province, and is located in the Mojave Desert, southeastern California, USA. The compound mantle xenoliths from Cima represent outstanding candidates to illustrate the processes that occur prior to their delivery to the surface by alkali-basaltic volcanism. In particular, the mineral assemblages and the lithologic layers carry information about partial melting and mantle metasomatism. Our major goal is to identify: 1) the signatures that were recorded during the ascent of these mantle xenoliths toward the surface and 2) to unravel the principal processes that controlled the formation of the different layers of the mantle xenoliths. Our applied methods were EMP (major elements), LA-ICP MS (trace elements), EMP X-ray maps and micro-XRF elemental maps on three composite amphibole-bearing, mantle xenoliths (samples: Ci-1-196, Ci-1-254 and Ci-1-546).

Mineralogical, textural and compositional characteristics of the assemblages observed within the mantle xenoliths from Cima Volcanic Field reveal a continuous succession of metasomatic processes. Further, the xenoliths share characteristics indicating heterogeneity at scales from hand-specimen to grain scale: heterogeneous lithologies in close contact, pyroxene zonation, amphibole breakdown, formation of glass and armalcolite. Their petrogenetic evolution involved partial melting of the silicate minerals, infiltration of reactive melts and dissociation of minerals (transformation of original lithologies) en route to the surface. The infiltration by alkali-basaltic melts and interaction with the peridotite-wall rock selectively formed dunite layers. The presence of small idiomorphic rapidly quenched crystals (e.g., spinel), glass and armalcolite indicate a very short timescale of reactions en route to the surface. The evidence suggests that these rocks followed multi-stage histories that included transport from >1.0 GPa to the surface within a very short period of time.

Textures in mantle peridotite rocks revisited: a quantitative approach

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Abstract

We present a new approach to the quantitative characterization of mantle-derived peridotites rocks. Our method uses optical scanning, skeletonisation and computerised measurement of individual grain-section areas. This provides an observer-independent quantitative description of grain-size textures, as seen in thin-section. This method has been applied to 92 spinel peridotite xenolith samples from a variety of alkali basaltic sources, 11 kimberlite-hosted garnet peridotite and spinel peridotite xenoliths, 5 tectonically emplaced massifs and 7 ultramafic ureilite meteorite samples. For some of the samples, multiple thin-sections were prepared so that variability within these samples could be explored. The results for all samples show a linear relationship between the arithmetic mean size and the standard deviation of grain size. This suggests that peridotite textures form a continuous series rather than discrete groups, as previously implied. The marked positive skewness observed in the distributions is consistent with log-normal or power-law functions with fractal characteristics. This suggests that textural development in mantle peridotites is the result of processes dependent on the Law of Proportionate Effect. Three dimensional visualisation in situ using X-ray C-T techniques, together with SEM images of mineral components isolated by Electric Discharge Disaggregation, support the contention that at least some of what is seen in thin-sections results from random sectioning of concave (involuted) crystals.

Keywords: *peridotites, xenoliths, textures, quantitative petrology*

The problem with qualitative characterization of textures

It has long been recognised that mantle peridotites show wide textural variations reflecting a history of deformation, recrystallisation and grain growth. Mercier and Nicolas (1975) defined three main textural groups from their study of spinel peridotite xenoliths: a) Protogranular, which was regarded as the "oldest texture" showed a near absence of deformation and was characterized by "grain sizes of olivine and enstatite of ca. 4mm, with diopside and spinel having grain sizes of ca. 1 mm; b) Porphyroclastic, considered to be formed by plastic flow of protogranular material and showed large strained grains (porphyroclasts) completely surrounded by smaller unstrained grains (neoblasts); c) Equigranular, i.e. fine - grained, strain - free crystals with a "typical grain size" of 0.7 mm.

Numerous authors have added modifications to the basic classifications proposed by Mercier and Nicolas (1975). Lenoir et al. (2000) suggested that the term "protogranular" should be restricted to samples that show specific clusters of spinel and pyroxene, and reclassified other protogranular xenoliths as "coarse granular". Zangana (1995) added two transitional groups ("protogranular - porphyroclastic" and "porphyroclastic - equigranular"). The general tendency to add and redefine terminology reinforces the view that qualitative criteria and assessments are inevitably subjective, so that the definition of the objects being measured should be stated in terms of numbers.

Methodology

The challenge is to find readily accessible physically measurable parameters that describe aspects of the 'texture' and to make sufficient measurements in a cost effective manner for the observations on different samples to have statistical significance. For this purpose rock thin-sections provide the most immediately available two-dimensional features for measurement.

To facilitate measurement of a polycrystalline rock thin-section, the first stage is to recognise the discrete mineralogical identity grain boundaries and to reduce these to a basic outline (a process known as "skeletonization"). A grain can be bounded by other grains belonging to the same phase or to a different mineral phase. Thus both intra-phase and inter-phase boundaries need to be detected. However a grain is not subdivided by cleavage lines, cracks or graduated strain deformation patterns. Two discrete grains of the same mineral phase, touching each other, will generally be differentiated by a sharp change in birefringence colour and extinction angle (intra-phase boundary) with crossed polarizers. Whilst the high relief and birefringence of the mineral components of peridotite xenoliths helps in visual recognition of phase boundary outlines and the detection of spurious sub-divisions, these still present major problems for automation of the process with geological specimens.

For our study, initially described by Tabor et al. (2010), a method has been devised using a readily available photographic film scanner fitted with a medical slide holder that accommodates a standard microscope (2.5 x 7.5 cm) slide. Using this, a whole thin-section can be readily imaged with pairs of crossed-polars, set at different angles to the slide, and also in white or plane polarised light. Images produced by this means were then combined manually on a light-box to produce the mineral outlines. These outlines were then digitised on flat-bed scanner prior to analysis using computer programs that employed pixel-counting techniques to measure lengths and areas.

Some assessment of the 3-dimensional size and shape distributions of xenolith component mineral grains has been attempted by two methods: (*i*) Disaggregation of xenoliths by a technique claimed to effect the separation without extensively compromising the original components (Rudashevsky et al. 1995); (*ii*) non-destructive visualisation mineral identity components by means of X-ray computed tomography (CT-scanning) (Mees et al. 2003).

The materials for the present study included spinel peridotite xenoliths from Neogene and older basalts in Europe and the USA, spinel and garnet peridotites from kimberlites from South Africa and Siberia, tectonically emplaced massifs in the Spanish Betics and French Pyrenees, together with some extra-terrestrial samples in the form of ultramafic ureilite meteorites.

Results

This study shows that textures in mantle-derived spinel peridotite xenoliths, from different types of localities, can be quantified using manual skeletonization and digital image analysis software. The method has also been successfully applied to kimberlite-hosted xenoliths, samples from tectonically emplaced ultramafic massifs and some ureilite meteorites. There is a linear relationship between mean grain-section area size and standard deviation of the grain-section area size for all the samples studied. This method provides a means for consistent comparison of samples that is independent of the observer. This indicates the generality of the processes involved.

Examples of protogranular peridotite and equigranular peridotite designations that form the two end-members of qualitatively assessed textures (Mercier and Nicolas, 1975) are clearly distinguished using this method. Porphyroclastic peridotites tend to overlap protogranular ones at larger grain-section area sizes and equigranular ones at smaller grain-section area sizes, suggesting that spinel peridotite textures form a continuum rather than being discrete entities. This is further supported by the observation that, with some thin-sections, although different areas may show a variation in mean grain-section area size and standard deviation, they still plot on the same linear relationship.

Markedly skewed and peaked grain size distributions were observed in this study. It is difficult to assign distribution functions with any certainty but they are not incompatible with a lognormal probability distribution function. It is probably better when looking at a range of observations to use non-parametric methods to examine and compare measured grain-section area sizes and to plot them on the graph of the linear mean grain-section area size versus standard deviation of mean grain-section area size.

Since all the samples examined have the marked skewed peak and long right-hand (larger size) tail in common, it is reasonable to suppose that this is characteristic of the population from which they were drawn. It is therefore possible that the apparent variations in texture might be no more than the statistical fluctuation to be expected when drawing small (random) samples from the very much larger population representing the upper mantle. In these circumstances it is probably even more important to avoid terminology that might be thought to imply separate/discrete states and formation mechanisms of mantle lithosphere peridotites.

The pattern of the apparent grain-size distributions, seen in thin-sections or on an exposed surface of mantle rocks, has fractal characteristics. Whether this is at least in part a result of the sectioning process being applied to the complex involuted shapes, or a reflection of the underlying three dimensional component shapes, is less clear.

Both the X-ray C-T study and the 'SelFrag' disaggregation and fragment visualisation study by SEM suggest that the mineral components of mantle-derived peridotites can have complex interconnecting, non-convex features. Thus three-dimensional deductions from a single thin-section image are inadmissible. Interpretation of thin-section patterns as 'separate grains' can be to some extent a result of the sectioning process.

Conclusions

Our study suggests that the shallow lithospheric mantle, represented by xenoliths and other samples, has been subject to tectonic and metamorphic processes of comminution and/or grain growth that are dependent on a Law of Proportionate Effect. Kottler (1950) stated that both mechanical grinding and recrystallization can give rise to very similar mathematics. However, from both the disaggregation and visualisation and computed tomography experiments, it is clear the mineral components are not convex bodies and show both size and shape dispersity. Thus the use of assumption-based stereology to derive three dimensional parameters from two dimensional thin-section images is inadmissible. The X-ray experiments suggest that C-T scanning may be a possible route to investigate grain shapes, if higher resolution can be achieved to minimise partial-volume effects. The materials used in the present study are predominantly representative of the sub-continental lithospheric mantle, but the methods devised could equally well be applied to oceanic peridotites.

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Surface metasomatic reaction between host basanites and mantle peridotite xenoliths from Moesian Platform

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Abstract

We present the first detailed study of mineralogical and chemical modifications of peridotite xenoliths during magma transport and cooling at the Earth's surface. The xenoliths in three large basanite domes from the Moesian Platform, North Bulgaria, exhibit different degrees of mineralogical and chemical interaction with their host which strongly depend on their position in the dome structure, i.e on the duration of reaction with host magma. Our study demonstrates that chemical and mineral modification, although starting at the time of entrainment of xenoliths at mantle depths, was completed mostly during their residence in the magma on the surface.

Keywords: *peridotite xenoliths, surface metasomatism, trace elements, Sr and Nd isotopes, Moesian platform*

Introduction

Variations in the chemical composition of ultramafic xenoliths brought to the surface by alkaline and, rarely, by supra-subduction magmas, are thought to reflect chemical heterogeneity in the lithosphere. In many studies it is assumed that the effect of interaction between xenoliths and host basalt is minimal, and thus bulk and cryptic metasomatism of the xenoliths are generally attributed to processes that occurred in the upper mantle, prior to their incorporation into the host magma. However, some studies (e.g. Shaw and Edgar 1997; Klügel 1998, 2001; Shaw et al. 2006) have shown that mantle xenoliths may react with their host melts, causing effects which are very difficult to distinguish from the supposed metasomatism occurring in the mantle. According to Klügel (1998), xenolith-host reaction may take place over years to decades in the mantle reservoirs or during residence in a crustal chamber. Scambelluri et al. (2009) suggested that modification can start immediately before and/or during xenolith entrainment in the host alkali basalts. Experimental work by Shaw and Dingwell (2008) explored the possibility of textural modifications of xenoliths during magma cooling at the Earth's surface, however, they concluded that most changes occur during the transport of xenoliths. To date, there is no detailed study on the possible modification of mantle xenoliths near or at Earth's surface conditions.

The most appropriate objects for such a study would be large magmatic bodies with different rates of crystallization, e.g. lava flows, sills, domes or dikes. The rationale of collecting samples from both the quickly cooled outer part and the slowly crystallized interior of such bodies is that it may enable us to distinguish the role of transformation of xenoliths during transport and cooling on, or close to, the surface.

Results

Three large Miocene basanite domes from the Moesian Platform, North Bulgaria, contain abundant spinel peridotite xenoliths. The xenoliths exhibit different degrees of mineralogical and chemical interaction with their host which strongly depend on their position in the dome structure. Location of the xenolith is easily recognizable by the changes of groundmass texture and size and composition of minerals. We divide three textural types of groundmass: (1) fine-grained, typical for the outermost brecciated and thin columnar jointed parts of the domes (FGG); (2) intermediate-grained in the region with large columnar joints (IGG), and (3) holocrystalline (HCG) in the massive interior. Typically, the peridotite xenoliths (mostly spinel lherzolites, followed by harzburgites and dunites) consist of primary olivine (Ol-$Fo_{90.1-91.9}$), orthopyroxene (Opx-Mg# 90.0-92.7), clinopyroxene (Cpx-Mg# 90.7-94.5). Primary brown spinel (Sp) is a high Al_2O_3 and MgO spinel-chromite solid solution with low TiO_2 contents. The Mg# varies between 69.8 and 78.6 and Cr# ranges from 12 to 49.

Most of the studied xenoliths have been percolated to various degrees by melts and vapor along networks of fractures and grain boundaries, forming irregular veinlets and pools of glass or trails of melt inclusions and sulfides within their constituent minerals. In addition, constituent minerals of the xenoliths in contact with the veinlets and pools and host rocks show variable reaction phenomena and chemical zoning. An increasing grade of interaction was observed in the xenoliths from the FGG-facies to the HCG-facies and also with degree of deformation of the xenoliths, which was interpreted by Marchev et al. (2010) as the result of increasing degree of interaction of the xenoliths with the host lavas. Protogranular spinel lherzolite xenoliths from the fine-grained brecciated carapace of the domes show very thin fine-grained reaction rims around orthopyroxene and thin diffusion zones around spinel and olivine. The reactions are limited mostly to the contact of the xenoliths. Modeling of concentration profiles of xenolith's olivine suggest very short residence time of 1–3 days in the lavas and, therefore, rapid ascent rate at velocities around 0.5–1.5 km/h. Cpx from the xenoliths is always strongly depleted in LREE and Sr and have DMM Nd-values isotopic characteristics. Xenoliths from the interior of the domes are much more strongly affected by the host basanites. This is recorded in the wider reaction rims around Opx leading up to their entire consumption, transformation of Sp into chromite, and Fe-Mg diffusion profiles in Ol up to 400 μm long. Calculations from the Ol diffusion profiles indicate interdiffusion time up to 200 days. Times obtained from Ca concentrations from the carapace and interior are from 8 to more than 700 days, respectively. Cpx is variably enriched in LREE and Sr, from several times with respect to the depleted xenoliths to complete equilibration with the host basanites. Their Sr and Nd isotopic compositions are also similar to the host basanites. Porphyroclastic xenoliths exhibit the strongest reaction phenomena facilitated by infiltrated melt, particularly in the dome interior.

Mineral composition of the pool and vein phases

Microphenocrysts and microlites in both pools and veins are represented by Ol, Cpx, Sp, biotite, apatite and sulfides, accompanied by plagioclase, K-Na feldspar, nepheline and analcime in the xenoliths in the IGG and HCG facies and, rarely by glass in the FGG-based xenoliths. Sulfides are more abundant in the dunite pools.

Ol microphenocrysts and microlites from the glass pools and veinlets, which are not directly connected with the host basanites, show large compositional variations. In the spinel lherzolites Ol variations are Fo_{89-84} in the FGG to $Fo_{88-73.5}$ in the HCG. The pool Ol in the harzburgites and dunites is more Mg-rich ($Fo_{93-88.5}$). Compared to the primary Ol, the one in the pools is enriched in CaO (0.3-0.1 wt. %). Ol from the larger veins, which are directly connected with the host basanites, has lower Mg content (Fo_{77-71}) and higher CaO content (0.60-0.33 wt.%).

Cpx from the dunites and harzburgites hosted in the FGG facies; are high Mg# (94.4-86.6), very poor in Al_2O_3 (0.02-1.7 wt.%) and TiO_2 (0.03-0.20 wt.%), rarely with Ti- and Al-rich rim (2.7 and 6.3 wt.%, respectively). Cpx microphenocrysts and microlites) from the glass pools in the IGG and HCG-hosted spinel lherzolites and dunites is mostly zoned aluminian subcalcic titanian ferroan diopside (Mg# 81.5-72.5), with up to 10.3 wt.% TiO_2 and up to 5.7 wt.% Al_2O_3, similar to the composition of phenocrysts of the host basalts. Occasionally, their central core preserves Ti-poor, Mg-rich (Mg# 91.5-89.5) compositions. Cpx from the veins connected with the host basanites has Ti- and Al-rich compositions similar to that from the pools in IGG- and HCG-hosted xenoliths.

Phlogopite is found either (1) scattered throughout the fine-grained aggregate of Ol and Cpx, replacing Opx crystals, reactions around Sp and in pools and veins or (2) forming rims around the spinel enclosed in dunite Ol. These two types of phlogopite differ in chemistry. The most characteristic feature of the first type is its very high TiO_2 which decreases from 12.4-10.0 wt.% in the vein plogopite to 10.9-8.0 wt.% TiO_2 in the pools. In addition, it shows a regular increase of MgO from the groundmass phlogopite (10.8-14.6 wt.%) through the vein (15.4-16.5 wt.%) to pool (16.6-24.0 wt.%), accompanied by increase of Cr_2O_3 from 0.03-0.1 wt.% to 0.1-2.2 wt.%. The second one is Mg- and Cr-rich (MgO – 24 wt.% and Mg# 92.6; ~2.0 wt.% Cr_2O_3) and Ti-poor (~0.5 wt.% TiO_2). It shows evidence that it was formed by an access of a free fluid phase through a network of veins reaching the Sp. Its composition suggests strong interdiffusion of elements between the fluid and host Sp and Ol.

K-Na feldspar, nepheline and and analcime in the xenoliths in IGG and HCG have compositions similar to those from the groundmass. Nefeline is low K, with 1.6 to 3.4 wt.% CaO, whereas analcime has 3.7 wt. % K_2O and 1.6 wt.% CaO.

Glass composition

Fresh glass was found in 3 xenoliths from the outer carapaces of Chatala and Vurha and the interior of Kamuka. The glasses from Chatala and Vurha are in the reaction halos around Sp and Opx (Fig. 9a) , whereas in Kamuka is in melt inclusions from the sieved texture of Cpx). Glass around the Sp and Opx are brown, with 56.6-59 wt.% SiO_2 nd low MgO (~0.5 wt.%). The glass from the cpx sieved texture is more evolved with SiO_2 63.5 wt.% and not detected MgO. All they have high and similar Al_2O_3 (23.23-21.2 wt.% Na_2O) (5.5-7.7 wt.%) and K_2O (6.9-7.2 wt.%). These compositions are similar to many other occurrences of glass in peridotite xenoliths and fall in the groups of K- and Na-alkali silicate glasses of Coltorti et al. (2000). As the result of slow cooling or alteration, the melt or glass in IGG- and HCG-hosted xenoliths forms a fine-crystalline mass or is converted to a mass of chlorite and clay minerals, respectively.

Where the reactions took place?

Melt pockets, composed of altered or fresh glass, Cpx, Sp, K feldspar, ilmenite, apatite and very rare Ti-phlogopite in the mantle peridotites, previously have been interpreted by many authors as products of alkaline mantle metasomatism formed at mantle depth (Ionov et al. 1994; Zingrebe and Foley 1995; Wulff-Pedersen et al. 1996, 1999; Lustrino et al. 1999; Kogarko et al. 2007; Cvetković et al. 2010). Comparable in composition and mode of occurrence Ti-phlogopite from the East Serbian xenoliths, was attributed by Cvetkovic et al. (2010) to infiltration and reaction of peridotites with metasomatic fluid formed in the lithosphere before the xenoliths were entrained into basanitic melt. The basanitic melt itself originates from melting of the metasomatised peridotitic mantle. There is a number of evidence that the reaction processes in the Moesian platform xenoliths took place during cooling of the basanitic domes at the surface or near the surface. The absence or minor reactions in the xenoliths from the carapace of the basanite domes along with depleted nature of the clinopyroxene clearly show that the short time transport (1-3 days) do not cause considerable mineralogical and chemical modification of the xenoliths by host magma. The only visible transformation concerns some dunites, which formed fine-grained stubby Ol and Cpx. In addition, the mineral assemblages of the veins and pools in IGG and HCG, consisting predominantly of plagioclase, K feldspar, nepheline and analcime, identical to the groundmass compositions, indicate crystallization at very low pressure from a melt similar to the host basanite. The observed gradual major element changes of the high-Ti biotite, Cpx and Ol compositions from groundmass to veins and pools are easily explained by infiltration of basanitic melt into xenoliths and chemical exchange with mafic minerals. The degree of re-equilibration depends on the time of interaction. Finally, diffusion profiles in the Ol and reaction coronas in the Opx in contact with these veins and pools are of similar size to the minerals in direct contact with the host basanites, suggesting that much of the metasomatic reactions occurred at the place of emplacement of the basanitic bodies.

Conclusions

Our study demonstrates that chemical and mineral modification, although starting at the time of entrainment of xenoliths at mantle depths, was completed mostly during their emplacement on the surface. We also show that residence of xenoliths in thick domes, dikes and lava flows will result in partial or total resetting of their Sr and Nd isotopic systems.

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Lithospheric Mantle heterogeneity at the northern margin of the Deseado Massif, in South Patagonia

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Abstract

Patagonia is a back-arc region dominated by two massifs, the Somoncura Massif in northern Patagonia and the Deseado Massif in southern Patagonia. Whether Patagonia is a single microcontinent or an accreted terrane represented by the two massifs is still an ongoing debate.

During Miocene to Pleistocene ages xenolith-bearing alkaline basalts erupted along Patagonia.

Mantle xenoliths from Don Camilo, an area located on the North margin of the Deseado Masiff in Patagonia, comprise spinel bearing lherzolites, harzburgites and dunites, wehrlites, clinopyroxenites and gabbros. The most common rock type among the collected samples is spinel-lherzolite followed by dunites. Harzurgites wehrlites and gabbros are less widespread. Spinel-lherzolites and harzburgites have protogranular textures whereas dunites have equigranular to equigranular tabular textures. There are two different kinds of dunites: dunite (1) and dunite (2), which differ in their olivine Mg# and NiO contents. In dunite(1) the olivine Mg# and NiO content vary from 90.5 to 91.5 and from 0.39 to 0.42 wt.% respectively. The Mg# and the NiO content of the olivine in dunite (2) range from 87.0 to 90.0 and from 0.22 to 0.38 wt.% respectively. Both kinds of dunites contain fine grained interstitial diopside. Hydrous phases, besides one sample that contains amphibole, were so far not found. The clinopyroxenes in the spinel lherzolites show a systematic decrease of AL_2O_3 content in the rim, compare to core and suggest relative slow ascend of the xenolith bearing host lava.

The bulk REE in spinel peridotites are depleted in LREE [(La/Yb)N=0.34-0.85)] while the dunites are enriched in LREE [(La/Yb)N=3.49].

LA-ICP-MS analyses of cpx show that a number of the studied spinel peridotites experienced cryptic metasomatism. According to the clinopyroxene REE and other incompatible trace elements, three groups of spinel spinel lherzolites have been recognized: group I has depleted LREE abundances, group II is highly enriched in LREE (20-30 x PM) and group 3 has moderate LREE enrichments. The core of some clinopyroxenes in group II has depleted LREE similar to those in group I, apparently representing relict cores before the metasomatism took place. In addition the metasomatized clinopyroxenes are significantly enriched in Sr, Th and U. Evidently, the metasomatic agent was rich in fluids (high LREE, Sr, Th and U).

In both dunites the interstitial clinopyroxene appears to be of metasomatic origin. The clinopyroxene from dunite (1) has enriched LREE (10 x PM) and LILE suggesting that the metasomatic agent was fluid-rich silicate melt similar to the metasomatic agent of clinopyroxenes from group II spinel lherzolites. The clinopyroxene from dunite (2) has depleted LREE abundances and low HREE indicating that they have been crystalized from melts. The relatively low Mg# and NiO of the olivine in dunite (2) and the depleted in REE interstitial clinopyroxene suggest a cumulate origin where the clinopyroxene is the intercumulus phase.

Calculated equilibrium temperatures cover the range from 800 to 1100 °C. The remarkable wide range of equilibration temperatures of the xenoliths indicates that they have been extracted from various but largely different depths.

The clinopyroxene radiogenic Sr and Nd isotopic ratios vary considerably from 0.702671 to 0.75788 and from 0.51229 to 0.513251 respectively, indicating a high heterogeneity consistent with the variably affected by metasomatic events mantle lithosphere underneath Don Camilo.

The model calculations have shown that the Lithospheric Mantle beneath Don Camilo, in Santa Cruz province is fertile and that spinel peridotites experienced low degree of partial melting (2-8% batch melting in the spinel peridotite).

Mesozoic palaeogeography of Adria: Hints on the origin of the Skutari-Pec Line

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Abstract

The external sector of the Hellenides shows remarkable lateral variations in structural style and geometry of the frontal thrust. Several lines of evidence suggest that this structural complexity is related to the paleogeographical arrangementof the Mesozoic units, which wereprogressively accreted to the fold-and-thrust belt. Lineaments, which are transversal to the main trend of the Hellenides are commonly encountered at various scales. The most important of these are the Skutari-Pec and the Cephalonia lines. The origin of these transversal lineaments has been much debated and the ideas proposed range from relatively recent strike-slip faults to inherited and reactivated Mesozoic boundaries. In this contribution it will be argued that the Mesozoic palaeogeography of the Adria eastern margin is the main factor controlling the location and development of both the Skutari-Pec and the Cephalonia transversal features. The two transversal structures currently represent different stages of the evolution of similar processes, whereby differential fore-thrusting occurred across the lineament. A large lateral displacement of the internal units, namely the Pindos/Krasta-Cukali basinal sediments and Mirdita ophiolites, occurs along the Skutari-Pec transversal line. The shallow water limestones of the more external Kruja domain, however, are not offset, although a change in structural style occurs in the offshore, across the trend of the Skutari-Pec line, at the tectonically active thrust front. Palaeomagnetic results indicate that the Miocene-Pliocene clock-wise rotation of the western arm of the Aegean opening was accomplished just south of the Skutari-Pec line. On the other hand, the pattern of GPS velocites shows that the larger outward displacement within the Hellenide fold-and-thrust belt is currently occurring south of the Cephalonia line, where the Eastern Mediterranean oceanic lithosphere is subducted. Units belonging to the Apulian platform occur south-eastward of the Cephalonia line, and seismic profiles acquired around the Ionian Islands suggest that these units may represent a narrow continental finger, surrounded by an oceanic domain. Units belonging to the continental margin of Adria have been accreted north of the Cephalonia line during the Miocene and Pliocene. In this areait can be shown that the presence of basin and platform successions affected the structural style of the frontal thrust, as well asthe thickness of the adjacent foreland basin. Altogether, the Skutari-Pec and Cephalonia lines, as well as the other smaller transversal lines, contribute to accomplishing the large-scale clock-wise rotation that characterizes the western Hellenides, which is driven by trench retreat. This first order evidence is related to a general theme than can be recognized within the Mesozoic eastern margin of Adria, which is characterized by a system of shallow water platforms and pelagic basins. The basins appear to become wider and deeper towards the south-east and upto the point of being floored by oceanic crust. The platforms, on the other hand, appear to become narrower south-eastward, and they possibly rest on very thin continental crust. In this last case, where the width of the continental domain is under a critical value, trench retreat can occur unimpeded, allowing a differential advancement of the frontal thrust.

A Generalized Geophysical Overview Of Shkodër-Pejë Deep Transversal Fracture

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Abstract

This paper provides an overview of geophysical data including gravity, magnetic, paleomagnetic, geothermal, seismological and remote sensing methods for the Cukali tectonic subzone, where it meets the deep transversal Shkodër – Pejë fracture. In addition, marine seismic data, and hydrological observations on the shelf of the Southern Adriatic Basin are reported. Data on the regional geological setting have been of great help for the present investigation, particularly the regional geological-tectonic setting of the Shkodër-Pejë sector in the Mediterranean Alpine Folded Belt, an important and deep disjunctive tectonic element.

Both geological surveys and mapping do not report any trace of deep transversal Shkodër – Pejë fracture outcrop at the Earths' surface. Consequently, different notions such as "Scharung" (1901), "deviation", "an accident", "transform transversal fault", "transverse fault", "deep transversal fracture" have been proposed. In addition, unreasonable claims for its existence have been repeatedly made, due to different concepts gained over time. Here, geological surveys without any consideration of geophysical data have been of great help.

Geophysical survey polygons have been carried out in the aforementioned region in the last two decades. Gravity and magnetic anomaly maps, paleomagnetic studies, heat flow density map, satellite imagery provide interesting information regarding the tectonic setting in the depth of the region. They document that the Shkodër – Pejë lineament represents a deep transverse vertical fracture, which also affects the Moho discontinuity. Here, the fracture amplitude is approximately 4 km. It decreases towards the Earth's surface until its extinguishment in some segments.

Keywords: *Mediterranean Alpine Folded Belt, Shkodër-Pejë transversal, geophysical anomalies, deep fracture, gravity anomalies inversion.*

1. Introduction as a historic review

The Hellenides-Albanides-Dinarides, a branch of the Mediterranean Alpine Folded Belt, are interrupted by a deep transversal tectonic fracture in the Shkodër-Pejë segment. This fracture is correlated with the contact between the Eurasian and African Plates in the Drini Bay in Adriatic Sea. For the first time Cvijich (1901) called this fracture "Scharung". Later on it was called "deviation" or "accident", "element inherited from the Tethyan Ocean paleogeography", and "Faille transversale Scutari-Pec". Based on the geosyncline theory, Albanian geological studies do not report any information about this fracture. Only later, some authors, who admit the opening of the Mirdita Ocean and interpreted this transversal as oceanic transform fracture. Shkodër-Pejë transform fault is represented by the north-western front of the ophiolitic belt (Peza et al. 1971, Melo 1986; Melo et al. 1991; Kodra et al. 1994; Xhomo et al. 2002), or this transversal is represented by the northern border of Cukali subzone as natural geological border between Alps Zone and Cukali ones (Papa et al. 1991). According to Qirinxhi A., the co-author of Geological Map of Albania at scale 1:200,000, is important to show that the existence of Shkodër – Pejë thrust and its position cannot being observed and mapped during geological field surveys, but, perhaps, exist in the depth (Qirinxhi et al. 1991). Seismological investigations carried out by Sulstarova et al. (1972) emphasize the presence of an active fault zone following the well known Shkodër-Pejë direction.

2. Materials and methods

The geological map of Albania, the tectonic map at the scale 1:200,000, the neotectonic map of Albania and seismic investigations provide information about the geological-tectonic settings of the Shkodër-Pejë region. In addition, integrated surveys and studies carried out in the

Shkodër-Pejë fracture zone by Frashëri et al. (2009) such as seismic studies, seismic hazard estimation, gravity and heat flow density maps of Albania, paleomagnetic data, collected from the paleomagnetic studies in Albania during 1991-1995 (Mauritsch et al. 1993; Kissel et al. 1995). Remote sensing based on Landsat and Modis data was used to identify some regional geological features and to investigate the ground temperatures.

3. Results and discussion

The complex methods applied in northern Albania and in the Adriatic Sea provide important information about the deep structure of the Albanides, which is of great importance for understanding the Shkodra-Peja fracture zone. Geophysical investigations report the block character of the crystalline basement of the Albanides (Frashëri et al. 2009). The thickness and the location of these blocks are shallower in the Mirdita Tectonic Zone. The block structure is controlled by a system of NW-SE longitudinal faults as well as transverse ones. Geothermal energy is related to increased heat flow through these fractures. The Shkodër-Pejë deep fracture represents a deep dislocation, which transversally divides the Albanides in two parts. This deep fracture is generally considered a multi-phase transversal tectonic fault zone, with a north-eastern extension that strikes about 30^{o}. Consequently, the Shkodër-Pejë deep fracture divides two large areas with different geological settings and geological history, but not only in the continent, also to the orogenic front in the Adriatic Shelf.

3.2. Gravity and Magnetic data

Gravity and magnetic surveys rerport that generally the Albanian Alps zone exhibits a minimum in the Bouguer gravity anomaly map. Crossing the Cukali subzone, an upward linear trend of increasing intensity of the Bouguer anomaly could be noted towards the Mirdita zone, due to a vertical and deep dislocation. The inversion model suggests an offset of the Moho Discontinuity by about 4 km (Fig. 1).

3.3. Paleomagnetic surveys data

Paleomagnetic studies report that the Shkodër - Pejë belt represents a transition zone between an area of counter-clockwise rotation in the north, and one with clockwise rotation in the south (Fig. 2). Consequently, this belt is as a great tectonic impact on the Cukali subzone. Thus, the

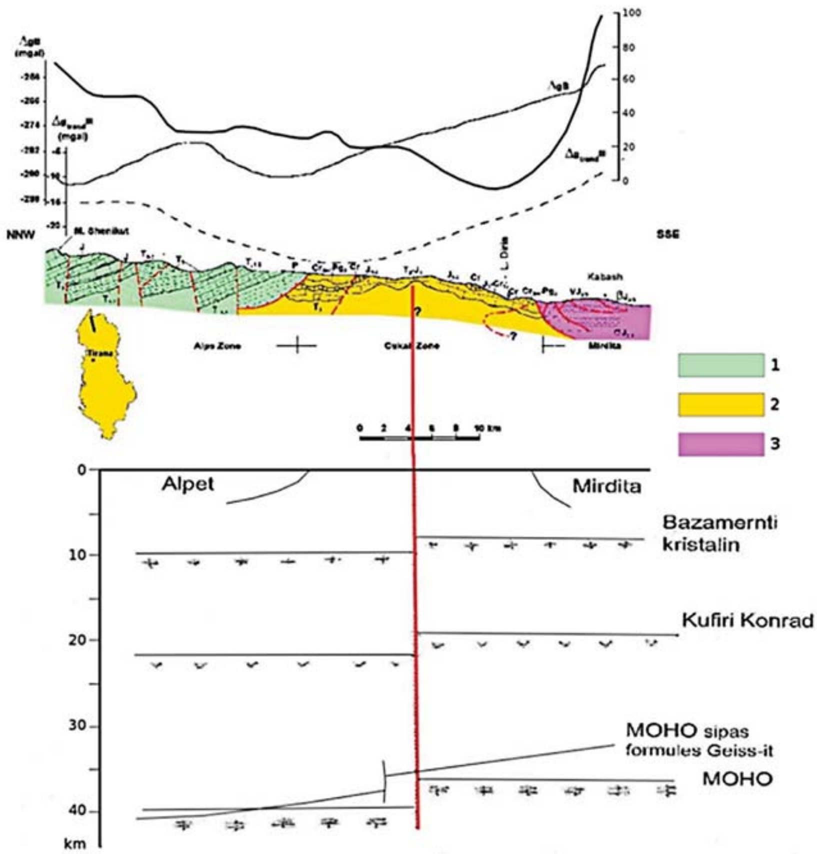

Figure 1.
Gravity Bouguer Anomaly (Δg) and Magnetic Anomaly (T) profile I-I, Mountain Sheniku at the Albanian Alps-Kabash in Mirdita zone, and gravity inversion results.

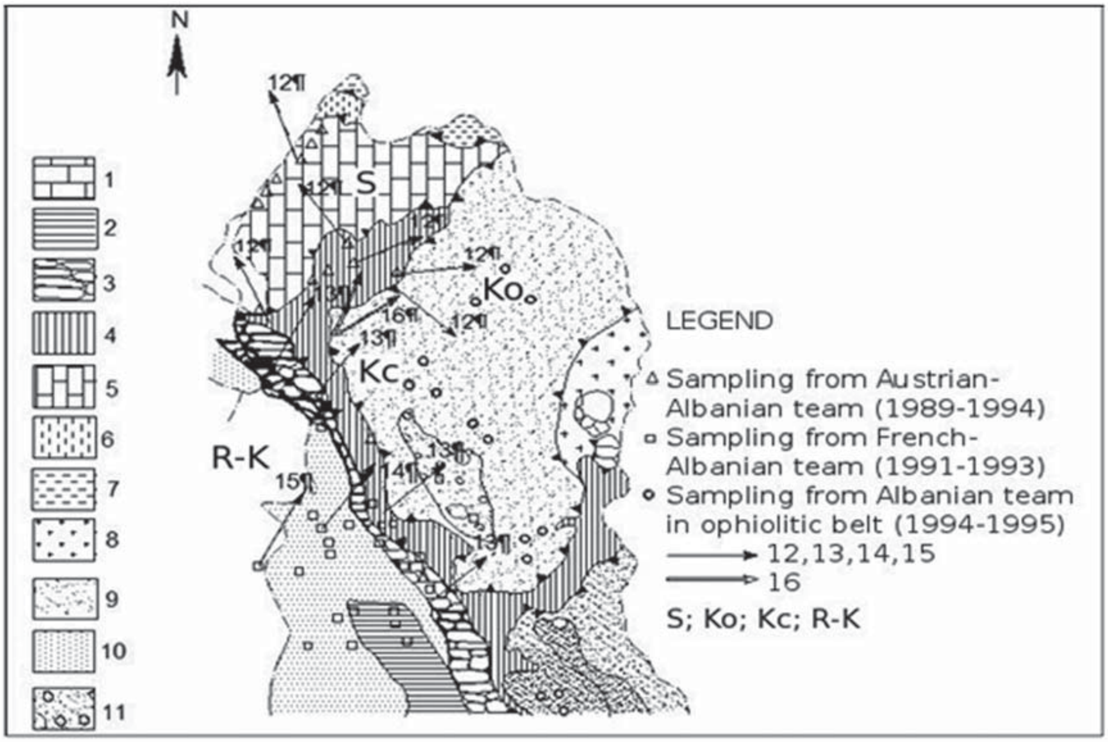

Figure 2. Scheme of the paleomagnetic echantionage in Northern Albania, during 1989-1994.
1-Sazani Zone; 2-Ionian Zone; 3-Kruja Zone; 4-Krasta-Cukali Zone; 5- Albanian Alps Zone; 6-Vermoshi Zone; 7- Gashi Zone; 8-Korabi Zone; 9-Mirdita Zone; 10- Periadriatic Depression; 11-Mollasic depressions; 12- Jurasic limestone; 13- Upper Cretaceous-Eocene limestone: 14- Middle Neogene molasse; 15- Pliocene formation; 16- Ultrabasic rocks; 17-Overthrust

Shkodër-Pejë lineament defines a transition zone, which separates the Albanian Alps including the Dinarides (counterclockwise rotation) from the Albanides and Hellenides (clockwise rotation).

3.4. Seismological pecularities related to Shkodra-Peja seismoactive tranversal fault zone

Seismological studies carried out during the last half of the 20th century in Albania have been of great help for the mapping of seismogenic longitudinal and transversal deep tectonic fault zones of the Albanides in an area where the Shkodër - Pejë transversal fault zone is located. The focal mechanism solutions obtained in the northern littoral side of the Shkodër - Pejë fault zone suggest that, the compression axis has an azimuth of 16^o and a 10^o plunge, while the tension axis has an azimuth of 124^o and a 79^o dip. On the southern side of the Shkodër - Pejë fault zone, the compression axis strikes towards 274^o with a 10^o deep, while the tension axis is oriented 164^o, dipping 64^o (Sulstarova 1988).

3.5. Heat Flow density anomalies

Geothermal studies in Northern Albania have been carried out in 19 boreholes and in one deep well. Two Heat Flow Density anomalies axes are extend from northeast to southwest, over the overthrust tectonics in the northern border of the ophiolitic belt. The radiogenic heat generation of the ophiolites is very low. Consequently, the increase of the heat flow in the ophiolitic belt relates to the heat flow transmitted from greater depth. The granites of the crystalline basement, by radiogenic heat generation, represent the heating source. Heat flow anomalies depend on intensive heat transfer along deep and transversal fractures. The continuation of the Shkodër-Pejë fracture in the Albanian Adriatic Shelf in the Drini Bay passes over an epicenter of Heat Flow. This correlation argues for a relation of the geothermal anomaly with depth fractures of the Earth's Crust in the Adriatic Shelf.

3.6. Remote sensing and GIS information

A study by Landsat imagery has presented a sketch of thrust tectonics in Northern Albania, which clearly shows the main segments of the Shkodër-Pejë transversal fault (Fig. 3).

4. Conclusions

A number of conclusions can be drawn from the present study. Firstly, gravity data inversion indicate that the Shkodër-Pejë zone is a vertical deep transversal fracture that separates two blocks

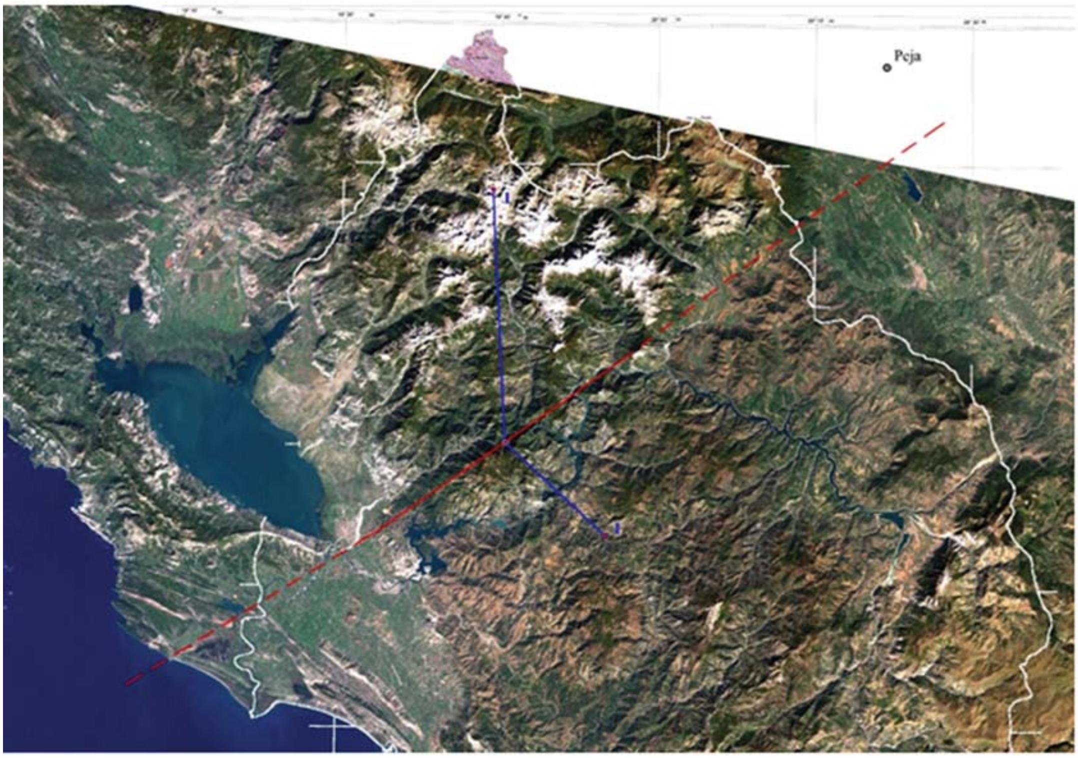

Figure 3. Satelite image of Shkodër-Pejë transversal fault in Northern Albania.

of the Earth's crust. The fracture represents a seismic active belt, interrupting the MOHO Discontinuity with an offset of about 4 km, which decreases towards the Earth surface. Secondly, paleomagnetic studies report that the Shkodër-Pejë transverse fault represents a transition zone between the clockwise rotation of the Albanides and Hellenides and the counterclockwise of Albanian Alps and Dinarides.

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A new 1:10,000 geological map of the Skutari-Pec Normal Fault and surroundings, northern Albania - evidence of orogen - parallel extension

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Abstract

The NW-SE trending Dinarides-Hellenides fold-and-thrust belt accommodated shortening related to subduction of the Adriatic plate beneath the European plate. This belt is offset along the Skutari-Pec Line (SPL) which trends NE-SW, perpendicular to the belt, and coincides with several major changes: (1) Paleogeographic units of the Adriatic margin (High-Karst and Pre-Karst Units) exposed on the NW side of the SPL are missing to the SE; (2) back-arc extension has modified the fold-and-thrust belt to the SE, whereas to the NW such extension is minor or absent; (3) kinematics of the SPL are controversial, with some studies emphasizing its role as a thrust that emplaced Mirdita (West Vardar) ophiolites onto Tertiary flysch of the Adriatic margin, and others as a normal fault (Skutari-Pec Normal Fault, SPNF).

A new 1:10,000 scale geological and tectonic map of the western end of the SPNF reveals cross-cutting relationships between key structures that constrain the following sequence of deformational events:

D1 – intra-oceanic obduction documented by the occurrence of mélange with components of oceanic lithosphere (serpentinite, altered basalts, pelagic sediments) within the Mirdita Ophiolite Unit as well as relics of metamorphic sole (amphibolites). NE- and SW-plunging stretching lineation on the mylonitic foliation of the amphibolite metamorphic sole is consistent with NE-SW transport during obduction.

D2 – top-W to -SW nappe transport during Adria-Europe collision as evidenced by the imbrication of the ophiolitic sequence above with siliciclastic shale containing lenses of sandstone, chert, altered basalt and massive limestone. This imbricated sequence overlies partly carbonate flysch of the Budva-Krasta-Cukali nappe of presumed Maastrichtian (?) to late Eocene age.

D3 – orogen-parallel extension along the SPNF. This normal fault dips c. 25° to the S and overprints D2 nappe contacts. Fault striae indicate top-SE motion of the hangingwall block. Other variously striking, steeply dipping faults offset D2 nappe contacts, but their age with respect to the SPNF is unknown.

Cross-cutting structural relationships indicate that D3 extension clearly post-dated intra-oceanic obduction (D1) and Cenozoic nappe stacking (D2). Mapping also reveals that the SPNF has no continuation farther west than the reservoir lake "Vaut te Dejes". Displacement related to normal faulting continues to the south along the D2 thrust of the Mirdita Ophiolite Unit onto slivers of Korab-Pelagonian and the Budva-Krasta-Cukali units. Near the city of Shkoder, away from the SPNF, the High Karst and Pre-Karst units are missing between the Shkoder Ophiolite Klippe and the underlying Budva-Krasta-Cukali Unit; therefore, the SPNF cannot be invoked to explain the NW-to-SE, orogen-parallel thinning and disappearance of the High-Karst and Pre-Karst units. We propose that this omission is due to a lateral ramp of an earlier SW-directed D2 thrust that rooted in the Budva-Krasta-Cukali Unit, a unit that is exposed on either side of the SPNF. The ramp probably nucleated along an older Mesozoic transform fault that delimited the East Bosnian-Durmitor, High-Karst and Pre-Karst carbonate platforms to the south. We note that this inferred ramp is located immediately NW of the SPNF and the Shkoder Ophiolite Klippe.

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Tectonics related to rotation at the western end of the Skutari-Pec Normal Fault

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Abstract

The Skutari-Pec Normal Fault (SPNF) is a SSE-dipping normal fault that trends subperpendicularly to the External Dinaric chain between Bairam Curri and Shkoder. At its western end near Shkoder, it juxtaposes Mirdita ophiolites in its hangingwall with the folded and imbricated Triassic-to-Eocene sequence of the Krasta-Cukali Unit in its footwall. The SPNF coincides approximately with an older lineament, the Skutari-Pec Line (SPL), that is marked by along-strike changes in the Cenozoic units derived from the Adriatic margin; NW of the SPL in the Albanian Alps, the High-Karst and Pre-Karst Units have a combined thickness of some 6 km, but thin out toward the SPL and are largely missing to the SE in Albania. There, the Mirdita (West Vardar) ophiolites directly overlie the Budva-Krasta-Cukali Unit with only locally intervening slices of Korab (Pelagonian) Unit and/or possibly of Jurassic mélange (Schmid et al. 2014).

The footwall of the SPNF is exposed over much of its length in the Cukali half-window, which is bounded to the NW by the basal thrust of the overlying High-Karst Unit. The Krasta-Cukali Unit is the structurally lowest nappe offset by the SPNF. The underlying Kruja Unit is not offset, but is affected by along-strike bending in the vicinity of Shkoder (see Fig. 1). The SPNF dips ca. 35° to the SSE and carries S- to SSE-plunging striae with top-SE shear-sense indicators. This is consistent with down-throw of the Mirdita ophiolites and orogen-parallel extension. To the south of the SPNF, SE-plunging striae overprint the gently NE-dipping basal thrust of the Mirdita ophiolites and the underlying early Paleogene flysch of the Krasta-Cukali Unit. This indicates that top-S to -SSE orogen-parallel motion reactivated this older SW-directed thrust.

Geologic mapping reveals that the SPNF extends as a single normal fault as far as the western end of the “Vau Te Dejes” reservoir lake, just east of Shkoder. West of this point, no SPNF is evident and the Mirdita ophiolites form the Shkoder Klippe, which is isolated from the main body of Mirdita ophiolite and lies directly on an intermittent layer of Jurassic mélange. The mélange at the base of this klippe in turn overlies a thin layer of Late Cretaceous-Paleogene flysch of the Krasta-Cukali Unit along a subhorizontal contact; the Korab, Pre-Karst and High-Karst Units elsewhere underlying the main body of Mirdita ophiolite are entirely missing here. The basal contact of the Shkoder Klippe is cut by SE-dipping thrusts and normal faults which are themselves offset by an E-W trending dextral strike-slip fault in line with the SPNF to the east. Southwest of Shkoder, near the Albania-Montenegro border, the Dinaric nappe stack comprises (from top to bottom) the High-Karst Unit, a much-reduced Budva-Krasta-Cukali Unit and the Kruja Unit. South of Skhoder, the Kruja Unit on the Albanian side is rotated some 20-30° clockwise with respect to its Montenegrinian equivalent. Taken together, these structures accommodated clockwise rotation and shortening.

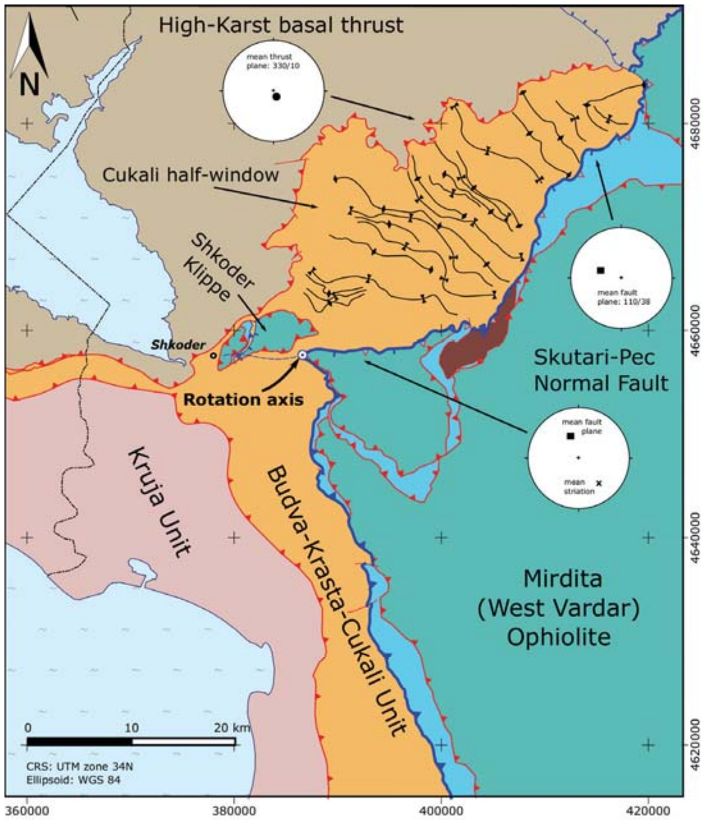

Figure 1. Tectonic map of the Shkoder area showing the western end of the Skutari-Pec Normal Fault and related structures (blue) and Paleogene thrust contacts (red) and fold axial traces (black). See text for explanation. Map modified from Cionoiu (2013) and Zertani (2013).

We propose the existence of a vertical axis of clockwise rotation within the Krasta-Cukali Unit west of Shkoder, i.e., at the western end of the SPNF, where orogen-parallel extension reduces to zero (Fig. 1). Extension is expected to increase going away from this axis towards the northeast. Clockwise rotation about this axis is consistent with the observed S to SE motion of the main body of Mirdita ophiolites above Krasta-Cukali Unit to the southeast of Shkoder, as well as with clockwise rotation of the Kruja Unit and the occurrence of transpressional structures in the Shkoder area. Note that the absence of the Korab, Pre-Karst and High-Karst Units beneath the Shkoder Klippe cannot be attributed to extensional excision because the SPNF as defined above does not affect this area. Rather, this omission may be due to a Mesozoic or Paleogene precursor like the SPL, for example, a NE-SW trending transform (Auboin and Dercourt 1975) that delimited the SE ends of the High-Karst, Pre-Karst and Korab carbonate platforms and/or that accommodated differential shortening of the Dinaric orogen (Schmid et al. 2014). The SPNF is therefore a younger fault that nucleated along the SPL.

The age of clockwise rotation and orogen-parallel normal faulting along the SPNF is not yet well constrained. The SPNF cuts Paleogene sediments and folds of the external Dinarides in its footwall. Fission track ages from flysch in the footwall along the eastern end of the SPNF near Bajram Curri indicate rapid cooling related to extension in latest Oligocene-early Miocene time (Muceku et al. 2008, their sample AM15-00 from the Albanian Alps). This coincides with the age of thrusting of the Kruja Unit onto the Ionian Unit SE of Shkoder. We therefore propose that coeval orogen-parallel extension, thrusting and clockwise rotation in this area accommodated SW-retreat and radial expansion of the Hellenic arc during rollback subduction (see Kissel et al. 1995 and many others).

Keywords: *Dinarides, orogen-parallel extension, orogenic rotation*

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Sheared to bits – A working hypothesis and evidence for a large shear zone accommodating the inversion of lateral crustal motion in the SW Balkans

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Abstract

Caught between the northeastward movement of the Dinarides and the southwestward movement of the southern Hellenides an area of continental crust largely coinciding with Albania and NW Greece has to accommodate an inversion of crustal motion that resulted from a slab break-off from the subducted African Plate underneath the southern Balkans and successive rollback of the subduction zone. The Skutari-Pec Line and the Kefalonia Fault are major NE-SW trending active fault zones forming the northern and southern limits of the transitional zone within which the inversion takes place. Another major seismic zone in between is the Lushnja-Elbasan-Diber Line, also known as Shëngjergj Corridor. However, apart from the intensely studied Kefalonia Fault, the kinematics as well as the regional tectonic context of these major tectonic zones are insufficiently understood. Even less is known about smaller NE-SW trending transform faults that have not even been placed on geological maps in many cases despite plenty of seismic and morphological evidence.

We have investigated an exemplary case of one such transform fault in central Albania that has long been suspected to run parallel to the Shëngjergj Corridor across the Bulqiza Ophiolite Massif and in the prolongation of which lies Albania's capital, Tirana. So far, the determination of its kinematics within the substantial and lithologically homogenous section of oceanic crust that is the Bulqiza Massif has been difficult, although the assumed fault manifests itself by the presence or absence of major chromite ore deposits and a slightly different mineralogy on either side. Our geomorphological and geological investigations strongly support the presence of an active right lateral strike-slip fault through direct observation of fault breccias, tectonic terraces and subsidence. Furthermore, through SEM/EDS and XRF analyses we could finally identify a specific breccia that has long been associated with the assumed fault as, in fact, a cataclasite. This type of fault breccia forms in detachment faults of ocean ridges or thrust zones of accretionary complexes, which in this case means prior or during the obduction of the Bulqiza ophiolite. Thus, as an internal feature of the original ocean crust, it represents a valuable marker that could be used to determine spatial offsets along the Bulqiza transform fault.

Referring to published data and supported by our findings from a number of field surveys in eastern Albania we suggest a basic working hypothesis of (neo-)tectonic movements for the area between the Skutari-Pec Line and the Kefalonia Fault that puts the NE-SW trending tectonic features into a coherent context. Accordingly, the succession of major seismogenic zones (e.g., Shëngjergj Corridor) and smaller scale NE-SW trending right lateral strike-slip faults (e.g., Bulqiza Fault) in the area of Albania and NW Greece represents a large shear zone that accommodates the inversion of crustal motion observed between the Dinarides and southern Hellenides or the Skutari-Pec and Kefalonia transversals, repsectively. Despite plenty of evidence this concept has remained vague in existing literature, mainly due to a lack of available detail to pin down its individual elements. Further work on the ground in form of focused geological studies and geomorphological, seismic and satellite-based surveying is required in order to establish a more complete inventory of the transform faults in the postulated shear zone and to develop a budget of individual lateral offsets that fully compensates for the inversion of crustal motion. It is due to the dispersal of lateral stress over a sequence of transform faults that devastating earthquakes in the area are relatively rare compared to more focused fault systems such as the notorious North Anatolian Fault. Still, a better understanding of the kinematics of the transform faults as well as their past development is highly desirable as this will not only improve risk assessments with regard to natural hazards but may also hold further clues towards the recent history or current development of the underlying subduction zone.

Tectonic structure and emplacement of the Fanos granite in the Axios Zone (Macedonia, N. Greece)

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Abstract

The Fanos granite occurs in the Peonia Subzone of the Eastern Axios-Vardar Zone in Northern Greece. It is a Late Jurassic (158 ±1 Ma), N-S trending granite, intruding the Mesozoic back-arc Geuvgeuli ophiolitic complex (Peonia Subzone). For the better understanding of the geotectonic evolution of the broader area, the Fanos granite is compared with the Mid-Late Jurassic Kastaneri volcano-sedimentary formation located in the eastern part of the Paikon Massif, onto which the Guevgeuli ophiolites were obducted. The major topic addressed by this study is the origin of the Fanos granite as well as itspossible geotectonic setting within the Neotethys ocean (=Axios/Vardar ocean). The rock samples of the area where analyzed by X-ray fluorence for major and trace elements. Taking into account our structural and geochemical data along with the existing isotopic and geotectonic data of the broader Axios/Vardar Zone, we suggest that the studied granitic rocks were formed during intra-oceanic-subduction within the Axios-Vardar ocean (=Neotethys).

Keywords: *Axios Zone, Fanos granite, Geuvgeuli ophiolitic complex*

Introduction - Geological setting

The Hellenides are subdivided into several tectonostratigraphic units (Fig. 1). In Northern Greece, the Axios Zone, comprises the Almopia Subzone in the West, the Paikon Subzone in the centre and the Paionia Subzone in the East (Mercier 1968; Ricou and Godfriaux 1995; Brown and Robertson 2003). Several models have been proposed for structural evolution and tectonic setting of this area. The Geuvgeuli ophiolitic complex is part of the Paionia Subzone and forms a distinct NW-SE trending body, exposed both in Greece and Yugoslavia (Fig. 1). This Mesozoic complex has the form of a large ophiolitic thrust, obducted onto the eastern part of the Paikon Massif (Fig. 2a). The Guevgeuli ophiolites are intruded by the Fanos granite, a Late Jurassic (158 ±1 after Anders et al. 2005), N-S trending granite (Fig. 2a,b). For the better understanding of thegeotectonic evolution of the broader area, the Fanos granite is compared with a volcano-sedimentary formation of Mid-Late Jurassic age, the Kastaneri Formation, located inthe eastern part of the Paikon massif (Paikon Subzone).

Our study addresses three major topics: a) the origin of the Fanos granite, b) the geochemical correlation between Fanos granite and Kastaneri formation and c) the relationship of the granite with the remnants of an oceanic island-arc or an active continental margin geotectonic setting located in the Neotethys (=Axios/Vardar) ocean.

Data and methods

The Fanos granite is composed of three main rock types, namely aplitic granite, coarse grained granite and microgranitethat evolved by fractional crystallization (Christofides et al. 1990). The rock samples collectedin the study area,are granites, aplitic granites, microgranites, rhyolites, quartz diorites, migmatites and amphibolites. According to field observations during our study, the initial intrusivecharacter of the granitic bodies at the eastern contact of the Fanos granite with the host ophiolitic rocks is well preserved. On the other hand, taking in to account the overall structural setting for the broader area of the Axios zone and Pelagonian nappe (Vergelyand and Mercier 2000; Brown and Robertson 2003; Kilias et al. 2010; Katrivanos et al. 2013) the western contact is overprinted by a few meters thick, westward-vergent semiductile thrust zone, probably of Late Jurassic-Early Cretaceous age.

The samples were analysed by X-ray fluorence for major and trace elements. The granite shows peraluminous characteristics, high-K calc-alkaline affinities and I-type features. The trace element

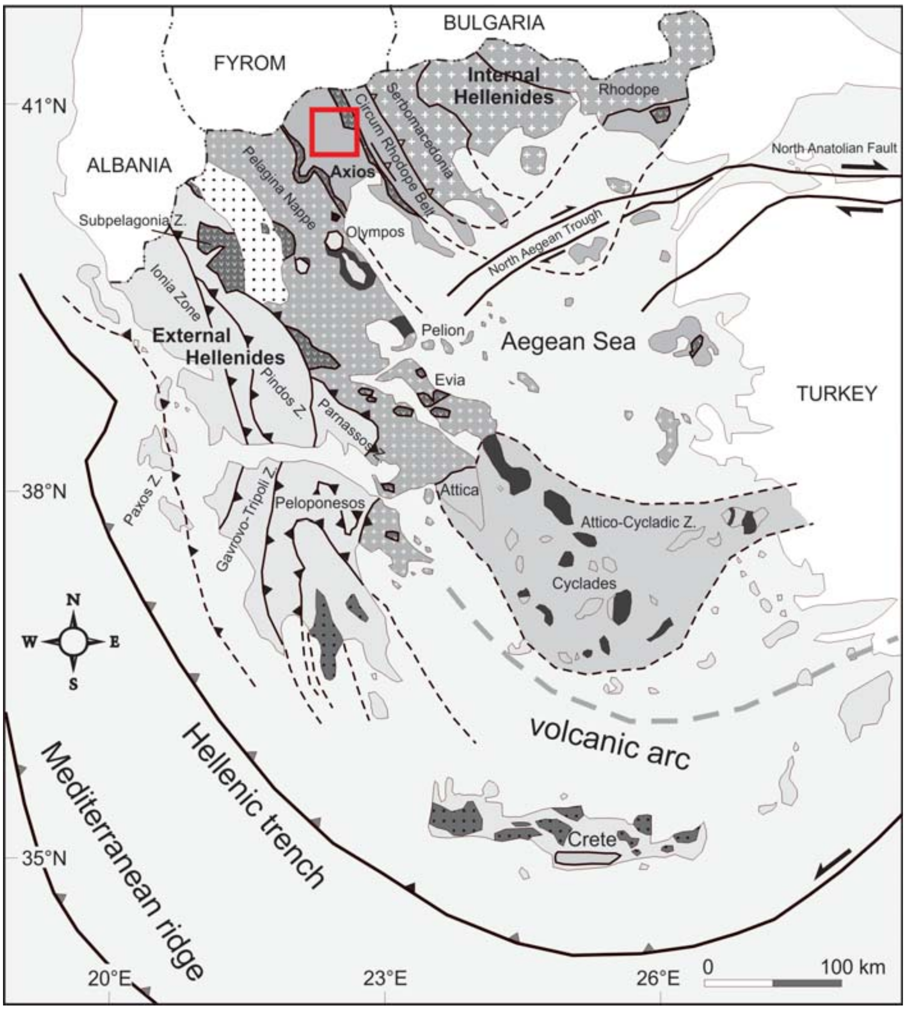

Figure 1.
Geological map showing the main structural domains of the Hellinides (Kilias et al. 2012). The red rectangle indicates the geographic locationof the area of study.

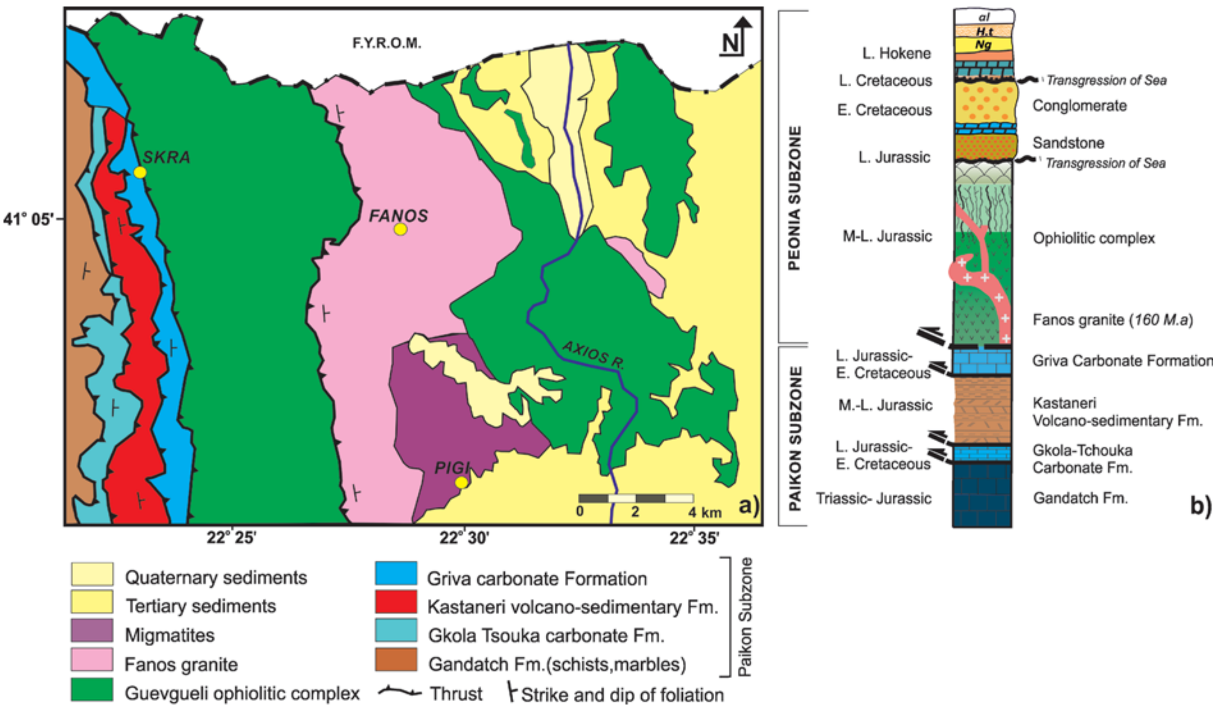

Figure 2.
a) Simplified map of the study area. IGME geological maps of Greece, sheet Skra and Evzoni, (modified after Anders et al. 2005),
b) Summary of the tectono-stratigraphy of the Paikon and Peonia Subzones.

patterns along with the isotopic composition of the rocks indicate the absence contamination bycontinental crustal material. Moreover, the geochemical data imply a common origin ofthe Fanos granite and the Kastaneri formation.The Sr initial isotopic ratios of the granite range between 0.70519 and 0.70559 (Šarić et al. 2008) while the Nd initial isotopic ratios range between 0.51236 and 0.51239 (Šarić et al. 2008) reflecting EM-I (Enriched Mantle-I) component.

Conclusions

According to our structural and geochemical investigations, in combination with the existing isotopic and geotectonic data, we propose amodel forthe geotectonic setting of the Fanos granite. During the Late Jurassic, an initial phase of an intra-oceanic subduction occurred in the Axios-Vardar (=Neotethys) oceanic area. At the same time, along the subduction zone, the metamorphic sole started to form, (Fig. 3a). Gradually an ensimatic island arc together with a back arc basin evolved. This stage is connected with the formation of the initial magma of the Fanos granite and the volcano-sedimentary formation of the Kastaneri (Paikon Subzone; see Fig. 3b).

Finally, in the Late Jurassic, the Fanos granite was emplaced together with the westward obducted ophiolite onto the eastern Pelagonian continental margin. A high pressure-low temperature metamorphism (HP-LT) of Middle to Late Jurassic age was suspected by Baroz et al. (1987) and isrelated to the tectonic loadcaused by thrusting of the ophiolites (Fig. 3c).

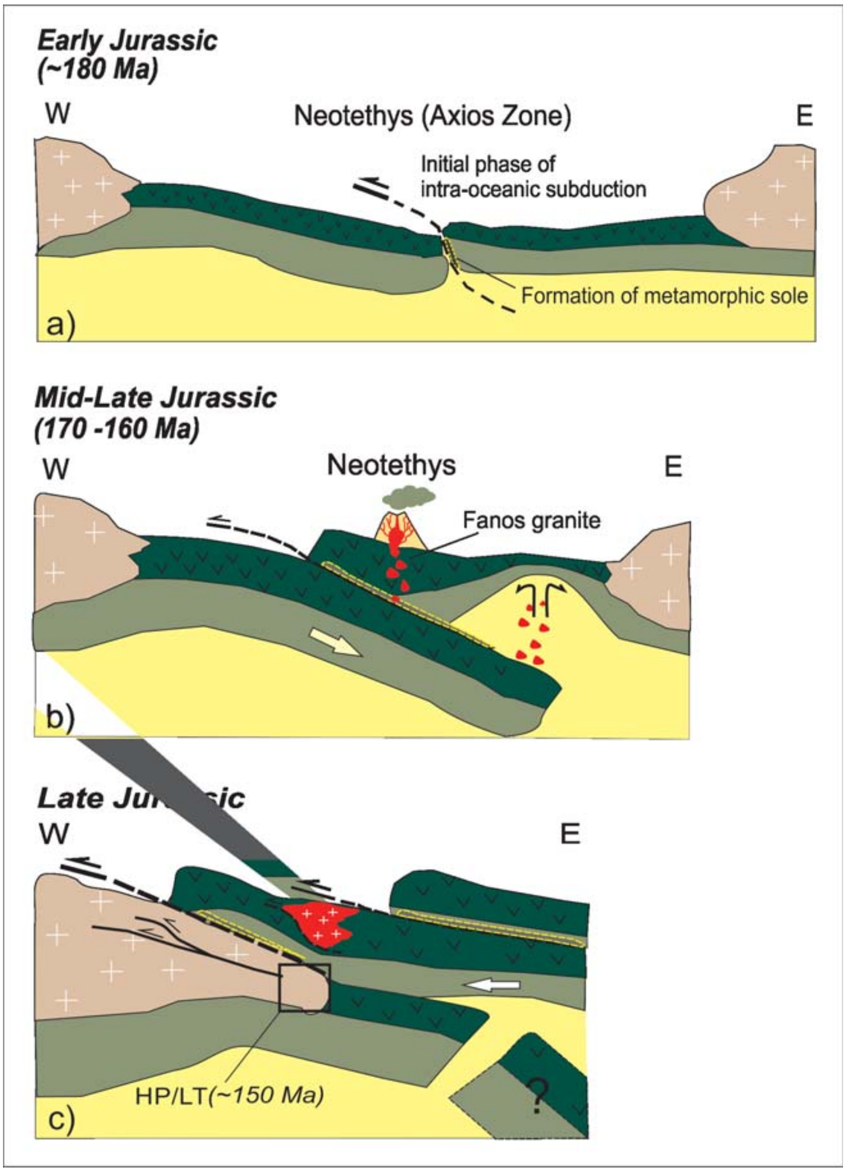

Figure 3. Proposed model showing the geotectonic position of the Fanos granite in an island–arc setting during anintraoceanic subduction in the Axios/Vardar ocean (=Neotethys). The tectonic emplacement of the granite took place together with the westward obduction of the Neotethyan ophiolites of the Axios/Vardar ocean onto the Pelagonian continental margin.

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Thermochronological evidence for late orogenic (Mio-Pliocene) extension south of the Shkodër-Pejë line.

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Abstract

Albania occupies a central position within the Dinaro-Hellenic alpine mountain belt. The Albanian orogen is characterized by three fundamental units: a Western Fold-and-Thrust Belt (WFTHB), a Central Belt (CB) characterized by the occurrence of ophiolitic nappes, and an Eastern Internal Complex (EIC). The WFTHB covers about half of the superficies of Albania, and reappears in eastern Albania in the Peshkopi tectonic window. The CB shows a very complex structural arrangement. North of the Shkodër-Pejë line, the Albanian Alps and Gashi Zones can be correlated with the Karst and Durmitor Zones of Montenegro and represent the southern continuation of the Dinaric nappe system. South of the Shkodër-Pejë line, the Mirdita zone is characterized by a huge ophiolitic nappe. The EIC corresponds to the Korabi Zone, to be correlated with the Drina-Ivanjica zone in Dinarides of former Yugoslavia, as well as with the Pelagonian Zone of the Hellenides.

Fission-track (FT) and (U-Th)/He analysis on apatite and zircon allow to better constrain the thermal history of this mountain belt, especially to the south of Shkoder-Peje line. The (U-Th)/He ages show that the western and northern parts of the CB were cooled under ~70 ºC from 55 Ma to 24-35 Ma. This is in strong contrast with the EIC where the rock formations of this zone were cooled under ~70 ºC from 9.3 to 4.5 Ma. The observed east-west trend across the Albanides, with older cooling ages in the west, and younger cooling ages in the east, ,is also reflected in apatite FT and zircon (U-Th)/He ages. Only the higher-temperature zircon FT ages do not show any significant differences on both sides of this area. Thermal modeling based on the available low-temperature thermochronologic data, in particular the apatite (U-Th)/He ages, provides clear evidence for a phase of rapid exhumation of the EIC around 3-6 Ma, reaching a rate of about 1.2 km/m.y., while the western CB record much slower exhumation since the Eocene (<0.1 km/m.y.), (Muceku et al. 2006, 2008).

The strong lateral gradient in rock uplift rates implied by the thermochronologic data suggests accommodation of this variation by faulting. The present-day structure of the Albanides, with major west-dipping faults forming the boundary between the Mirdita and Korabi zones and occurring within the Korabi zone constrains such faulting to be extensional along reactivated NNW-SSE trending former thrust faults and NE-SW strike-slip fault systems. The Late Oligocene to Early Miocene crustal thickening and shortening in the Albanides has changed to an extensional regime in the eastern part of the orogeny at about 6 Ma.

More thermochronological data are needed in order to constrain the timing and exhumation rate involved by the displacement across the Shkodër-Pejë fault line. However our low termochronological data obtained to the south of this line are in good agreement with the regional structural information in this area (Handy et al., in this volume and Schmid et al., in this volume). We suggest that the recent extensional regime in the eastern part of Albanides is also one important component for the differential clockwise rotation and SW-retreat of Albanides with respect of the Dinarides.

This study demonstrates that the combination of (U-Th)/He and FT thermochronology is a powerful tool to better constrain the exhumation history of an orogenic wedge in the front and back of a continental subduction regime

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Nature and role of the Skutari-Pec Line in the context of the geology of the Balkan Penninsula

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Abstract

The Skutari-Pec "Line" (SPL) comprises a broad SW-NE striking transverse corridor of at least crustal-scale dimensions. At the earth's surface it is marked by a normal fault (Handy et al. this volume), the SE-dipping Skutari-Pec Normal Fault (SPNF). The SPNF accommodates top-SE movement of a hanging wall consisting of a formerly obducted and approximately 7 km thick slab of ophiolites (West Vardar or Mirdita) with slices of the Korab Unit at the base.The footwall consists of anover 10 km thick external Dinaridic nappe stack overlying the Budva-Krasta-Cukali-Pindos Unit, from bottom to top: High Karst Unit (Malsia e Madhe), Pre-Karst Unit including a slice of Bosnian Flysch at its top (Valbona and Vermoshi) and the East-Bosnia-Durmitor Unit (Gashi). However, in the hanging wall, i.e. to the SE in theHellenides, no trace of this massive nappe stack is found. This is evident in the Peshkopi window where the Drina-Ivanjica Unit (= Korab) directly overlies the Budva-Krasta-Cukali Unit while the intervening units (High Karst, Pre-Karst and East-Bosnia-Durmitor) are missing. This nappe stack either stayed behind in the footwall of the thrust, which emplaced the Korab-Mirdita sheet onto the Budva-Krasta-Cukali Unit, or never existed SE of the SPL. In any case, normal faulting along the SPNF alone is unable to explain this fundamental difference in the structure of Dinarides and Hellenides.

A precursor of the SPNF, located in and along the SPL corridor, must be largely responsible for this difference. Exact age and nature of this precursor, largely causing the along-strike change in the structure of Dinarides and Hellenides, are uncertain. Since thrusting at the base and within the High Karst, Pre-Karst and East-Bosnia-Durmitor nappes is of Maastrichtian to Late Eocene age, this precursor was probably active during the same time interval. The most puzzling feature of the precursor of the SPNF is that it dextrally offsets the front of the obducted W-Vardar ophiolites by some 80 km along the SPL corridor. A sinistral offset would result when assuming that the thick High Karst, Pre-Karst and East-Bosnia-Durmitor nappe stack stayed behind during the thrusting of the Korab-Mirdita sheet over the Kruja Zone.

Age and throw of the SPNF are yet loosely constrained. Syn-rift Lower Miocene conglomerates near Pec, bordering the Metohia basin, indicate an Early Miocene age. A fission track sample from the footwall (Gashi, sample 15 of Muceku et al. 2008) rapidly cools below 100 °C around 30 Ma and below 60° around 18 Ma, which indicates moderate amounts of exhumation. Note that normal faulting is considerably younger in the Peshkopi window (Late Miocene to recent; Muceku et al. 2008). The SPNF is part of a larger network of Miocene and younger normal faults. These are oriented orogen-parallel to the NW of the SPNF and reachall the way to the Sarajevo basin. The most important normal fault adjacent to the Peshkopi window down-throws the Mirdita ophiolites relative to the Korab Mesozoic and strikes N-S. NE-wards the SPNF splays into orogen-parallel and perpendicular branches. The variations in orientation indicate multidirectional Miocene extension. Near Shkoder, the SPNF does not affect the Dalmatian (Kruja) Unit, whichmerely undergoes a sudden change in strike. This strongly suggests that Miocene extension across the SPNF terminates SW-ward at a rotation pole located near Shkoder and responsible for clockwise differential rotation of Hellenides with respect to Dinarides (Handy et al. 2014) associated with the rollback of the Hellenides.

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Low-temperature evolution of the Serbo-Macedonian massif (SE Serbia): evidence from Ap and Zr fission-track analysis

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Abstract

Serbo-Macedonian massif (SMM) is a crystalline terrane situated between the two diverging branches of the Eastern Mediterranean Alpine orogenic system, the northeast-vergent Carpatho-Balkanides and the southwest-vergent Dinarides and the Hellenides. It is outcropping from the Pannonian basin to the Aegean Sea along central and southeastern Serbia, southwestern Bulgaria, eastern Macedonia and central Greece. Its affiliation to European or African plate basement is still questionable due to the lack of reliable geochronological dating and detailed structural investigation along its boundaries. The massif is also a key area to understand the bipolarity of the Alpine orogenic system, as well as the interaction of the Pannonian and Aegean back-arc extension during the Cenozoic time.

SMM has been traditionally considered to comprise an Upper (low-grade) and a Lower (medium to high-grade) complex. The protoliths of both units have been reported as volcano-sedimentary successions, which have subsequently experienced several stages of deformation and metamorphism. Additionally, both units have been intruded by magmatic rocks during several distinct pulses.

We have applied fission-track analysis on apatites and zircons from the rocks of the SMM coupled with structural field observations in order to reveal its low-temperature evolution. Two distinct phases of cooling have been distinguished in the study area. The region west of Južna Morava River has experienced relatively fast cooling through zircon and apatite closure temperatures (300-60 °C) during the late Cretaceous (94-67 Ma). This event is interpreted as a post-orogenic cooling following the regional nappe-stacking event ("Austrian" phase). In the eastern part of the study area, same late Cretaceous cooling has been recorded by the zircon data, whereas the apatite has remained at temperatures higher than 120 °C (but lower than ~200 °C) prior to the late Eocene extension and post-magmatic cooling (39-35 Ma). The Crnook area is an exception since both zircon and apatite fission-track data have revealed a late Eocene (45-38 Ma) cooling event related to the extension and the exhumation of the apparent dome structure along low angle normal faults. Thus, the Crnook dome has been recognised as a continuation of the Osogovo-Lisets extensional complex in Serbia.

Jurassic and Cretaceous paleogeographic and paleotectonic evolution of the Western Carpathians, as seen in the heavy mineral spectra of the detritic formations

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Abstract

More than 500 Jurassic to Cretaceous samples from all important tectonic units of the West Carpathians were analysed for heavy minerals. The aim was the comparison of heavy mineral spectra with paleogeographic consequences. The research showed, that in the Jurassic, two main Jurassic heavy-mineral provinces were distinguished in the Western Carpathians, which represent megaunits with different pre-rift and syn-rift evolution.

The first province is represented by the G-Z-R-T heavy-mineral assemblage (garnet, zircon, rutile, tourmaline). It is typical for most of the Pieniny Klippen Belt and Flysch Belt units (both Outer Carpathian zones) and is probably related to Gresten Zone and autochthonous Jurassic cover of the Bohemian Massif margins. Among garnet grains, pyrope-amandine types dominate over the almandine and subordinate spessartine and grossular types. Source- rocks of the pyrope-almandine garnets are high to ultra-high pressure rocks of the lower continental crust, such as granulites and eclogites. Granulitic pebbles were also found in the flysch conglomerates of the Silesian Unit (Flysch Belt), coming from hypothetic Silesian Cordillera. All these facts led to opinion that the Outer Carpathian units were originally derived from the southern margin of the Bohemian Massif, where its Moldanubian Zone contains large granulitic massives. However, comparison with Jurassic sediments of the Polish Platform cover in Cracow-Wieluń Upland showed that pyrope-almandine garnets are not restricted solely to the south of Bohemian Massif, but may occur in masses also in Poland, although their source is not precisely located. This made the provenance of the Outer Western Carpathian crustal segments more ambiguous.

Among the Pieniny Klippen Belt units, Drietoma and Haligovce units have clear affinity to the Central Western Carpathians. These units were not integral part of the Pieniny Klippen Belt but they were involved to this zone later, during Tertiary.

The second important Jurassic assemblage, T-Z-R (tourmaline, zircon and rutile), is typical for Central and Inner West Carpathian units. This assemblage was impoverished due to resedimentation from older sediments and due to intrastratal dissolution. The assemblage is tourmaline-dominated. As evident from microprobe analyses, the major portion of tourmaline came most likely from low-grade metamorphics which are now not present in the crystalline basement (except Gemericum), whereas most of zircon and rutile came from older sediments. Borinka Unit and Tatric units from Malé Karpaty Mts., which are dominated by tourmaline and apatite have similar heavy mineral spectra to Nordrahmenzone of the Eastern Alps which has similar proposed paleogeographic position as does Borinka Unit. The only difference is in provenance of part of tourmaline.

On the basis of some index heavy minerals it is likely that source of Nedzov Nappe clastics (containing considerable amount of staurolite) was Tatric-Veporic type of crystalline complexes.

Various bluish amphiboles and some bluish varieties of tourmaline in Silicic Jurassic came most likely from Gemericum. An overall lack of chromium spinels indicate that no larger obduction of ophiolites occurred in the Western Carpathian units during Jurassic. Only in the innermost, Meliata Unit, which was undergoing subduction and closure during the Middle and Late Jurassic, Cr-spinels occur in the deritus.

Cr-spinels become dominant all over the Western Carpathians in the Cretaceous sediments since Albian. The rest of heavy mineral assemblages correspond with the earlier, Jurassic assemblages, i.e. G-Z-R-T in the Pieniny Klippen Belt and T-Z-R assemblage in the Central Western Carpathians. The chemical analyses show that their source-rocks were almost invariably of harzburgitic origin. This is surprising, as the preserved closest primary ophiolitic remnants of the Meliata or Penninic oceans contain Cr-spinels of exclusively lherzolitic pattern.

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Coupling sequential restoration of balanced cross-sections and low-temperature thermochronometry: the case study of the Polish-Ukrainian Carpathians

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Abstract

The tectonic and thermal evolution of the Carpathian belt is still matter of heated scientific discussion. According to the commonly accepted interpretation the Carpathians result from the collision of the ALCAPA and Tiza-Dacia microplates with the Eastern European Platform and the following subduction of the Meliata-Maliac oceanic crust below the former microplates. The remnant of this ocean is interpreted to be the so-called Pieniny Klippen Belt (PKB), a narrow sheared belt located between the two main tectonic domains building the Carpathian chain: the Inner (IC) and Outer Carpathians (OC). The IC are formed by the Precambrian crystalline basement and Paleozoic to Mesozoic deposits unconformably overlain by the Paleogene successions belonging to the Central Carpathian Paleogene Basin (CCPB). The OC are made of Upper Jurassic to Late Miocene siliciclastic deposits stacked in several thrust sheets during the Oligocene till the Miocene. The PKB is formed by Mesozoic mega-blocks surrounded by Upper-Cretaceous to Paleogene less competent matrix. In the last decade some works suggested an alternative interpretation for the PKB origin, doubting its role as oceanic suture. With this contribution we suggest a new scenario in which the PKB is the foreland basin of the IC range. Our interpretation is even supported by previously published sedimentological observations suggesting a similarity between the lithologies forming the Mesozoic Inner Carpathian cover and the olistolites and olistostromes within the PKB. In addition we focused on the exhumation histories of the Carpathian belt evaluating the role of the extensional tectonics, thrusting and regional uplift in its cooling history. A new approach has been applied to validate the proposed tectonic scenario. Seven balanced cross-sections have been constructed across the Central-Western Carpathians. Their sequential restoration allows us not only to investigate the Carpathian tectonic evolution and calculate shortening values but also predict the cooling ages of different region along the present-day sections. By comparing the predicted age profiles with the measured low-temperature thermochronometric data (such as apatite fission track and apatite (U-Th-Sm)/He data) the exhumation can be constrained to the last 20 Ma. In addition, the predicted age profiles give us information about magnitude and timing of thrust sheet displacement. Three different regions can be recognized, characterized by different shortening, exhumation timing and processes. The Western Polish Carpathians are affected by syn-thrusting exhumation due to erosion and shortening values increasing eastwards (from 46 % to 56 %). In the Eastern Polish Carpathians, structural data and rapid exhumation rates coming from thermal modelling suggest that erosion is mainly triggered by post-thrusting low-angle normal faults. On the other hand, the Ukrainian Carpathians are not affected by post-thrusting normal faulting and the erosion is likely associated with post-thrusting regional uplift. According to our sequential restoration, the shortening calculated for this region is nearly constant (ca. 51 %) along the whole Ukrainian region.

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Cenozoic exhumation of the Rila Mts. (Bulgaria) as constrained by multi-system low-temperature thermochronology

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Abstract

The Rila Mountains in SW Bulgaria represent the north-western most coherent part of the Rhodope Metamorphic Complex, and provide an exciting area to study processes related to core complex exhumation. In currently accepted view the Rhodope Metamorphic Complex is an Alpine nape pile that formed during subduction and collision processes that lasted from Jurassic to Paleogene times. Since the Late Eocene (40 Ma), the southern parts of Balkan Peninsula were affected by processes of intensive crustal extension related to the retreat of the Hellenic subduction system. The extensional setting caused the exhumation of the Rhodope Metamorphic Complex (including Rila Mts.). Timing, rate and duration of the exhumation process(es) in the Rhodope Metamorphic Complex have not yet been sufficiently resolved, mainly due to paucity of geochronological data. In this study we present new zircon (U-Th)/He, apatite fission track and apatite (U-Th)/He data from the Rila Mts. in an attempt to reconstruct the post-orogenic unroofing history and constrain the topographic evolution of this mountain range. The three low-temperature thermochronometers bracket the cooling history in the ~200-40 °C temperature range, and in combination with new and previously published structural/kinematic data, enable us for the first time to place precise and accurate quantitative constraints on the timing, rates and kinematics of the Rile Mts. core complex during exhumation. Our new low-temperature thermochronological data revealed three distinct tectono-thermal stages in Rila basement complex evolution: (i) In the late Eocene-Early Oligocene, the Rila basement complex experienced a rapid cooling that is recorded by published high-temperature geochronometers as well as by ZHe, AFT and AHe thermochronometers. Taken together, the geo- and thermochronological data indicate the cooling from >700 °C to <100 °C temperatures within less than ~10 myrs. This cooling episode is interpreted as being related to unroofing of Rila basement complex, which was tectonically exhumed as a footwall by top-to-N/NNW down-throw of hanging-wall along a low-angle North Rila detachment fault. (ii) In the Late Oligocene-Early Miocene, the Rila basement complex experienced a heating event that partially and/or fully reset both fission track and (U-Th)/He systems in apatites with lower He retentivity and lower fission track annealing resistivity. The Late Oligocene-Early Miocene reheating corresponds well with the short pulse of top-to-south thrusting of the hanging-wall documented along northern boundary of the Rila-Rhodope massif. The hanging-wall units (Sredna Gora Basement and Thrace Unit) were thrust along reactivated detachment and related secondary failures directly on the Rila basement (footwall) or onto the Oligocene sediments. Therefore, the Late Oligocene-Early Miocene reheating revealed by thermochronology data most likely records tectonic burial of the Rila basement complex. (iii) In the Middle-Late Miocene, the Rila basement complex experienced a final cooling to near-surface temperatures. Timing of the Miocene cooling coincides with the age of the 'Aegean extension' in SW Bulgaria. Therefore, the cooling can be explained as recoding a (re)exhumation of the Rila basement complex (footwall) by reactivated low-angle detachments in the extensional tectonic regime. Rila basement complex thus experienced two core-complex style exhumation events in the Cenozoic. Based on our new low-temperature thermochronological data we argue that the Middle-Late Miocene extension and the Late Eocene-Early Oligocene extension are two separate events as already reported from the south-western parts of the Rhodope Metamorphic Complex.

Late Cretaceous to Paleocene exhumation in the Rodna mountains (Eastern Carpathians, Romania) inferred from zircon fission track analysis

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Abstract

This study (Gröger et al. 2013) presents zircon fission track data from the Bucovinian nappe stack (northern part of the inner East Carpathians, Rodna mountains) and a neighbouring part of the Biharia nappe system (Preluca massif) in Romania (Fig. 1). The fission track data is integrated with thermochronological data from literature (Culshaw et al. 2012; Strutinski et al. 2006) and the tectonic and sedimentary evolution of the area in order to unravel the thermal history and its structural evolution. The increase of metamorphic temperatures towards the SW detected by the zircon fission track data suggests SW-wards increasing tectonic overburden (up to at least 15 km) and hence top NE thrusting (Fig. 2). Sub-greenschist facies conditions during the Alpine metamorphic overprint only caused partial annealing of fission tracks in zircon in the external main chain of the Central East Carpathians. Full annealing of zircon points to at least 300°C in the more internal elements (Rodna mountains and Preluca massif).

The zircon fission track central and single grain ages largely reflect Late Cretaceous cooling and exhumation. A combination of fission track data and stratigraphic constraints points to predominantly tectonic differential exhumation by some 7-11 km, connected to massive Late Cretaceous extension not yet detected in the area (Fig. 2). Later events such as the Latest Cretaceous (“Laramian”) juxtaposition of the nappe pile with the internal Moldavides, causing exhumation by erosion, re-burial by sedimentation and tectonic loading during the Cenozoic had no impact on the zircon fission track data; unfortunately it prevented a study of the low temperature part of the Late Cretaceous exhumation history.

Key words: *Alpine metamorphism, Rodna mountains, Eastern Carpathians, thermochronology, zircon fission track analysis*

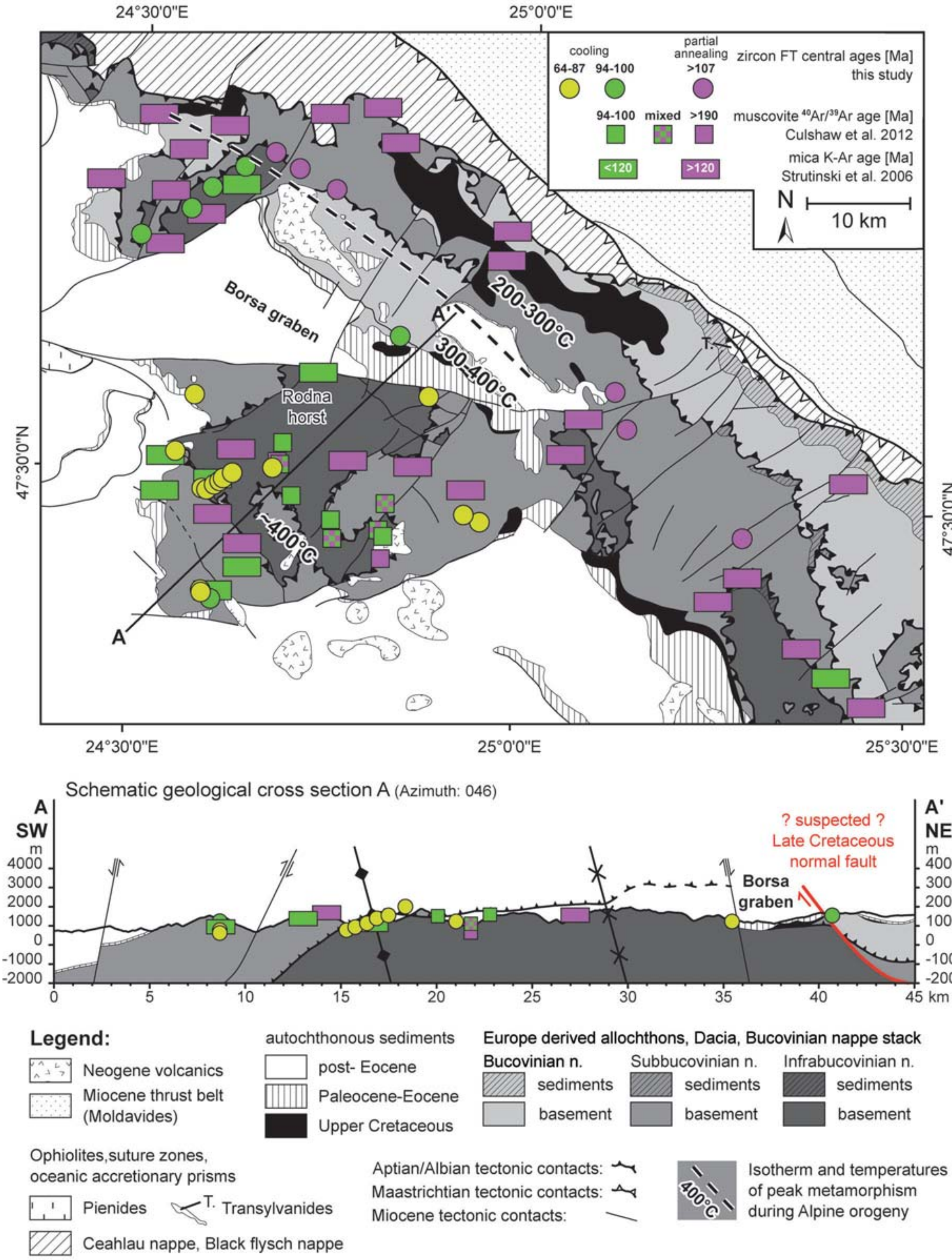

Figure 1. Tectonic overview of the Alpine-Carpathian-Pannonian area (after Schmid et al. 2008); rectangle indicates the location of the study area at the northern edge of the Dacia Mega-Unit.

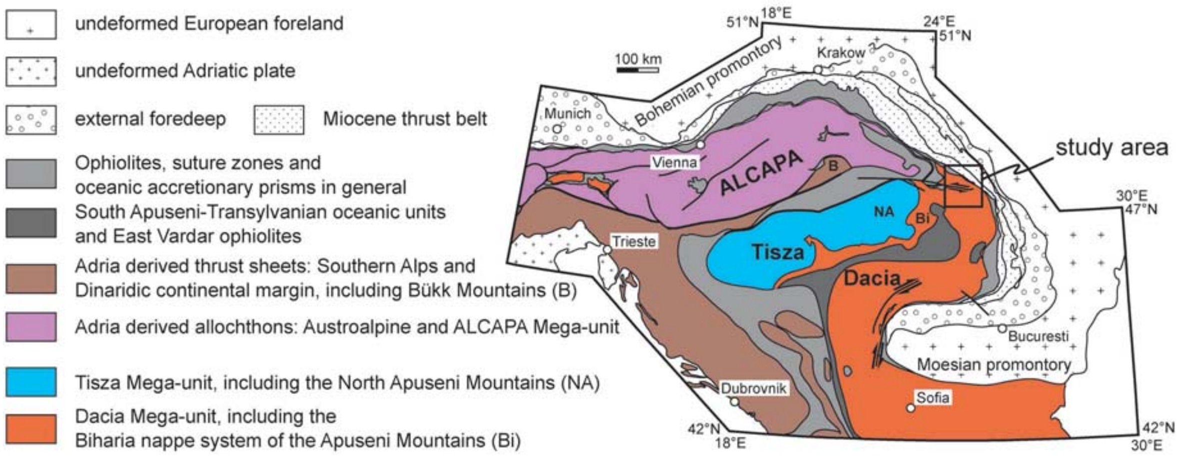

Figure 2. Map and profile displaying estimates of maximum temperature reached during Early Cretaceous metamorphism based on the zircon fission track data of this study combined with estimates based on K-Ar- and 40Ar/39Ar-data compiled by Strutinski et al. (2006) and Culshaw et al. (2012). The compilation suggests increasing temperatures towards the SW. Sub-greenschist facies conditions prevailed along the NE part of the Maramures mountains and the Central East Carpathians chain where partial annealing of zircon is observed while Cretaceous-age greenschist-facies prevailed within the Rodna horst and in the Preluca massif (ESE of Fig. 2). There is an overall but rather unsystematic tendency towards younger isotopic as well as zircon fission track towards the SE, suggesting later cooling in the more internal, i.e. SE, areas.

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Variscan Rakovec geosuture in the Inner Western Carpathians: A cornerstone in thoughts concerning location of the Paleotethys branch inside the Alpine-Carpathian orogenic belt

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Abstract

The Rakovec geosuture (cf. Németh 2002), located along the northern rim of Gemericum (Inner Western Carpathians), represents the zone of collision closure of the Lower Paleozoic-Pre-Gzelian basin with oceanic crust, having well preserved demonstrations of Variscan subduction-exhumation and collision kinematics, Permian overheating and younger Alpine tectonic overprint.

The dominating Variscan structures in the E-W trending segment of this geosuture are represented by foliation planes with medium to steep dip to N, locally NE and NW. Nearly subhorizontal lineations indicate the top-to-SE transpression exhumation kinematics. In the Eastern Gemericum, where the course of the Rakovec geosuture is bent to NW-SE by the younger Alpine overprint, the trend of older Variscan foliation planes is rotated correspondingly. Similarly, the lineations manifest top-to-SW pre-Alpine exhumation and overthrusting. The collision closure of the basin in the Rakovec zone is dated back to 323-275 Ma (Upper Serpukhovian to Cissuralian, def. phase VD1a, Németh in Radvanec et al. 2007).

Recent research of the Rakovec geosuture in the line of elevation points Ostrá (998) – Babiná (1278) – Šajby (1095) revealed a wide zone of exhumed sequences, including the fragments of metagabbros derived from the base of continental crust. Exhumed lithologies are characteristic with pervasive plastic deformation with well-developed a-structures (ductile stretching lineations, a-fold axes). In the case of exhumed metagabbros there was found pervasive mylonitization, ranging from protomylonites to ultramylonites. Some exhumed blocks contain shape of "exhumation balls".

Magmatic assemblages of exhumed Lower Carboniferous clinopyroxene gabbro (350 Ma, SHRIMP, Putiš et al. 2009) is represented by dominating diopside and Ti-diopside porphyroblasts, Sr-plagioclase and a mixture of ilmenite-rutile. The peak of HP metamorphism (deeper immersion of separated gabbro blocks into the subduction slab) was recorded by co-existing pair Sr-epidote + jadeite (Middle-Upper Pennsylvanian; 300-310 Ma, SHRIMP, l.c.). During the metagabbro exhumation and related retrograde metamorphic phase, the Sr content in Sr-REE-epidote gradually lowered towards its margin. Next there originated omphacite, biotite, phengite, albite ± glaucophane and winchite. Exhumation of metagabbro in pumpellyite-actinolite facies into the Upper Carbonifereous accretion prism was accompanied with its ductile deformation. Exhumed metagabbro has registered also following Permian metamorphism (262 Ma, zircon rim, SHRIMP, l.c.), owing to the hot line beneath the collision terrane (cf. Németh 2005; Radvanec et al. 2007). This Permian overheating caused the origin of S-type granites. In the metagabbro, a new high-temperature and low-pressure assemblage of edenite-pargasite-hornblende ± taramite, titanite and epidote-zoisite has crystallized in the epidote-amphibolite facies (deformation phases VD1b and VD2; cf. Németh in Radvanec et al. 2007).

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Preliminary results of K-Ar dating of clay fault gouges from the Idrija and Sava faults (Slovenia) and the Ribnovo fault (Bulgaria)

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Abstract

The age of movements along brittle faults can be constrained in many cases by low-temperature geochronological methods (like fission track dating) or the interplay between faulting and magmatic activity and/or sedimentation in syntectonic basins. However, these approaches must fail where the vertical offset along a fault is small, such as for strike-slip faults, and where magmatic and sedimentary time markers are lacking. In such cases, K-Ar (or encapsulated $^{40}Ar/^{39}Ar$) dating of clay fault gouges is a potential method for dating the activity of brittle faults. Previous studies yielded plausible results especially in crystalline basement terrains where all clay contained in the gouge is expected to be authigenic and, ideally, newly grown illite is the only potassium-bearing mineral phase in the gouge. In such a case, illite may grow at different times during protracted faulting and ages obtained from K-Ar dating would reflect only an instant of a longer faulting period. Whether this instant is closer to the onset or the end of faulting depends on various factors such as contamination of the gouge by protolith material and the growth kinetics of illite (or other K-bearing minerals) during faulting. Ample presence of protolith material may bias the data towards ages predating fault activity. On the other hand, illite growth may continue after fault activity has ceased.

In order to assess these factors, we sampled gouges in Slovenia and Bulgaria where brittle faults of (apparently) well-constrained age developed in completely different country rocks that are significantly older than faulting. K-Ar dating was performed on the <2 μm fraction separated from the fault gouges. The Ribnovo fault in southwest Bulgaria affects gneisses, schists, and marbles of at least Late Jurassic age that do not contain clay minerals. A gouge sample from this fault gave an age of 35.1 ±0.7 Ma, which coincides exactly with the time of faulting as constrained by syntectonic sediments and crosscutting relationships with igneous rocks. For the Idrija and Sava faults in northwest Slovenia, a post-Sarmatian (post-12 Ma) activity is documented by their relationships with the South Alpine thrust front and pre-tectonic sediments, respectively. For the Sava fault, the samples yielded ages of 87.8 ±1.8 Ma and 44.6 ±0.9 Ma. The protoliths are Middle to Upper Triassic marlyschists and Middle Triassic shales and carbonates, respectively. The samples from the Idrija fault were collected from a trench made by the Geological Survey of Slovenia in 2012. The protoliths of the gouges are Upper Permian dolostone and sandstone of the Gröden formation. From individual branches of the Idrija fault, we obtained three fault gouge ages of 108.1 ±2.2 Ma, 111.1 ±2.2 Ma, and 113.1 ±2.3 Ma. Clay separated from the Gröden sandstone protolith yielded an age of 82.3 ±1.7 Ma.

The data from the Sava and Idrija faults are obviously older than the commonly assumed timing of these faults. Although further investigations (mineralogical characterisation of the gouge, dating of finer-grained fractions) may help to solve this dilemma, we draw the following preliminary conclusions. (1) Ages from the Idrija fault do not reflect the time of faulting but Cretaceous growth of illite, probably promoted by fluids circulating in the highly porous Gröden sandstone. (2) Irrespective of the true age of faulting, the fact that fault gouge ages from the Idrija fault are older than ages for the clay size fraction of the protolith can be explained by reduced illite growth (fluid activity) within the gouge once it is formed. (3) Radiometric fault gouge dating is more likely to give plausible and more easily interpretable results if the protolith is free of precursor clay.

Tectono-thermal history of the Southern Gemericum Unit dated by microprobe monazite geochronology and its correlation with Pb zircon ages (Western Carpathians, Slovakia)

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Abstract

The Southern Gemericum basement in the Inner Western Carpathians experienced a polyphase regional deformation. Differences of the pre-Alpine and Alpine events have been constantly discussed. To address this, monazites from metapelites and acid metavolcanic rocks were dated using the Th-U-Pb electron-microprobe method. Chemical composition of monazites was acquired by the electron microprobe Cameca SX-100, at Geological Survey of Slovak Republic in Bratislava. Three monazite generations, Precambrian, Early Paleozoic and Alpine have been recognized in the greenschist facies metapelites and acid metavolcanic rocks of the Southern Gemericum basement. Both, inherited magmatic monazite grains in metavolcanites and rare relics of detrital monazites within the polyphase monazite grains in metapelites yielded the Precambrian age in the time span of 550-660 Ma. They prove the provenance and derivation from deeper crustal Cadomian fragments. High-Y magmatic monazites of Early Paleozoic age (444 ±13 Ma and 477 ±7Ma) have been recorded in the acid metavolcanites and their metavolcaniclastics. These ages fit roughly within the previously published magmatic zircon (SHRIMP) age determinations (at 494 ±1.7 and 464 ±1.7 Ma), that clearly indicate two-phase volcanic activity in the Early Paleozoic Southern Gemericum basin (Vozárová et al. 2010). The Southern Gemeric metavolcanic and related metavolcaniclastic rocks have rhyolitic to dacite-andesite composition, peraluminous, and similar to those of calc-alkaline high-K series. The geochemical data are consistent with the presumed orogenic geodynamic setting. The study of more than 140 zircon grains from the acid metavolcanites of the Early Paleozoic Gelnica Group sequence confirms the existence of the two phase Upper Cambrian-Ordovician (494 and 464 Ma respectively) volcanic activity (Vozárová et al. 2010). The Upper Cambrian volcanic arc developed upon the Neoproterozoic cratonic basement that originally formed a part of the peri-Gondwanan Avalonian volcanic arc. The second phase of volcanic activity was associated with the reactivation of the Cambrian magmatic arc with a possible extension, and the crustal melting might be reflected in the "inherited" orogenic features of these volcanic rocks. The traces of the inherited zircon of the Meso, Paleoproterozoic and Archean ages within the magmatic zircon cores confirm the affiliation of the source to the wider Gondwana hinterland, with the strong affinity to the Avalonia-Amazonia domain what is based on detrital zircon age data (Vozárová et al. 2012). The Early Paleozoic magmatic monazites were partly overprinted by the low-Y Alpine monazites (133 ±5 Ma and 184 ±16 Ma) at their grain rims. In Al-rich metapelites, the newly-formed low-Y monazites of Alpine age occur commonly, reflecting thus the polystage compression geodynamic evolution with the three distinct peaks at 100 ±8 Ma, 133 ±5 Ma and 190 ±16 Ma, respectively. No data as the evidence of the pre-Alpine metamorphic events were observed in metapelites. Only some monazites yield the age indications for the Permian extensional thermal re-heating (260-290 Ma). On the basis of these monazite age data we presume the strong overprinting of the Southern Gemericum basement due to the polyphase Alpine deformation at least in the greenschist facies conditions. The monazites from the Southern Gemericum rock basement record the three types of ages: i) the primary low-grade metamorphic monazites related to the Alpine polyphase compression tectonics in the metapelites with the dominant Cretaceous ages; ii) the primary Ordovician magmatic monazites, with the rare Jurassic/Cretaceous low-grade metamorphic overprinting at their grain rims; iii) the protolith age of the detrital monazite grains from metapelites was assessed at 550 – 660 Ma.

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Late Cretaceous Banatitic magmatism and metallogeny in the frame of the Eoalpine tectonics from the Carpathian-Balkan orogen

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Abstract

The Late Cretaceous Banatitic magmatic and metallogenetic belt from the Western Carpathians (Slovakia), Apuseni Mts. (Romania), Southern Carpathians (Romania and Serbia) and Srednogorie (Bulgaria) is rich in copper ores, commonly associated with Pb-Zn, Au-Ag, and subordinately with Mo, Bi, W, Fe, Co, Ni and B. Mineral deposits are strongly differentiated with respect to host rock types and depth of magma emplacement.

Keywords: *Late Cretaceous, banatites, volcano-plutonic belt, Central-SE Europe, porphyry copper, massive sulphide, skarn, vein (epithermal and mesothermal) deposits*

Widespread volcanic structures and plutonic bodies of age 92 to 72 Ma are exposed from western Romania, via north-eastern Serbia – northern Bulgaria, to European Turkey, and were also found in many boreholes crossing the Pannonian Basin, from Romania, Serbia, Croatia, Hungary and Slovakia. Von Cotta (1864) described as Banatites several acid intrusions with associated ores, crosscutting Jurassic and Early Cretaceous limestones in Banat hills (SW Romania). Late Cretaceous igneous rocks are known in an L-shaped belt, from NW Romania, via SW Romania and NE Serbia, to N Bulgaria and European Turkey (Giuşcă et al. 1965). This L-shaped area of plutonic, subvolcanic or volcanic bodies hosting important Cu, Mo, W, Au, Ag, Fe, PGE deposits was named *Banat-Srednogorie Belt* by Popov (1981), *Banatitic Magmatic and Metallogenetic Belt (BMMB)* by Berza et al. (1998), respectively *Apuseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt (ABTS)* by Popov et al. (2002). Palaeomagnetic studies showing a Tertiary clockwise rotation up to 90° for the N-S-trending (in Romania) part of the L-shaped area, recent palaeogeographic reconstructions have restored the outcrop area as an E-W-trending Late Cretaceous magmatic-metallogenetic lineament (1000 km long) with the Apuseni Mountains in the western part and the Srednogorie in the eastern one, anywhere not larger as 100 km. Integrating to this belt the 81 Ma old Rochovce pluton with Mo & W ore from the Slovakian Western Carpathians (Kohut et al. 2013), more 200 km have to be added, over the Pannonian Basin, at the north-western end of the Banatitic Late Cretaceous magmatic-metallogenetic lineament.

Geochemical signatures of magmas formed in a subduction zone being typical for the Banatitic Belt, most proposed genetic models involve subduction, mainly using a northward subduction of the oceanic Tethian crust (Boccaletti et al. 1974, etc.), namely the Eastern Vardar Ophiolitic Unit, according to the tectonic model of SE Europe by Schmid et al. (2011). There are additional genetic models of the BMMB: rifting (Popov 1981), tear-off of the subducted oceanic slab (Neubauer 2002), roll back of the subducting slab (von Quadt et al. 2005), extension on the upper plate with intra-arc rifting (Georgiev et al. 2012), all applied to a belt of magma formation.

Berza (2004) has plotted on a tectonic map of ALCAPA (Alps - Carpathians - Pannonian Basin) Late Cretaceous igneous rocks known from outcrops and from drillings (below the Pannonian, Transylvanian and Dacian Neogene basins), adding also tuffs of same age from the Outer Eastern Carpathians, from the Danubian of the Southern Carpathians and from the Moesian Platform, pointing to a huge area of dissemination of volcanic products towards the European foreland. Fig. 1 uses the tectonic concept of Schmid et al. (2011) of the Alpine collision zone in Central and SE Europe for similar plot of Late Cretaceous magmatic products. The existence of igneous activity during 20 Ma on a 1000 x 1000 km large area, with local time span of 5-10 Ma (mostly between 85-75 Ma), in the aftermath of the Eoalpine collision which has generated Aptian to Turonian thrusting in the Carpathians and the Balkans, reminds well the extension of Late Carboniferous - Permian volcanism and plutonism in Variscan terranes, now either in situ in Western

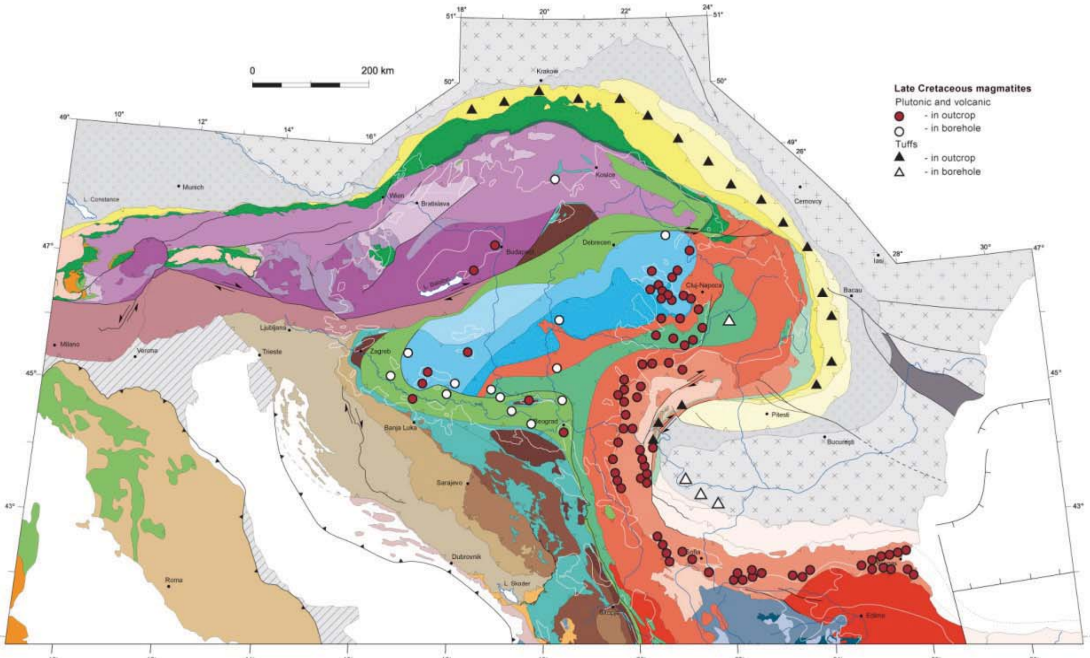

Figure 1. Late Cretaceous igneous rocks occurrences. Tectonic frame after Schmid et al. (2011).

and Central Europe, or dragged in the basement of Alpine nappes from Southern Europe.

As for the widespread Late Carboniferous-Permian magmatism, a regional underplating with basic magma at the base of the crust can also be postulated as genetic model for the Late Cretaceous magmatism recorded in SE Europe. The parallel is also justified by similar development of continental or marine basins for Late Carboniferous to Permian Variscan Europe and of Gosau-type Cretaceous basins in Alpine Europe, firstly continental then marine, where volcano-sedimentary formations are common. The more rich association of metallic deposits with the Late Cretaceous magmatism points to differences in the two episodes of regional magma generation, possibly due to longer and stronger subduction of oceanic crust in the Eoalpine versus the Variscan orogeny.

The studies of von Cotta (1864) upon the Fe-Cu-Pb-Zn skarn deposits from Banat are the first widely cited papers to define a class of “contact-deposits” found at the contact of igneous intrusions and limestones. Since then, the mineralization related to the Banatitic Magmatic and Metallogenetic Belt is described as mainly porphyry copper, massive sulphide, skarn and vein (epithermal and mesothermal) deposits (Berza et al. 1998).

Copper metallogeny is predominant and distinguishes the BMMB in the context of the larger Alpine-Balkan-Carpathian-Dinarides belt (e.g. Ciobanu et al. 2002; Heinrich and Neubauer 2002; Moritz et al. 2004). Copper ores are commonly associated with Pb-Zn, Au-Ag, and subordinately with Mo, Bi, W, Fe, Co, Ni and B. Mineral deposits within the BMMB are strongly differentiated with respect to host rock types and depth of magma emplacement. Shallower hypabyssal bodies are hosts for porphyry copper ores with Cu ± Au, Ag, Mo: e.g. Moldova Nouă (S Banat, Romania), Majdanpek, Cerovo, Veliki Krivelj, Bor (Timok, Serbia), Elatsite, Chelopech, Assarel (Panagyurishte district, Bulgaria). High-sulphidation epithermal deposits are sometimes spatially associated with larger porphyry copper systems (e.g. at Bor South-Timok Magmatic Complex – Banješević and Large 2014). Subeconomic porphyry copper (± Mo) accumulations are also present at Oravița, but hydrothermal alteration is far less pervasive than at Moldova Nouă. Large shallow porphyry-style systems with pyrite halos (and/or skarn halos) extend only south of Poiana Ruscă (N Banat) but they lack economic mineralization: e.g. Tincova-Ruschița, Șopot-Teregova-Lăpușnicel.

Copper and base metal skarn deposits form the most widespread metal accumulations across the BMMB. Some occurrences are set apart by prominent Fe metallogeny (e.g. Ocna de Fier, Mașca Băișoara). Ocna de Fier is considered typical for fluid plume mineralization in a proximal skarn setting (Cook and Ciobanu 2001). Forsterite skarns host a magnetite – chalcopyrite – bornite mineralization which represents the inner Cu-Fe core of the deposit (Cook and Ciobanu 2001). Scheelite forms significant concentrations in the Cu-Mo mineralization of Băița Bihor and Oravița. Bismuth sulphosalts are minor but ubiquitous components of many skarn deposits. Extremely rich and diverse bismuth sulphosalt assemblages have been described at Băița Bihor, Valea Seacă, Ocna de Fier and Oravița-Ciclova (Romania).

Regional zoning of skarn deposits in correlation with Upper Cretaceous subduction settings was postulated by Vlad (in Berza et al. 1998; Vlad and Berza 2003) who distinguished two major metallogenic segments within the BMMB (Apuseni Mountains and Southern Carpathians), each one still amenable of division into further units (sub-belts, zones and districts). Local zoning is well expressed for numerous ore environments in the BMMB. At Băița Bihor, the areas closest to the magmatic sources are enriched in molybdenite. Towards the external zones, Mo-rich ores grade into Mo-W-Bi-Te (in calcic skarns) or Cu-W-Bi (in magnesian skarns), Pb-Zn (in magnesian skarns and sedimentary schists) and finally into boron mineralization overlapping dedolomitization zones. At Dognecea-Ocna de Fier, Ciobanu and Cook (2000) described a Cu-Fe → Fe → Pb-Zn metal zoning around a single granodiorite core in the deepest part of the deposit.

The polyascendant character of skarn deposits in the BMMB has either been asserted (e.g., Popescu and Constantinescu 1977; Cioflica and Vlad 1981) or argued against (Ilinca 2012). Extensive sampling and detailed investigation of ore paragenesis over numerous skarn deposits in the BMMB, plead for coeval and isochronous mineralization, most probably formed from the differentiation of a single fluid. Moreover, apart from several cases of prominent metallogeny (e.g. Fe at Ocna de Fier), the overall paragenetic sequence for virtually all mineral deposits in the BMMB is roughly the same, both as mineral phases and deposition sequence. Ilinca (2012) separated the following ore deposition sequences:

- ***Stage 1*** (”siderophile” - Fe ± Co, Ni, As, Mn) - iron oxides and sulphides, Co, Ni, Fe arsenides and sulpharsenides, with subordinate Fe-Mn calcic silicates. The stage signifies the highest deposition temperatures and a continuous decrease of oxygen fugacity (e.g. hematite → magnetite, magnesioferrite) vs. increase of sulphur fugacity (pyrrhotite → pyrite ± nickeline, rammelsbergite, cobaltite, gersdorfite, Co-pentlandite, linnaeite, bravoite, siegenite, millerite).

- ***Stage 2*** (Pb,Zn ± Ag, Bi, Fe) – forms the bulk of the mineralization in numerous occurrences across the BMMB. The stage is represented by galena (with up to 10 mol% matildite) and sphalerite usually with 14-15 mol% FeS). Invariably, the direct contact between galena and siderophiles, shows the late character of the Pb-Zn phases.

- ***Stage 3*** (Pb, Bi ± Ag, Sb, Te, Cu) – contains Pb–(Ag)/Bi sulphosalts – lillianite homologues, cosalite, cannizzarite, galenobismutite and Bi (±Pb) tellurides. Some Pb-Bi sulphosalts are formed on older galena, most probably belonging to the previous stage. Stage 3 members often substitute galena and siderophile sulphides likely to belong to previous stages.

- ***Stage 4*** (”copper metasomatosis” (CM) – Cu, Bi ± Pb, Ag, Au, Mo, W) – is distinguished by an increase of Cu content in sulphides and sulphosalts. Massive deposition of chalcopyrite, cubanite, bornite and fahlore minerals (tetrahedrite-tennantite, enargite, luzonite) occur in this stage, most frequently on Fe, Zn, Sb, As phases of earlier stages. ”Chalcopyrite disease” phenomena, i.e. chalcopyrite (± bornite, mackinawite) DIS in sphalerite are widespread. Bi-sulphosalts are particularly sensitive to CM transformations. First Bi phases show an increased Bi_2S_3/PbS ratio compared to previous stages and grade towards decreasing Bi/Cu ratio: proudite, lillianite (with up to 2.9 at.% Cu), felbertalite, (high Cu) cosalite, cuproneyite, junoite, nuffieldite, bismuthinite derivatives. In antimony dominated assemblages, bournonite is formed. The highest Cu contents are embodied by (cupro) makovickyite, paderaite, hodrushite and kupčikite and pure Cu-Bi sulphosalts such as emplectite and wittichenite.

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Timing of polymetallic Pb-Zn mineralisation in the Laki district, southern Bulgaria – constraints from $^{40}Ar/^{39}Ar$ dates

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Abstract

The Central Rhodopean Dome (CRD), in southern Bulgaria and northern Greece, is composed of high-T, low-P gneisses and marbles which were exhumed along detachment faults during post-collisional extension, resulting in widespread magmatisation and local anatexis. Peak metamorphic temperatures are recorded at 35.9 ± 0.2 Ma (Ovtcharova et al. 2003), whereas cooling below ~300 ºC occurred between 36 and 34 Ma (Kaiser-Rohrmeier et al. 2013). Regional acid magmatism (~33-30 Ma; Ovtcharova et al. 2001), occurring throughout the CRD as dykes and sub-volcanic bodies, cross-cuts detachment faults and sedimentary basins, and is commonly spatially associated with polymetallic Pb-Zn veins and metasomatic replacement bodies.

The CRD hosts six Oligocene Pb-Zn mining districts: Laki, Davidkovo, Ardino, Enyovche, Madan and Thermes (from north to south), all of which display similar mineralisation styles (polymetallic veins and metasomatic replacement bodies) and are all located proximal to the Middle Rhodopean detachment fault. Despite these similarities, previous studies, based on ^{40}Ar-^{39}Ar dating of sericite indicate a significant age difference between the Laki (~29.5 Ma) and the Madan (~30-30.5 Ma) districts, which suggests an overall younging of mineralisation towards the north (Kaiser-Rohrmeier et al. 2004).

This study applies high-precision $^{40}Ar/^{39}Ar$ thermochronology to hydrothermal and metamorphic K-feldspar from the Laki mining district. In order to better constrain the timing of mineralisation, K-feldspar separates were dated from vein selvages and a mineralised polymictic volcanic breccia containing intergrown hydrothermal K-feldspar and sulfides. Hydrothermal K-feldspar from non-mineralised sub-volcanic bodies were also dated to establish the extent of the hydrothermal activity in the Laki district, while metamorphic K-feldspar from gneiss spatially unrelated to mineralisation was dated to constrain the upper age limit of metamorphic K-feldspar in the vein selvages.

Our data obtained from hydrothermal and metamorphic K-feldspar reveal three stages: (1) ~33.5-33 Ma, pre-mineralisation metamorphic K-feldspar; (2) ~32-30 Ma, K-feldspar from vein selvages and mineralised polymictic breccia; and (3) ~29.5-27 Ma, post-mineralisation hydrothermal K-feldspar from non-mineralised sub-volcanic bodies. $^{40}Ar/^{39}Ar$ dates from stage (1) closely match U-Pb zircon dates from sub-volcanic bodies in the Laki district, which form part of the Borovitsa volcanic zone (~33 Ma; Ovtcharova et al. 2001), and therefore can be interpreted as being thermally reset by magmatism. The range of $^{40}Ar/^{39}Ar$ dates displayed during stage (2) is indicative of partial to complete resetting of metamorphic K-feldspar by the hydrothermal, mineralising fluid. Consistent minimum dates of ~30 Ma from the vein selvages and corresponding hydrothermal K-feldspar dates obtained from a mineralised polymictic breccia from the Chetroka mine, as well as fluid temperatures of 300-350 °C recorded during the main stage of mineralisation in the Djurkovo mine, suggest that mineralisation in the Laki district ceased at ~30 Ma, and was coeval with hydrothermal activity in the Madan district to the south. Post-mineralisation hydrothermal fluid circulation (at temperatures <200 °C) during stage (3) resulted in the precipitation of hydrothermal K-feldspar within the previously altered sub-volcanic bodies from 29.5-27 Ma, possibly corresponding to previously published $^{40}Ar/^{39}Ar$ sericite dates from the Laki district.

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The ChukaruPeki copper gold deposit

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Abstract

The ChukaruPeki copper-gold deposit is located within the central zone of the Timok Magmatic Complex (TMC). The TMC is a part of the Carpathian-Balkan Metallogenic Arc (CBMA) and the western part of Tethyan Belt. The TMC developed as an extensional back-arc basin during the Upper Cretaceous (86-83 Ma). It was deformed during the Alpine orogeny-Laramide orogeny phase. The TMC has one of the highest endowments of copper hand gold in the Tethyan Belt.

The Chukaru Peki deposit is located within the Brestovac-Metovnica exploration permit in eastern Serbia, about 6 km to the SSE of the historic Bor deposits and mining facilities infrastructure where a new flash smelter is in the final phase of construction. CukaruPeki is a concealed copper-gold deposit covered by younger Miocene sedimentary rocks that unconformable overlie a late Cretaceous andesite volcanic, volcaniclastic and sedimentary rocks.

By end of 2013, the company Rakita Exploration had drilled over 27,800 m in order to define main characteristics of this newly-discovered mineralization, and results confirmed a significant potential volume of mineralized material. Exploration in 2013 was focused on defining contours and grade of the upper, smaller but high-grade copper and goldhigh-sulfidation massive sulfide body, with lesser but significant drilling on the lower, underlying porphyry-type mineralization. This exploration generally confirms the continuity of mineralization of the upper body, and the deep drilling confirms that lower porphyry-style mineralization is of potentially significant size, with most of the drill holes being terminated in mineralization due to depth capacity of drill rigs.

The transition from the shallower high sulfidation towards porphyry-style mineralization is locally gradational, but in part also shows cross-cutting relationships, with the high-sulfidation mineralization clearly overprinting porphyry-type mineralization wherever paragenetic relationships are clear. The best grades in the high-sulfidation body are 291.2 m@ 5.13 % Cu and 3.4 g/t Au (including 53.8 m@ 16.84 % averaging 12.60 % Cu and 7.07 g/t Au (FMTC-1223); in transition massive sulphide-porphyry zone 493.3 m@ average 0.92 % Cu and 0.18 g/t Au (FMTC-1214), and in porphyry style 493.3 m@ 0.86 % Cu and 0.25 g/t Au (FMTC-1218).

Timing and Geochemical Characteristics of Magmatism Associated with Porphyry-Type Mineralization in the Eastern Pontides, Turkey: Implications for ore-formation within the Pontide Paleo-Magmatic Arc

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Abstract

A sequence of several subduction, collision and post-collision events with associated ore deposits since the Jurassic explain why the Tethyan-Eurasian Metallogenic Belt (TEMB) is currently one of the most attractive exploration targets for diverse mineral resources within the Alpine-Himalayan orogenic system.

Turkey lies in the central part of the TEMB, and comprises mainly three tectonic units with distinct stratigraphic and structural features. These are the Anatolides-Taurides, the Arabian Platform and the Pontides. The three terranes at the north of Turkey named: Strandja, İstanbul and Sakarya, are grouped in a tectonic entity known as the Pontides extending from the Aegean Sea in the west to the Eastern Pontides in the east. The geological evolution of the EW-trending Pontides has been mainly linked to intense magmatic activity as a result of the subduction of the Paleo-Tethyan Ocean during pre-Cretaceous time and northward subduction of the Neo-Tethyan Ocean during the Cretaceous. The Eastern Pontides are an excellent example of Cretaceous arc-related magmatism with more than 2 km thick volcanic-volcaniclastic sequences and widespread plutonic rocks. The Eastern Pontides are subdivided into a southern and a northern zone. The northern zone is dominated by Cretaceous-Cenozoic volcanic and granitic rocks, whereas the southern zone mainly consists of pre- Cretaceous units (e.g. Akın 1979; Okay and Şahintürk 1997) (Fig. 1). The northern and southern zones of this belt host numerous porphyry type, volcanogenic massive sulphide (VMS) and epithermal type mineralizations (e.g. Giles 1973; Pejatoviç 1979; Akıncı 1984; Çağtay 1993; Soylu 1999; Revan 2010; Eyupoglu et al. 2014; Revan et al. 2014). This study focuses on, from west to east, the Elbeyli-Ordu, Emeksen-Giresun, Güzelyayla-Trabzon and Ulutaş-İspir porphyry-type mineralizations in the Eastern Pontides (Fig. 1). In this contribution, we present new U-Pb zircon age data acquired by LA-ICP-MS, which allow us to constrain ore-forming events in the Eastern Pontides.

The Elbeyli-Ordu Mo-Cu±Au, Emeksen Mo and Güzelyayla Cu-Mo prospects are located in the northern zone, whereas the Ulutaş-İspir Cu-Mo prospect is located in a transition zone between

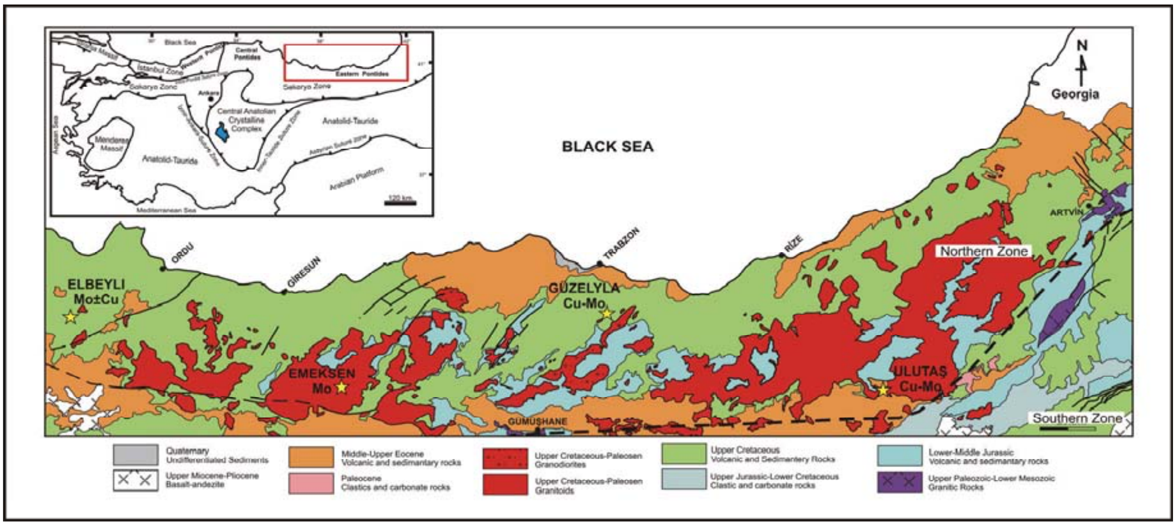

Figure 1. Simplified regional geological map of the Eastern Pontides and location map of the Elbeyli Mo±Cu, Emeksen Mo, Güzelyayla Cu-Mo and Ulutaş Cu-Mo prospects (modified after MTA (2002)), inset shows major tectonic units of Anatolia (simplified after Okay and Tüysüz 1999).

the northern and the southern zones. Our new data show that the Elbeyli-Ordu Mo-Cu mineralization is hosted within a 77.0 ±1.3 Ma old monzodiorite with shoshonitic characteristica. Pyrite, molybdenite, chalcopyrite, fahlore and enargite are the main ore minerals in stockwork and fracture-controlled NW-oriented quartz veins with argillic and sericitic alteration halos. The Emeksen Mo mineralization is situated nearly 40km southeast of the Elbeyli-Ordu prospect. NW- and NE-striking quartz veins crosscut a calc-alkaline granite dated at 78.54 ±0.79 Ma and a granodiorite dated at 78.68 ±0.50 Ma. Molybdenite and pyrite are the main sulfide minerals within an intense sericitic alteration zone. The Güzelyayla Cu-Mo mineralization is located about 50 km south of the city of Trabzon, and consists of a stockwork-type Cu-Mo mineralization crosscutting an adakitic dacite porphyry and late Cretaceous calc-alkaline andesite. Chalcopyrite, pyrite, pyrrhotite, covellite and chalcocite are typically enriched in stockwork-type quartz veins within a potassic alteration zone, whereas molybdenite enrichment is related to late-stage quartz veins within a sericitic alteration zone. The Ulutaş Cu-Mo mineralization in the İspir-Erzurum area consists of dissemination, stockwork and NW-striking vein containing chalcopyrite and molybdenite. The Ulutaş mineralization is hosted within a highly sericitized quartz-porphyry that intruded into a 132.94 ±0.60 Ma calc-alkaline porphyrytic quartz monzonite.

In conclusion, the new U-Pb age zircon ages, lithogeochemical and radiogenic isotopic data of granitic rocks associated with the Elbeyli, Emeksen, Güzelyayla and Ulutas mineralizations in the Eastern Pontides suggest that they formed in an arc-related environment during subduction of the Neo-Tethyan ocean during the Cretaceous, and that they most likely originated from amphibole- and plagioclase-bearing sources.

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Fluid inclusion study and Raman spectroscopy of hydrothermal quartz from the Certej epithermal ore deposit, Apuseni Mts., Romania

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Abstract

The Certej low sulphidation epithermal Au deposit, one of the most important ones in Romania, occurs at the southeastern part of the Apuseni Mts. within the well-known “Gold quadrangle”. It is a small-scale ore deposit in the European Goldfields Ltd, 2010 classification, with estimated reserves of 47 million tons at 1.6 g/t average Au content (i.e. 2.41 million ounces Au) and 11.5 g/t average Ag content (i.e. 17.3 million ounces Ag). The licensed company will extract and process 32.8 million tons of primary ore and further 14.1 million tons of waste dump material during its planned 16 years of operation period.The disseminated Au mineralization with invisible gold is hosted in Miocene amphibole andesite and brecciated Cretaceous and Neogene sedimentary rocks (sandstone, microconglomerate and black claystone). The ore deposits are closely related to the calc-alkaline andesite-dominated volcanic and intrusive activity (14.7-7.4 Ma) in the Apuseni Mts., representing the “Internal segment” of the Carpathian-Pannonian Neogene-Quaternary igneous province. The characteristic mineral association of the studied ore deposit consists of pyrite, sphalerite, galena, chalcopyrite, tetraedrite-tennantite series minerals, bournonite, arsenopyrite, pyrrhotite and mackinawite accompanied by quartz, calcite and barite as gangue minerals. Pyritization, silicification, adularization, carbonatization and sericitization are the prevailing hydrothermal alteration types in relation to the main mineralization stage. Our research was focused on the study of fluid inclusions found mostly in hydrothermal quartz crystals of representative samples collected at various levels of the former subsurface mine and of the current open pit covering a vertical extent of the ore deposit of 170 m. More than 500 individual fluid inclusion measurements have been conducted using a Chaixmeca-andUSGS type heating/cooling stageat the Mineralogy and Petrology departments of Eötvös Loránd University in Budapest, Hungary. According to the results obtained, the primary and secondary fluid inclusions in quartz and sphalerite crystals were trapped from a heterogeneous (boiling) fluid. Measured homogenization temperature ranges between 178.8 and 333.8 °C with a maximum frequency value, coincident with the average, at 240 °C. We consider these values representative of the fluid inclusion entrapment temperatures. The determined eutectic temperatures of the fluid inclusion brines range between -19.3 and -24.4 °C (probably corresponding to a KCl-bearing H_2O-NaCl system), while freezing point depressions from -4.1 to -0.1 °C. The final melting temperature mostly occurred between -0.1 and -3.3 °C and thus fluid inclusion salinities are in the range 0.18-5.41 wt.% $NaCl_{eq}$. These data allowed for pressure calculations and determination of the corresponding depths of the paleo-watertable (100 - 300 m) at the time of the mineralization processes. Vapor-rich fluid inclusion compositions in selected quartz crystals were determined using Raman spectroscopy, and allowed us to calculate the abundance of the main chemical components as follows: H_2O=67.00–99.98 %, N_2=0.00–7.24 %, and CO_2=0.00–29.75 %. The quantitative data obtained, characteristic for hydrothermal fluids, allow us to better understand the paleoenvironment and the chemical and thermodynamic conditions in which the Certej Au deposit was formed.

REE mobility during advanced argillic alteration in some epithermal and porphyry copper systems from Central Srednogorie, Bulgaria

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Abstract

REE distribution and behaviour during hydrothermal alteration in three deposits is presented. REE are relatively inert during propylitization and become partly mobile with increasing of alteration degree in intermediate argillic and sericitic types. In advanced argillic alteration MREE and HREE are strongly depleted while LREE are immobile. LREE are concentrated in the new-forming minerals-alunite, APS minerals and clay minerals. The mobility of REE is controlled mainly by pH, the concentration of complexing ions (SO_4^{2-}, Cl^- F^-) in the hydrothermal fluids and the presence of appropriate minerals which host them in their structures.

Keywords: *geochemistry, REE, advanced argillic alteration, APS minerals, Bulgaria*

Introduction

Despite of relative immobility of rare earth elements (REE) in the most of geological processes recent investigations of their concentration in hydrothermal fluids and hydrothermally altered rocks have shown that, under particular conditions, REE can become mobile during hydrothermal alteration. REE mobility is favored by low pH, high water/rock ratios and abundant complexing ions (CO_3^{2-}, F^-, Cl^-, PO_4^{3-}, SO_4^{2-}) in hydrothermal solutions, being preferentially complexed by Cl^- and SO_4^{2-} in acid conditions (Fulignati at al. 1999, and references therein). The study of REE mobility can be used to better understand the evolution of ore-forming magmatic-hydrothermal systems both epithermal and porphyry copper systems.

Geological setting

Data for the REE concentration in hydrothermally altered rocks were obtained from the Asarel porphyry copper deposit, Petelovo low-grade porphyry Au-Cu deposit and Pesovets epithermal system from the Panagyurishte ore region, Central Srednogorie. The ore region is part of the Late Cretaceous Apuseni-Banat-Timok-Srednogorie (ABTS) magmatic and metallogenic belt (Popov et al. 2002) - a result of subduction of Tethyan oceanic crust under the European continental margin that generated Upper Cretaceous volcano-plutonic complexes and associated ore deposits (Dabovski et al. 1991). Panagyurishte ore region is situated in the central part of the Srednogorie zone and is defined by development of intensive magmatic and volcanic activity and formation of many porphyry copper and Cu-Au epithermal deposits.

The Asarel porphyry copper deposit is hosted by volcanic (andesites, latites, basaltic andesites, dacites) and porphyritic (quartz-diorite, quartz-monzonite, granodiorite and granite porphyry) rocks of Asarel magmatic center and partially in Paleozoic metamorphic and plutonic basement (Nedialkov et al. 2007). Propylitic, argillic, sericitic and advanced argillic alteration types are described in the deposit (Popov et al. 1996). Advanced argillic alteration is divided in two subtypes: acid-chloride (pyrophyllite, dickite, diaspore) and acid-sulphate (alunite).

The Petelovo low grade porphyry Au-Cu deposit is hosted by Krasen-Petelovo volcano-plutonic structure with andesite effusive rocks, subvolcanic dacite and subvolcanic-hypoabyssal granodiorite to quartz-diorite porphyry (Tsonev et al. 2000). The following altered rocks which form good expressed lateral zoning are distinguished: propylitic, sericitic and advanced argillic (dickite-kaolinite, pyrophyllite, alunite, monoquartz (massive and vuggy silica) and multiply advanced argillic altered rocks) (Radonova 1969; Chipchakova and Stefanov 1974; Hikov 2005).

The Pesovets epithermal system is with unknown ore perspective. Intensive hydrothermal alterations of advanced argillic, propylite-argillic and propylitic types are affected the volcanic and pyroclastic rocks with andesite to latite composition (Radonova 1966; Hikov 2001). Advanced argillic alteration is of acid-sulphate type (alunite rocks) and acid-chloride type (kaolinite ± topaz and diaspore-pyrophyllite+zunyite bearing rocks in the deeper parts of the system).

Results

Samples from fresh and altered rocks from the three deposits were analyzed by ICP-MS after 4-acid digestion in ACME Lab., Canada. Results for REE were obtained from the all alteration types described in the each deposit: propylitic, argillic, sericitic, advanced argillic (pyrophyllite, dickite, diaspore, kaolinite, alunite, multiply advanced argillic) and monoquartz (massive and vuggy silica). Results are presented together for the three deposits because REE patterns in the same alteration types are very similar.

REE concentration in the unaltered volcanic and porphyritic rocks from the studied deposits (andesite, basaltic andesite, dacite, granodiorite porphyry – Asarel; diorite porphyry – Petelovo; latite – Pesovets) is between 90 and 120 ppm. Chondrite-normalized REE patterns in these rocks are characteristic for island-arc subduction-related magmas (Pearce 1982) with enrichment of LREE in relation to HREE ($(La/Yb)_{cn}$ vary from 5.02 to 11.5) and comparatively flat HREE patterns ($(Gd/Yb)_{cn}$: 1.58-2.09) as well as weakly expressed negative Eu anomaly (0.72-0.88).

REE concentration in propylitic, intermediate argillic and sericitic altered rocks and their chondrite-normalized patterns are similar to those in fresh volcanic rocks. Visible mobility of MREE and HREE is seen with increasing alteration degree in argillic and sericitic alteration and especially near the advanced argillic rocks. LREE do not show differences with respect to parent rocks, only weak mobility of LREE is visible in sericitic alteration probably as a result of beginning apatite dissolution.

Significant changes in the behaviour of REE are observed in advanced argillic alteration (acid-choride and acid-sulphate types). REE patterns in pyrophyllite altered rocks show MREE and HREE fractionation, which is stronger in dickite-, kaolinite- and diaspore-bearing rocks. The mobility of MREE and HREE is related to increased F^- ions activity and low pH of fluids (Fulignati et al. 1999), and their ability to form stable complexes in these conditions. Relative immobility (sometimes with slight enrichment) of the LREE is explained not only with the instability of their complexes, but also with the presence of aluminium phosphate-sulphate (APS) minerals, which contain some amounts of La, Ce and Nd (Hikov 2005; Hikov et al. 2010). The ability of LREE for sorption in kaolinite group minerals can also explain the relative immobility of LREE (Aja 1998).

REE behaviour in alunitic and multiply advanced argillic altered rocks is very similar to the dickite, kaolinite and diaspore altered types while the depletion of MREE and HREE is stronger than in the pyrophyllite advanced argillic rocks. Relative stability of LREE is connected with the presence of alunite and the ability of accommodation of these elements into the alunite lattice in the place of potassium (Fulignati et al. 1999; Kikiwada et al. 2004). APS minerals from the alunite zone also contain small amounts of LREE – usually low up to 1%, but there are cases with high LREE content in florencite-svanbergite solid solutions (s.s.) (Hikov et al. 2010). There are no differences in REE patterns between the samples of alunitic rocks from different temperature associations.

Silicic alteration facies (monoquartz, topaz-quartz altered rocks) is characterized by strong depletion of all REE. It can be explained by their extraction from altered rocks by the extremely low-pH hydrothermal fluid and the lack of secondary minerals which can take them in their lattice.

Discussion and conclusion

The results for the REE concentration in hydrothermally altered rocks from the studied deposits from the Central Srednogorie show comparatively inert behaviour of REE during the propylitic, intermediate argillic and sericitic alteration of volcanic rocks and slight fractionation with weak mobility of HREE in argillic and sericitic altered types. This is due to the nearly neutral pH of the fluids and the low water/rock ratio during these types of alteration. Starting of mobility in LREE is registered in the sericitic altered rocks. This is connected to the dissolution of primary apatite, which can be stable or can dissolve also during sericitic alteration (Stoffregen and Alpers 1987).

During advanced argillic alteration in low-pH environment and high activity of SO_4^{2-} (for the alunite rocks) or of Cl^- and F^- (for the pyrophyllite, dickite, kaolinite and diaspore rocks) strong fractionation of REE occurs. The mobility of MREE and HREE is connected with the high activity of F^-, low pH of the fluids (Fulignati et al. 1999) and their ability to form stable complexes in these conditions. LREE are relatively immobile (with slight enrichment in some samples) due to their entrance in the lattice of appropriate minerals like alunite, APS minerals and clay minerals (Aja 1998; Fulignati et al. 1999; Kikiwada et al. 2004; Hikov et al. 2010). The presence of PO_4^{3-} and Sr^{2+} is of important significance to form APS minerals. Decreasing of pH leads to apatite dissolution (Stoffregen and Alpers 1987) while Sr accumulates in advanced argillic alteration zones (Hikov 2004). Liberated LREE immediately take part in the new-forming APS minerals - svanbergite, woodhouseite - svanbergite s.s., woodhouseite, alunite - svanbergite s.s. In single cases the quantity of LREE is higher and florencite-svanbergite s.s. may form as cores in svanbergite crystals (Hikov et al. 2010). S, O and H stable isotope data show that alunite and APS minerals in the studied deposits are formed from magmatic–hydrothermal fluid between 200 ºC and 300 ºC (Hikov 2005; Hikov et al. 2010). All REE become very mobile in the silicic altered rocks. High activity of F^- ions and the lack of new minerals to accommodate REE are the main reasons for their depletion.

Similar behaviour of REE during advanced argillic alteration was found in many high-sulphidation and porphyry copper systems (Arribas et al. 1995; Fulignati et al. 1999; Khashgerel et al. 2008; Parsapoor et al. 2009; Georgieva et al. 2012). We believe that this behaviour of the REE is characteristic for advanced argillic alteration and high-sulphidation style epithermal environment. These REE signatures can illustrate the main stages in the evolution of the hydrothermal fluids in both epithermal and porphyry copper systems.

On the other hand different cases are described as well: depletion of all REE (Barzegar 2007), various behaviour of REE during different stages of alunite formation (Deyell et al. 2005), increasing of LREE while HREE have not systematic behaviour (Karakaya 2009). These differences suggest that, besides the pH and the fluid composition, many other local factors, such as presence of appropriate minerals to accommodate REE, permeability of the altered rocks, kinetics of the alteration, development of later supergene events, have important role for the REE mobility.

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Magmatic and ore-related breccias in the Elatsite porphyry-copper deposit (PCD), Bulgaria

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Abstract

Several ore-related breccia types are associated with the porphyric granodiorite intrusions in the Elatsite Cu-porphyry deposit, Bulgaria, and they contain: 1) magmatic breccias, 2) magmatic hydrothermal injection breccias, 3) collapse decompression breccias, 4) mosaic breccias, 5) crackle breccias and 6) pebble dike breccias. Both clast supported and matrix supported breccias are widespread. All of them occur as single or clusters of pipe-like bodies with steep (65-80^o) to vertical dips, ranging from centimeter to meter scale and rarely to 5 x 30 m in size. Pre-, syn- and post-mineralization breccias have also been recognized.

Key words: *Magmatic breccia, mosaic breccia, collapse breccia, Cu- porphyry deposits*

Introduction

Ore-related breccias commonly occur in PCD of magmatic arcs (Corbett and Leach 1998, Sillitoe 2010) and seems to be a characteristic feature for the porphyry-epithermal systems of the Tethyan–Eurasian metallogenic belt (TEMB). The Elatsite PCD is one significant example of various ore-related breccia types that has been revealed during the exploration of the deeper deposit levels (Ivanov, exploration reports 2006-2013; Nedialkov et al. 2012).

Geology of the Elatsite deposit

The formation of the Elatsite PCD is related to the porphyritic intrusions. The porphyritic complex is formed in five intrusive impulses (von Quadt et al. 2002). Porphyries of quartz monzodioritic (MDP) and granodioritic (GDP) composition are dominant. Layer-like shaped and bended bodies of quartz-monzodiorite porphyries known as "small Elatsi intrusion" (Kalaidzhiev et al. 1984) were intruded at hypabyssal to sub-volcanivc levels into the Paleozoic anhimetamorphic to green schist complex (PGS) and the equigranular granodiorites of the Vezhen pluton. Both rock types, GDR and MDP, contain microgabbro or gabbrodiorite enclaves of cm to decimeter scale as a result of mingling between acid and basic magmas. K-feldspar haloes, between several mm up to 1-1.5 cm wide rim the mafic enclaves in places. K-silicate alteration dominated by quartz, biotite, K-feldspar is the most widespread alteration type. Propylitic, Q-sericitic, argillic and Q-adularia-carbonate alterations are also present. The ore mineralization (91.88-92.44 ± 0,3 Ma Re/Os age – Zimmermann et al. 2003, 2008) was developed in seven mineral assemblages 1. Q-Mt (M-veins); 2. Mt-Bn-Chp (A-veins); 3. Q-Py-Chp (B-veins); 4. Q-Mol; 5. Q-Py (D-veins); 6. Q-Gl-Sph; 7. Carb-Zeol (Strashimirov et al. 2002). During the successive deposition of Q-Py-Chp, Q-Mo, Q-Py and Q-Gl-Sph assemblages progressively cooling (535-200 ^{o}C), and dilution of the high saline fluids from wt.% 60-44 to 25-20 NaCl equiv occur. Most of the economic Au and Cu in the deposit are precipitated as a result of boiling processes during the deposition of Q-Py-Chp assemblage (Kehayov et al. 2003; Tarkian et al. 2003).

Bornite-chalcopyrite-magnetite rich veins with K-silicate alterations (A-type veins) dominate in the central parts of Cu-porphyry system with transitions to Q-Py-Chp (B-type of veins), and late Q-Py veins (D-type veins) accompanied by a Q-sericitic alterations. Seven distinct fault and veins systems are developed in the Elatsite PCD. Two of them are important to explain the deposit ore-magmatic structure: The strike-slip fault zone "Elatzite – 1" with SE-NW trend (125-135^o) steeply dipping (75-85^o) at SW is dividing SW hanging wall from NE footwall block. An additional important ore-controlling function show the "Pristanishtenska" subvertical fault zone with NE-SW trend (70-80^o) determining the elongation of the Cu-porphyry stockwork body.

Breccia types

Based on their appearance and mode of formation the studed breccia types may be classified as follows: 1) magmatic breccias, 2) magmatic hydrothermal injection breccias, 3) collapse decompression breccias, 4) mosaic breccias, 5) crackle breccias and 6) pebble dike breccias. The ore-related breccias in Elatsite PCD occur as single or clusters of pipe-like bodies with steep (65-80^o) to vertical dips. The studied breccias occupy the southern and central parts of the deposit. The breccia pipes occur in the higher parts of GDR, quartz-diorite porphyries (QDP) and MDP in addition to the contacts with the host PGS and earlier porphyries. Most of the observed breccias range in horizontal dimensions from tens of centimeters to meters and 5 X 30 m in vertical size. Magmatic contact, injection, and pebble-dyke breccias have been generated due to volume increasing as a mechanical effect of the intrusion pressure, while the change of magmatic and hydrothermal fluid pressure has led to formation of magmatic-hydrothermal and collapse breccias.

The most commonly observed magmatic and hydrothermal ore related breccia types that have been formed during the magmatic-hydrothermal transition in the Elatsite Cu-porphyry system are as follows:

Two types of magmatic breccias related to volume expansion were distinguished: 1) Magmatic breccia at the intrusive contact formed during the magmatic intrusion; 2) Magmatic breccias formed after explosive brecciation and introduction of magma in the free space of the lower part of the breccia pipe. Both types are morphologically distinguished during fieldwork studies. They are often monomictic, matrix supported with magmatic porphyritic matrix. Magmatic hydrothermal breccias are from matrix (Fig. 1) to fragment supported. Fragments in magmatic-hydrothermal breccias (Fig. 2) are angular to rounded, occurred in the PGS (schists and hornfelses), the MDP and rarely in GDR. The matrix consists of rock-flour that is almost entirely milled. Decompression collapse breccias have been commonly observed in the apical parts of the GDR where pegmatite-aplite veins and lenses are also abundant.

According to the systematics of Corbett and Leach (1998) several magmatic hydrothermal breccias could be distinguished: 1) pebble dikes, 2) magmatic hydrothermal injection breccias (Fig. 3), 3) collapse breccias, 4) mosaic breccias (Fig. 2).

Figure 1. Matrix-supported magmatic breccia, 1120 ml.

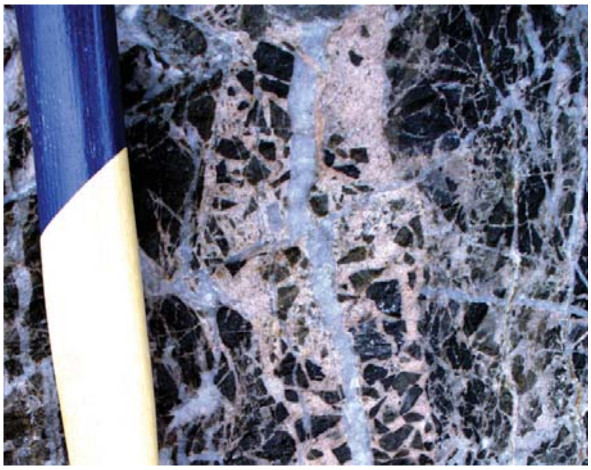

Figure 2. Clast-supported mosaic breccia, 1090 ml.

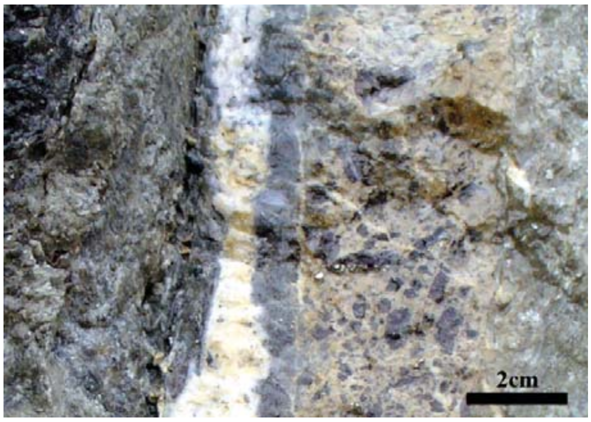

Figure 3. Magmatic-hydrothermal injection brecciaon the contact between GDR and PGS (hornfelses), 1060 ml.

host rocks. The first released high temperature supercritical fluids cause the high temperature K-silicate alteration with K-Feldspars, hydrothermal black mica (phlogopite – Mg# = 66-82; Fig. 4), magnetite and quartz. Closely associated with K-silicate alteration are formed quartz-magnetite mineralization and gold, Ag, PGM, Cu, Te, Se and Bi minerals (Tarkian et al. 2003). Phlogopite (Fig.

4) is fine-grained replacing the mafic minerals (magmatic biotite and amphibole), veinlets or is uniformly distributed in the rock volume, in the case when K-silicate alteration affects the milled matrix. K-silicate alteration was formed above 600 °C (Stefanova et al. 2014).

Magmatic relictic textures are present when alteration is less intensive. Quartz-feldspar aggregates are micro to fine-grained, allotriomorphic. The rarely observed sharp contacts between Q-Fsp aggregates with various grain size could be the result of different K-silicate alteration impulses. The latter seem to be triggered by the explosive release of fluids due to several magmatic impulses that also explaining

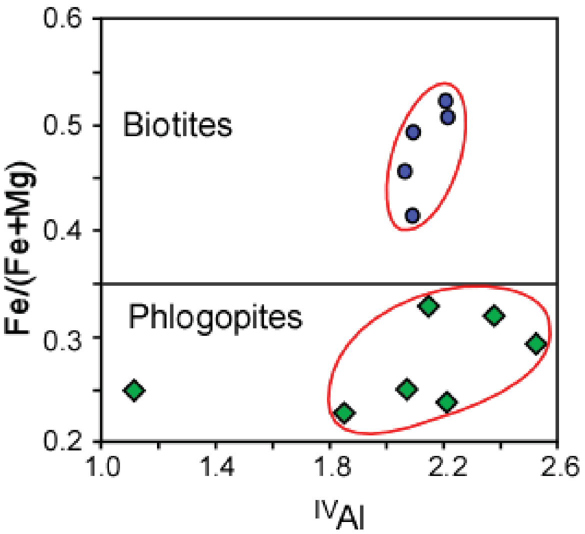

Figure 4. Composition of magmatic biotites and hydrothermal phlogopites.

the link between high temperature Q-Fsp veins. Later, with the progressive downward shift of the magma solidification front (Sillitoe 2010) the rise of cooler hydrotherms, affect the K-silicate altered rocks and provoke the chloritization overprint on phlogopites. Chlorites are determined as ripidolites or picnochlorites (Fig. 5) with Mg# = 75-59. According to the chlorite geothermometer (Klein and Koppe 2000) the temperature of this chloritization of the phlogopite is at 250-290 °C that is also in accordance with the fluid inclusion studies (Kehayov et al. 2003; Tarkian et al. 2003). The Cu-porphyry paleosurface erosion ensures the deeper penetration of meteoric waters and their mixing with the hot rising fluids. The fracture controlled quartz-sericite alteration overprinted the earlier alteration products and mineral assemblages.

Hydrothermal breccias are commonly fragment supported, although in cases matrix-supported breccias occur. The breccia's fragments consist of Py, Chp and rarely of Gl and Sph with sharp angular outlines and commonly up to 1-2 cm in size.

Post-mineralization carbonate-rich breccias occupy as a rule the outer peripheral zones of the Cu-rich core, although in some cases occur in the central part of reactivated faults where quartz-adularia-carbonate alteration is superimposed, on K-silicate altered breccia. The mineralization is disposed in fissures, veinlets, narrow brecciated zones, or cavities. Adularia is idiomorphic, transparent, with typical rhombic shaped crystals. Carbonate minerals (calcite, Mn-calcite, siderite), fill veinlets and cavities where are associated with

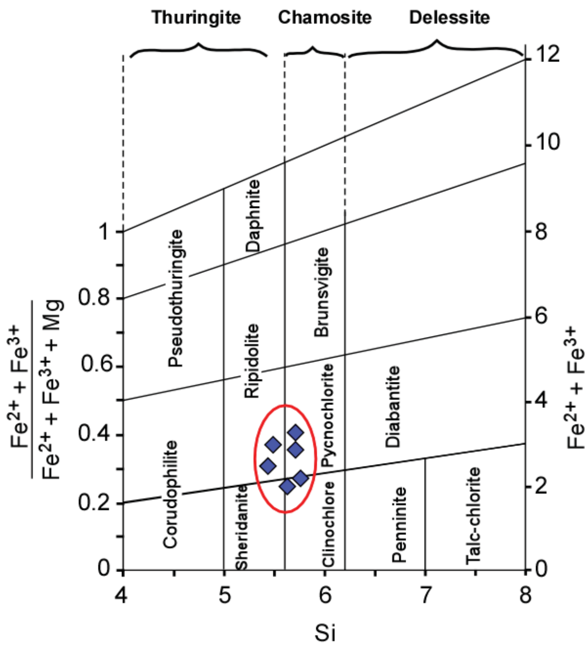

Figure 5. Composition of chlorites.

zeolites (heulandite) and/or hydrothermal apatite. Comparing the chemical compositions of different K-feldspars we establish that the magmatic K-feldspar phenocrysts are with relatively high Ab and An components, K-feldspar from high temperature K-silicate alteration are An component free and adularia have pure composition without An and Ab components.

Conclusions

The first Q-monzodiorite porphyritic intrusion is followed by brecciation and high temperature K-silicate alteration of host rocks (Pz granodiorites, green schists and hornfelses). The second GDP intrusion caused the new brecciation, the formation of breccia pipes and a new impulse of K-silicate alteration.

During the deeper magmatic chamber evolution, the front of the intensive magmatic fluid release shifts downward and on the high-temperature K-silicate alteration is overprinted by lower temperature phyllic and Q-adularia-carbonate alterations.

Breccia pipes, related mainly with the GDP intrusion are formed either with explosive fluid release from the magma or during the magma interaction with the magmatic fluids and meteoric waters.

Crackle and mosaic breccias with rock floor or hydrothermal matrix are fragment supported and occur in parts of the pipes due to fluid pressure expansion.

Clast supported collapse breccias due to drop of magmatic fluid pressure and volume reduction have been more rarely observed.

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Detachment-related Sb-Pb-Zn-Ag-Au-Te mineralization in Kallintiri area, northeastern Greece: Mineralogical and geochemical constraints

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Abstract

The Kallintiri deposit in northeastern Greece is a Sb-Pb-Zn-Ag-Au-Te mineralization deposited in the brittle to ductile transition within and above a low-angle shear zone, probably a detachment fault. The deposit is hosted within silicified marbles and argillic-sericitic altered schists of the Mesozoic Makri Unit and occurs in the form of disseminations, high-angle quartz-barite-carbonate veins and breccias. Ore deposition includes an evolution from early pyrite, followed by low-iron sphalerite, galena, chalcopyrite, bournonite and fahlore group minerals, and then by Sb-As stage containing antimonite, arsenopyrite and realgar. Precious metals were deposited as electrum and gold-silver tellurides, as well as in sulfosalts (Ag-rich tetrahedrite). Geochemical analyses from the Sb-rich ore show elevated content in Hg, Te and Tl in the mineralization. The Kallintiri deposit shares some features in common with the detachment-related sedimentary rock-hosted low-sulfidation mineralization in Bulgaria. Uncommon for Kallintiri mineralization is the presence of graphite intergrown with pyrite and galena suggesting reducing conditions from carbonic fluids during ore deposition. A magmatic contribution is supported by the first discovery of tellurides in the system. Oxidized Maastrichtian - Paleogene sediments in the broad Kallintiri area, represent a very favorite environment for exploration of sedimentary rock-hosted Au mineralization in the Greek Rhodope region.

Keywords: *detachment related mineralization, native gold, gold-silver tellurides, stibnite*

Introduction

The Rhodope metamorphic terrane (Bulgaria and Greece) is one of the most significant metallogenic provinces of Europe hosting a large number of ore deposits, partly controlled by detachment faults, partly by magmatic activity (Arikas and Voudouris 1998; Melfos et al. 2002; Marchev et al. 2005; Márton et al. 2010; Moritz et al. 2010, 2014; Voudouris et al. 2011). According to Bonev et al. (2013) in the eastern Rhodope Massif, the Kesebir–Kardamos and the Byala reka–Kechros domes expose a crustal section that includes the following units from the base to the top: (i) a lower high-grade basement unit of continental affinity, (ii) an upper high-grade basement unit of mixed continental–oceanic affinity, (iii) a low-grade unit consisting of Mesozoic rocks of continental margin and intra-oceanic affinity (Makri Unit in Greece), and (iv) a sedimentary and volcanogenic unit of Maastrichtian/Paleocene–Miocene syn- and post-tectonic cover sequences.

In southeastern Bulgaria, a distinct group of low-sulfidation epithermal gold-silver prospects (e.g. Ada Tepe, Rosino, Stremtsi, etc.), is hosted by Maastrichtian to Paleocene syn-detachment, clastic sedimentary rocks overlying metamorphic basement rocks, located along the hanging-wall of a major detachment fault bounding the northern part of the Kesebir-Kardamos dome (Marchev et al. 2004; Márton et al. 2010). Similar deposits are not yet discovered in the Greek part of Kesebir-Kardamos- and Biala reka–Kechros domes. However several gold prospects on the periphery of both domes may suggest a high potential for future gold discoveries. The Kallintiri prospect, located on the southwestern edge of the Biala reka–Kechros Domes, has been the locus of extensive antimony exploitation during the last century (Dimou et al. 1985), as well as of recent exploration of gold by the Greek Geological Survey (Michael et al. 2013). Michael at al. suggested that the Sb-Au polymetallic mineralization is controlled by a shear zone separating rocks of Rhodope massif from the low-grade Mesozoic rocks of the Makri Unit. Disseminated free gold occurs in quartz matrix of silicified marbles along the thrust fault, and as secondary gold enrichment within oxidized ores. NW-trending normal faults are the most important controlling structures for antimony mineralization. Faults are associated with intensive alteration zones characterized by quartz, dolomite, calcite, kaolinite, ankerite, garnierite and jasperoids.

This paper presents new geological, geochemical and mineralogical data of Kallintiri mineralization, emphasizes the first find of precious metal tellurides in the area and discusses possible genetic aspects of the deposit.

Materials and Methods

Seventy eight polished sections and twenty fine polished-thin sections of host-rocks and sulfide mineralization were studied by optical microscopy and a Jeol JSM 7001FA Scanning Electron Microscope equipped with back-scattered imaging capabilities and with an EDX detector at the laboratories of the Section of Earth and Environmental Sciences, University of Geneva. Operating conditions were: 15 kV and 20 nA, with a beam diameter <1 μm. Mineralized samples were analyzed for their trace element content by Aqua Regia digestion with Ultratrace ICP-MS analysis at ACME analytical laboratories (Vancouver, Canada).

Results

The Kallintiri mineralization is controlled by a major low-angle, ductile to brittle shear zone (probably a detachment fault) that parallels the regional east-west structural trend. This shear zone separates high-grade rocks of the Rhodope massif (footwall) from low-grade marbles and calc-schists of the Makri Unit (Circum-Rhodope Belt) (hanging wall). The marbles and calc-schists of Makri Unit hosting the mineralization are strongly mylonitized and exhibits silicic and sericitic-argillic alteration, mainly consisting of quartz, muscovite, kaolinite and carbonates. Fluid circulation along the shear zone resulted in black and white massive silicification of the marbles (formation of jasperoids, Fig. 1A), and deposition of NW-trending quartz-barite veins in high-angle tension gashes (up to 3 m wide and tens of meters long) crosscutting the overlying calc-schists (Fig.1B), and extending into supra-detachment Eocene conglomerates and sandstones. Carbonate replacement by silica close to the contact of the jasperoids with less silicified marbles resulted in the formation quartz veinlets network (e.g. Boxwork texture). Late colloform banded quartz-carbonate veins crosscut the low-angle fault, and all overlying lithologies. The mineralization features a polymetallic assemblage that includes sulfides, sulfosalts, tellurides and native elements and occurs as: (a) High-grade ore zones, within the quartz-barite veins, often comprising banded

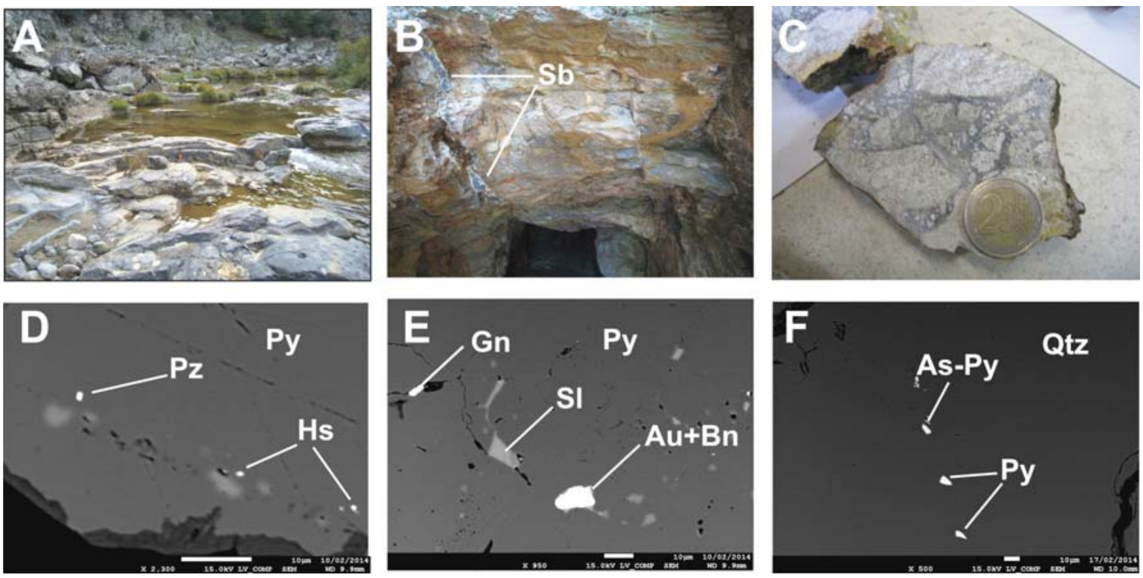

Figure 1. (A) General overview of the low-angle shear zone and jasperoid formation within the marbles of Makri Unit, (B) Abandoned mine following the NW-trending Sb-rich mineralization (Sb) along the high-angle veins in the schists, (C) Breccia with silicified schist fragments cemented by pyrite, galena and low iron sphalerite, (D) the tellurides hessite (Hs) and petzite (Pz) as inclusions in pyrite (Py), (E) native gold (Au), bornite (Bn), galena (Gn) and Fe-poor sphalerite (Sl) included in pyrite (Py), (F) Arsenic-rich pyrite (As-Py) and As-free pyrite (Py) included in quartz (Qtz).

textures, (b) disseminated within the silicified marbles and schists, and (c) breccia-style, present within the quartz-barite veins (Fig. 1C) but also in large breccia bodies above the shear zone. The ore paragenesis in both the low-angle shear zone and the high-angle quartz-barite veins includes an evolution from early pyrite which is followed by low-Fe sphalerite, galena, bournonite minor chalcopyrite and fahlore group minerals and then by antimonite, Pb-Sb sulfosalts, realgar and native antimony. Native gold (electrum) and gold-silver tellurides (petzite and hessite) occur as inclusions in pyrite either as isolated grains or in association with bornite, chalcopyrite, pyrrhotite, galena and Fe-poor sphalerite (up to 2.5 wt.% Fe) (Fig. 1D, E). Both As-poor and As-rich (up to 2.3 wt.% As) pyrite were detected (Fig. 1F). Graphite, intergrown with pyrite and galena is a common mineral especially in disseminated mineralization within the sheared marbles. Arsenopyrite postdates pyrite and sphalerite and probably introduced contemporaneous to antimonite. Annealing textures in antimonite ores indicates contemporaneous ore deposition and deformation along the shear zone. Bulk ore analyses of three antimonite-rich samples containing both stage I and II ores are presented in the Table 1. The analyses indicate elevated content in Ag (>100 g/t), Sb (>0.2 wt.%), Te (up to 6 g/t), Hg (up to 16.4 ppm), Tl (up to 4.6 ppm) and low content in Au (up to 62 ppb), Mo and Bi.

hosted within a low-angle marble-hosted silicified shear zone, which is accompanied by barite, minor muscovite similar to the silicified detachment fault at Ada Tepe (named "the Wall"). (2) Part of the mineralization is hosted in high-angle, normal faults above the detachment crosscuting the calc-schists of Makri Unit, and extending in the supra-detachment Maastrichtian(?) – Paleogene conglomerates and sandstones, similarly to Ada Tepe. Voluminous outcrops of similar supra-detachment sediments in unconformity contact with the metamorphic rocks are widespread in the broad area. These sediments are impregnated with iron oxides probably after pyrite. (3) Ore textures (boxwork texture, colloform banding, jasperoid formation, breccias) and ore mineralogy (As-rich pyrite, arsenopyrite, and presence of the Au-Ag tellurides petzite and hessite and visible gold) at Kallintiri, also occurs at Ada Tepe (Marchev et al. 2004). Antimonite-realgar mineralization and Hg- and Tl-enrichment characterizing the Kallintiri ore (also a common feature for Carlin-type deposits elsewhere, Cline and Hofstra 2000), are absent from Ada Tepe deposit. In addition, the presence of graphite and arsenopyrite at Kallintiri suggest reducing conditions at low-sulfidation states during ore deposition. However, fluctuations of the fluid sulfidation state is indicated by the presence of low-Fe sphalerite, which rather suggests an intermediate-sulfidation fluid character. Native

Table 1. ICP-MS analyses of bulk ore from Kallintiri area (Fe in wt.%, Au and Hg in ppb, the rest elements in ppm).

Sample	Fe	Ag	Au	Hg	Cu	Zn	Pb	As	Sb	Co	Te	Tl	Mo	Bi
Kal1	0.04	>100	20	4495	335	2020	0.04	5.4	>2000	20.4	6.1	2.4	0.24	0.2
Kal2	0.04	>100	62	16370	490	>10000	2940	92.5	>2000	38.6	4.8	4.6	0.26	0.21
Kal3	0.03	>100	4.3	5820	191	803	1.5	4.3	>2000	16.5	3.6	3.6	0.01	0.06

Discussion and Conclusions

The Kallintiri mineralization shares many features in common with the detachment-related mineralization at Ada Tepe in Bulgaria as described by Marchev et al. (2004) and Márton et al. (2010). For the later deposit, a low-angle detachment fault facilitated hydrothermal fluid circulation and led to main ore deposition through listric faults in supra-detachment conglomerates and sandstones (Márton et al. 2010). It is suggested that the sedimentary rock-hosted, low-sulfidation, gold prospects in southern Bulgaria predate the onset of Tertiary magmatism in the Rhodope region, and display several features characteristic for Carlin-type deposits (Marton et al. 2010; Moritz et al. 2014). At Kallintiri deposit: (1) Ore mineralization is partly

gold and the tellurides are closely related to bornite and chalcopyrite resembling assemblages from porphyry-epithermal ores in western Thrace. On the absence of sufficient fluid inclusion, stable isotope and radiometric data, the classification of Kallintiri deposit is speculative. Fluid inclusion data (Michael et al. 2013) indicate ore deposition for the schist-hosted antimony polymetallic veins in the range from 190° to 330 °C at salinities from 0.2 to 7 wt.% NaCl equiv. Gold mineralization in marble-hosted silicified shear zones took place in the range 150-268 °C at salinities 5.8-7.0 wt.% NaCl equiv. Both styles of mineralization were deposited from aqueous-carbonic fluids and a magmatic contribution is proposed on the basis of sulfur isotopic data ($\delta^{34}S$ = 1.5) for the Sb-polymetallic mineralization (Michael et al.

2013). The above fluid characteristics resemble those reported from Miocene post-collisional Sb-Au mineralization controlled by a hydrothermal convection system driven by magmatic bodies emplaced along the South Tibetan detachment, Himalayan orogen (Yang et al. 2009). A partial magmatic contribution to the Kallintiri ore system is also supported by the first discovery of tellurides. Widespread occurrences of oxidized Maastrichtian - Paleogene sediments located in the broad Kallintiri area, represent a very favorite environment for future discoveries of sedimentary rock-hosted Au mineralization in the Greek Rhodope region.

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Neotethyan rifting-related ore indications in the NE Hungarian Darnó Unit: metallogeny of an accretionary mélange complex

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Abstract

The geology of the NE-Hungarian Darnó Unit is rather complex, thus understanding of its features was not satisfying until the past decade. According to the most recent investigations, it is composed mostly of a Jurassic accretionary mélange complex, which causes the observed variety of the rock types and geological structures. The magmatic and sedimentary rock blocks of the mélange represent different evolutionary stages of the Neotethys; e.g. Permian and Triassic sedimentary rocks of rifting related, marine origin, Triassic pillow basalt of advanced rifting related origin and Jurassic pillow basalt of back-arc-basin opening related origin are also present. Several ore indications occur in this small (~10km^2) unit, though until the recent times, they were poorly investigated, mostly because of the lack of knowledge on the geological background.

A copper (and gold) ore occurrence in the Permian marly-clayey limestone, an iron ore occurrence in the Triassic sedimentary succession, a copper (and silver) ore occurrence in the Triassic pillow basalt series and a copper ore indication, which occurs both in the Triassic and Jurassic pillow basalt series were also studied.

The framboidal pyrite-bearing Permian marly limestone series is found in deep drillings only (~1000 m depth from the surface). Framboidal pyrite, euhedral pyrite overgrowths (both with high Au contents), disseminated euhedral and anhedral pyrite (without overgrowth), anhedral chalcopyrite, galena and sphalerite were recorded, which cause a slightly enriched total metal content of 100-200 ppm of the mineralised sedimentary rocks. The investigated minerals were formed under reducing, anoxic marine sedimentary conditions, in several steps; during synsedimentary, early diagenetic and epigenetic processes. These characteristics are typical of the weakly mineralised type of the black-shale hosted copper deposits, which can form during the early stages of a rifting process.

The Middle Triassic, hematite-bearing siliceous sedimentary rock contains a syngenetic, submarine hydrothermal quartz-hematite mineralization, which may have >30 % Fe_2O_3 content. The trace element content (Fe>>Mn, low Cr, Co, Ni and Cu content) support the (submarine) hydrothermal origin, together with the characteristics of the hydrothermal fluid (average minimum formation temperature is 110 °C and average salinity is 4 wt.% NaCl equiv.). Thus, a sedimentary exhalative origin is suggested for this occurrence, which can be a typical process related to the advanced rifting stage.

The reddish grey-coloured, Triassic, amygdaloidal, submarine basalt contains native copper-bearing calcite-laumontite veins of 0.5-30 cm thickness. Besides those minerals, quartz, phillipsite and barite occur as gangue minerals and native silver, acanthite, galena, hematite and copper oxides-hydroxides occur as ore-bearing phases. The formation conditions (140-200 °C formation temperature and low salinity, <1 wt.% NaCl equiv., more and more reducing and pH neutral environment) suggest a process significantly different from the syngenetic submarine hydrothermal events. However, the characteristics of the host rock, its alteration and the mineral paragenesis described in this study fit with a Michigan-type ore forming model, which is a typical epigenetic hydrothermal process during rifting events.

Both the Triassic and the Jurassic pillow basalt blocks contain epigenetic quartz-prehnite veins of 0.5-50 cm thickness. These veins may contain chalcopyrite, bornite and their alteration products (malachite, azurite, cuprite, covellite), as well as chlorite, epidote and pumpellyite. The minerals have formed from a low salinity (2-3 wt.% NaCl equiv.), 228-258 °C parent fluid at a pressure up to 1.1 kbar. The results suggest a regional Alpine metamorphism-related origin for this occurrence.

All the studied localities fit well into the recent, new geological model of the investigated area. Except the last, Alpine metamorphism-related occurrence, the studied mineralization represent the different evolutionary stages of the Neotethyan rifting and their recent, close setting is the result of the accretionary mélange formation. Thus, the Darnó Unit became a perfect natural laboratory for studying and understanding the characteristic features of the rifting related ore forming

Tectonic, stratigraphic and structural controls on the formation of hydrothermal ore deposits in northwest Timok, Serbia

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Abstract

Avala Resources Ltd. is actively exploring a major, N-S trending zone of magmatic-hydrothermal ore deposits including Cu+/-Au porphyry, polymetallic Pb-Zn and, recently discovered, sedimentary rock-hosted Au deposits located on the NW margin of the Timok Magmatic Complex (TMC). The presented genetic model comprises intermittent reactivation of deep Variscan-aged basement structures beneath the Mesozoic cover which exerted an important influence on the generation of locally enhanced permeability which subsequently controlled fluid flow into lithologically controlled sites of low to moderate temperature hydrothermal ore deposition related to a large magmatic-hydrothermal system. Cenozoic preferential exhumation exposed the deeper high temperature parts of hydrothermal systems but also preserved high-level low-temperature mineralization types side by side.

Keywords: *northwest Timok, hydrothermal ore deposits, basement fault, reactivation*

Introduction

The TMC is a N-S oriented, 85 km long, Upper Cretaceous magmatic metallogenic belt and hosts a range of magmatic-hydrothermal ore deposits including world class high-sulphidation Cu-Au (Bor, Čukaru Peki) and porphyry Cu-Au (Veliki Krivelj, Majdanpek) mineralization. The NW part of the TMC (NWTMC) – centered on the Potoj Čuka monzonite and bounded by major faults related to the Blagojev-Kamen-Rudaria fault system (Fig. 1) – is characterized by diverse ore deposit styles. Gold and silver mineralization with low temperature element association has been discovered at several prospects (Bigar Hill, Korkan, Kraku Pešter; current indicated resources totaling 2.38 Moz of Au metal at 1.6 g/t Au average grade) along stratigraphic contacts of Early Cretaceous limestone-sandstone, S1 and S2 unit sandstone (Fig. 2), and in steeply dipping fracture zones in the clastic rocks and andesite sills. Recently, high grade polymetallic carbonate replacement mineralization has been reported from Korkan East (current inferred resources totaling 1.37 Mt of ore at 3.4 g/t Au, 44 g/t Ag, 0.6 wt.% Pb and 0.5 wt.% Zn), which is mostly located along the brecciated limestone and sandstone contact, and in karstic zones of the limestone. High grade polymetallic skarn mineralization has been previously identified in Bigar, Valja Saka and the SW Umka area. Porphyry gold-only mineralization was discovered at Čoka Rakita in association with potassic altered dioritic stocks (significant drill intercepts include 116 m @ 1.15 g/t Au and 47 m @ 2.15 g/t Au). The E part of the NWTMC (Kraku Ridji, Dumitru Potok, and Valja Štrz prospects) is marked by low to moderate grade copper-gold porphyries associated with potassic altered dioritic stocks (all resource numbers by Avala Resources Ltd. press releases, 2010-2014).

Geodynamic setting, geochronology and stratigraphy of northwest Timok

The easternmost magmatic complex in the Serbian part of the Western Tethyan Metallogenic belt is the TMC and comprises the largest exposure of Late Cretaceous calc-alkaline magmatic rocks in the Carpathian-Balkan area. Plate reconstructions show that the TMC segment originally had an E-W orientation in Upper Cretaceous times (Schmid et al. 2008 and references therein). The structural complexity, the present-day L-shape geometry of the region and clockwise rotation (~30°) of the TMC segment reflects large-scale oroclinal bending during post-collision escape tectonics throughout the Tertiary, including major transcurrent fault systems with an overall dextral displacement in excess of 100 km and associated alternating transpressive and transtensional episodes (Fig. 1; Maţenco and Schmid 1999). Late Cretaceous magmatic activity has been documented during a 10-millon-year period from ~89 Ma to 78 Ma and has been interpreted to generally progress from E to W (Fig. 2B and references therein), younging across strike towards the subduction that this hydrothermal system could be slightly younger (around 80.5 Ma). Intrusion of the Potoj Čuka monzonite followed the emplacement of the

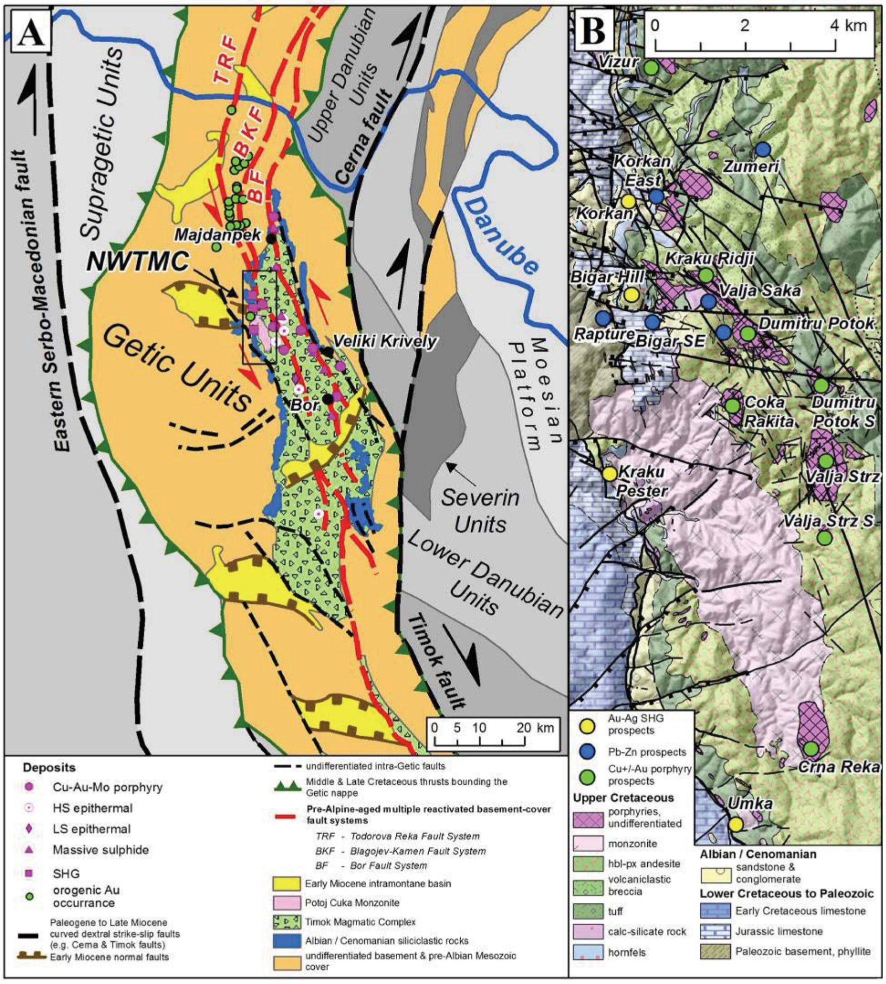

Figure 1.
A) The location of the NWTMC within the Cretaceous arc segment of the Western Tethyan Metallogenic belt.
B) The geologic map of NWTMC area showing the most important ore prospects.

zone. This process can be related to an arc under extension and gradual steepening and rollback of a northward subducting lithosphere slab, derived from the Vardar ocean.

The stratigraphic relationships of NWTMC are summarized in figure 2A. Late Cretaceous monzonite and diorite complexes (in forms of dykes, stocks and sills) intruded the volcano-sedimentary units (Banješević 2010). The existing age data suggests that intrusive activity and related porphyry mineralization in the NWTMC area spanned about 5 million years, and postdated the magmatism in the E part of the TMC (Fig. 2B and references therein). The Dumitru Potok and Valja Štrz porphyry Cu-Au systems may be very close in age, having formed around 82 Ma. The available age constraints for Kraku Ridji indicate dated porphyry Cu-Au prospects in the area (77-80 Ma). However, field observations and cross cutting relationships suggest that the porphyry stocks at Crna Reka and the SHG mineralization at Kraku Pešter are younger than the monzonite.

Structural framework and mechanical controls

The Timok area has undergone a protracted Variscan to Alpine tectonic history (Fig. 3). The thick-skinned ductile deformation associated with regional Variscan low-grade metamorphism has been overprinted by later brittle deformation associated with several stages of Alpine tectonics including renewed thick-skinned nappe stacking and subsequent escape tectonics involving oroclinal bending around the W corner of the Moesian platform (Kräutner and Krstić 2002,

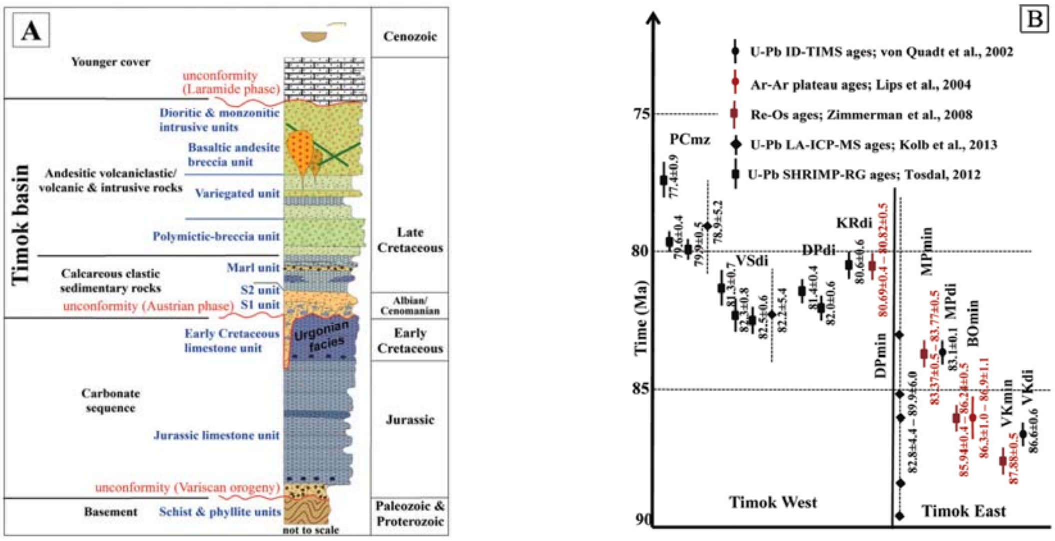

Figure 2.
A) Schematic stratigraphy of the NWTMC.
B) Representative radiometric ages for intrusive rocks and related hydrothermal mineralization from NWTMC, in comparison to existing ages from Timok East. Abbreviations: BO-Bor, DP-Dumitru Potok, KR-Kraku Ridji, MP-Majdanpek, PC-Potoj Čuka, VK-Veliki Krivelj, VS- Valja Štrz, di-diorite, min-hydrothermal mineralization, mz-monzonite.

Iancu et al. 2005).

The strain imposed on the previously faulted Variscan basement and Early Mesozoic cover during Alpine oblique convergence has been partitioned and localized at main N-trending Alpine orogenic contacts but also at inherited NNW-trending anisotropies such as the Bor, Todorova Reka and Blagojev-Kamen-Rudaria fault systems which may resemble a Variscan-aged basement suture that strikes oblique to the Alpine orogenic contacts. This resulted in a protracted history of re-shear along favorably oriented segments of these fault systems and created contrasting styles of deformation including antithetic block rotation and associated sinistral dislocations and various fold and fault geometries in the overlying cover sequences. Intermittent reactivation of these deep Variscan-aged basement structures beneath the Mesozoic cover exerted an important influence on the subsequent sedimentary deposition, intrusive, deformation, and mineralization history of the Mesozoic cover, which can be observed by stratigraphic, structural and magmatic features. Stratigraphic features include systematic thickness variations, rapid facies changes, growth fault sequences and sedimentary debris-flow breccias in clastic rocks overlying basement fault terminations. Faults related to the formation of the TMC basin and related volcanic depocentres, the alignment of porphyry clusters, the long axis of the Potoj Čuka monzonite and mappable surface structures controlling linear NNW trends of different types of mineralization in cover sequences all correspond well with the trace of these reactivated basement-cover structures.

Importantly, multiple reactivations of these basement-cover fault systems generated localized enhanced permeability which subsequently controlled fluid flow into lithologically controlled sites where fluid-rock interactions and the cooling of sulphide-rich fluids appear to have controlled hydrothermal ore deposition. Cenozoic oroclinal bending caused large dextral strike-slip fault systems, subsequent intramontane extensional basins and preferential exhumation juxtaposing both relatively shallow and deep erosion levels revealed by contrasting mineralization and alteration styles compared to the central and E parts of the TMC.

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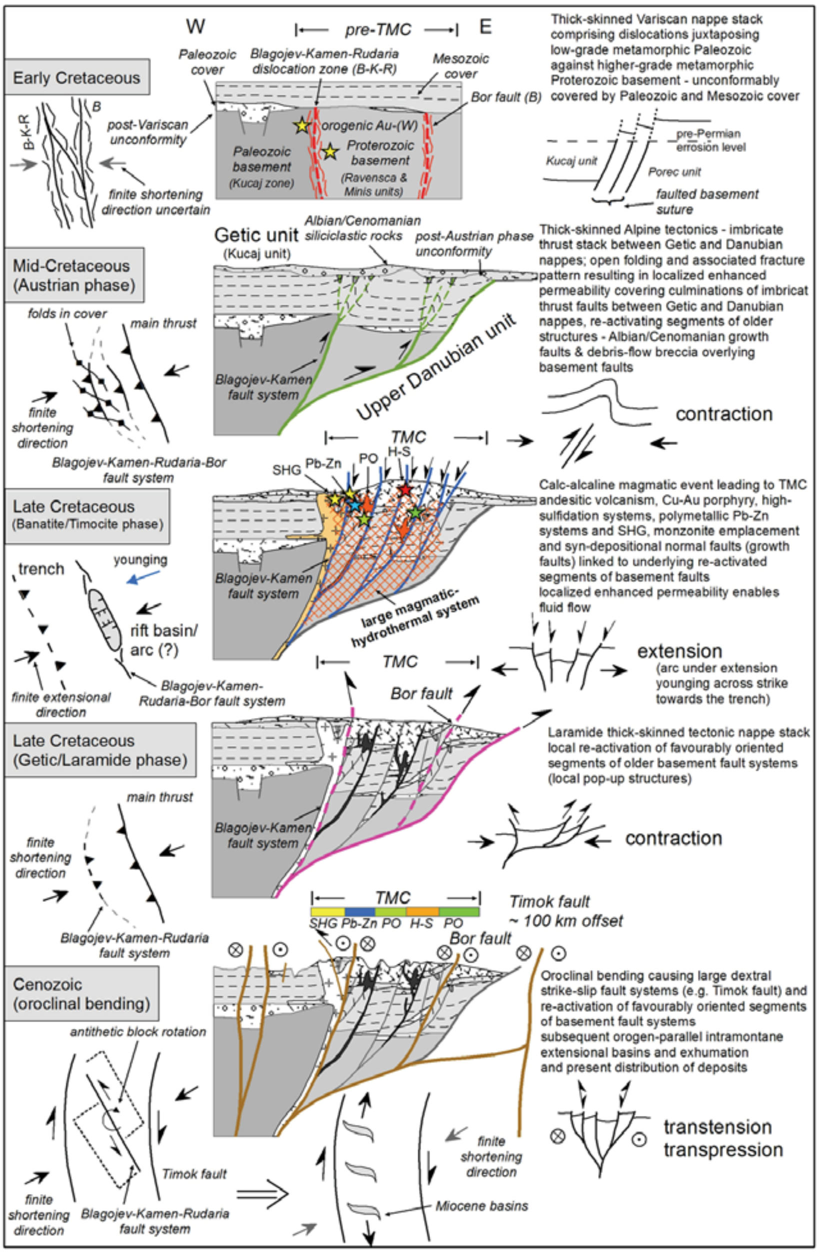

Figure 3. Proposed reactivation model for basement faults in the TMC in a series of schematic cross sections with emphasis on the formation of fault-related permeability enhancement and subsequent mineralization.

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Petrographic Study of the Magmatic Phases and Hydrothermal Vein Types from Degrmen Au-Cu Mineralization (Southern Serbia)

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Abstract

The Degrmen Au-Cu porphyry prospect is located in Southern Serbia, at the western part of the Oligocene Lece Magmatic Complex (LMC), 230 km south of Belgrade. In this area (formerly named as “Kravarske Planine ore field”) exploration was conducted by Serbian state during 1984-1987 period. Since 2011, the “Dunav Minerals doo” exploration company completed a preliminary resources drilling in the area, which proved the presence of a large moderate-grade Au-Cu mineralized body (see Dunav Resources ltd press releases http://www.dunavresources.com/s/NewsReleases.asp).

The aim of our study is a detailed characterization of the magmatic phases and the hydrothermal vein types occurring at the Degrmen Au-Cu porphyry prospect. Samples were selected from 3 representative drill holes along a north-south section through the prospect. Investigations by transmitted and reflected polarized light microscopy, scanning electron microscopy with energy dispersive spectrometry (SEM) and X-ray powder diffraction were performed.

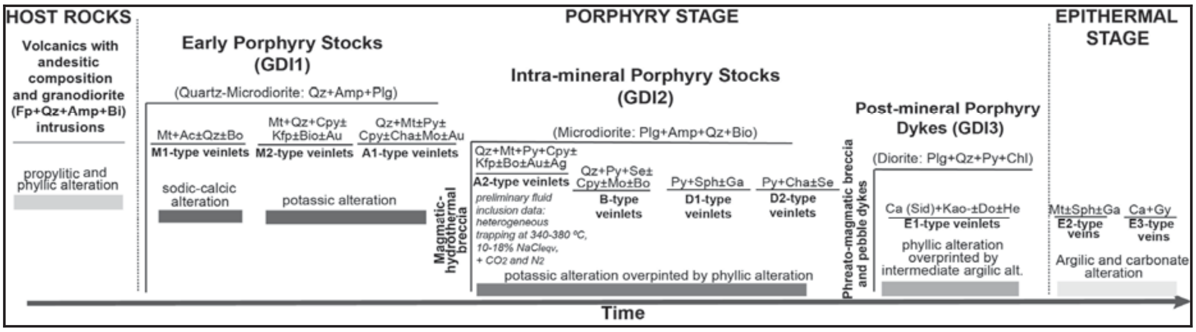

Figure 1. Time relationship between the main magmatic and breccia events and porphyry and epithermal ore stages in the studied part of Degrmen ore prospect. Abbreviations: Ac-actinolite, Ag-silver, Amp-amphibole, Au-gold, Bi-biotite, Bo-bornite, Ca-calcite, Cha-chalcocite, Cpy-chalcopyrite, Do-dolomite, Fp-feldspar, Ga-galena, Gy-gypsum, He-hematite, Kao-kaolinite, Kfp- K-feldspar, Mo-molibdenite, Mt-magnetite, Plg-plagioclase, Py-pyrite, Qz-quartz, Se-sericite, Sid-siderite, Sph-sphalerite.

The area of Degrmen porphyry mineralization is build up by several porphyry stocks with subvertical pipe-like geometry, intruded into an andesitic volcanic and volcaniclastic sequence. We have distinguished three porphyry intrusive phases, separated by magmatic and hydrothermal breccias, and several successive porphyry veinlets and associated alteration assemblages (Fig. 1). The early main mineralized intrusion is elongated along N-S direction, it is composed of fine to medium grained equigranular quartz-microdiorite (~60 % plg, 20-25 % qz, 10 % amp) and it suffered strong sodic-calcic, potassic and phyllic alterations. The intra-mineral suite is forming NW-SE oriented pipe-like bodies, are composed of medium to coarse grained porphyritic microdiorite (~70 % plg, 15 % amp, 10% qz, 5% bi) and they show weak potassic and moderate phyllic alteration overprint. Post-mineral intrusions were formed as narrow dykes (1-10 m) and they suffered propylitic and argillic alteration. Copper is dominantly hosted by chalcopyrite (up to 30 µm size), or rarely bornite (usually as 1-10 µm size inclusions in magnetite) and chalcocite in early M and A-type veinlets or as dissemination associated with sodic-calcic and potassic alteration. Hypogene chalcocite and covellite frequently occurs at the expense of chalcopyrite (as replacements) where primary porphyry assemblages are overprinted by late E-type epithermal veins. Gold and silver mineral phases (µm size; usually as electrum) were observed by SEM in association to copper sulphides.

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Tran Au-Ag±Wdeposit in Western Bulgaria: a new Intrusion-Related Gold System in the Variscan belt of Europe

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Abstract

New data for the magmatism, hydrothermal alteration, mineralization styles, isotope geochronology, mineralogy, fluid-inclusionsand elemental geochemical associations are combined in the present study to characterize the Tran Au-Ag±W deposit in Western Bulgaria. The main features of the deposit define it as intrusion-related gold system (IRGS): its association with reduced plutons; well-defined structural control on intrusion and mineralization; diverse mineralization styles, including veins, stockworks, dissemination; wide range of gold grades; approximately coeval magmatism and mineralization at 330-333 Ma; low sulfide content; apparent correlation of Au and Bi; and the presence of CO_2 in hydrothermal fluids. These characteristics are useful for further prospecting for IRGS in the Variscan Belt of Eastern Europe.

Keywords: *gold-tungsten, IRGS, Variscan.*

Introduction

To date there are three main well defined magmatic and metallogenic belts (MMB) on the territory of Bulgaria that host numerous ore deposits and occurrences. The most famous of themare the Cretaceous belt with some big porphyry-Cu (Elatsite, Assarel) and epithermal Cu-Au deposits (Chelopech) and the Tertiary belt with epithermal-Au (Ada Tepe) and basemetal (Pb-Zn) deposits (Madan, Laki). In the Palaeozoic MMB there are no active mines nowadays, however mining activity in the past was concentrated on some mesothermal vein type Au and base metal deposits, e.g. Zlata (which means "gold") in Tran region, W Bulgaria or Pb-Ag replacement type (Chiprovtsi in W Balkan Mountain). In this study we focus on the Tran region, where a new Au-Ag (± W) deposit was defined by Euromax Resouces Ltd during their exploration campaign (Metodiev et al. 2012). It was classified as intrusion-related gold deposit (IRGD; www.euromaxresources.com) that is formed in the granites of the Lutzkanmagmatic complex – the Lutzkan and Ruy plutons (Belev 1960; Dragov 1960; Dyulgerov et al. 2010) and their host rocks.

The intrusion-related gold deposits (IRGD) are an economically important class that is underrecognized in SE Europe. World-class IRGD occur within magmatic provinces best known for tungsten and/or tin mineralization. All major IRGD (Thompson et al. 1999; Lang and Baker 2001; Hart 2007) are Phanerozoic in age, mainly Middle Cretaceous (Fort Knox and the whole Tintina belt in Alaska and Yukon) and Carboniferous-Devonian (Murantau, Mokrsko, Salve, Vasilkovskoe, Timbarra, Kidston, Pataz). IRGD are generally associated with various mineralizationlike skarns, veins, disseminations, stockworks, replacements, and breccias, called IRG systems (IRGS). The deposits of this type are genetically related to felsic domes, stocks or plutonic intrusions. Auriferous quartz veins preferentially concentrate in the brittle carapace at the top of small plutons, where they form bulk-tonnage, low-grade Au deposits characterized by a Au-Bi-Te-W metal assemblage. Here we present new data on the magmatism, mineralogy, hydrothermal alteration, styles of mineralization, and elemental geochemical associations, isotope geochronology and stable isotope data, as well as fluid-inclusion data for the deposits in the Tran region (Logo, Nadezhda, Ruy, Tumba, Zlata, Krushev Dol and Krastato Darvo, collectively called "Tran"). They will be discussed as indicative for IRG-type deposits and useful as possible criteria in further prospecting for Au-Ag-W in the Variscan Belt of the Balkan Peninsula.

Geological setting

The basement in the area of the Tran deposit consists of Neoproterozoic amphibolite facies metamorphic rocks and Lower Paleozoic low-metamorphic gabbro-diorites, metagranitoids, metabasalts and carbonaceous metasediment rocks. They are intruded by the granitoids of the Lutzkan magmatic complex (LMC; the northern Ruy pluton and the southern Lutzkan pluton and their dykes) and overlain by Devonian, Permian, Triassic and Jurassic sediment rocks (Fig. 1). Paleogene subvolcanic Na-dacites and rhyolites are intruded as sills, dikes and larger bodies in the granites and the basement rocks at 43-47 Ma (Marchev et al. 2012).

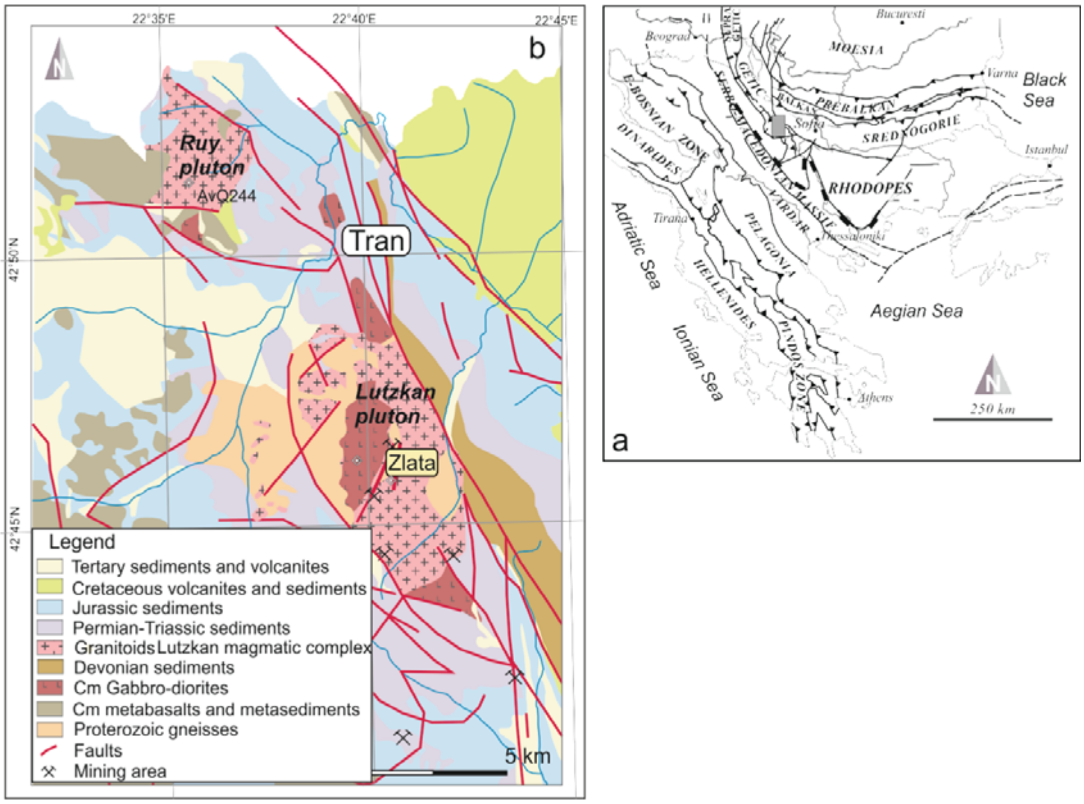

Figure 1.
a) Sketch tectonic map of the Balkan peninsula with the location of studied area (modified after Sandulesku, 1984);
b) Simplified geological map ofTran deposit area in western Bulgaria with the position of Ruy and Lutzkan plutons (Lutzkan magmatic complex).

The Ruy pluton is a relatively homogeneousbody and consistsofmonzogranite and aplitic leucogranite. The Lutzkan pluton is more complex, monzogranite is the most voluminous variety, but granodiorites and leucogranites also occur (Dyulgerov et al. 2010). The plutonic rocks are followed by dyke activity with syenite and granite composition. The granitoids from both plutons are I–type, metaluminous and show considerable incompatible trace elements enrichment, notably Sr, Rb, Ba, Th and U, as well as Be and F. Accessory minerals are zircon, sphene, allanite and Fe-Ti phasesof the magnetite-ilmenite series. Sphene and ilmenite prevail clearly over magnetite and argue for reduced magmatism. The rocks were formedat 333.60 ± 0.66 Ma (granites) and 328 ± 2.4 Ma (granite-porphyry dykes; Peytcheva et al. 2011). Initial Sr isotope values of ~0.708 and εNd values between –6 and –8 attest for a considerable crustal contribution to the magmas.

Mineralization styles

Economic mineralization in LMC is located predominantly in N-NE or NW striking sheeted veins, following the main tectonic structures and the intrusive contacts, but also in numerous quartz-sericite-pyriteveins/veinlets and stockworks or disseminated in the granites. The mineralization is preferentially embedded in the brittle to plastic-brittle parts of the most intensively tectonized zones, possibly in the carapace at the top and side of Ruy and Lutzkan plutons,as well asin the host metagabbros (rarely metagranites). Tectono-magmatic and/or hydrothermal brecciasare observed in the granitoids from boreholes.

Hydrothermal alteration, mineralization and element associations

The following stages of alteration and mineralization are distinguished in the Tran deposit: (1) quartz-K-feldspar; (2) quartz-sericite-pyrite-scheelite-molybdenite; (3)ankerite-siderite; (4) quartz-pollymetallic; (5) calcite; and (6) chlorite. An oxidation zone is developed in the deposit too. The second and fourth stages are of greatest economic interest, when the precipitation of scheelite with gold, and basemetalswith gold occurred.

The magmatic rocks from the studied area are affectedby different types of hydrothermal alteration in a varying intensity. K-feldspar alteration is the earliest hydrothermal alteration but it is comparatively weak and weakly preserved as well. The dominant hydrothermal alteration of the host rocks of all compositions is of quartz-sericite (± pyrite) type, varying from sporadic to pervasive. Albite alteration of plagioclase and chloritization (± carbonatization) of mafic minerals accompany less intensive sericitic alteration. The subsequent hydrothermal events are carbonatization with early ankerite-siderite mineralization and later calcite. The last hydrothermal event is the deposition of late chlorite veinlets.

Monotonous quartz-sericite (± pyrite) alteration is characteristic for the Paleogene sill-like bodies of the deposit. The primary texture of subvolcanic rocks is preserved, sericite is usually very fine-grained, and calcite is common in the groundmass together with quartz in tiny veinlets. A strong silicification can be observed in some bodies from the surface.

The newly obtained data for the ore and gangue minerals and their distribution in the deposit largely coincides with the published data for the old mine Zlata (Dragov 1960). The implementation of modern in-situ analytical techniques provides new information for trace-element composition of the minerals, and metal distribution, whereas new mineral species were also found. The main ganguemineralsare quartz, K-feldspar, albite, muscovite (sericite), phenakite (identified for the first time in Bulgaria), ankerite-siderite-calcite, chlorite, barite, celestite, fluorite, zircon, thorite, monazite, xenotime, allanite, apatite and rutile. The main ore minerals are pyrite, scheelite, wolframite, molybdenite, galena, chalcopyrite, bornite, tetrahedrite-tennantite, Bi-sulfosalts, native gold and electrum, native silver, whereas the bulk concentration of sulfides is not high.

Ore element associations are controlled by the distribution of the second and fourth mineralization stages that are spatially separated in some parts of the deposit. Consequently, association of Au with either W, or As, Bi, Pb is observed, or the geochemical anomalies of all these elements are overlapping.

P-T conditions and fluid source

Oxygen isotope data on hydrothermal quartz and scheelite are indicative of dominantly magmatic origin of the mineralizing fluids at Trun. Quartz-hosted fluid inclusions are CO_2-rich, but usually very small in size in the ore-bearing stages. Temperatures of 600-550 °C can be assumed for the early stages of mineralization, based on the Zr-in-rutile thermometer, applied to hydrothermal rutile. Temperatures of 390-350 °C to 300 °C are estimated for the quartz-sericite-pyrite-scheelite-molybdenite stage by the stability of galenobismutite and secondary fluid inclusions in quartz. Lower temperatures 250-220 °C are calculated for the formation of the late hydrothermal chlorite veins. The depth of emplacement is estimated to be 7-8 km for the pluton (consequently for some veins too) to 1-3 km for some lower-temperature mineralization.

Timing

The mineralization is linked with the granitoids and their dykes, which is suggested by the field relationships and by the fact that in some cases dykes and veins are using the same fault structures. This conclusion is supported by Re-Os dating of molybdenite at 330 ±1.3 Ma and U-Pb dating of rutile in the same range, but with larger uncertainties. It shouldbe mentioned that former model Pb-Pb ages of galena and pyrite from Zlata deposit are also Carboniferous (Amov 1981).

Distinguishing features of IRGS

The Tran deposit shares important features of "reduced" IRGS model, defined by Hart (2007), such as: (1) association with reduced, felsic plutons; (2) relatively deep levels of intrusion (7-10 km);

(3) well-defined structural control on intrusion and mineralization features; (4) diverse deposit styles and wide range of gold grades; (5) coeval timing of depositwith the associated, causative pluton; (6) mineralized zones in the intrusion itself and the host rocks; (7) low sulphide content; (8) strong presence of CO_2in hydrothermal fluids; (9) apparent correlation of Au and Bi; and (10) low grade, bulk tonnage type deposit.

Conclusion and perspectives

So far Tran is the best-defined IRG deposit in the Variscan belt in SE Europe but there are numerous occurrences associated with Paleozoic granitoids in the same region. The global knowledge for this deposit type is developing quickly and every year there is an improved knowledge of IRGS (mainly because of the growing activities in Alaska and Yukon). Having inmind the relatively low level of ore exploration for the last decades in Europe and the lack of good understanding for this type of systems, new discoveries of this type of deposits is just a matter of time.

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Cenozoic magmatism in the border area of W Bulgaria – E Macedonia - SE Serbia: temporal evolution, geochemical trends and fertility in changing compression-extension regime

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Abstract

The Balkan Peninsula is one of Europe's mineralized regions with world-class ore deposits. Numerous porphyry Cu-(Au-Mo) and epithermal Au-(Cu) deposits are related to Upper Cretaceous calc-alkaline magmatism formed during oblique northward subduction of the Tethys beneath the European continent and slab roll-back. The next time period with important Pb-Zn-Au-Cu mineralization is Cenozoic (mainly Oligocene) and related to post-collisional magmatism. We present here integrated U-Pb zircon, Sr-Nd-Hf isotope and geochemical analyses on Palaeogene rocks from W Bulgaria, SE Serbia and E Macedonia (FYROM) with the aim to constrain the temporal and tectono-magmatic evolution of the region that favoured significant ore-formation.

After the cease of the Upper Cretaceous subduction at ~70 Ma and the accretion of the Morava-Rhodope/Getic-Supragetic units the region is marked by a collision/compression and break of magmatism. The magmatism started again at ~60 Ma when rift-like alkaline basalts in eastern Serbia formed (Cvetković et al. 2013). They were followed (after a next break?) by adakite-like sodic calk-alkaline rhyolites-dacites at 47-43 Ma in the Kraishte magmato-tectonic zone (Harkovska et al. 2004). Trace element geochemistry defines mainly volcanic arc granite (VAG) affinity of these rocks. They are enriched in LREE, with Ta-Nb negative anomaly, shallow negative Eu anomaly and with a sum of REE 70-100 ppm. Adakite-like character is defined by Sr/Y>45 (48-71), Y content lower than18 ppm (5.9 ppm to 8.3 ppm) and La/Yb>20 (30-40). Sr-Nd whole rock and Hf-zircon isotope data define a mantle dominated source ($^{87}Sr/^{86}Sr_{(i)}$ 0.7047-0.7051; εNd between -0.2 and +2.4; εHf-zircons of +4 to +10). Eocene adakite-like magmatic rocks can be traced further to S-SE in the Rhodopes and are likely related to mantle underplating and partial melting of subduction-enriched lithospheric mantle, but asthenospheric OIB-like mantle source could be an alternative option (Marchev et al. 2013).

After a next break of around 10 Ma the Cenozoic magmatism continued in Besna-Kobila-Osogovo-Thasos/Ruen and Lece-Chalkidiki magmatic and metallogenetic zones (MMZ) with related Pb-Zn-Au±Cu and Cu-Au±Pb-Zn mineralization (Harkovska 1984; Serafimovski 1993). The magmatism in the Ruen zone started in Surdulitsa (SE Serbia) at 36-34 Ma with still quite primitive magmatism despite of the fractionated granitoid composition of intrusive and subvolcanic products. Surdulitsa magmatism should be considered separately from the rest of magmatic rocks in the Ruen zone. The latter reveal an younger age of 32-30 Ma and crustal-dominated granitic/rhyodacitic composition ($^{87}Sr/^{86}Sr_{(i)}$ 0.709-0.716; εNd -6 to -10; εHf-zircons -2 to -8). The magmatism migrated further to SW and show magmatic ages of 29-24 Ma in Kratovo-Zletovo and the Buchim-Borov dol. Less radiogenic strontium ratios (0.7060) and slightly negative εNd values (-2.6 to -3.1) characterize the magma, which is considerably more mantle influenced. Again, in both MMZs the trace element geochemistry defines mainly VAG affinity, enrichment in LREE, and Ta, Nb and Ti negative anomalies. These features are typical for magmas that are generated in the metasomatized subduction enriched mantle lithosphere. The magmatism changed to mainly normal andesite-rhyolite type, but contemporary adakite-like magmas also occur.

Timing and geochemical characteristics of Paleogene magmatism in studied area suggest a repeated change of compression/collision and extension episodes that were plausible for the generation of fertile magmatism. The latter reveal signature of subduction-enriched mantle source but magma composition was additionally crustal modified and controlled by the composition and thickness of the interacted crust.

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Magmatism associated with porphyry Cu-Mo deposits of the composite Tertiary Meghri-Ordubad pluton, southern Armenia, Lesser Caucasus

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Abstract

The Lesser Caucasus extends from the Black Sea to the Caspian Sea and is a key area to understand the metallogenic and geodynamic link between the western and eastern domains of the Tethys belt. In particular, the southern part of the Lesser Caucasus records a long lasting geological and metallogenic evolution, from the Jurassic to the Cenozoic, which is well documented by magmatic rocks and ore deposits of the Mesozoic Kapan block and the Cenozoic Zangezur-Ordubad zone of southern Armenia.

The composite Meghri-Ordubad pluton, which hosts porphyry Cu-Mo and epithermal deposits, has been chosen for this study because it exhibits Eocene, Oligocene and early Miocene intrusive rocks, which are associated both in time and space with porphyry Cu-Modeposits (Fig. 1). Magmatic processes related to the formation of Tertiary porphyry deposits will be investigated. No modern studies have been carried out so far onthe link between magmatism and hydrothermal ore bearing fluids in this pluton.

By combining U-Pb (ID-TIMS and LA-ICP-MS) zircon and Re-Os molybdenite geochronology, we illustrate nearly continuous magmatism associated with ore-forming events from the Eocene (50 Ma) to early Miocene (20 Ma). The whole-rock geochemistryof the Eocene and Miocene plutonicrocks are very similar and indicate a calc-alkaline affinity, whereas the Oligocene magmatism is characterized by an alkaline affinity. The differences in major elements strongly suggest a different source for these magmas. Trace element characteristics reveal typical subduction-related signatures for the Eocene to Miocene magmatic events (negative anomalies in Nb, Ta and Ti, enrichments in LILE and flat HREE profile). Furthermore, the Oligocene rocks contain high-aluminum amphiboles (hastingsite to pargasite) whereas the Eocene and early Miocene rocks contain low-aluminum amphiboles (hornblende to actinolite), suggesting that the Oligocene rocks may have crystallized at greater depth than the Eocene and Miocene rocks.

Preliminary Nd and Sr isotopic compositions from the magmatic rocks broadly indicate an increasing mantle-derived component with progressively younger magmatic events, with decreasing $^{87}Sr/^{86}Sr$ ratios (0.70393-0.70463) and increasing $^{143}Nd/^{144}Nd$ ratios (0.51240-0.51285).

Whole-rock geochemistry and isotope results show some differences between the Eocene, Oligocene and early Miocene rocks. These differences make the composite Meghri-Ordubad pluton one of the best areas to investigating the link between magmatism and ore-formation during subsequent subduction, collision and/or post-collision eventsalong the Tethys belt. The systematic characterization of the different Tertiary magmatic suites will allow us to illustrate different magmatic processes associated with different geodynamic environments leading to the formation of porphyry Cu-Mo deposits.

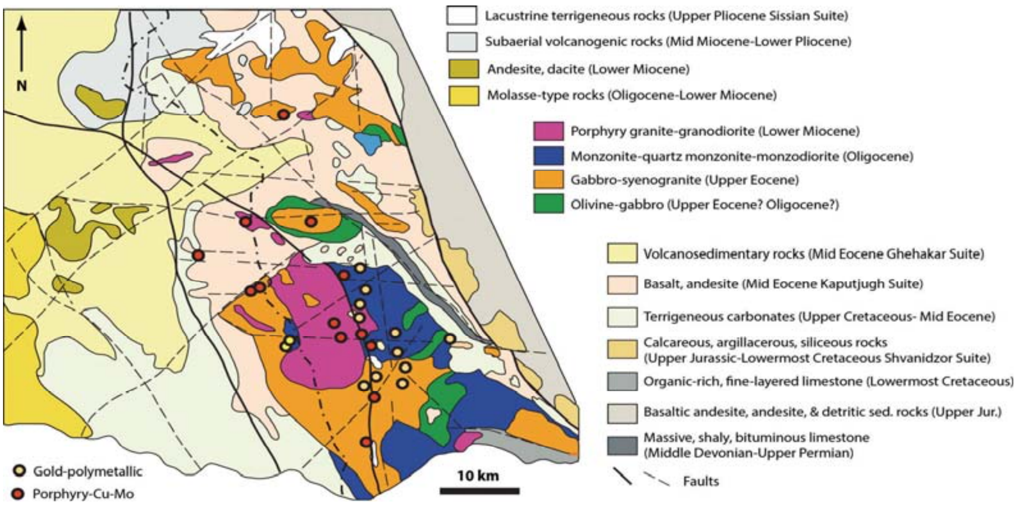

Figure 1. Simpified geological map of the composite Tertiary Meghri-Ordubad pluton. After Karamyan et al. (1974).

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The Ilovitsa porphyry Cu-Au deposit: vein sequence,sulfide deposition and fluid inclusion study

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Abstract

The Ilovitsa porphyry Cu-Au deposit is located 30 km away from the town of Strumitsa, SE FYR Macedonia. It is hosted in a Triassic granite (251.90 ±0.89 Ma, Georgiev et al. 2013).The latter intrudes into the metamorphic rocks of the Vertiscos-Ograzhden Unit of the Serbo-Macedonian massif. Formation of the Ilovitsa deposit is related to the intrusion of multiple Tertiary porphyry intrusions (called the Ilovitsa Stock) and dykes. The Ilovitsa stock that hosts the Cu-Au mineralization is made up by two main intrusions with a similar granodioritic composition dated by ID-TIMS at 30.31 ±0.05 Ma and 30.13±0.03 Ma (Georgiev et al. 2013). The authors have determined that the ages of the dykes are between 28.8 and 29.6 Ma.

The main goal of the present study is to distinguish the relative timing of different vein types, vein minerals and related hydrothermal alteration. In addition, we determined the temperature conditions of their formation based on a fluid inclusion study where appropriate fluid inclusion assemblages were found. For that purpose 7 drill holes were sampled and around 80 samples were collected for laboratory analyses. Cross-cutting relationships were used to distinguish the relative timing of vein formation. SEM-CL petrography was then used for identification and textural correlation between successive quartz types, sulfidesand fluid inclusion assemblages. Representative fluid inclusion assemblages were selected for further analyses by microthermometry.Hydrothermal veins were named according to their mineral assemblages and quartz textures. All analyses were performed at ETH Zurich.

We have distinguished several successive vein types: Magnetite or quartz-magnetite veinlets are up to few cm thick with potassic alteration. Quartz, where present, is granular with a homogeneous CL-gray luminosity. Barren quartz veins are divided into two subtypes: granular and crystalline quartz veins. Granular quartz veinlets are thin, with irregular walls and are related to potassic alteration. The quartz grains are anhedral with CL-dark luminescence. Crystalline quartz veins are composed of subhedral to euhedral quartz crystals that have oscillatory zoning ranging in luminosity from CL-gray to CL-bright. Data from microthermometry of brine inclusions show that they were formed at temperature higher than 600 °C. Generally, these veins were reopened and filled with minerals from later mineral assemblages in the central parts. Magnetite-bornite-chalcopyrite veinlets are rare in Ilovitsa. Pyrite-chalcopyrite±hematite form thin veinlets cutting the earlier vein types. Inclusions of gold in chalcopyrite are observed. These veins typically contain only minor amounts of CL-dark luminescent quartz. Fluid inclusions suitable for microthermometry undoubtedly connected to the formation of this quartz were not found that is why we could not constrain the temperature of formation of these veins. Quartz-molybdenite veins commonly contain open spaces lined by euhedral quartz crystals with oscillatory zoning. Generally, symmetric lines of molybdenite flakes, growing adjacent to the vein walls, are observed. Based on microthermometry of brine inclusions, we determined that these veins are high temperature ($T > 600°C$). Quartz-pyrite veins with sericitic alteration cut all of the above described veins. These veins contain only small amounts of CL-dark luminescent quartz and pyrite.Microthermometry data of two-phase fluid inclusions showed that they were formed at a temperature around 290°C. Quartz-galena-sphalerite (±pyrite, chalcopyrite) veins are widely distributed in Ilovitsa. Quartz forms idiomorphic crystals with oscillatory zoning. Microthermometry data of two-phase fluid inclusions trapped in sphalerite crystals show temperatures between 300 °C and 270 °C. Quartz-carbonate veins were formed during a post-ore stage. Carbonates are found in thin veinlets as well as in voids of earlier formed veins.

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U/Pb dating of CA-treated zircons obtained by LA-ICP-MS and ID-TIMS: constraints for the life times of ore deposits and their geological interpretation

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Abstract

Magmatic-hydrothermal copper ore formation involves multiple pulses of subvolcanic porphyry intrusion, vein opening, and hydrothermal ore deposition. It is driven by larger subjacent magma reservoirs, acting as the source of fluid and ore-forming components. High-precision U-Pb ages of individual zircon crystals from porphyries immediately predating and postdating Cu-Au mineralization show a significant spread of reliably concordant ages. This demonstrates zircon crystal formation over a protracted period of ~1my, which is interpreted to record the lifetime of the magma reservoir from which porphyries and ore fluids were extracted. Chemical Abrasion Isotope-Dilution Thermal Ionization Mass Spectrometry (CA-ID-TIMS) is known as a high precision technique for resolving lead loss and improving the interpretation of U/Pb zircon age data. Here, we argue that combining CA with the widely applied Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS) improves the precision and accuracy of zircon dates, while removing the substantial parts with lead loss, reducing data scatter, providing meaningful geological interpretations. The samples of dating are magmatic rocks chosen from different geological time periods (one Paleozoic, one Mesozoic and three Cenozoic). All zircon separates are analysed by LA-ICP-MS before and after CA, and age data are compared with the CA-ID-TIMS $^{206}Pb/^{238}U$ dates dates that are considered as the most accurately obtainable age. All CA-treated zircon crystals show up to 50 % less data scatter compared to the non-CA treated zircon grains and thus a reduction of the calculated errors is apparent.

Keywords: *Ore deposits, Life time, geochronology, Cu-Au porphyry*

Selected sample material

For our study several geological samples with different magmatic ages were selected (see Intern. Chronostratigraphic Chart – www.stratigraphy.com): a) 24 Ma (Oligocene), b) 76 Ma (Upper Cretaceous), c) 330 Ma (Carboniferous), and the zircons were dated also by the high-precision "conventional" CA-ID-TIMS technique, using the Thermo-Scientific TritonPlus mass spectrometer. All samples are of magmatic origin and represent a geological time range between 0.2 and 330 Ma.

Instrumentation – ICP-MS system

Instrument parameters used during the course of this study are detailed published by Guillong et al., (2014) and von Quadt et al. (2014). The data presented here were acquired using an Elan 6100 ICP-MS (PerkinElmer, Norwalk, CT, USA) coupled to an 193 nm ArF-Excimer laser ablation sysytem similar to a Geolas system (Coherent, USA). The laser was operated at 10 Hz, spot size was 40 micrometer and a fluence of 4 J cm^{-2} was used. All experiments were performed using helium as carrier gas. The second laser system was acquired using an Element-XR SF-ICP-MS (Thermo Fisher, Bremen, Germany) coupled with a 193 nm Excimer laser (Resonetics Resolution S155-LR) that was operated at 5 Hz and a fluence of 2.0 J cm^{-2}. The spot size for obtaining the data for the young zircons was 30 µm.

Analytical protocol: TIMS and LA-ICP-MS

TIMS: All analyses were carried out using the $^{202-205}Pb/^{233-235}U$ spike of Earthtime (ET) Working Group (see www.earth-time.org) which has been internationally intercalibrated and proven to yield $^{206}Pb/^{238}U$ interlaboratory reproducibility better than 0.1 %. Isotopic analyses were performed on TritonPlus thermal ionization mass spectrometer (TIMS) equipped with a digital ion counting system of a MasCom multiplier. Total procedural Pb blank was estimated at 1.0 ±0.25 pg and corrected with the following isotopic composition: $^{206}Pb/^{204}Pb$ = 18.08 ±0.22, $^{207}Pb/^{204}Pb$ = 15.62 ±0.28, $^{208}Pb/^{204}Pb$ = 38.05 ±0.59 (all ±2σ). Common lead in excess of this blank was corrected using the model of Stacey and Kramers (1975) for an age of 330 Ma, 76 Ma and 24 Ma, respectively. The model Th/U ratio was calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio assuming concordance. The uncertainty of the concentration of U and Pb in the spike solution (±0.1%) was taken into account and propagated to each individual analysis. The PbMacDAT program was used for age calculation and error propagation (Schmitz and Schoene 2007). Calculation of concordant ages was done with the Isoplot/Ex v.3 program of Ludwig (2001).

LA-ICP-MS: Samples and standards were ablated in an air-tight sample chamber flushed with He for sample transport. Data were collected in discrete runs of 20-24 analyses, comprising 11-15 unkowns bracketed before and after by three analyses of the primary standard zircons GJ-1 (Jackson et al. 2004) and secondary zircons 91500 (Wiedenbeck et al. 1995), Plesovice (Slama et al. 2008) and Temora (Black et al. 2004). Data were collected for up to 70 s per analysis with a gas background taken during the initial ca. 30 s and ablation for 40 seconds. Preliminary selection of the background, analysis signal intensities, instrumental drift correction and data calculation was performed using the Glitter (van Achterberg et al. 2001) and Iolite (Paton et al. 2010. 2011) software. The GJ-1 $^{206}Pb/^{238}U$ ratio of 0.09761 was used as reference. Concordia age calculation, weighted mean averages, intercept ages and plotting of concordia and weighted mean diagrams were performed using the Isoplot/Ex rev. 2.49 (Ludwig 2001).

Results

TIMS data: Two samples represent magmatic pulses of the Cu-Au porphyry at Buchim, Macedonia. Five out of six zircon crystals of the andesite 248-2 yield overlapping concordant U-Pb ID-TIMS ages of 24.422 ± 0.025 Ma. The high uranium concentrations between 794 ppm and 2298 ppm result in high $^{206}Pb/^{204}Pb$ ratios and reduce the influence of common lead for the U-Pb calculation. Both U-Pb concordant ages of the samples 029-5 and 248-2 are not distinguishable within analytical error and thus the life time of the two magmatic pulses is less than 170 ka.

The U-Pb concordant age calculation of a Cretaceous granodioritic sample, DG026, has an Uranium concentrations between 498 ppm and 682 ppm and no inherited lead components were treated by CA. The calculation leads to a Concordia age of 76.413 ± 0.088 Ma. The obtained U-Pb age for this granodiorite confirms it is part of the >1600 km long Cretaceous magmatic belt in Eastern Europe, hosting several active Cu-Au porphyry deposits.

The granite sample AvQ244 belongs to the geological basement in western Bulgaria (Dyulgerov et al. 2010; Burg 2011) and its TIMS result is the most complicated. The zircon grains have a Uranium concentration between 332 ppm and 2171 ppm. Of the 7 TIMS analyses, one is older than, and 2 younger than the main population of 4 aliquots. Together they can be taken to indicate a discordia with an upper intercept of ~340 Ma. The interpretation is that there is some inherited zircon in the sample, and that CA-treatment has failed to eradicate zones that have lost Pb now represented in the two younger aliquots. The four consistent concordant analyses give a concordia age of 333.60 ± 0.66 Ma confirming that this granite sample is part of the Variscan Lutzkan magmatic complex.

LA-ICP-MS: All samples (248-2, 059-1, DG026, AvQ244) were analysed using the Elan 6100 system or the Element-XR; more details are given by Guillong et al. (2014). Most of the analysed zircon crystals belong to the Late Oligocene intrusion period, and only some analyses point to an earlier magmatic phase. The calculated $^{206}Pb/^{238}U$ ages of the non-CA-treated zircon grains are 23.76 ± 0.27 Ma, 23.28 ± 0.25 Ma and 24.01 ± 0.29 (059-1, 029-5, 248-2). The maximum time range including the error covers a period of 1.27 Ma. There are some local maxima within the age spectrum, e.g. the seven youngest U-Pb analyses of sample 029-5 build up a slightly younger group, sample 248-2 has a large range of $^{206}Pb/^{238}U$ ages from ca. 25.5 Ma to 22.4 Ma; the ages > 24.5 Ma are offset from the smooth curve. All CA-treated zircons from samples 059-1, 248-2 and 029-5 show an even distribution based on the age difference between the lowest and highest obtained $^{206}Pb/^{238}U$ age. The obtained $^{206}Pb/^{238}U$ average ages of the CA-treated zircons are 24.57 ± 0.28 Ma, 24.41 ± 0.21 Ma (059-1, 029-5) and 24.28 ± 0.15 Ma (248-2) and they overlap perfectly. Based on geological field relationships all of these magmatic rocks which formed the Cu and Au ore deposit intruded in a short time window. The CA-ID-TIMS $^{206}Pb/^{238}U$ Concordia age is 24.45 Ma (029-5 & 248-2) and using the CA-LA-ICP-MS method an age of 24.35 Ma (029-5 & 248-2) was obtained, both ages overlap within the uncertainty. An important observation is that CA treatment appears to reduce age scatter. Scatter of the $^{206}Pb/^{238}U$ ages of 0.29 Ma for CA-treated zircons is lower, compared to a 100 % greater scatter (0.73 Ma) for non-CA zircons.

Cretaceous and Oligocene zircons. The non-CA and CA treated zircon data set shows high MSWD values (>10) which returns to the interpretation that the data set includes more than one population. Nevertheless, the CA-LA-ICP-MS $^{206}Pb/^{238}U$ average age of 331.8 ± 4.7 Ma coincides with the CA-ID-TIMS Concordia age of 333.60 ± 0.66 Ma. Non-CA treated zircons of sample AvQ244 yield a considerably younger mean average $^{206}Pb/^{238}U$ age 306.2 ± 10 Ma and the data scatter is wider (280 - 340 Ma).

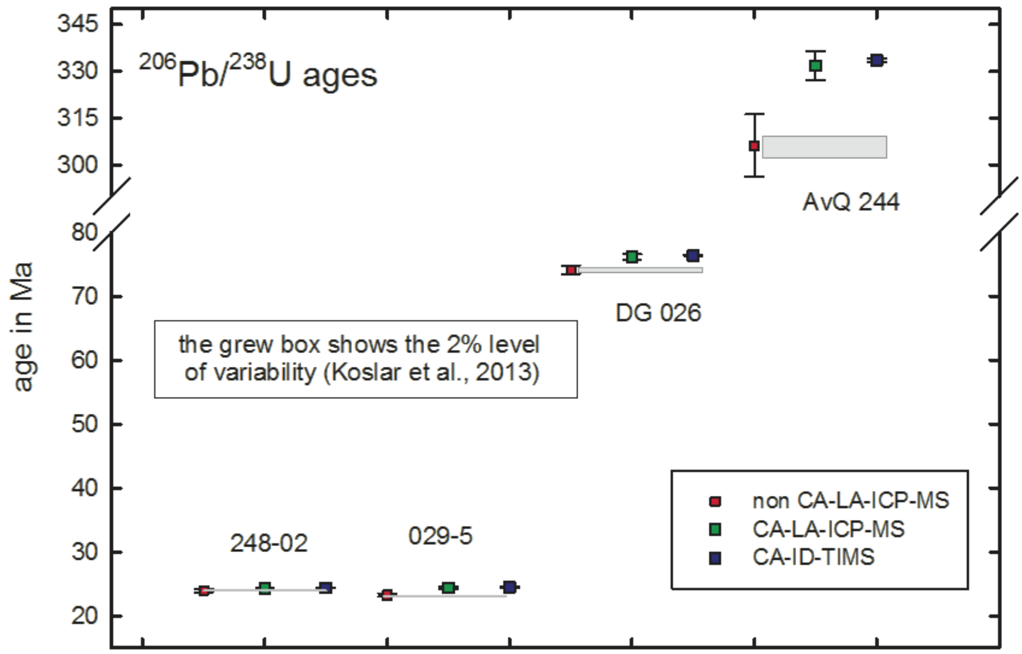

Figure 1. Summary $^{206}Pb/^{238}U$ of Ca and non-CA treated zircon grains of samples with Miocene, Createaceous and Variscan in age (analysed by ICP-MS and CA-ID-TIMS).

Sample DG026 clearly shows the difference in $^{206}Pb/^{238}U$ ages acquired from non-CA and CA treated zircons. The obtained $^{206}Pb/^{238}U$ ages are 76.13 ± 0.45 Ma and 74.14 ± 0.65 Ma (95 % conf.) for the CA and non-CA treated zircons; the range of the U-Pb ages increases from 4.3 Ma (CA zircons, 5.8 %, 74.1-78.4 Ma) up to 6.4 Ma (non-CA zircons, 8.9 %, 71.7-78.1 Ma). The obtained ages of CA-treated zircons coincide within error for LA-ICP-MS and ID-TIMS method (von Quadt et al. 2011; Schoene et al. 2012).

A total of 48 analyses were performed on the "oldest" Carboniferous geological sample AvQ244, a Variscan basement granite from western Bulgaria. The zircon sets for CA and non-CA treated zircons show distribution patterns of $^{206}Pb/^{238}U$ ages that are similar to the Upper

Conclusion

The obtained $^{206}Pb/^{238}U$ ages of all non-CA, CA- LA-ICP-MS and CA-ID-TIMS samples are plotted in Figure 1. A grew box references the 2 % level of variability (Koslar et al. 2013) and is centered to the non-CA ages. The Figure 1 show $^{206}Pb/^{238}U$ age difference between non-CA and CA ages and an increasing age difference up to older $^{206}Pb/^{238}U$ ages. One samples with an age around 24 Ma show an age overlapping between non-CA and CA treated zircon grains, but samples 059-1, 029-5, DG026 and AvQ244 are not overlapping between non-CA and CA treated zircon grains.

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Carbonate-replacement and vein-type Pb-Zn-Ag-Au mineralization at SyrosIsland, Cyclades: Mineralogical and geochemical constraints

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Abstract

Polymetallic Pb-Zn-Ag-Au mineralization at southern Syros Island occurs as disseminations and massive sulfide bodies replacing marbles, along schist foliation planes and in veins crosscutting marbles and schists of retrogressed high-grade rocks. The mineralization consists of base metal sulfides (pyrite, arsenopyrite, Fe-rich sphalerite, galena, pyrrhotite, stibnite, molybdenite), sulfosalts (Ag-rich tetrahedrite, famatinite, bournonite, bismuthinite, cosalite, stannite), tellurides (hessite) and very minor oxides (magnetite). Bulk ore analyses are consistent with the ore mineralogy and show elevated content in Mo, Sn, Bi, Ag, Au, Te, Se and Hg in the ore. We suggest an intrusion-related origin for the Syros mineralization, assuming a buried Miocene porphyry Mo±Cu granitoid at depth, feeding the system with volatiles and metals. The magmatic-hydrothermal system evolved from a high temperature- towards lower temperature stage under generally reducing and low sulfidation conditions, as indicated by the presence of early arsenopyrite, pyrrhotite and Re-free molybdenite, and by late stibnite and Ag-sulfosalts. The Syros mineralization resembles other magmatic-hydrothermal systems in the Attic-Cycladic area as for example Lavrion deposit. Deformation and mineralization at Syros were contemporaneous and ore introduction took place during the semi-brittle to brittle deformation stage of the host rocksin the footwall of the low-angle Vari detachment fault.

Keywords: *detachment-related deposit, carbonate-replacement, molybdenite, Syros island*

Introduction

The island of Syros belongs to the Attic-Cycladic massif that includes various styles of mineral deposits (e.g. skarn, carbonate-replacement, porphyry, and epithermal-type) in Lavrion, South Evia, Mykonos, Tinos, Kythnos, Sifnos and Milos islands (Vavelidis 1997; Skarpelis 2002; Voudouris and Economou-Eliopoulos 2003; Tombros et al. 2004; Neubauer 2005; Voudouris et al. 2011). These deposits are genetically related to the emplacement of Oligocene-Miocene magmatic rocks in the Aegean region during the exhumation of metamorphic core complexes along large-scale detachment faults under an extensional tectonic regime (Skarpelis 2002, 2007; Neubauer 2005). On Syros Island metamorphic rock-hosted polymetallic sulfide deposits are firstly described by Melidonis and Constantinides (1983) mainly from the central and southern parts of the island. This study presents new geological, mineralogical and geochemical (bulk ore) data from the massive sulfide mineralization at Syros, aiming to investigate the mode of occurrence of metallic mineral assemblages in the deposits, as well as to discuss and interpret their formation by comparing them to other structurally controlled deposits in the Attic-Cycladic Zone.

Geology and Mineralization

Syros Island belongs to the Attic-Cycladic Zone, which has undergone a Late Cretaceous-Eocene deformation and eclogite/blueschist - facies metamorphism, followed by Late Oligocene to Miocene post-orogenic extension of the Aegean continental crust that was accompanied by exhumation of metamorphic core complexes, and by greenschist- to amphibolite-facies overprint of the high-pressure rocks (Altherr et al. 1982; Avigad and Garfunkel 1991; Jolivet et al. 2013). According to Soukis and Stockli (2013) southern Syros is characterized by the tectonic juxtaposition of three major tectonometamorphicunits along at least two detachment faults. From bottom to top these are (1) the Cycladic Blueschist Unit (CBU), (2) the tectonically overlying greenschist-facies UpperUnit, and (3) the Vari Unit, which is dominated by amphibolites and poly-deformed quartzofeldspathic gneisses. Structural- and new zircon and apatite (U–Th)/He data indicates that the observed tectonic configuration of SE Syros is theresult of multiple temporally distinct exhumation and unroofing episodes along three detachment faults (Soukis and Stockli 2013): (a) an early Miocene semi-brittle episodewhich juxtaposed Vari Unit and Upper Unit, (b) a major middle Miocene (~15–13 Ma) exhumation phase along the brittle Azolimnos detachment (now eroded) which rapidly exhumes Vari Unit and Upper Unit rocks, and (c) a late Miocene(~10–8 Ma) detachment faulting event along the brittle Vari Detachment, responsible for the tectonic juxtaposition of the CBU against the Upper Unit and the Vari Unit. Polymetallic ore deposits at Syros consist of massive and disseminated sulfides of Pb, Zn, Fe, Cu, Ag, Sb and Bi, as well as of highly oxidized gossan-type formations (Melidonis and Constantinides 1983; this study). The ores at Rozos, Tourlos and Azolimnos areasoccuralong the contacts between marbles and schists of the CBU, as carbonate-replacement bodies within marbles, along foliation planes of schists, and as veins crosscutting the above formations. Mineralization at Rozos and Tourlos is hosted in calc-schists and is probably controlled by the overlying (now eroded) Vari detachment fault (K. Soukis, pers. comm.). Pyrite and sphalerite accompanied by quartz gangue are the main metallic minerals in the carbonate-replacement bodies at Rozos and Tourlos area. In addition, epithermal style, banded quartz-chalcedony-carbonate veins with galena, pyrite and chalcopyrite crosscut marbles and schists at Tourlos. At Azolimnos, the mineralization is hosted within schists and marbles of the CBU adjacent to the Vari detachment fault. It consists of galena and sphalerite veins and breccias crosscutting Fe-oxide metasomatized marbles. Quartz and calcite are gangue minerals.

Methods

Twenty polished sections of sulfide mineralization were studied by optical microscopy and a JEOL JSM-5600 Scanning Electron Microscope equipped with an Oxford LinkISIS 300EDX microanalysis system, at the University of Athens, Department of Mineralogy and Petrology. Operating conditions were: accelerating voltage 20 kV, beam current 0.5 nA with a beam diameter of 1-2 μm. Two mineralized samples were analyzed for their trace element content by Aqua Regia digestion with Ultratrace ICP-MS analysis at ACME analytical laboratories (Vancouver, Canada).

Results

The mineralization features a polymetallic assemblage that includes sulfides, sulfosalts and minor oxides. The following metallic minerals are recognized: pyrite, arsenopyrite, sphalerite, magnetite, pyrrhotite, galena, chalcopyrite, molybdenite, stibnite, tetrahedrite, bournonite and famatinite. Molybdenite, stibnite, tetrahedrite, bournonite and famatinite are reported for the first time at Syros. At Rozos area, paragenetially early pyrite includes sapatite, molybdenite, galena, magnetite and rutile and is surrounded by sphalerite (Fig. 1a). Arsenopyrite is intergrown with pyrite. Sphalerite is Fe-rich (16.7-19.8 mol % FeS) and includes pyrrhotite and galena. Re-free molybdenite appears as small-sized lath-shaped crystals (up to 30 μm), enclosed within pyrite ands sphalerite (Figs. 1a and 2a). Galena is present in all mineralized areas (e.g. Rozos, Tourlos and Azolimnos) and is Bi, Ag and Sb free. In oxidized samples from Rozos area galena accompanies stibnite (up to 20 μm subhedral crystals)in goethite cavities probably suggesting a renewed hydrothermal event after supergene oxidation (Fig. 1b). At Azolimnos area, galena is the main oremineral, including tetrahedrite, famatinite and bournonite (Fig. 1c). Two groups of tetrahedrite were recognized at Azolimnos, both included in galena: (1) Cadmian (up to 5.7

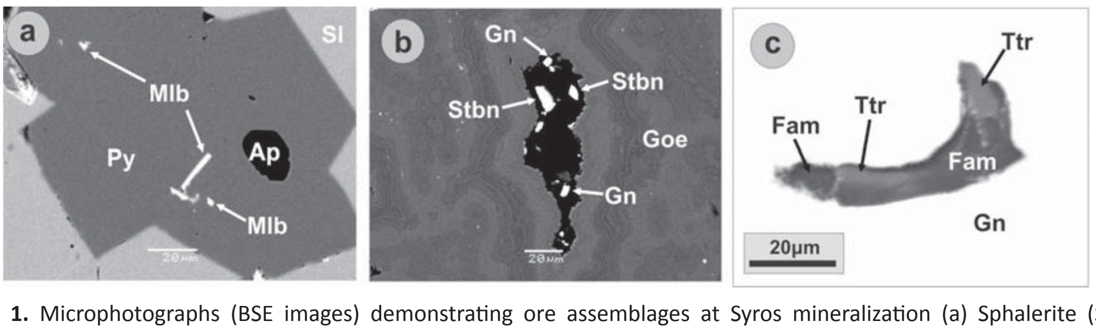

Figure 1. Microphotographs (BSE images) demonstrating ore assemblages at Syros mineralization (a) Sphalerite (Sl) surrounding pyrite (Py), which includes molybdenite (Mlb) and apatite (Ap), sample SYR1, Rozos area; (b) Galena (Gn) and stibnite (Stbn) in geothitic (Goe) ore, Sample SYR1, Rozos area; (c) Famatinite (Fam) and tetrahedrite (Ttr) within galena (Gn), sample SYR3, Azolimnos area.

wt.% Cd), Plumbian (up to 10.6 wt.% Pb) and argentian (up to 18.7 wt.% Ag) tetrahedrite, which are depleted in Fe and Zn, and (2) zincian (up to 7.6 wt.% Zn) tetrahedrite, with Ag up to 4.4 wt.% and no Cd and Pb (Fig. 2b). Famatinite with minor As-content (up to 0.3 wt.%) and bournonite are almost stochiometric and appear closely related to tetrahedrite as inclusions within galena (Fig. 1c). Trace-element analysis for the SYR1 sample from Rozos (Table 1) shows relatively high concentrations of As (presence of arsenopyrite), Sn (23.4 ppm) and In (5.8 ppm) indicating the presence of Sn-In bearing minerals. Although Mo is low (<1 ppm) molybdenite is present in the ore. The sample SYR3 from Azolimnos shows high concentration of Mo (5.9 ppm), Au (1.2 ppm), Hg (>50 ppm), Te (2 ppm), Se (3.3 ppm), Bi (6.3 ppm) and Ag (>100 ppm) suggesting the presence of tellurides and bismuth sulfosalts in the ore (see below). Elevated Ag content is attributed to the presence of Ag-rich tetrahedrite.

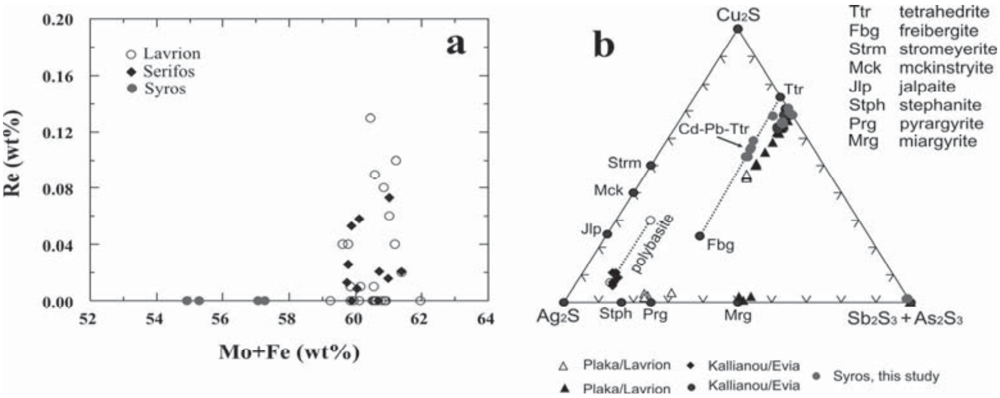

Figure 2. (a) Binary diagram Re vs (Mo+Fe) showing the absence of Reinmolybdenite at Syros. Molybdenite from Lavrio and Serifos deposits are plotted for comparison (from Voudouris et al. 2010); (b) Ternary Cu-Ag-(Sb+As) diagram demonstrating compositions of tetrahedrite and stibnite analyzed in the present study. Tetrahedrite and other silver-bearing minerals from Lavrion and Eviaare plotted for comparison.

Table 1. ICP-MS bulk ore analyses from two mineralized samples from Syros (Au in ppb, Pb and Zn in wt.%, the rest elements in ppm). SYR1: Rozos area, SYR3: Azolimnos area. b.d.: below detection.

Sample	Mo	Cu	Ag	As	Au	Sb	Bi	Hg	Se	Te	Sn	In	Pb	Zn
SYR1	0.76	191.1	25.9	6360	11.6	51.8	0.71	b.d.	1.4	0.03	23.4	5.81	0.86	>1%
SYR3	5.93	2606	>100	262.6	1191	1824	6.34	>50	3.3	2	<0.1	0.36	>1%	>1%

Discussion–Conclusions

Mineralogical and geochemical data from this study (presence of molybdenite and elevated Mo, Bi, Sn, Te, Au content in the ore) combined with previous mineralogical results (e.g. the presence of Bi-bearing minerals, cosalite and bismuthinite, the Sn-bearing mineral stannite, and the telluride hessite; Melidonis and Constantinides 1983), are consistent with a magmatic-hydrothermal origin of the mineralization at Syros. High-temperature hydrothermal fluids (as indicated by the presence of molybdenite) were released from a concealed porphyry Mo±Cu mineralized body beneath the southern part of the Island, penetrating marbles and schists and depositing ores in a manner similarly to Lavrion deposit. On the absence of radiometric data the age of mineralization is not known, however we suggest it to be contemporaneous to thelate Miocene (~10–8 Ma) detachment faulting event along thebrittle Vari Detachment. Both Rozos-Tourlos and Azolimnos mineralization evolved from a high-temperature magmatic-hydrothermal stage (as indicated by the presence of pyrite-arsenopyrite, molybdenite, cosalite and bismuthinite) towards lower temperature, epithermal conditions (presence of epithermal-style veins, stibnite, and tetrahedrite, famatinite exsolved in galena). The mineralogic data suggest ore deposition from generally reducing fluids under low sulfidation states (e.g. presence of arsenopyrite, Fe-rich sphalerite, Re-free molybdenite; e.g. Voudouris et al. 2010), however the presence of tetrahedrite-famatinite in some ore suggest fluctuations in fluid sulfidation states as described from Lavrion deposit (Voudouris and Economou-Eliopoulos 2003; Bonsall et al. 2011). Textural observations indicate that ore introduction took placeduring the semi-brittle to brittle deformation stage of the host rocks in the footwall of the low-angle Vari detachement fault.

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Silver-rich sulfide mineralization at Vani, western Milos Island, Greece: New mineralogical evidence for epithermal ore deposition in a shallow submarine environment

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Abstract

The Vani Ag prospect is a high-grade epithermal mineralization located along the NW-trending Kondaros-Katsimouti-Vani fault, NW Milos Island, Greece. The prospect is hosted in calc-alkaline dacite domes and volcaniclastic sandstones and represents the NW extension of the Pb-Zn-Ag-Mn Katsimoutis-Kondaros mineralization. It occurs proximal to the Vani exhalative manganese deposit. The Ag content of the prospect is derived from Ag-bearing phases (native silver, argentite/acanthite, silver halides and argentian covellite). Mineralogical evidence like the presence of skeletal habits of sulfides, presence of hydrothermal anglesite, covellite and silver halides that were formed after dissolution of the primary silver and lead-bearing minerals, verifies earlier work that mineralization along the Kondaros-Katsimoutis fault is the product of seawater oxidation and was formed in a submarine setting after reaction of hydrothermal fluids with seawater.

Keywords: *Silver mineralogy, shallow submarine epithermal, seawater oxidation, Milos Island, Vani*

Introduction

Milos Island is one of the most densely mineralized areas in Greece, characterized by epithermal Au-Ag and base metal deposition within a Plio-Pleistocene volcanic edifice. Metallic mineralization on Milos was the subject of several mineralogical and geochemical studies, with base- and precious metal mineralization in western Milos Island having been classified as either Kuroko- (Hauck 1988; Vavelidis and Melfos 1998), seawater-dominated epithermal (Kilias et al. 2001; Liakopoulos et al. 2001; Marchik et al. 2010), shallow submarine epithermal- (Alfieris 2006; Stewart and McPhie 2006; Alfieris et al. 2013), or hybrid volcanogenic massive sulfide (VMS)-epithermal types (Naden et al. 2005). A modern analogue for the setting of epithermal - style mineralization in western Milos is the shallow submarine Kolumbo hydrothermal vent field located 7 km NE of Santorini Island in the Hellenic arc (Kilias et al. 2013). In a previous work, Alfieris and Voudouris (2005) described base metal and Ag-bearing epithermal mineralization along the NW-trending Kondaros-Katsimouti fault (Fig. 1a). This vein-system extends NW towards Cape Vani, where epithermal banded quartz - chalcedony - barite - Mn - Fe veins form a feeder zone to the Vani stratiform Mn - Ba - Pb - Zn mineralization (Alfieris and Voudouris 2005). It is suggested that the Kondaros-Vani fault, played a major role in the formation of the Vani manganese deposit, since manganese deposition represents the final hydrothermal manifestation of the major Pb-Zn-Ag±Cu±Mn Katsimoutis-Kondaros epithermal system, and that the latter represents the sub-seafloor feeder zones of the stratiform Mn - Ba - Pb - Zn deposit that formed on the sea floor at Cape Vani (Alfieris and Voudouris 2005). The aim of the current study is to present a new high-grade Ag mineralization close to Vani, to describe its mineralogical characteristics and discuss the role of seawater oxidation in its formation by comparing it with other mineralized areas in western Milos and elsewhere.

Geology and Mineralization

Milos Island is located in the central part of the L. Pliocene to Recent South Aegean Active Volcanic Arc (Fytikas et al. 1986). Calc-alkaline volcanic activity in western Milos spans a period from ~3.5 Ma to the present and originated from several emergent eruptive centers (Fytikas et al. 1986; Alfieris 2006; Stewart and McPhie 2006; Alfieris et al. 2013). The main volcanic units are: L. to U. Pliocene submarine acid pyroclastic rocks, U. Pliocene to L. Pleistocene transitional pyroclastic rocks, pumice flows and dacitic-andesitic flow domes and lavas, and L. Pleistocene submarine or subaerial acid subvolcanic rocks. Miocene to Pliocene extensional tectonics resulted in four main fault trends: NW–SE, N-S, NE-SW and a E-W trend. The Vani Agprospect is located along the NW-trending Kondaros-Vanifault and occurs proximal to the Vani manganese deposit. The mineralization is hosted within propylitically and argillically altered dacitic flow dome and volcaniclastic sandstone andshows features typical of low-intermediate sulfidation deposits like colloform banding and brecciation (Fig. 1b,c). The mineralized system consists of banded veins and stockworks, including alternating bands of quartz-chalcedony containing base metals sulfides withearly deposition of Fe-poor sphalerite (<0.7 wt.% Fe), followed by galena and then by argentite/acanthite and native silver. Galena occurs either as isolated skeletal grains or rimmed by argentite/acanthite (Fig. 2a,b). Native silver occurs in grains up to 3mm isolated in the quartz matrix (Fig. 1c) or is replaced by bromianchlorargyrite (Fig. 2c). Br ranging from 0.15 to 0.31 apfu replaces Cl in the structural formula. The silver halide is intergrown with quartz and calcite, suggesting its primary hydrothermal origin (Fig. 2c). Argentite or its lower temperature polymorph acanthite forms either monomineralic grains (often in skeletal form) within the quartz matrix or included in anglesite (Fig. 2a,b,d). It contains up to 6 wt.% Cu (cuprian

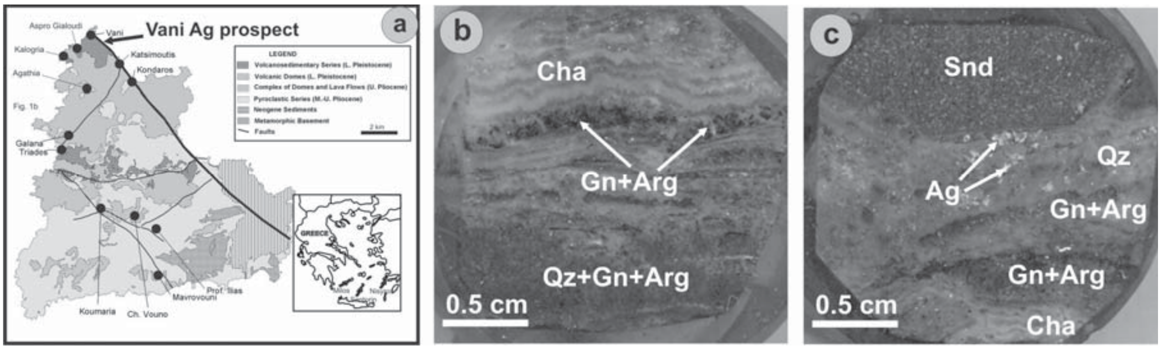

Figure 1. (a) Simplified geological map of western Milos showing the location of the Vani Ag prospect and other base and precious metal deposits (after Alfieris and Voudouris 2005); (b,c) Handspecimens showing alternating bands of black massive silica with galena and argentite (Qz+Gn+Arg), chalcedony (Cha) and galena-argentite (Gn+Arg). Native silver (Ag) occurs disseminated within quartz (Qz). Sandstone (Snd) with hematite contains disseminated mineralization.

and Ag-bearing phases, Fe-Mn oxides, barite and calcite.

Methods

Twenty polished sections of sulfide mineralization were studied by optical microscopy and a JEOL JSM-5600 Scanning Electron Microscope equipped with an Oxford LinkISIS 300EDX microanalysis system, at the University of Athens, Department of Mineralogy and Petrology. Operating conditions were: accelerating voltage 20 kV, beam current 0.5 nA with a beam diameter of 1-2 μm.

Results

The metallic mineral assemblages at the Vani Ag prospect consist of sulfides (pyrite, covellite, chalcocite, galena, sphalerite, bornite, argentite/acanthite), oxides (hematite), silver halides (bromianchlorargyrite) and native metals (Ag). Deposition took place in several alternating pulses, argentite; Fig. 1e). Anglesite is present either as isolated grains in the quartz matrix (without any contact to galena) or usually enclosing galena butwith a rim of argentite/acanthite separating anglesite from galena. These observations suggest that anglesite is of hydrothermal origin (see discussion). Hypogeneargentiancovellite (with up to 10.3 wt.% Ag) is associated with argentite (Fig. 2d). Hematite is very common in the ore either in well-shaped crystals or in framboidal form.

Discussion - Conclusions

Alfieris et al. (2013) listed a number of mineralogical characteristics indicative that the western Milos deposits might have formed under shallow submarine to subaerial conditions as suggested by Naden et al. (2005): (a) Cu-sulfides that replaced chalcopyrite at the deeper levels of Profitis Ilias deposit that were likely formed during the combined action of seawater oxidation of chalcopyrite and late-stage hydrothermal pulses,

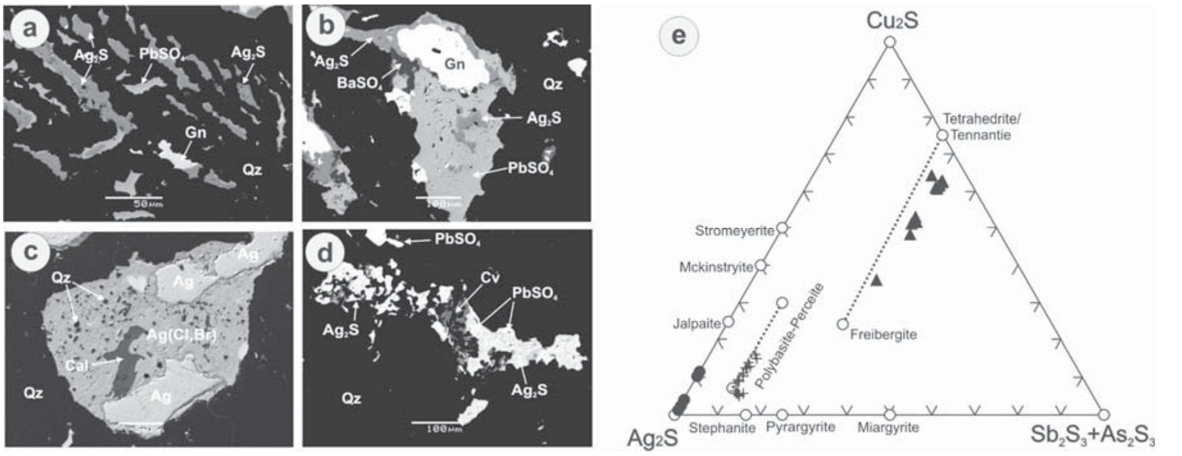

Figure 2. (a to d) Microphotographs(BSE images)demonstrating ore assemblages at Vani Agmineralization: (a) Skeletal-shaped galena (Gn), argentite (Ag_2S) and hypogene anglesite ($PbSO_4$) in quartz (Qz) matrix); (b,c) Galena (Gn) is surrounded by argentite (Ag_2S) and then by anglesite. Barite ($BaSO_4$) and quartz (Qz) are gangue minerals; (d) Anglesite and covellite (Cv) associated with argentite; (e) Chemical composition of Ag-bearing sulfosalts in terms of the Ag-Cu-(Sb+As) ternary diagram (after Alfieris et al. 2013). Theoretical compositions are shown as open circles. Filled circles (this study), triangles represent composition of the tetrahedrite-group minerals andcrosses are compositions of polybasite-pearceite from Kontaros-Katsimouti. Compositional ranges of tetrahedrite-freibergite and polybasite solid solution are shown by dashed lines for reference.

(b) presence of atacamite and silver halogenides (e.g. chlorargyrite, iodargyrite), in the upper part of ProfitisIlias, (c) presence of framboidal pyrite, (d) skeletal intergrowths of sphalerite, pyrite and galena at Kondaros-Katsimoutis, (e) high abundance of stratiform and vein-type barite; and (f) the presence of aragonite at Kondaros-Katsimoutis.

This study presents additional mineralogical criteria, which demonstrate that the Vani Ag prospect was deposited under shallow submarine epithermal conditionswithseawater involvement in the system. The exact temperature of ore formation at Vani Ag prospect is not known bcause of the absence of fluid inclusion data. However, chalcedonic silica in the system is suggestive of temperatures <180 °C (Fournier 1985). These temperatures are intermediate between those suggested by Alfieris et al. (2013) for Katsimoutis-Kondaros ores (e.g. ~230 °C) and the 100 °C considered on the base of fluid inclusion data for manganese ore deposition at Vani (Kilias et al. 2007). Mineralogical information (presence of adularia at Kondaros-Katsimouti) and fluid includion data suggest boiling conditions along the Kondaros-Katsimouti-Vani hydrothermal system. For the Vani manganese deposit extreme boiling of seawater and seafloor exhalative hydrothermal activity around 100 °C and mixing of seawater either with condensed boiled-off vapor or heated meteoric water is suggested by Kilias et al. (2007).

At the Vani Ag prospect, interaction of primary sulfides and native elements with oxidized seawater resulted in the formation of anglesite and of silver halides replacing galena and native silver respectively, in a manner similar to that described for Profitis Ilias by Alfieris et al. (2013). The skeletalform of galena and argentitein the studied material suggests very rapid precipitation from mineralized plumes discharging immediately below, or on the seafloor (e.g. Tivey et al. 1995). Polybasite, pearceite, pyrargyrite, argentiantetrahedrite and freibergite are the main silver minerals at Kondaros-Katsimoutis mineralization, where small exsolved grains within galena predominate (Alfieris et al. 2013). However, they are absent at Vani Ag mineralization, which is highly enriched in native silver and argentite. The Vani Ag prospect represents a higher exposed level in the system than Kondaros-Katsimouti ores, which are mainly enriched in base metals. This vertical metal zonation within the Kondaros-Katsimouti-Vani mineralized system resembles other epithermal Ag deposits elsewhere as for example Pachuca Real del Monte, Mexico (Dreier 2005).

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Ukrainian part of the Upper Jurassic reef belt of Europe and correlation with adjacent regions

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Abstract

The Upper Jurassic reef belt, formed in northern periphery of Tethys and widespread in Europe, extends over area of Ukraine and further to the Caucasus. Comparison of reef facies of the Upper Jurassic in the Carpathians, Precarpathian, Predobrogea, Crimea and the Caucasus has shown that most completely carbonate shelf facies of North Tethys province are represented in Ukrainian Precarpathian. Oxfordian bioherms are present in all regions except the northern part of Western Ukraine. Tithonian-Berriasian barrier reef is fixed in Ukrainian Precarpathian, in the Crimea, in the North Caucasus. In the Western Carpathians predominantly pelagic facies are present, and in the Polish Precarpathian, Predobrogea and Caucasus reef and peripheral facies are more common. Upper Jurassic sediments are significantly eroded in the north-west of Ukraine, Belarus and Poland.

Key words: *Upper Jurassic, Ukraine, reefs, facies, correlation*

Introduction

The Upper Jurassic reef belt, formed in northern periphery of Tethys and widespread in Western Europe (Wilson 1975, etc.), extends over area of Ukraine (Carpathian region, Predobrogea, Crimea) and further to the Caucasus. Our research has allowed carry out the correlation of these formations within Ukraine and with adjacent territories.

Materials and methods

In the west of Ukraine the Upper Jurassic reef sediments outcrop in the Folded Carpathians and Volyno-Podillya and were opened by the wells in the Transcarpathian depression, Carpathian Foredeep and adjacent part of the East-European platform. In the south of Ukraine these deposits in large-scale outcrop in the Crimean Mountains and were opened by drilling in the Southeastern Crimea, Predobrogea, and continue to adjacent territory of Moldova.

We have conducted a complex study of materials of drilling and natural sections of these deposits having used biostratigraphical, lithologic-sedimentary, microfossils and microfacies analysis having taken into account results petrographic, paleontological and geophysical studies fulfilled by other experts. The correlation of these deposits with similar formations in Poland, Belarus and the Caucasus have been carried out using the literary data.

Discussion and Results

The Upper Jurassic deposits in the regions studied were formed in a common North Tethys paleobasin that predetermined their similarity in lithology and fossil characteristics. In Ukrainian Precarpathians there are all facies of reef complex. In the Western Carpathians there are mainly pelagic facies, and in the Polish Precarpathians, Predobrogea depression and the Caucasus reef and peripheral deposits are more usual. The Upper Jurassic sediments are considerably eroded in the north-west of Ukraine, Belarus and Poland. Complex tectonic dislocations caused fragmentary occurrence of deposits in the Carpathians and allochthonous position of most sections in the Crimea. Analysis of facial composition of these deposits has allowed identifying the main criteria for their correlation.

Carpathian region. In Ukrainian Precarpathian Upper Jurassic and Lower Cretaceous sediments (Oxfordian-Lower Valanginian) compose a common complex of carbonate rocks genetically related to reef-building processes taken place during Late Jurassic and Early Berriasian (Zhabina and Anikeyeva 2007). Reef zone extends as submeridional stripe to 100 km long and 11 km width. The Oxfordian reefs were separate buildups (to 145 m thick), built by sponges at the bottom and by corals and algae above. At the top they are overlapped by the oncolitic limestones. Deposits between bioherms are composed by bioclastic, biomicritic, sandy and brecciated limestones interbedded with siltstones and breccias. Kimmeridgian reef facies is represented by the succession of biomicritic and bioclastic limestones (to 450 m thick), with algal-sponge bioherms (10–70 m) at different levels. In Tithonian-Early Berriasian a barrier reef which created by corals, sponges, algae, bryozoans, stromatopores was formed. To the west the reef facies are replaced by fore-reef ones – biomicritic and bioclastic limestones, limestone breccia, mudstones, siltstones, sandstones, cherts. To the east reef facies are replaced by back-reef shallow-water limestones (bioclastic, biomicritic, oncoidal) and dolomites. At that time in the back-reef zone along the barrier reef small mollusk-algal bioherms were formed. In the Lower Kimmeridgian carbonate back-reef facies are replaced to the east by the evaporite lagoon sediments – dolomites, anhydrites, gypsum, mudstones, siltstones, sandstones and breccias. The upper part of carbonate complex in Precarpathian was considerably eroded.

In Ukrainian Carpathians Upper Tithonian-Lower Berriasian rocks occur in allochthonous bedding as parts of olistolites in Pieninian and Marmarosh zones. In Pieninian zone they are represented by silicified limestones with interlayers of silicified argillites of fore-reef facies. In Marmarosh massif Upper Jurassic is represented by deep-water limestones with crinoideas, jaspers with radiolarians, siliceous shales, sandstones, mudstones, conglomerates, breccias or bioclastic limestones situated among the volcanic rocks.

In Transcarpathian depression there are fore-reef facies of Upper Tithonian–Lower Berriasian: bioclastic limestones and marls with numerous calpionellids, and also sandstones, mudstones, siltstones.

Kovel ledge. In the Northwestern Ukraine, in the area of the Shatsk Lakes the Upper Jurassic deposits are also greatly eroded. There are only shallow-water bioclastic limestones and calcareous sandstones of Oxfordian (Havrylyshyn 1993), which may be juxtaposed with Oxfordian back-reef facies of Ukrainian Precarpathian.

In Belarus the Upper Jurassic carbonate formations are Oxfordian - Lower Kimmeridgian and also were significantly eroded. These Oxfordian bioherms are similar to those of reef belt in Precarpathian and are represented by bioclastic and silicified limestones and spongolites of Lower Oxfordian, silicified partly limestones of Middle Oxfordian and coral and sponge limestones of Upper Oxfordian (in the west). Marine sediments of Lower Kimmeridgian are distinguished conditionally (Akimets and Karimova 2005).

Poland. Farther to the west the Upper Jurassic reef complex extends to the Poland Carpathians (Niemczycka et al. 1997). Reef facies are represented by Oxfordian buildups (up to 200 m thick), formed by siliceous sponges and serpulids at the bottom and coral colonies above. At the top they are also overlapped by the oncolitic limestones. They are among limestone-marl deposits to the south of Olsztyn–Poznan line. The series of sponge, sponge-coral, bioclastic silicified limestones are known in area Yarchuv-Narol-Ciechanow. At the south (near Krakow) the Oxfordian reef facies are replaced by thickness of saccocoma-peloidal calcarenites (with radiolarians) interbedded with cherts, dolomites, blocks of sponge limestones. This succession is similar to fore-reef facies in Ukrainian Precarpathian. To the east (behind Warsaw) there are shallow-water and lagoon deposits: terrigenous formations of lower Oxfordian (Lublin area), oolitic and micritic limestones of Middle and Upper Oxfordian. Kimmeridgian deposits in Poland are considerably eroded and represented by back-reef bioclastic limestones (to the south of the Olsztyn–Poznan line) and lagoon dolomites and anhydrites (south of Lublin area). The Lower Kimmeridgian shell limestones, limestones and marls of Eastern Poland correspond to Lower Kimmeridgian back-reef facies of Ukrainian Precarpathian. In the Southeast of Lublin area there are lagoon deposits of Lower Kimmeridgian, similar to the lagoon-evaporite facies of Ukrainian Precarpathian. Upper Kimmeridgian bioclastic limestones and dolomites in Southern and Eastern Poland are similar to Upper Kimmeridgian back-reef facies of Ukrainian Precarpathian. In Lublin area they are replaced by the dolomite-anhydrite complex (absent in Ukrainian Precarpathians).

Tithonian deposits in Poland are eroded even more. In Lublin area they are represented by the shallow-water oncolitic limestones of Lower

Tithonian (similar to back-reef facies of Ukrainian Precarpathians), and in the area from Poznan to Olsztyn - by lagoon-evaporite deposits. In Southern Poland (near Zagortsushe) there are sediments of open carbonate shelf (dolomites, limestones and marls with dinocyst and tintinnids) (Tithonian – Lower Berriasian), similar to fore-reef facies of Ukrainian Precarpathian.

Thus, the Upper Jurassic carbonate complex in Poland is similar to reef formations in Western Ukraine. Unlike sections of Ukrainian Precarpathians they are greatly eroded, there are not revealed reef facies of Kimmeridgian and Tithonian and Kimmeridgian fore-reef facies; and lagoon-evaporite facies are represented in all units of the Upper Jurassic.

In Predobrogea (Ukraine and Moldova) reef zone of the Upper Jurassic extends along the southeastern edge of Predobrogea depression and are represented by coral bioherms (Middle-Upper Oxfordian) (Leshukh et al. 1999). In southeast of depression Oxfordian pelagic sediments are limestones with clays interbedded; in central part they are limestones and marls interbedded with mudstones (Lower Oxfordian), in central and western parts they are clays with siltstones, sandstones, limestones (Middle-Upper Oxfordian). In the south and east of the depression there are back-reef and lagoon facies of Middle-Upper Oxfordian (limestones interbedded with sandstones, siltstones, dolomites and gypsum).

Kimmeridgian deposits are represented mainly lagoon-evaporite strata (anhydrite, gypsum, halite). In the western and central parts of the depression there are carbonate rocks (limestones, marls, dolomites), in the north predominate terrigenous rocks (conglomerates, sandstones, siltstones, mudstones).

Tithonian deposits are lagoon facies – shales, siltstones, sandstones, gravelites, interbedded with anhydrite and gipsum. Only in the central part of the basin there are back-reef limestones of Tithonian-Berriasian.

Thus, in Predobrogea are distributed mainly shallow-water facies, the reef zone are identified only in Oxfordian.

Crimea. Upper Jurassic deposits in Crimea are represented mainly by reef facies (Leshukh et al. 1999; Zhabina and Anikeyeva 2007, 2009). They are parts of olistolites of Massandra, Gornokrymean and Yayla olistostromes which outcrop in the Crimea Mountains (Yudin 2000) and are also opened by wells in the Southeastern Crimea.

Reef facies are represented by Lower Oxfordian reefs and bioherms (eastern Mount Crimea), Middle-Upper Oxfordian coral-algal bioherms with oncolitic limestones on the top, Lower Tithonian reef limestones (Mount Ay-Petri), Upper Tithonian-Lower Berriasian bioherms (west) and Upper Tithonian-Lower Berriasian coral reefs (Southeastern Crimea).

In Oxfordian deposits there are back-reef, nearshore and evaporite facies. Lower Oxfordian is composed by back-reef algal sandy limestones interbedded with conglomerates in the western Mountain Crimea, In the east it is represented by back-reef fine-grained limestones with interbedded sandstones and clays or shallow nearshore succession of gravelites, conglomerates, sandstones, siltstones, limestones. Middle Oxfordian-Lower Kimmeridgian facies are back-reef algal, bioclastic limestones with small coral-algal bioherms (western part) and nearshore formations of clays and sandstones (eastern part). Lagoon deposits are known only in the Upper Oxfordian (layer of gypsum in conglomerates at Mount Kyrchug (Borisenko et al. 1974). Oxfordian bioherm sediments are overlapped by Kimmeridgian fore-reef succession of open shelf limestones (Iograf ridge).

In Lower Tithonian there are back-reef facies – oncoidal, biomicritic, micritic limestones of Yayla and nearshore successions of gravelites, sandstones, clays and limestones in the eastern Mountain Crimea. Upper Tithonian-Lower Berriasian back-reef deposits in Southeastern Crimea are represented by oncolitic, bioclastic and biomicritic limestones and marls with interbedded mudstones. Fore-reef facies of Tithonian are known in the west (flish-like interbedded clays and bioclastic limestones with limestone packs), Upper Tithonian-Lower Berriasian ones – limestones interbedded with mudstones in the Southeastern Crimea.

In general outline the Crimean Upper Jurassic facies are similar those of the Carpathian region. However, there are some differences: the whole vertical zonation of Oxfordian bioherms isn't observed; evaporites of Kimmeridgian and Tithonian are absent, there is high content of terrigenous component in reef deposits: in Oxfordian terrigenous successions with lenses and interbedded limestones predominate, Kimmeridgian and Tithonian complexes in some areas are composed by terrigenous rocks only. It is characteristic for the Crimean region significant thicknesses of reef sediments: Oxfordian buildups are more than 500 m thick, and their host successions - up to 2000 m. In addition, in Crimean deposits there is not traced the whole reef facial pattern because of the strong tectonic disturbance of the region.

In the Caucasus in Upper Jurassic carbonate complex there are reef, fore-reef, back-reef and lagoon-evaporite deposits (Thodria 1988).

The Oxfordian – Tithonian barrier reef extends in the Northern Caucasus along the northern periphery of the Georgian block.

Back-reef facies of Oxfordian are in the Northern Caucasus (limestones, dolomites, in the east sandstones and marls); shallow-water deposits are known in Georgia (sand-clay formation, calcareous sandstones and sandy limestones). Back-reef Kimmeridgian and Tithonian deposits (mainly bioclastic limestones, also oncoidal in Tithonian) spread in the North Caucasus.

Nearshore and lagoon sediments are represented in Western Georgia (Kimmeridgian-Tithonian) and in the east of the Northern Caucasus (Tithonian); they are predominantly variegated carbonate-siliciclastic successions with layers of anhydrite, gypsum and halite.

Oxfordian-Tithonian fore-reef facies extend to the east of the Northern Caucasus and in the Northwest of Abkhazia.

Thus, by the composition of reef facies the Upper Jurassic complexes of Caucasus and Carpathian regions are similar, but differ by the presense of evaporites of Upper Kimmeridgian and Tithonian in the Caucasus.

Conclusions

Comparison of reef facies of the Upper Jurassic in the Carpathians, Precarpathian, Predobrogea, Crimea and the Caucasus has shown that most completely carbonate shelf facies of North Tethys province are represented in Ukrainian Precarpathian. Oxfordian bioherms are present in all regions except the northern part of Western Ukraine. Tithonian-Berriasian barrier reef is fixed in Ukrainian Precarpathian, in the Crimea, in the North Caucasus. In the Western Carpathians predominantly pelagic facies are present, and in the Polish Precarpathian, Predobrogea and Caucasus reef and peripheral facies are more common. Upper Jurassic sediments are significantly eroded in the north-west of Ukraine, Belarus and Poland. Primordial structure of the reef belt was significantly deformed by succeeding tectonic dislocations.

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Geochronological and geochemical studies on crystalline rocks from the central Serbo-Macedonian massif with implications on its pre-Alpine evolution

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Abstract

The Serbo-Macedonian Massif (SMM) represents a composite crystalline terrane situated between the two diverging branches of the Eastern Mediterranean Alpine orogenic system, the northeast-vergent Carpatho-Balkanides and the southwest-vergent Dinarides and the Hellenides. It is outcropping from the Pannonian basin in the north, to the Aegean Sea in the south, along the central and southeastern Serbia, southwestern Bulgaria, eastern Macedonia and central Greece. Its affiliation to European and/or African plate basement is still questionable due to the lack of reliable geochronological data and a detailed structural investigations. The SMM is the key area for understanding the bipolarity of the Alpine orogenic system, as well as the interaction of the Pannonian and Aegean back-arc extension during the Cenozoic time.

The SMM is traditionally considered to comprise an Upper (low-grade) and a Lower (medium to high-grade) unit. The protoliths of both units are reported as volcano-sedimentary successions, which have been intruded by magmatic rocks during several pulses. Here we present the results of our four-year project aimed at discerning the main magmatic episodes and the geodynamic evolution of the SMM and its environs. In order to obtain the protolith ages, LA-ICP-MS analyses were carried out on zircon grains from 24 ortho- and para-metamorphics as well as undeformed igneous rocks. Additionally, we were able to constrain the geotectonic settings of formation for the total of 30 whole-rock samples by obtaining the main oxide and trace element measurements.

The new geochronological constraints coupled with the field evidence, allowed us to conclude: a) The Lower complex of the SMM consists of Cadomian (569-558 Ma) volcano-sedimentary sequences and magmatics, which were consequently intruded by igneous rocks from late Cambrian to Early Silurian (528-439 Ma); b) The Upper SMM (i.e. Vlasina or Morava unit) represents a volcano-sedimentary sequence, which is intruded by the Cadomian (562-550 Ma) and Cambrian (521 ± 4 Ma) magmatic rocks; c) No evidence of Ordovician and Silurian magmatism in the Upper complex were revealed by our research; d) The Upper complex is structurally overlain by a deformed Silurian-Devonian sedimentary sequence; e) Additional pulses of magmatism, represented by Carboniferous (328-304 Ma), and late Permian (255-253 Ma) weakly deformed rocks constrain the lowest age for the penetrative high-strain ductile deformation. This conclusion is in accord with the reports from the Lower complex in Bulgaria (i.e. the Ograzhden block); and f) The youngest magmatic event in the SMM recorded by our study took place in the late Eocene (35-32 Ma) related to the intrusion of Surdulica granodiorite and associated latitic volcanism. However, even younger (Oligocene to Quarternary) volcanic activity is known at periphery of the SMM.

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On the age of the Carpathian-Balkan pre-Alpine ophiolites in SW Romania NE Serbia and NW Bulgaria

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Abstract

Following the separation in the Romanian South Carpathians by Murgoci (1905) of a Cretaceous great "Getic" nappe and an autochthonous unit, Codarcea (1940) named the autochthonous, "Danubian" and described on top of the Danubian sedimentary cover, the Severin nappe. "Getic domain" and "Danubian domain" was designated for the origin of this Cretaceous great nappe and autochthonous, respectively (Codarcea 1940). The Severin oceanic realm of Jurassic age was placed in between these two continental blocks. As for the Mesozoic formations, it was emphasized on the absence of the Trias on the Danubian domain in contrast with its ubiquitous appearance on the Getic domain. Furthermore, within the Danubian domain pre-Alpine basement, basic-ultrabasic rock-bodies were figured (i.e. Plavişeviţa and Iuţi mafic-ultramafic complexes; Codarcea 1940).
The intense mapping activities carried out during the second half of the XX century unraveled the Alpine nappe structure of both, the Getic and Danubian domains in the South Carpathians. As for the mafic-ultramafic complexes, they could presumably mark the trace of a Variscan intra-Danubian suture. Beside these complexes, the suture includes also at least the Deli Jovan basic-ultrabasic massif in Serbia.
An extended model for the Carpathian-Balkan region developed by Haydoutov (1989), comprises two pre-Alpine continental blocks (i.e. Moesian platform and Thracian continental fragment) separated by the so-called Thracian Variscan suture. The Thracian continental block comprises the Rhodopes,the Serbo-Macedonian massifs and the Getic domain of the Romanian South Carpathians, while the Serbian and the Bulgarian territories between Moesia, Rhodope and Serbo-Macedonian massifs represent the elements of the Thracian suture, which includes also the Danubian domain. These elements of the Thracian suture are represented by the late-Proterozoic Balkan ophiolites (Tcherni Vrah, Zaglavak, Deli Jovan and Tisoviţa-Iuţi fragments), covered by the Cambrian Berkovitsa island arcassociation. The ophiolite-island arc association was obducted over the Moesian platform margin during the early-Ordovician time, yet its original birth place closed only during the Variscan orogeny. The timing in this model is based on the presence of an early Cambrian Archaeocyathus, reported by Kalenic (1966), in a carbonate level overlying the Deli Jovan massif, and attributed to the Berkovitsa Group.
Latter, Haydoutov and Yanev (1997) slightly modified the previous model, by recognition of the Protomoesian and Thracian micro-continents. The Protomoesian microcontinent consists of the Balkan and Moesian terranes amalgamated after the early-Carboniferous time. The ophiolites from the Balkan-South Carpathians chain, together with the island arc association as part of the Balkan terrane are called the "Balkan assemblage".
The model of Haydoutov and Yanev (1997) was further encouraged by an U/Pb Concordia upper intercept age of 563.7 ± 5 Ma, on a sample from the Tcherni Vrah gabbro (von Quad et al. 1998). This age was extensively used, with minor changes, for further interpretations (e.g. Savov et al. 2001; Yanev et al. 2005; Haydoutov et al. 2010; Kounov et al. 2012).
Since 1998, the geochronology of the Balkan-South Carpathian pre-Alpine ophiolitic complex advanced, and new ages certify the Devonian age. Zakariadze et al. (2006) reported from the Deli Jovan fresh gabrro samples, a U/Pb SHRIMP zircon age of 405 ± 2.6 Ma, a U/Pb lower Concordia intercept age of 399.7 ± 5.2 Ma and a Sm/Nd isochron age of 406 ± 24 Ma. Plissart (2012) dated using Sm/Nd isochrons on whole rock and minerals, several samples from Tisoviţa-Iuţi and Deli Jovan massifs. From the Tisoviţa-Iuţi gabbros, the whole rock isochron yield 412 ± 80 Ma and four mineral isochrons yield 380 ± 34 Ma, 390 ± 52 Ma, 382 ± 46 Ma, and 386 ± 25 Ma. Three samples from the Deli Jovan massif combined with 7 samples from the Tisoviţa-Iuţi massif yield a whole rock isochron of 409 ± 38 Ma. Considering all the Sm/Nd ages, together

with the U/Pb ages, the early Devonian age of the Tisovița-Iuți and Deli Jovan massifs appears as well established.

The authors of this abstract sampled a gabbro and a plagiogranite from the Zaglavak massif. The U/Pb zircons ages dated by LA-ICP-MS method yield 388.1 ± 5.1 Ma for gabbro and 383.9 ± 4.2 Ma for plagiogranite. Therefore, our new data confirm the early Devonian age of the intra-Danubian, or Carpathian-Balkan pre-Alpine ophiolite. The data also suggest a Rheic suture and a complex Danubian basement: Avalonian toward the Moesia, and very likely Cadomian toward the Getic domain. At the same time, the Berkovitsa island arc association, do not represent the cover of the Carpathian-Balkan ophiolites. It probably forms a Variscan tectonic unit trusting over the ophiolites. Except the Tcherni Vrah ophiolite, the Danubian domain is probably missing in Bulgaria and east of the Iskar River, where only the Berkovitsa unit can be found. The correlation between the South Carpathians pre-Alpine terranes and the Balkan terranes south of Danube remains still unresolved.

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Geochronology and emplacement conditions of Motru Dyke System (South Carpathians, Romania)

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Abstract

Within the framework of South Carpathians (Romania), there have been described and divided three major tectonic units (Danubian Unit, Severin Nappe and Getic-Supragetic Unit) composed of a system of nappes, emplaced in the time of Alpine orogeny (e.g. Berza et al. 1994; Balintoni et al. 1997, 2011; Iancu et al. 2005).

The Danubian basement units are mainly composed of medium-grade metamorphic rocks intruded by several granitoid plutons of Neoproterozoic age (Liégeois et al. 1996; Balintoni et al. 2011) and also by a number of Variscan granitoid plutons (Balica et al. 2007).

The extensive system of dykes (known as Motru Dyke Swarm – MDS) whose age is still under debate (i.e pre-Silurian) (e.g. Berza and Seghedi 1975; Féménias et al. 2008) penetrates through the Danubian basement units, covering an area of about 2000 km^2. The MDS is defined by heterogeneous geochemical compositions represented by a complete medium-K calc-alkaline to shoshonitic differentiation series, ranging from basaltic andesites to rhyolites (46.59-68.79 wt.% SiO_2). Due to the crosscutting relationship with the Variscan post-collisional granitoid plutons and based on additional geochemical and isotopic data, a new timing and tectonic setting of emplacement is proposed, although our zircon U/Pb isotopic ages and, recently monazite chemical ages have been proven to be inherited, and do not clearly meet our age assumptions (i.e. Variscan).

The initial 87Sr/86Sr ratios (0.70745-0.73746) do not confirm the previous assumptions (e.g. Féménias et al. 2008), regarding the emplacement setting, sourced in a unique and homogenous mantle reservoir. On the contrary, our data outline a mixing of sub-crustal and crustal derived melts. The presence of a crustal component is also supported by the large presence of xenocrystic zircon and monazite grains in MDS.

The Sr and Nd isotopic data reveals that 92 % of the samples (12 out of 13) collected from the system's exposed areas support the idea of a dominant crustal component. In addition to that, the initial εNd values calculated assuming an age of emplacement of 300 Ma are dominantly negative (εNd = -16.1 to -4.7).

Additionally, although the trace elements distributions resemble those previously reported (eg. Féménias 2008) generally they point to a source heterogeneity. One trend reveals low abundances of Nb, P and Ti while other trends reveal enrichments in these elements along with Th, Pb, Zr, Y. The trace elements data point to enriched sources of incompatible elements. Thus, consistent with the data and geological evidences, we can limit the emplacement age and origin of MDS to Late Paleozoic (Carboniferous), during time of the post-collisional late Variscan extensional event, and deriving from a mixed crustal and subcrustal reservoir.

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A new approach to provenance studies using detrital metamorphic zircon

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Abstract

Conventional detrital zircon studies follow a quantitative approach. In this idea, we selected and analyzed a random zircon population in order to obtain a representative age distribution of the source areas. In the best-case scenario, the spread of ages will provide information on theprimary sources and, by comparison with samples fromother similar areas some relationshipscan be inffered.

However, it is very frequent that the zircon can survive to more than one complete sedimentary cycle (erosion, transport and deposition), therefore the ages might not represent direct link to the primary sources but recycled material. Furthermore, by analysing only the magmatic areas (as is it commonly made in detrital zircon studies) can introduce an undesirable bias in the obtained ages, and the loss of important tectonic information.

Recent studies have found that the use of monazite add valuable information on the provenance of sediments, otherwise lost if only detrital zircon isanalysed.

In this study we have combined a conventional detrital zircon study with a qualitative approach, i.e., selecting a specific zircon population to obtain distinct information on the provenance of the sediments. First, random populations of zircon from two metapelitic granulite samples from the upper Neoproterozoic sequence in the eastern Pyrenees have been analysed by LA- ICP-MS. Then, from the same sample metamorphic-looking zircon crystals were selected and dated usinga SHRIMP-RG instrument. In the late case, the isotopic data together with the compositional data were performed only on the rim of the zircon.

In the first case, the results are comparable to other peri-Mediterranean samples, with the main age population corresponding to the Cadomian–Pan-African orogenic events. An abundant Mesoproterozoic age cluster, less common Paleoproterozoic ages, two peaks in both late and early Neoarchean, and some Meso- and Paleoarchean ages were obtained. By comparisonto other Iberian detrital zircon studies, our samples are slightly different. This suggests a different position between both areas, at least during late Neoproterozoic times. To obtain such an age distribution, the Pyrenean massifs should have been located in the northern margin of Gondwana, close to Sardinia, in front of the Arabian-Nubian shield.

In the second case, the results were striking, because the Mesoproterozoic agesstrongly dominate. Furthermore, compositional data (mainly Yb/Gd, Th/U and U/Ce ratios) confirm the metamorphic originof most of the zirconrims.

The preservation of the metamorphic rimsin detrital zircons has important consequences in the interpretation of the source region. Metamorphic rims are usually metamict, sincethey have high U contents and, consequently, they are less resistant to physical abrasion during transport. If these rims are preserved, we can infer that the zircon is not recycled material, but instead it represents a primary source. Furthermore, the source must be close, so the zircon does not have time to be abraded during transport.

Using this qualitative approach (or a combination of methods) in detrital zircons studies in other areas will provide new and important information on the provenance of sediments that, in turn, will help to pinpoint the paleoposition of the strand of terranes in northern peri-Gondwana from the Neoproterozoic through the Paleozoic, until the closure of the Tethys Ocean.

New geochronology data on the Lower Cambrian age of the Frolosh Metamorphic Complex (Frolosh Unit) and Kadiytsa Formation – SW Bulgaria

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Key words: *SW Bulgaria, U-Pb zircon dating, detrital zircons, metabasic rocks, metasandstones*

Introduction

The aim of this study is to present the new results from the in-situ LA-ICP-MS U-Pb zircon dating of the few samples respectively-metabasic rocks from the Frolosh Metamorphic Complex (Frolosh Unit) and metasandstones from the succession of the Kadiytsa Formation.

Geological background and field relationships

The Frolosh Unit (Peychev et al. 2012; Frolosh Metamorphic Complex-Pristavova, Ilieva - In: Milovanov 2009; Frolosh Formation - Zagorčev 1987, 2001) consists of metabasics, actinolite-chlorite and chlorite schists, calcareous schists, phyllites and metasandstones. The metabasics are presented by lens-like bodies of metalherzolite (?) metadolerites, metadiabases (probably representing lava flows) and layers of metamorphosed basic tuffs, all with dark-green colour. The whole complex has undergone greenchist-facies metamorphism, and was intruded by gabbroids, diorites and granites (Struma diorite formation - Stefanov and Dimitrov 1936).

The Frolosh Unit shows the following relationships with the other rock types (Units) in the border area of FYR of Macedonia and Bulgaria. The high-grade metamorphics of Ograzhden Unit (Maleshevska Metamorphic Complex) are thrusted along Kadiytsa thrust over the lower-methamorphic rocks of Frolosh Unit in the vicinity of Sushitsa village. Going futher to the southwest the contact between Ograzhden Unit and Frolosh Unit is tectonic. The upper boundary of the Frolosh Unit in the vicinity of Kadiytsa summit probably represents initially unconformable (erosional) contact with the metasediments of Kadiytsa Formation. To the northwest of Kadiytsa summit, Rakovo type granites and Struma diorites are believed to be intruded within the Frolosh Unit (Milovanov 2009). In the southernmost parts of Padesh graben the boundary of the Paleogene sediments of the Suhostrel Formation and Frolosh metamorphics represents a normal fault. In the vicinity of Mehandzhiyski chukar summit, the Eocene sediments of Komatinitsa Formation are transgressively and uncomformably overlying the Frolosh Unit.

The Kadiytsa Formation (Zagorčev 1987, 2001) consists of phyllites, actinolite-chlorite schists, amygdule metadiabases, metaandesites, calcareous schists and inpure marbles that interbeds with levels of metamorphosed sandstones with single gravel clasts and fine pebble conglomerates. On the Bulgarian territory the rocks studied crop out only around the summit of Kadiytsa at the border area with FYR of Macedonia. The upper boundary of the Kadiytsa Formation is not preserved due to the present erosional cut. The lower boundary of the unit is probably unconformable with the granular, schistose metadiabases and the greenschist rocks of the Frolosh Unit. The degree of metamorphism of the rocks from the unit corresponds to the greenschist facies.

Sampling and analytical techniques

For the present study we sampled one of the largest metadiabasic bodies (sample 529) within the Frolosh Unit. It's location is around 3 km to the west of Sushitsa village (1.5 km southeastern from Gogovtsi village) close to the road to Kadiytsa Summit. We also sampled two coarse-grained metasandstones representing levels from the succession of Kadiytsa Formation, from the southern and northern parts of the slopes of Kadiytsa summit (sample 531 and 532 respectively). The in-situ LA-ICP-MS age measurements (U-Th-Pb method) were carried out at the Geological Institute of the Bulgarian Academy of Sciences, Sofia. For the present study we used a spot diameter of 35 μm and frequency of 8 Hz. The reproducibility of the data during this work was estimated measuring GJ1 and Plezoviche zircon standards. The zircons for the in-situ analyses are separated using magnet and heavy liquid separation. The $^{207}Pb/^{206}Pb$, $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, and $^{208}Pb/^{232}Th$ ratios were calculated using GLITTER® software (Macquarie University) and corrected for both instrumental mass bias and elemental and isotopic fractionation. Ages were calculated and presented using ISOPLOT software.

U-Pb age data

Analysed zircons from the metadiabases (metadolerites) of the Frolosh Unit (samples 529) show crystallization Concordia age of 521.7 ± 6.9 Ma. Different clusters for the inherited component are distinguished at 580; 660, 760 and 1372-1379 Ma (Fig. 1).

The detrital zircons analyzed from the

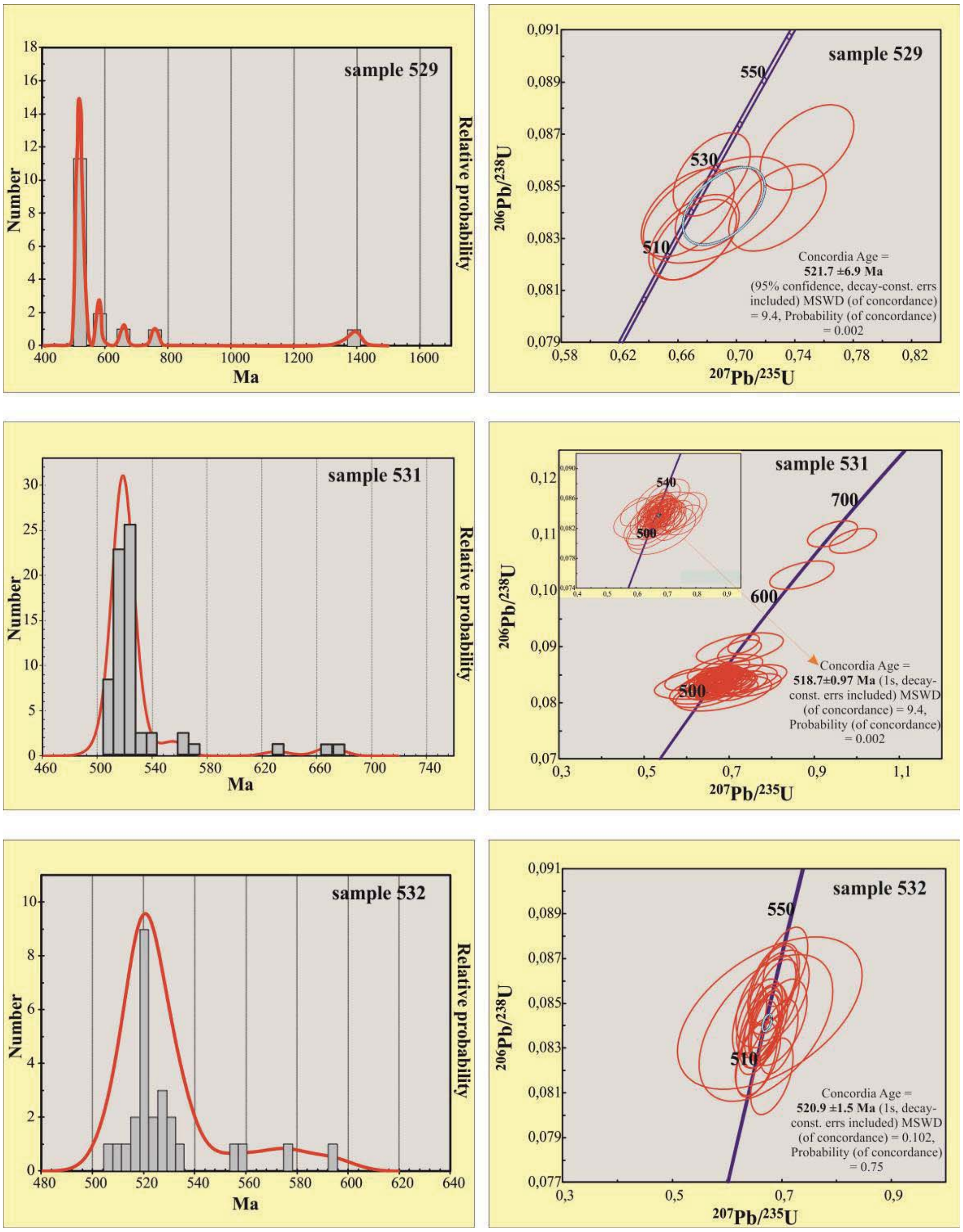

Figure 1. Probability density plot (left) and Concordia diagrams (right) of magmatic zircons from metabasic rocks (sample 529 – N 41º48’31.38”, E 22º58’47.56”) – Frolosh Unit and detrital zircons from metasandstone beds (sample 531 – N 41º47’38.86”, E 22º57’30.55”; 532 – N 41º47’13.64”, E 22º57’56.59”) of Kadiytsa Formation.

metasandstones of the Kadiytsa Formation (sample 531 and 532) are pale beige to light brown, medium- to short-prismatic, slightly rounded by the sediment transport. Some of them reveal fine magmatic oscillatory zoning that corresponds to crystallization from zirconium-saturated magma and others lack of oscillatory zoning. This probably represents detrital component from different by composition magmatic rocks. The in-situ LA-ICP-MS data (89 zircon analyses) for most of the detrital zircons studied has similar $^{206}Pb/^{238}U$ age in the interval of 506-525 Ma. A few zircons (10 analyses) dated at 551-558, 590-630 and 666-673 Ma are also found.

Discussion and conclusion

The greenschist-facies complexes are widespread in the Southwest Bulgaria (Struma Superunit – Zagorčev 2001). Their composition and structure have been elucidated more than forty years ago, but their interrelations and contacts are still a subject of controversies. It is considered that the greenschists-facies metamorphic rocks (i.e. the Frolosh Unit) are cross-cutted by igneous rocks of the Struma diorite formation. The Kadiytsa Formation covers with a sharp and probably, initially unconformable contact the Frolosh Metamorphic Complex (Frolosh Unit) and its contact with the Struma Diorite Formation is unclear due to poor exposure. On the other hand the age of the Rakovo type granite (sampled to the northwest of Kadiytsa summit), which Milovanov et al. (2006) separated as distinct from the Struma diorite formation or Struma Diorite Complex (Milovanov et al., 2006, 2009) is 543.5 ± 3.9 Ma, is similar to the age of Delchevo pluton in FYR of Macedonia (Antic et. al. 2012). The older age of the Rakovo type granite (543.5 ± 3.9 Ma) is controversial to the age of the recently dated metabasics from the Frolosh Unit (521.7 ± 6.9 Ma – present study; 516.3 ± 2.1 – 532.1 ±Ma in: Zagorchev et al. 2011) in which is believed to be intruded. The geochronological data support most probably tectonic contact between the two Units.

Recently zircon U-Pb geochronology of rocks from the Frolosh and Struma complexes were carried out and yielded age ranges spread between 578.6 ± 1.8 and 516 ± 2.1 Ma (Zagorchev et al. 2011). This data as well as the present results confirm previous considerations (Zagorčev 1987; Graf 2001; Kounov 2002) about the Cadomian age of the Frolosh and Struma complexes.

In this context one of the main unclear questions is about the interrelations between the Struma Diorite Complex (including Rakovo type granite) and the Frolosh Metamorphic Complex (Frolosh Unit). The newly defined ages of the Frolosh Unit (521.7 ± 6 Ma) as well as the age of the major zircon detrital component of the Kadiytsa Formation (518.7-520.9 Ma) gives reason to be done a new rethinking of the relationships between the greenschist-facies metamorphic complex and igneous complexes with Ediacaran – Cambrian ages in the area of the Southwest Bulgaria.

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Pre-Alpine events in the Central Western Carpathians: an excursion from old crystalline towards Late Hercynian processes (Slovakia)

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Abstract

The considered area is confined between two regional tectonic lines expressed by the Early-Tertiary structure of the Klippen Belt in the north and the Paleo-Alpine (presumably Lower Cretaceous) contact with Gemeric Paleozoic units in the south. Crystalline of Central Western Carpathians (CWC) build the basement of the Alpine mega-blocks – Tatric and Veporic Units, which are mostly correlated with Underaustroalpine, Bajuvaric and Middleaustroalpine Units of the Eastern Alps.

The Alpine (Middle Cretaceous) tectonic reworking of the CWC was connected with the closure of Mesosoic basins and corresponds to greenschist facies metamorphism - generally rising from north to south. An undisputable practical field limit between the Alpine and Hercynian deformation events is marked by a widespread Lower Carboniferous granitic magmatism (cca 350 Ma), which fixed older deformation and/or produced periplutonic metamorphism. On the other hand, intensive Hercynian "granitization" frequently wiped out the older lithostratigraphical and structural relations. The volcano-sedimentary succession of Ochtiná Group (roughly corresponding to the Eastern Alpine Veitsch nappe) plays also an important role in understanding the Paleozoic evolution of the CWC crystalline. This Lower Carboniferous Unit is tectonically placed between the Gemeric Paleozoic basement (approx. Grauwacken Unit) and the Mesozoic envelope of the Southern Veporicum.

Based on lithology, tectonics, metamorphism and geochronological data, as U-Pb dating on zircon, mineral Ar/Ar dating and CHIME analyses (e.g. Bibikova et al. 1988; Kráľ et al. 1996; Gaab et al. 2005; Kováčik et al. 2005; Putiš et al. 2008), we have attempted to distinguish the pre-granitization metamorphic complexes. The CWC crystalline rock-assemblage can be tentatively divided into two groups: the "young" (upper) and "old" (lower) crystalline. Young crystalline complexes are composed by variegated material, ranging from oceanic crust to prevailing metasandstones of continental source. These units are also characterized by the absence of orthogneisses, leptyno-amphibolite complexes or garnet micaschists of higher metamorphic grade, which are symptomatic within the old crystalline rock-inventory. Age of the young crystalline can be placed to (Late Silurian?)-Devonian time, being supported by the scarce paleontological proof in the CWC crystalline rocks (Chlupáč in Buday et al. 1962), as well as by radiogenic dating of freely associated gabbroid rock (Putiš et al. 2009) (both data from Little Carpathians Mts.). Contact aureoles around Hercynian granites characterize thermal metamorphism spanned from various spotted/contact schists up to formation of cordierite-andalusite or pyroxenic hornfelses. Due to a relative higher position, this crystalline shows insignificant pre-granite Hercynian regional metamorphism, which is constrained max. to the lower/middle parts of the greenschist facies.

The old crystalline was usually affected by ductile deformation under barrovian amphibolite metamorphic facies. Old crystalline is also largely overprinted by Hercynian granitoids. Continental blocks of old crystalline might have provided source-material for the basins of the future young crystalline. A frame of old crystalline serves the Cambro-Ordovician (ca 480-510 Ma) paleovolcanics and granitoid intrusions ("I. magmatic period"). In this time common bimodal volcanism indicate rifting processes and breakdown of the older basement, presumably northern Gondwana Cadomian crust. Thus, the "lower" mica-schist complex in the Southern Veporicum may belong to the oldest rocks in CWC. The geodynamic evolution of the old crystalline should have been terminated by metamorphic and magmatic ("II. magmatic period") events, indicated by rather systematic Silurian-(Lower Devonian) geochronological data (ca 390-430 Ma). This time period possibly represents a hypothetic dividing line between the old and young crystalline. It is noteworthy, that both these age clusters remind the orogenic events in Caledonian areas.

The Pre-Alpine metamorphic events can be summarized into four to five age groups:

1. metamorphism prior and/or concomitant with Cambro-Ordovician intrusions; *2.* presumed Silurian - Silurian/Devonian event, connected with the tectonic climax of the old crystalline; *3.* Hercynian regional metamorphism in barrovian (partly HP) style; *4.* contact/periplutonic metamorphism caused by Lower Carboniferous granitoids; *5.* retrograde "post-granitic" Late Hercynian metamorphism (detected only in areas weakly affected by Alpine tectono-metamorphism).

Geochemistry and Sm-Nd analyzes on the Balkan-Carpathian Ophiolite (BCO – Romania, Serbia, Bulgaria): accretion of the easternmost oceanic basin of the Variscan cycle

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Abstract

The pre-Alpine basement of the Upper Danubian/ Balkan Alpine nappe (Southern Carpathians and Western Balkans) displays four ophiolitic massifs covering about 400 km^2: Tisovita Iuti (TI, Romania), Deli Jovan and Zaglavak (DJ and Z, Serbia) and Tcherni Vrah (TV, Bulgaria). Together they are grouped as the "Balkan-Carpathian Ophiolite" (BCO) and probably represent the relics of a unique oceanic domain, presently dismembered along 160 km by Oligocene Alpine tectonics. Previous petrological and geochemical studies on these four ophiolitic massifs are still controversial (mid-ocean ridge setting, Savov et al. 2001, or trench-proximal context, Maruntiu et al. 1997). The age of accretion of this oceanic crust is also still debated: Late Proterozoic-Early Cambrian (U-Pb zircon age of 563 ± 3 Ma, TV massif, von Quadt et al. 1998) or Early Devonian (406 ± 24 Ma by Sm-Nd mineral isochron, 405 ± 3 Ma by U-Pb SHRIMP zircon, DJ massif, Zakariadze et al. 2012).

A Pre-Alpine restoration of the Upper Danubian/ Balkan basement indicates that the four ophiolitic massifs originally laid along a WNW/ESE axis. Although all the sections of the oceanic lithosphere are not present in each of these massifs, together the four massifs display a longitudinal zonation through a complete ophiolitic pile, grading from the lower sections of the oceanic lithosphere at the paleo-W (TI: mantle serpentinites and dunitic cumulates) up to the upper sections at the paleo-E (TV: sheeted dyke and pillow lavas).

To constrain the geotectonic context of accretion of the BC oceanic crust, we performed microprobe analyses on spinels from mantle - derived serpentinites and chromitites from the TI massif, as well as whole rock geochemical analyzes (major and trace elements) on basalts from the four massifs. Spinels compositions from chromitites (Cr# = Cr/(Cr+Al): 0.39-0.48) indicate an interaction of the host peridotites with a MORB-type magma. This is in favor of an extensional setting (MOR, BAB) for the accretion of the BC oceanic crust. The composition of the fresh accessory spinels from the mantle-derived serpentinites (Cr# = Cr/(Cr+Al): 0.49-0.51) yields homogeneous estimates of 17 % for maximum partial melting of the BC mantle (Hellebrand et al. 2001). Moreover, three types of basalts have been distinguished on the basis of geochemical characteristics. Major elements systematic indicates that type-1 and type-2 basalts are globally consistent with liquid lines of descend of parental melts with low initial water contents as typical for MORBs (increase in TiO_2 contents and decrease in Al_2O_3 contents reflecting the late crystallization of magnetite and the dominant fractionation of plagioclase relatively to clinopyroxene). At the contrary, the type-3 basalts are consistent with higher water contents of their parental melts. Similarly, trace elements systematic shows a MORB-type affinity for the type-1 and type-2 basalts evidenced by flat REE patterns with depleted LREE and a slight Nb anomaly characteristic of mature back-arc basins (Pearce et al. 2005). Compared to the type-1 ones, the type-2 basalts would be issued from very low degrees of partial melting as seen by a significant enrichment in LREE. Type-3 basalts exhibit enriched patterns with pronounced negative Nb anomalies, typical of back-arc basin basalts. Finally, new Sm-Nd dating on fresh lower gabbroic rocks (whole rock isochron) from the TI and DJ massifs give an accretion age for the BCO crust at 409 ± 38 Ma, in agreement with the age of Zakariadze et al. (2012).

The BC ophiolite would thus be relicts of the easternmost oceanic basin related to the Variscan cycle, in a context of a back-arc system. In this scheme, we propose that the BC oceanic basin separated the Balkan Terrane at the north (formed by the Neamţu/Stakevci Cadomian (?) basement and the Eşelniţa-Berkovica sediments of the Upper Danubian nappe) from the Sredna Gora Terrane at the south (formed by the still unmetamorphosed Poiana Mraconia unit of the Upper Danubian nappe and the various units of the Getic/Sredna Gora nappe, both of them later involved in HP conditions). The closure of the BC oceanic basin, following a southwards subduction, led to the docking of these two Variscan terranes during a Carboniferous collision. The paleocontinental affinity of the Sredna Gora Terrane has been ascribed to North Galatia (Armorica-type, Balintoni et al. 2010) or South Galatia (Intra-Alpine-type, Stampfli et al. 2013) whereas the affinity of the Balkan Terrane appears more controversial (Avalonia, Balintoni et al. 2012 or North Galatia, Stampfli et al. 2013). Consequently, the BC oceanic basin would represent a back-arc opened either at the north or at the south of the Rheic ocean.

A Possible Permo- Triassic Thermo- Tectonic Event in Rodna Mts (East Carpathians, Romania)

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Introduction

The aim if this study was to characterize by Permo-Triassic tectono-thermal event imprinted rock in the Rodna Mts, which are a part of Crystallino-Mesosoic zone of East Carpathians orogen. In this region are known shear zones marking detachment planes of basement nappes with three type of single grain - Ar/Ar age clusters: predominant Cretaceous (95-100 Ma, Alpine nappe stacking event), predominant Triassic - Permian (230-290 Ma, probably represents reset ages of supposed Variscan precursors schists) and mixed, predominant Triassic - Permian age cluster with variable amounts of Cretaceous outliers (may represent Permian ages variably reset by Alpine reworking but older than 290 Ma were not identified) (Mosonyi 1998; Culshaw et al. 2012). A post-Variscan extension- related event previously described in Alpine orogen by Dallmayer et al. 1996, Schuster and Stüwe 2008, Stüwe and Schuster 2010, and is identified by igneous rocks and LP/HT metamorphism. By analogy with the Alps, in the Rodna Mts a Permo- Triassic thermal event should be record by Upper Paleosoic rocks (black quartzites, metabasites and marbles) in greenschist facies from shear zone between Alpine Subbucovinian and Infrabucovinian nappes. Based on Ar/Ar age data clusters interpretations (Culshaw et al. 2012), from the shear zones which could imprint both Lower Palaeozoic and Upper Paleozoic metamorphic rocks, a first step in this research was to study the Upper Paleozoic metabasites, dynamically metamorphosed in greenschist facies conditions. Polydeformed microstructural, paragenetic and chemical (trace and minor elements) features of these rocks were outlined. The metabasite samples were collected from Valea Vinului village (Izvorul Rosu Creek) (Fig. 1), from an outcrop of the mylonitised Upper Paleosoic (with mixed Ar/Ar age clusters) Cimpoiasa Group, Negoiescu Formation (Kräutner et al. 1978) on which shear deformation was imprinted during the Alpine Rodna Nappe emplacement. The Negoiescu formation of this group consists of around 500 m thick heterogenous rock sequence: actinolith- epidote schists, chlorite- albite- carbonate schists, albite-epidote- carbonate schists, chlorite- epidote schists, chlorite schists with albite porphyroblasts, chloritic

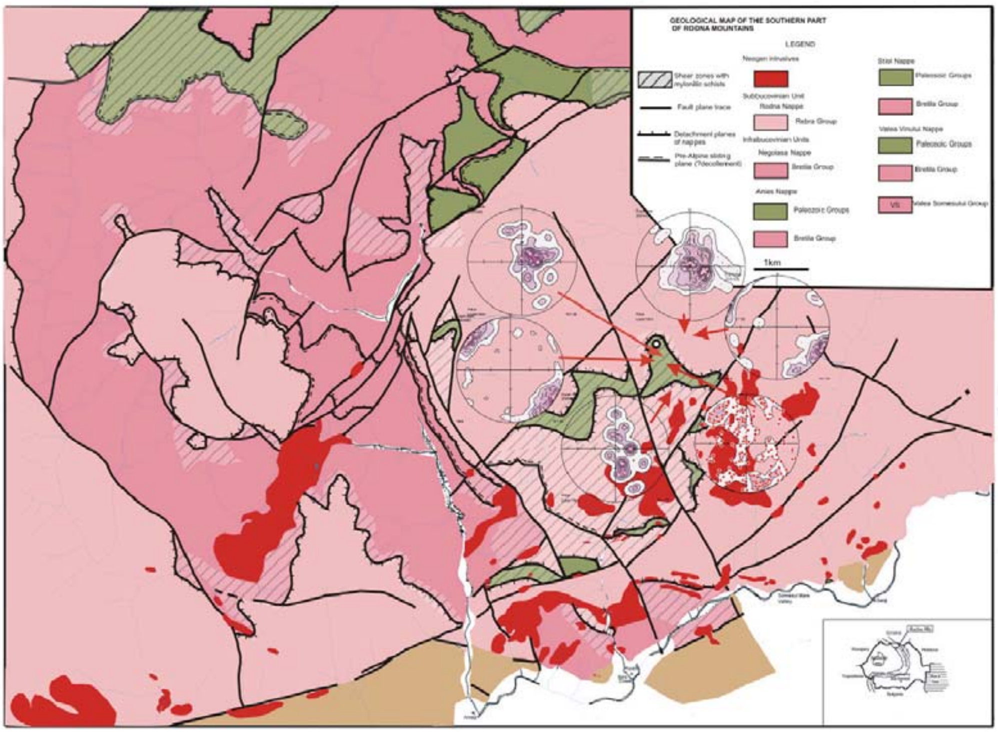

Figure 1. Tectonic map of the southern part of the Rodna Mountains. White circle = position of studied metabasite sample. Polar and axial projections of mylonitic foliations and lineations (in Rebra, Paleozoic and Bretila rocks) and quartz fabric (with bigger red points diagram) in mylonite. Brief evidence of NW-SE extension direction and low grade fabric of quartz (left-hand shearing overprinting a possibly earlier coaxial deformation fabric).

schists and chlorite- biotite- epidote- albite schists (the analysed rock type). Between the Upper Paleozoic Group and the spatially underlying Ordovician (Balintoni and Balica in press) Bretila Group is a Variscan shear zone reactivated during the Alpine tectonic event, but between the Upper Paleozoic Group and the overlying Ordovician (Balintoni and Balica, in press) Rebra Group is an intensive Alpine shear zone (Strutinski et al. 2006; Culshaw and Mosoyi 2012).

Materials and methods

Macroscopically, the analysed metabasite resembles chlorite biotite schists with amphibole, epidote and feldspar porphyroblasts, and texturally is an S-C mylonitic schist with an extension lineation (mineral lineation, boudins, crenulation axes) striking NW-SE (Fig. 2).

Scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) together with EDS X-ray mapping were performed using a Jeol 8600 JXA Superprobe on the thin sections prepared for fabric and mineral investigations. ICP-AES analyses for minor and trace elements in rock were also preliminarly used (Table 1).

Results

In thin sections of mylonitic schist cut parallel with the XZ fabric plane (Fig. 2), were identified at least 3 mineral assemblages (Figs 3-9): *the first* supposed one could be a relic igneous brown amphibole 1, some epidote porphyroblasts core zone; *the second*, relic one (with minerals along a relic S1 foliation plane): barroisitic (Na- Ca-) amphibole prisms (fissured and rotated passively by simple shear), plagioclase (oligoclase 18% An), chlorite 1, opaque minerals (Ti-magnetite,), epidote-clinozoisite group minerals (epidote 1: Al-rich (4.76-4.95 apfu and X_{Fe}= 100 Fe^{3+}/ (Fe^{3+}+ Al) = 26.1) core and epidote 2: Fe-rich rim 1 (1.76-2.02 apfu and X_{Fe}= 29.8-33.5) zone of some porphyroblasts), quartz and trioctahedral micas (of fish-like shape due to simple shear deformation, X_{Fe}= 0.51-0.53); *the last assemblage* is due to the strong dynamical metamorphic event in the shear zone in greenschist facies:, clinochlore (having X_{Mg}= 0.51-0.52, with pale bluish-green, green pleochroism), the epidote-clinozoisite group minerals as a narrow (10 micrometers) pale green epidote 3 rim (X_{Fe} = 31.3), i.e. the second overgrowth zone of earlier one, due to dynamic syntectonic recrystallisation, or as small (tens of micrometers) grained epidote 3 (±quartz±chlorite) lens discordantly disposed to the S1 foliation, plagioclase 2 as dynamically recrystallised earlier porphyroclasts' mantle or syntectonic albite porphyroblasts with curved inclusion (epidote, opaque minerals) trails, having pressure shadow cones struck along the mylonitic S plane, filled by carbonate, chlorite, titanite as small grain strings on the clinochlore boundaries (marking possible relic micas shapes) or along the mylonitic C foliation, micas (as greenish-yellow needles of phengite with high birefringence), along the fine grained epidote 3 mass, carbonate lens or microlithons, actinolite needle fans around albite porphyroblasts, ribbon quartz oriented parallel with mylonitic C foliation. The albite porphyroblast with epidote inclusions and actinolite can represent the decomposition products of earlier feldspars and amphiboles.

Based on dynamically recrystallised quartz and feldspar microfabrics (Paschierre and Trouw 1996) and dynamically recrystallised quartz paleopiezometry, (Bishop 1996; Twiss 1997) deformation temperature could be at low temperature (around 350-400 °C) and differential stress of max 2-4 Kb (Mosonyi 1998). Taking into consideration interpretations of Zircon fission track data of Groger et al. (2008) and combined with Ar/Ar-data of Dallmeyer et al. (1998) this temperature gradient could be explained by tectonic nappe stacking and overburden up to 20 km.

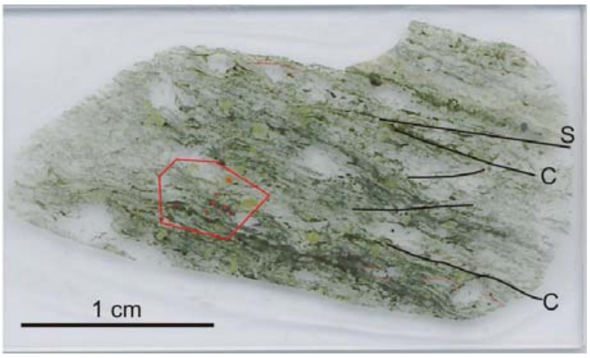

Figure 2. Metabasitic schist thin section. Microtextural features evidence an S-C mylonitic schist with porphyroblasts of Epidote and Albite. The area delimited by red contours was microprobed.

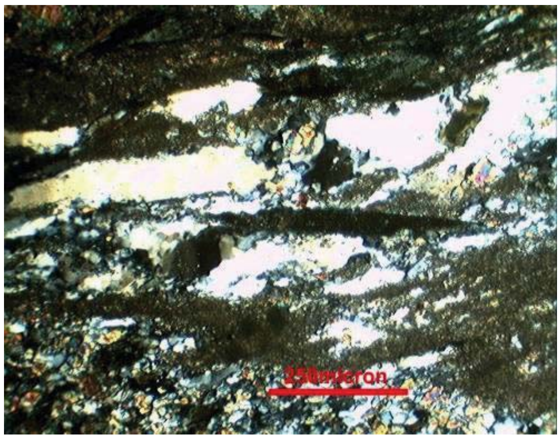

Figure 3. Ribbon quartz and mantled feldspar porphyroclasts. (1)

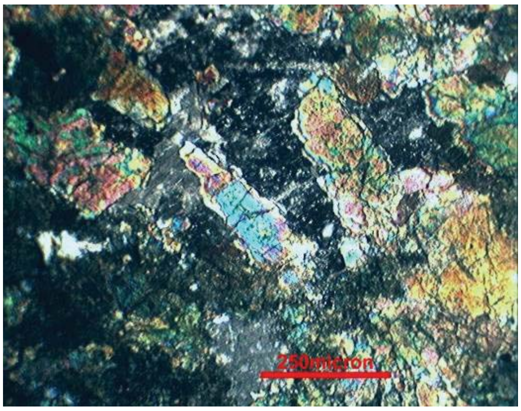

Figure 4. Zoned Epidot- Clinozoisite (core, rim) and a recrystallysed fine grained mantle.

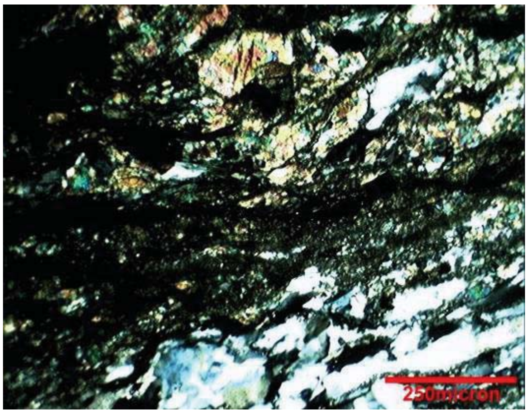

Figure 5. S-C mylonite with mantled feldspar and epidote porphyroclasts.

Figure 6. Bluish- green amphibol relics, fish mica and clinochlore, feldspar porphyroblast.

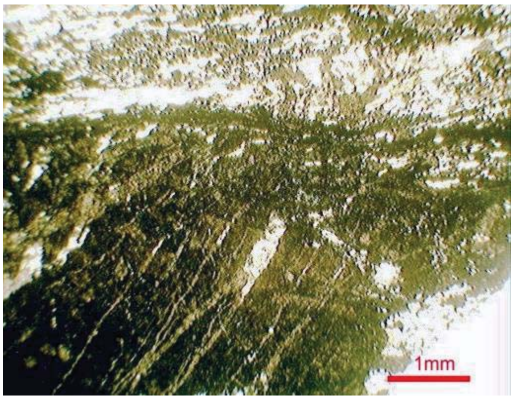

Figure 7. Relic, crenulated foliation and fine grained (greenish) epidote lens oriented along the crenulation foliation.

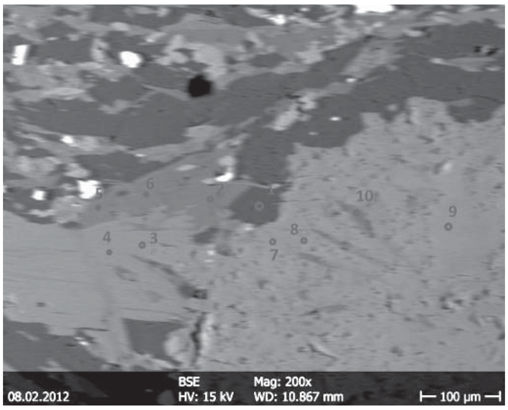

Figure 8. 10 =Act, 2= ccl, 3,4= Bi, 5= ccl, 6=feng, 7,8= Ep rim1 (Fe-rich), 9= Ep core (Al-rich).

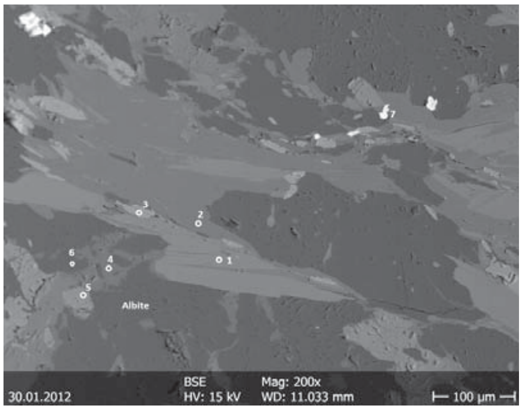

Figure 9. 1= Bi, 2= Ccl, 3= Tit, 4= Pheng, 5= Ep, 6= Ab and Albite with Si≠Se, 7= mt.

Figs 8, 9. BSE images of analysed minerals in thin sections. Ccl = synkinemtatic clinochlore Ab = albite porphyroblast with curved inclusion (Ep) trail (synkinematic rotated blast, Se = mylonitic C), its long axis parallel with the mylonitic S plane, Act = Actinolite, Ep = Epidote- Clinozoisite, Tit = titanite grains along the Ccl boundary and mylonitic C plane.

The geotectonic environment of metabasitic rock was preliminary studied by REE and minor element investigations (Table 1) and using different basic rocks- and tectonic environment discrimination diagrams such as Ti/100- Zr- Y*3 (Pearce and Cann 1973), Nb*2- Zr/4- Y (Meschede 1986), Ti/Y- Nb/Y (Pearce 1982), Th- Hf/3- Ta (Wood 1980, Fig. 10), La/10- Y/15- Nb/8 (Cabanis and Lecolle 1989, Fig. 11), Cr- Y and Cr- Ce/Sr (Pearce 1982).

Table 1. The main minor and REE analyses of greenschist (sample Izvorul Rosu) by ICP- AES.

ppm Ti	Zr	Y	Nb	Th	Hf	Ta	La	Cr	Ce	Sr
23700	432	55	74	6,2	8,8	4,9	60,5	70	120	468

Conclusions

The post-Variscan extension related basic rock studied is polydeformed (relic S1 and crenulation type S) rock, metamorphosed during Cretaceous events and, structured in an Alpine shear zone at T=350-400 °C, max 2-4Kb differential stress and general NW- SE extension direction. It has intracontinental rift derived alkali basaltic protolith and could mark a post-Variscan and Eo-Alpine thermo-tectonic event.

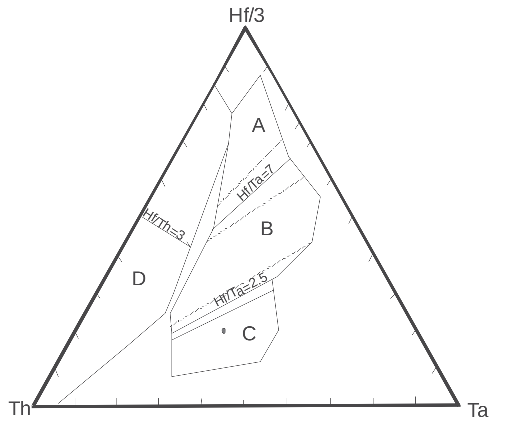

Figure 10. Discrimination diagram for basalts after Wood, 1980. A= N-MORB, B= E-MORB and with-in plate tholeiites, C= alkaline with-in plate basalts and point is our sample, D= volcanic- arc basalts.

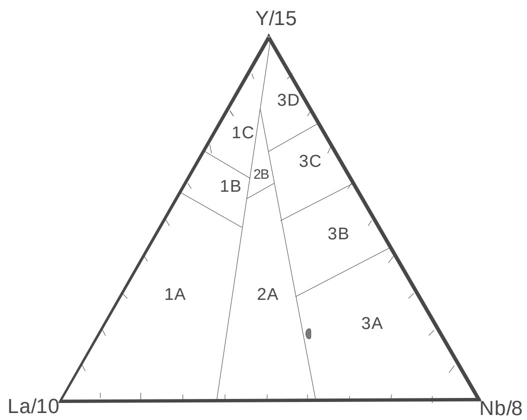

Figure 11. Discrimination diagram for basalts after Cabanis and Lecolle, 1989. Field 1= volcanic- arc basalts, field 2 = continental basalts, field 3 = oceanic basalts. 1A= calc-alkali basalts, 1C= volcanic- arc tholeiites, 1B is overlap area between 1A and 1C, 2A= continental basalts, 2B= back- arc basin basalts, 3A= field of alkali basalts from intercontinental rifts with our sample point, 3B and 3C= E-MORB, 3D= N-MORB

Keywords: *metabasite, post- Variscan, Alpine shear zone, East Carpathians*

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Pre-Alpine magmatic record in the roots of the Spanish Eastern Pyrenean Massifs – A link between western and eastern European Mediterranean Massifs

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Abstract

The pre-Alpine basement of the eastern Pyrenean massifs is constituted by a metasedimentary sequence from Neoproterozoic to Upper Ordovician. This sequence is intruded by various magmatic events (post-Cadomian, Middle and Late Ordovician) and we discuss their tectonic significance. Based on geochemical affinities, detrital zircon studies and other geological evidence, we find a better correlation between the Pyrenean massifs and peri-Mediterranean pre-Alpine massifs, so the Pyrenean basement could represent the westernmost outcrops of the central and eastern peri-Gondwana terranes.

Keywords: *post-Cadomian magmatic rocks, U-Pb geochronology, Sr-Nd data, western-eastern link*

Introduction

The Spanish Variscan massifs of the eastern Pyrenees are formed by a pre-Ordovician metasedimentary series that are essentially formed by greywacke-pelite, with interbedded marble and siltstone. Metamorphic conditions during the Variscan orogeny vary from greenschist to high temperature amphibolite facies, always at low pressure. In these metasediments, there is an important magmatic record from late Neoproterozoic to Middle-Late Ordovician, with an interlude during Cambrian times. These protoliths represent different magmatic evens related to the opening of a Neoproterozoic back-arc continental basin and to the birth and subsequent development of the Rheic Ocean during the Ordovician. Later on, syn-orogenic granodiorites, anatectic and post-orogenic granites intruded during the Variscan in different levels of that basement, accompanied by high temperature metamorphic gradients.

Pre-Variscan Magmatic events

The oldest magmatic event is Ediacaran/early Cambrian (570-560 Ma). Post-Cadomian tholeiitic lava flows; plutonic metagabbros; aluminous metagranites and transitional alkaline meta-monzogranites are present at the bottom of the pre-Ordovician metasedimentary series and represent a bimodal magmatism from a continental back-arc context (Castiñeiras et al. 2008). The isotopic signatures (Table 1) point to the presence of juvenile mantle-derived magmas and their magmatic differentiates. Aluminous melts of crustal provenance and transitional alkaline melts from mantle-crust interaction are also present. This compositional diversity of Cadomian-related magmas suggests that they were generated during the first stage of the opening of a continental back-arc basin that gave rise to the Rheic Ocean.

The following magmatic event ranges in age from Middle to Late Ordovician (470-455 Ma). This event begins with the intrusion of aluminous metagranites (470-465 Ma) that represent the most voluminous magmatic event in all the European Variscides (Liesa et al. 2011). Scarce contemporaneous tholeiitic basaltic sills are sometimes present, but the absence of zircon in these rocks precludes their dating. They crop out at the middle of pre-Ordovician metasedimentary series. This magmatic event represents the melting of the pre-Ordovician thickened upper crust.

During the Late Ordovician (455 Ma), a bimodal magmatism can be found interbedded in the Upper Ordovician metagreywacke-pelitic series. It is formed by acid calc-alkaline ignimbrites and subvolcanic dacite and rhyolite metaporphyries, of crustal origin. At the same time, metamorphosed intrusives such as dolerite sills, meta-aluminous and scarce aluminous granites are present at the basal part of the pre-Ordovician metasedimentary sequence (Casas et al. 2010; Navidad et al. 2010). This magmatism points to the progressive

Table 1. Sr-Nd of the Ediacaran basic and acid magmas (590-560 Ma).

	eNd	(143Nd/144Nd)0	(87Sr/86Sr)0
Juvenile mantle-derived magmas	+2 to -1	0.5118685 - 0.511998	0.707122 - 0.707610
Differentiated mantle	-1 to -4	0.5118839 - 0.511695	0.704474 - 0.709730
Aluminous crustal melts	-4 to -5	0.5117090 - 0.511678	0.708024 - 0.707653
Transitional alkaline melts	-2	0.5117594 - 0.511784	0.706245 - 0.707342

attenuation of the continental crust during the Ordovician evolution of the Rheic Ocean.

The relatively depleted eNd values (Tab. 2), between -1 and -3, indicate a mantle influence in the subvolcanic metaporphyries. More enriched eNd values (between -4 and -6) of the aluminous metagranites and calc-alkaline metatuffs could be interpreted as a mantle-crust interaction in an extensional geological setting related to the development of the Rheic Ocean.

The TDM model ages for the Neoproterozoic (Ediacaran) and Ordovician magmas vary between 1.2 and 1.7 Ga, suggesting that they could have been formed from a juvenile Mesoproterozoic crust with Paleoproterozoic (2.2 to 2.6 Ga) and minor Archaic (3.2 Ga) components. The similarity in model ages from all basic and acid magmatic protoliths is interpreted as a long period of melt extraction from a thick juvenile Neoproterozoic crust formed during the accretion of peri-Gondwana arc.

Detrital zircons from Neoproterozoic metapelites and Ordovician quartzites show age populations slightly different from other areas of the Iberian Massif, but they are quite similar to the age spectra recently obtained in Sardinia (Avigad et al. 2012), suggesting an equivalent position during most part of their geological evolution.

Correlation with the peri-Mediterranean realm

At the eastern area of the Mediterranean realm, Variscan massifs enclose similar protoliths in their lower Paleozoic metasedimentary basement. In Sardinia (Italy), Cruciani et al. (2013), and references therein, describe calc-alkaline volcanic rocks and plutonic orthogneisses of Middle to Late Ordovician age from an Andean-type diachronous arc located in the northern Gondwana margin. Orthogneisses of the same age are present in the Massif Central (Roger et al. 2004), and in the basement of the Alps, Late Ordovician granitic intrusions are distributed in different alpine tectonic units (von Raumer and Stampfli 1988; Schaltegger et al. 2003). In the Serbo-Macedonian massif (Greece), portions of meta-igneous rocks are included in an ancient active-margin succession of Middle Ordovician age (Meinhold et al. 2010). In SW Poland (Sudetes Massif), Ediacaran orthogneisses and bimodal metavolcanic rocks are widespread into an upper Cambrian-Lower Ordovician sequence that represents a passive continental margin of the Saxothuringian domain (Oberc-Dziedzic et al. 2010). In Turkey, pre-Early Ordovician arc-type magmatism formed by mafic orthogneisses and felsic volcanic rocks are cited by Ustaömer and Rogers (1999).

The northern Gondwana margin can be recognized in the Variscan belt of western and central Europe, although the dispersed fragments of post-Cadomian rocks found in the Mediterranean orogens suggests that it can be extended eastwards and that can attain, through the Turkish massif, the Iranian and Caucasus Mountains (see discussion in Şahin et al. 2013). Different interpretations with the geodynamic setting of Ordovician magmatism, related to an Andean-type arc andean-type or passive margin in the northern of Gondwana margin are actually in discussion.

Table 1. Sr-Nd of the Ordovician magmatic rocks (470-465 Ma).

	eNd	(143Nd/144Nd)0	(87Sr/86Sr)0
Aluminous metagranites	-4 to -5	0.511780 - 0.5118420	0.698724 - 0.710216
Subvolcanic metaporphyries	-3	0.512	0.516669 - 0.523305
Calk-alkaline metatuffs	-5 to -6	0.511757 - 0.5118050	0.684176 - 0.707025
Meta-aluminous metagranites	-1 to -4	0.512022 - 0.511989	0.660160 - 0.709528

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Sm-Nd garnet and U-Th-Pb$_T$ monazite ages in basement units of the South Carpathians: new data and a consistency check

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Abstract

Metapelite samples from two basement units of the South Carpathians (the "supragetic" Uria Unit and the Poiana Mraconia metamorphic complex in the Danubian Domain), for which few petrologic and chronologic data were available, were investigated in order to derive metamorphic ages, applying Sm-Nd garnet-whole rock and U-Th-Pb$_T$ monazite geochronology, and to test the consistency of the results. Both chemical and isotopic age data indicate a tectonothermal evolution of the Sibişel Formation at the Permian-Triassic boundary, whereas the Poiana Mraconia metapelite was found to be a juvenile Variscan metamorphic rock which reached peak conditions during the Carboniferous.

Keywords: *Sm-Nd, garnet, U-Th-Pb$_T$, monazite*

The general (and partially oversimplified) structural image of the South Carpathian basement units, involved together with their Palaeozoic and Mesozoic sedimentary covers in Mid- to Late Cretaceous thrust tectonics, encompasses three nappe systems: the Danubian, Getic and Supragetic domains (e.g. Iancu et al. 2005 and refs. therein). For the Danubian basement a peri-Gondwanan derivation (Balintoni et al., online first, and refs. therein), Proterozoic metamorphism and plutonism followed by a Variscan dynamic overprint is widely accepted, whereas for the Getic and Supragetic (or Getic-Supragetic) basement a large volume of age data (v. cited papers) indicate a Variscan tectonometamorphic evolution, also involving previously consolidated crustal fragments.

A pre-Variscan dominant overprint of the Danubian basement as well as a two-fold classification (Drăgşan and Lainici Păiuş) of lithologies correlated across all Danubian units was proposed by Berza et al. (1994). However, extensive Variscan plutonism (Balica et al. 2007) as well as Carboniferous and younger monazite ages, most likely representing metamorphic ages (Săbău and Negulescu 2014), indicate that in fact only the Lainici-Păiuş s.str. basement of the Variscan Vîlcan-Pilugu thrust sheet in the lower Danubian system had completed its tectonothermal evolution before the Variscan orogeny. Of particular interest are the Danubian units in the southern Banat, because they border the Lower Palaeozoic Tisoviţa ophiolites, and are subject to correlations with units appearing in the Upper/Lower Danubian tectonic sequence further north. The Poiana Mraconia basement type was involved in an east-vergent thrust over the ophiolitic complex.

Among the slivers separated from the Getic Nappe basement by tectonic lines of different styles and origins, claimed to represent the thrust plane of the Supragetic Nappe (Codarcea et al. 1967), the Uria basement unit is the only one for which a "supragetic" position can be documented in the field from its regional extension and flat-lying character of the boundary. Though the unit has been tentatively correlated with different other basement types, no detail of its metamorphic history or thermochronology is known so far.

In order to determine additional metamorphic ages, we collected representative metapelite samples from the Poiana Mraconia and Uria basement units and performed Sm-Nd garnet - whole rock and monazite U-Th-Pb$_T$ geochronology.

The Uria Unit sample (12Mo2) is a fresh micaschist from the Sibişel Formation, preserved amidst a dynamically retrogressed matrix characteristic for the unit. The mineral assemblage is represented by garnet, plagioclase, white mica, chlorite, chloritoid, staurolite, ilmenite, epidote, monazite, zircon, xenotime, and quartz. White mica is muscovite with 3.02-3.07 Si p.f.u. Fe-chloritoid (X_{Mg}=0.11-0.17) was found as inclusion in garnet and rarely in the matrix, whereas Fe-staurolite (X_{Mg}=0.12-0.14) occurs mostly in the matrix and rarely as inclusion in garnet rims. Relatively large garnet porphyroblasts preserve a prograde growth zoning, as the chemical composition varies from alm$_{57-59}$

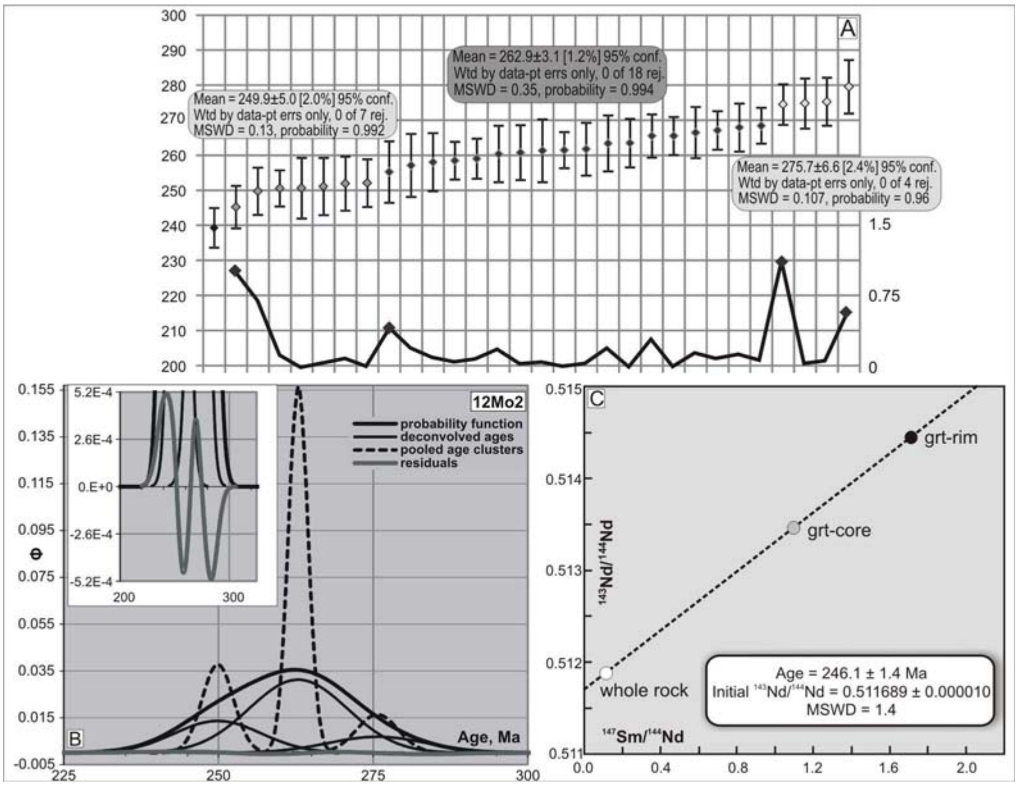

Figure 1

A. Age distribution plot and normalized age gradient (black line) for sample 12Mo2 (Mogoş Valley, Lotru Mts., Sibişel Formation).

B. Deconvolution of the probability distribution function; inset: plot of the residuals. C. Sm–Nd garnet (core and rim) – whole-rock isochron diagram for sample 12Mo2.

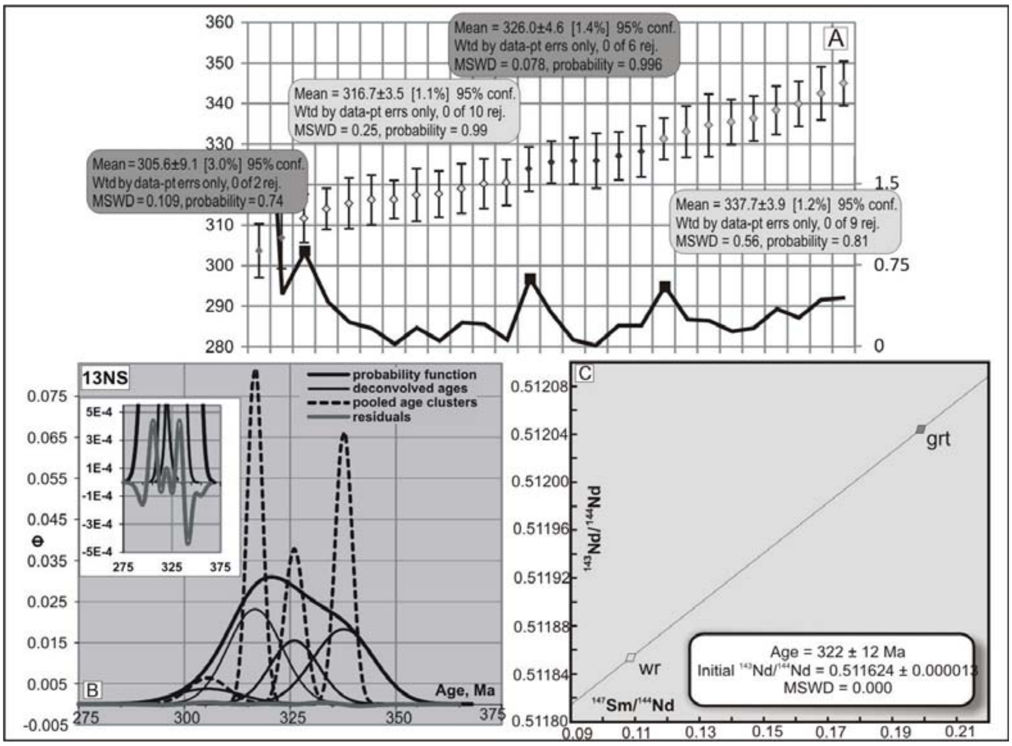

Figure 2

A. Age distribution plot and normalized age gradient (black line) for sample 13NS (Almăj Mts., Poiana Mraconia Formation).

B. Full deconvolution of the probability distribution; inset: plot of the residuals. C. Sm–Nd garnet – whole-rock isochron diagram for sample 13NS.

pyp_{3-4} grs_{20-18} sps_{5-6} (core) to alm_{70-73} pyp_{7-8} grs_{11-8} sps_1 (rim). Typically the inner part of the garnet is crowded with inclusions, displaying frequently a web texture around quartz grains, as well as partly digested relics of chlorite and chloritoid, pseudomorphs after lath-shaped precursors (probably the same phases) or their phantoms outlined by graphite dust. All features mentioned indicate a late-stage, monometamorphic prograde growth of garnet. Monazite grains of 150-300 µm size occur as inclusions in garnet, mica, and in the matrix. Similarly to garnet, the zonation is also monometamorphic, with U, Th and Y decreasing towards rims. In some matrix grains an overprint zonation is discernible, with high U, Th, Y – domains parallel to the foliation.

The Poiana Mraconia sample (13NS) is a garnet-kyanite-staurolite micaschist (Stan 1984) made up of garnet, muscovite, paragonite, chlorite, staurolite, kyanite, quartz, rutile, and apatite, xenotime, monazite, and zircon as accessory minerals. Garnet occurs as crystals up to 1 cm in size, rich in inclusions and often overgrowing folded portions of the matrix. The garnet compositions vary from alm_{60-62} py_{8-9} $gross_{10-12}$ $spess_{2-3}$ (core) to alm_{63-64} py_{20-21} $gross_2$ $spess_{0.2}$ (rim). The distribution of Fe, Mg, Ca, and Mn indicates a prograde concentric growth zoning pattern, deflected around folded matrix inclusions. Monazites grains up to 100 µm in size are mostly included in mica flakes.

From sample 12Mo2 two garnet fractions (core and rim) were drilled-out from large idiomorphic garnets, and only one fraction from sample 13NS, as no pure material could be obtained from inclusion-laden garnet cores, containing also xenotime and apatite. From both samples whole-rock powders were prepared. Chemical separation, spiking, dissolution and TIMS analyses were carried out at the University of Arizona.

Chemical compositions of monazite were analysed using a Cameca SX100 microprobe at the Institut für Mineralogie und Kristallchemie, Universität Stuttgart, by simultaneous measurement of both major and trace elements during the same session. Age values were calculated from an explicit approximation of the age equation, also allowing calculation of the individual age errors (Săbău 2012) and the age spectra were processed by pooling coherent age domains and performing the deconvolution of the global age probability function (Săbău and Negulescu 2013).

The monazite analyses from the Sibişel unit (12Mo2) yielded a Permian dominant cluster, followed by an Early Triassic secondary maximum (Fig. 1A,B), coinciding within analytical error with the Sm-Nd data, which cannot distinguish between garnet core and rim ages (Fig. 1C). The monazite analyses from the Poiana Mraconia Formation (13NS) display a typical Variscan (Carboniferous) age spectrum (Fig. 2 A,B) in the range of 337.7 ± 3.9 - 316.7 ± 3.5 Ma. The 2 point Sm–Nd isochron of 322 ± 12 Ma (Fig. 2C) is in good agreement with the dominant age cluster obtained from monazite data.

The fair coincidence between chemical and isotopic age data confirm the reliability of monazite chemical U-Th-Pb_T geochronology in estimating metamorphic ages. Both methods support a juvenile Variscan character for the Poiana Mraconia metapelite, as well as a post-Variscan tectonothermal evolution of the Sibişel Formation. In both cases garnet rim growth coincides with a static thermal climax slightly post-dating tectonic deformation.

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Unique provenances of Lower Triassic and Cretaceous sandstones of Tisia: U-Pb zircon and $^{40}Ar/^{39}Ar$ ages

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Abstract

We undertook a combined single-grain laser-ICP-MS U-Pb zircon and single-grain $^{40}Ar/^{39}Ar$ white mica age datingstudy of provenance of Permian rift and Lower Cretaceous synorogenicgreywackes of the westernmost part of the Tisia block (Medvednica and Samogorska Gora Mts.). The principal aim is to reveal the paleogeographic relationships of this part of Tisia.

Sample CRO-40C is a red sandstone of Samogorska Gora Mts. with a supposed Permian age. For zircons, we found the following U-Pb age groups from young to old: The youngest age 246.1 ± 1.3 Ma revealing a potentially maximum Early Triassic age of these red beds. Seven zircon grains range between 319.4 ± 1.8 Ma and 367.7 ± 2.3 Ma showing the importance of Variscan magmatism in the source region. A similar large age population (eight grains) ranges between 417.3 ± 5.0 Ma and 489.0 ± 2.5 Ma and argues for Ordovician to Silurian magmatism similar as four grains between 583.1 ± 5.2 Ma and 676.7 ± 4.4 Ma indicating Panafrican events. Interestingly, single grains are at 829.9 ± 4.6 Ma (Late Grenvillian) and 2072 ± 8 Ma (Early Proterozoic). Detrital white mica grains are currently measured with the $^{40}Ar/^{39}Ar$ method.

As the next younger time-step we investigated sample CRO-39A, which is a Lower Cretaceous greywacke of Samogorska Gora Mts. With the U-Pb method, we found the following age groups respectively single grains: a single grainat 216.0 ± 3.3 Ma indicates Late Triassic magmatism in the source region. Four grains range from 249.5 ± 3.8 to 254.2 ± 3.9 Ma showing magmatism at the Permian/Triassic boundary. Six grains range between 308.4 ± 4.7 to 363.1 ± 5.5 Ma (Variscan tectonothermal events). Further single grains are at 455.1 ± 6.9 Ma, 545.0 ± 8.2 Ma. 629.8 ± 9.4 Ma, 907.0 ± 13.2 Ma. 987 ± 14 Ma, 1671 ± 23 Ma, 1852 ± 25 Ma and 1940 ± 26 Ma and indicate Ordovician, Panafrican, Grenvillian and Early Proterozoic sources. The Ar-Ar ages of white mica of the same sample are as follows: A single grain is at 253.2 ± 1.6 Ma (Permian/Triassic boundary), thirteen grains between 304.7 ± 5.7 Ma and 369.3 ± 4.9 Ma constrain dominant Variscan tectonic events, five grains are between 430.3 ± 6.0 Ma and 460.2 ± 4.7 Ma and reveal Mid Ordovician to Silurian events, and a single grain is at 510.7 ± 21.6 Ma (late Panafrican).

Sample CRO-27 is again a Lower Cretaceous greywacke from Medvenica Mts. Three grains are between 247.9 ± 5.7 Ma and 263.9 ± 1.6 Ma, fifteen grains between 286.9 ± 1.8 Ma and 369.1 ± 2.3 Ma, and nine grains range from 386.8 ± 2.4 Ma to 430.0 ± 2.7 Ma. The first two populations are similar to Samogorska Gora Mts., the later population reveals a significant difference to Samogorska Gora. All grains of sample CRO-27, another Lower Cretaceous greywacke, gave Variscan ages.

In summary, the new data argue that Variscantectonothermal events are dominant in the source of Tisia and Mid Danubian Range. However, some other features are virtually unique. These include the missing Mesozoic Ar-Ar white ages in the Lower Cretaceous greywackes compared to previous reports from Dinarides (Ilic et al. 2005), tectonothermal events at the Permian/Triassic boundary monitored by both U-Pb zircon and Ar-Ar white mica ages, and the presence of a small population of Grenvillian U-Pb zircon ages arguing for likely Amazonian provenance within Gondwana. Furthermore, compared with Alps (Neubauer et al. 2007), the new data reveals a much higher importance of Ordovician to Silurian tectonothermal events, whereas Panafrican detritus is present but much less important than in Alps.

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U-Pb zircon ages of Middle-Upper Triassic magmatism in Southern Alps and NW Dinarides: Implications for the Southeast Mediterranean tectonics

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Abstract

Middle to upper Triassic magmatism is known to be widespread in central Southern Alps and in Dinarides since a long time and was increasingly reported from Western and Eastern Carpathians as well as from Hellenides. To constrain the whole age range and potential trends of magmatism, we present here six new laser-ablation ICP-MS U-Pb zircon ages mainly from thick tuff and subordinate stocks from the eastern part of Eastern Alps and northwestern Dinarides. Our new ages range from 245.8 ± 1.8 Ma (Bärental, South Karawanken unit) to 223.7 ± 1.5 Ma (Lojše, Sava fold region). The porphyritic andesite stock of Fužine (NW Dinarides) gave 233.7 ± 1.5 Ma. Foliated tuffaceousmetasandstone previously believed to represent a Carboniferous deposit of the Tolminnappe turned out to have an age of 233.7 ± 1.5 Ma, similar as tuffaceoussericiteschists of the same tectonic unit with age of 223.7 ± 1.5 Ma. Green lapilli tuffs of Riofreddo have an age of 236.5 ± 5.5 Ma. All tuffs also bear zircon xenocrysts. In those of the Southalpine unit, two age groups were found, ca. 444 ± 6 to 456 ± 8 Ma and 603 ± 7. At Fužine, a xenocrysticgrain yields 397 ± 5 Ma. We argue, therefore, that magmatism evolved on a Panafrican to Ordovician resp. Lower Devonian continental basement although magmatic rocks of these age groups are largely unknown in Southern Alps and NW Dinarides.

Interestingly, many high-precision ages of tuffs from the Alpine-Carpathian region are now available in the literature with the main purpose to correlate with biostratigraphy. These ages centerat ca. 241 to 238 Ma mostly around the older age group reported by our new ages, whereas younger ages are scarce. A regional survey is showing a wide range of petrographic and geochemical compositions with mainly calc-alkaline acidic compositions and rare mafic magmas to highly alkaline compositions including syenite plutons (e.g., Eisenkappel in Alps, Ditrau in Eastern Carpathians) and A-granites (Hrončok, Vepor unit of Western Carpathians), whereas those of Dinarides and Hellenides are largely of calc-alkaline composition. Consequently, these magmatic suites include elements of quite different tectonic significance. In terms of the geodynamic composition, these magmas are late within the rift process and rather at the stage of rift to drift transition of the Meliataocean. We speculate, therefore, that some magmas were generated by impingement of a mantle plume into the fully developed Meliata rift.

U-Pb Zircon Geochronology of Northern Metamorphic Massifs in the Biga Peninsula (NW Anatolia-Turkey): a new approach to the tectonostratigraphy of the region

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Abstract

Metamorphic massifs of the Biga Peninsula form two approximately ENE-WSW-trending belts. These two belts represent two different tectonic zones, separated by a NE-trending Alpine ophiolitic suture. The Sakarya Zone lies to the S-SE of this Alpine suture, and consists of the Kazdağ metamorphic complex, tectonically overlain by the Permo-Triassic Karakaya Complex. The metamorphic rocks, as an Alpine edifice located N-NW of the suture, have been assigned to the Rhodope and Serbo-Macedonian massifs of Bulgaria and Greece. The northern metamorphic belt is formed by the Karadağ massif in the west, the Karabiga massif in the east, and the Çamlıca massif in between. Following the detailed mapping of all the three massifs, LA-ICP-MS U-Pb zircon dating was carried out to different stratigraphic levels in order to compare them. Contrary to previous studies, our data indicate that the basement metamorphic associations in these three areas show similar characteristics concerning their litho-stratigraphic aspects. Zircon U–Pb LA–ICP–MS dating of samples from the three individual metamorphic massifs yielded the following data: maximum sedimentation ages of the protolith of mica schists in the range of 559 ±17 to 582 ± 30 Ma; crystallization age of the metavolcanic rocks protolith is of 577 ± 20 Ma, and crystallization age of the eclogites protolith is of 565 ± 9Ma. These ages clearly show that the metamorphic units of the northern massifs are comparable to each other. Also, the distribution of U-Pb zircon ages along the Concordia reveals interesting similarities among these three metamorphic massifs. In addition to the similarity of the maximum sedimentation ages and the crystallization ages of the protoliths of the metabasic rocks, there are two major complex tectono-thermal overprints (episodic lead loss events), at c. 330-300 Ma (Variscan?) and c. 100-10 Ma (Alpine and late Alpine?), respectively. Field mapping and analytical data indicate that the basement rocks of the northern massifs in the Biga Peninsula have a correlative Late Ediacaran to Early Cambrian stratigraphic range. Partly, Permian strata unconformably overlie the basement rocks in the Karadağ massif. Both tectono-thermal events are demonstrated by coeval episodic lead loss of many zircons in all samples from all areas. Finally, the results of this research do not support an Alpine suture between the two metamorphic belts of the Biga Peninsula.

Key Words: *U-Pb zircon dating, Ediacaran-Cambrian basement, Sakarya Zone, Biga Peninsula, NW Turkey*

A monazite U-Th-Pb$_T$ metamorphic ages survey in the South Carpathian basement units: delving into tectonic stacking and differential exhumation

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Abstract

Chemical U-Th-Pb$_T$ monazite ages provide details of the syn-metamorphic tectonothermal history of the basement units of the South Carpathians, assisting their distinction, correlation, and the understanding of their formation and evolution. Monazite ages in connexion with the metamorphic assemblages indicate complex Variscan tectonic stacking of juvenile and reworked units, and post-Variscan, Permian to Mesozoic, differential exhumation ensuing extensional collapse.

Keywords: *Monazite U-Th-Pb$_T$ geochronology, metamorphic ages, basement complexes, South Carpathians.*

Introduction

A tradition, longer than centennial, has been established up to now in the study of the basement complexes in the Carpatho-Balkan area. Yet, the advantages of such an extended accumulation of knowledge are at some extent counteracted by the fact that the definition, subdivision and correlation of "grandfathered" metamorphic basement units preceded several major steps taken meanwhile in understanding the evolution and dynamics of the lithosphere, as also principles and terminology pertaining to continuously developing formal lithostratigraphy. Quantitative metamorphic and geochronological data represent powerful criteria in testing the coherence of traditionally defined basement complexes, besides progressively providing rationale for separation and correlation of their subunits. The age of tectonometamorphic consolidation of basement fragments is potentially the most appropriate criterion in outlining units, and geochronology of a metamorphic mineral like monazite is highly suitable for determining it.

Analytical Approach

Metamorphic ages were determined on selected samples from the basement units of the South Carpathians using U-Th-Pb$_T$ microprobe geochronology. Both major and minor elements were determined in the same session on a Cameca SX100 microprobe located at the Institut für Mineralogie und Kristallchemie in Stuttgart, using an accelerating potential of 20 kV and a probe current of 200 nA in order to maximize peak/background ratios. Full chemical analyses were recorded and processed to obtain structural formulae, normalized chemical plots and model U-Th-Pb ages. Analytical data were corrected for peak overlaps; individual ages and associated errors were calculated using the approximation and corrections given by Săbău (2012). The age spectra obtained from each sample were handled according to the procedure outlined in Săbău and Negulescu (2013): plotting the general probability distribution function, selection of age domains approaching Gaussian distribution, calculation of a pooled average of the point data in each domain, and deconvolution of the global probability function anchored on the mean values of the pooled domains. The deconvolved age spectra were interpreted in connection with the metamorphic or magmatic history of the sample and the chemical shifts identified in the monazite populations on account of grain zonality and normalized elemental ratios.

Results and Discussion

The investigated basement units were the Danubian domain, the Lotru Metamorphic Suite in the Getic Nappe, the Făgăraş and Leaota Massifs.

The Danubian Nappe system represents the deepest tectonic level cropping out in the South Carpathians, consisting of several Alpine thrust sheets grouped in the lower and upper Danubian units (Berza et al. 1994, and refs. therein). In the lower Danubian Units a sequence of two Variscan thrust sheets was identified, the Parâng-Retezat Nappe straddling the Vîlcan-Pilugu Unit. This relationship was extended to other Alpine units in the thrust sequence, by implying a duplex structure of the Danubian and ascribing all lithologies to two basic types, the Drăgşan basement of the Parâng-Retezat unit and the Lainici-Păiuş basement of the Vîlcan-Pilugu unit (Seghedi and Berza 1994), in which also the basement units in the south Banat (Almăj Mts.) were included in virtue of general lithologic similarities. A widely accepted Cadomian age of the metamorphism and granitic plutonism is supported by isotopic data in the Lainici-Păiuş basement, and to a lesser extent in the other basement units. Monazite data obtained are in excellent agreement with the Proterozoic to Cambrian ages of the Lainici Păiuş basement, but all other units consistently yielded Variscan or slightly younger age spectra. The Lainici Păiuş data were collected from three typical lithologies, namely calc-silicate rock, K-feldspar diatexite determined were 629.5 ± 3.5 for uranothorite and 633.9 ± 3.2 for thorianite. The other two samples contain abundant monazite displaying age spectra consistent with a Proterozoic to Cambrian tectonothermal evolution (Fig. 1A,B) and bracket the granite age of 592 Ma (Balintoni et al. 2011).

At variance with the Lainici-Păiuş basement, micaschists from the Drăgşan basement show dominant Permian metamorphic ages (Fig. 1C). Similarly, monazite from all other units of the Danubian nappe system recorded Variscan ages down to Permian, starting from 369 ± 3 Ma (Fig. 2A) in the Ielova complex, Carboniferous ages of 338 ± 2 – 317 ± 2 in the Poiana Mraconia complex

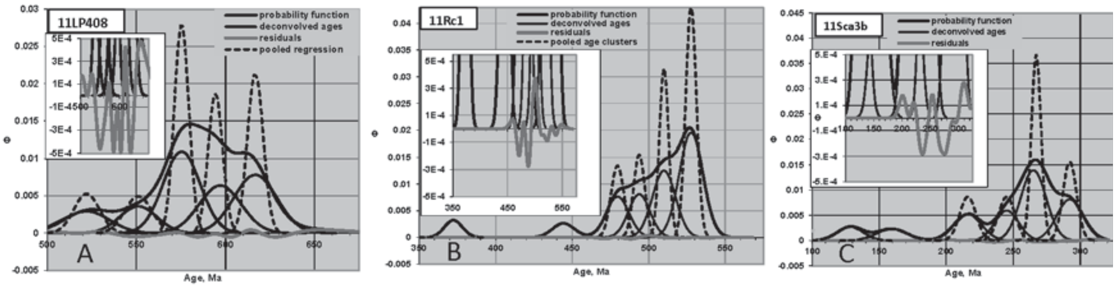

Figure 1. Monazite age patterns from the Lower Danubian units: Lainici-Păiuş basement (A,B) and Drăgşan basement (C).

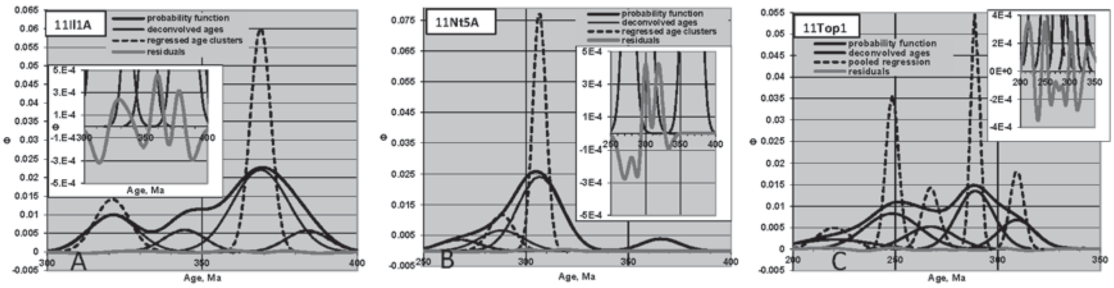

Figure 2. Additional age patterns from other Danubian basement complexes: Ielova (A), Neamţu (B), Corbu/Vodna (C).

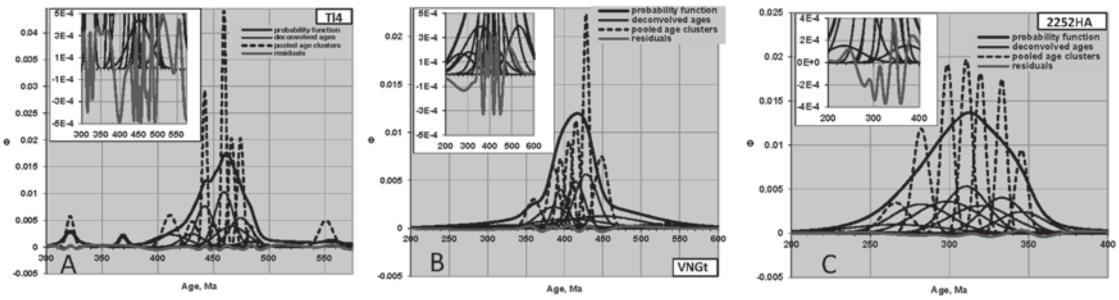

Figure 3. Age patterns from the Lotru Metamorphic Suite, Getic Nappe: pre-Variscan Valea Căprăreasa Complex (A, B) and the overlying Semenic synmetamorphic nappe (C).

(11Rc1) and high-grade gneiss associated to gneissic granitoids (Şuşiţa type) – 11LP408. In the calc-silicate rock no monazite was found, but uranothorite and thorianite appear in a diverse accessory assemblage alongside common sulfides, molybdenite, altaite and sperrylite; chemical ages (see also Negulescu et al. 2014), and dominantly Permian ages in the easternmost units (Fig. 2B,C).

The Lotru Metamorphic Suite of the Getic Nappe is composed of concordant synmetamorphic thrust

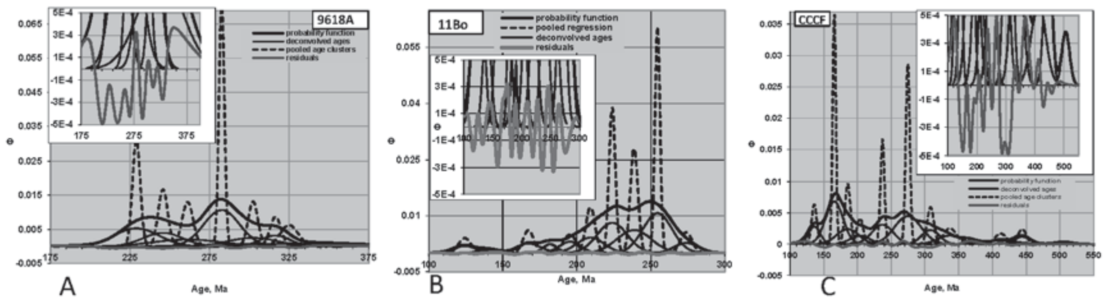

Figure 4. Rejuvenated rock units from the Lotru Metamorphic Suite.

sheets with contrasting metamorphic history. The uppermost Semenic Unit contains apparently monometamorphic garnet- and kyanite micaschists typically containing rutile. Lower units contain polymetamorphic sillimanite-grade, lower pressure schists and gneisses, with the exception of a high-grade gneiss-granite complex (Valea Căprăreasa) recording a strong high pressure overprint (kyanite + K feldspar), and only minor and local sillimanite-muscovite retrogression. The age spectrum preserved in this complex is clearly pre-Variscan, recording granitic plutonism at 474 ± 3 to 460 ± 3 Ma in metagranites (Fig. 3A) followed by the 442 ± 2 Ma pervasive high-pressure overprint well-expressed in both metagranites and host gneisses - 448 ± 9 Ma (Fig. 3B). In contrast, the overlying Semenic Unit displays an age spectrum typical of juvenile Variscan rocks, recording the age of the single metamorphic overprint and syn/late – metamorphic stacking in the interval 282-345 Ma (Fig. 3C).

The units containing lower-pressure sillimanite bearing assemblages typically contain higher-pressure relics and a complex distribution of monazite ages, descending from late-Variscan to Triassic. As a rule, higher grades and lower pressures of the most pervasive sillimanite-grade overprint correspond to younger ages, documenting differential uplift following the Variscan tectonic stacking (Fig. 4). The end-member of this evolution is represented by the Ursu dome, consisting of cordierite-sillimanite-K feldspar gneisses and anatectic peraluminous granites. The age spectrum of the granitoid rocks is remarkable as it contains an extended age spectrum (Fig. 4C), witnessing remobilization of Variscan and older basement, anatexis and emplacement of the biphasic dome structure as late as the Middle Jurassic (166 ± 2 Ma).

Monazite geochronology in the Făgăraş and Leaota Massifs also revealed tectonic imbrication of Variscan and pre-Variscan units. In both cases the lowermost term of the basement sequence displays a monometamorphic Variscan history in micaceous schists and gneisses. Structurally upwards, pre-Variscan crustal fragments containing metagranites typically displaying Lower Palaeozoic intrusion ages. In the Făgăraş Massif the 479 ± 2 Ma Valea Bolovanului granite intrudes a mafic complex strongly overprinted during the Variscan metamorphism, but bearing no evidence of previous metamorphic alterations. The Variscan overprint is strong and general at the scale of the massif; younger ages reaching the Permian-Triassic boundary appear in the structurally deepest level accessible, in dome-shaped structures on the northern slope of the Făgăraş Mts. Unlike in the Lotru basement, these dome structures do not display conspicuous metamorphic contrasts or low-pressure overprints. In the Leaota Massif, the remobilized pre-Variscan tectonic slice bears evidence of a complex pre-Variscan evolution, with Ordovician intrusion of the Albeşti Granite (462 ± 5 Ma) in an already consolidated metamorphic basement with a poorly constrained metamorphic age, followed by a Late Devonian (371 ± 7 Ma, Săbău and Negulescu 2013) tectonic stacking and higher-pressure overprint. The Variscan evolution is continued by emplacement of younger and less overprinted tectonic slices towards the top of the basement sequence.

Conclusions

Chemical U-Th-Pb_T monazite ages may provide detailed information regarding the tectonothermal history of the individual basement units of the South Carpathians, as also their coherence, the tectonic framework of their build-up and mechanisms governing their further evolution. For the Danubian units a more complex Variscan evolution and overprint is revealed than previously recognized, as also suggested by abundant Variscan plutonism dated by Balica (2007). Moreover, no pre-Variscan metamorphic ages were identified in any of the Danubian units but the Lainici Păiuş basement of the Vîlcan-Pilugu Variscan unit. An imbrication of reworked and juvenile metamorphic units is revealed by monazite geochronology, but also metamorphic assemblages, in various basement units, as exemplified by the Getic Nappe basement and the Leaota and Făgăraş Massifs, in otherwise broadly homogeneous and coherently-looking sequences. Differential uplift of various terms of the sequence is apparent in the Lotru Metamorphic Suite, where higher-grade and lower pressure conditions, together with contrasting unit boundaries, correlate with younging ages, eventually going down to Jurassic in gneissic-anatectic dome structures.

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Ordovician metamorphism in the Slavonian Mountains (Tisia Terrane): Geochronology, P-T characteristics and tectonic implications

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Abstract

The Slavonian Mountains in Croatia form one of the largest crystalline basement complexes within the Tertiary Pannonian Basin and provide important insight into the crustal evolution of the Tisia Terrane. Main lithologies are micaschists, paragneisses, migmatites and granitoids. Although an Early Palaeozoic/Baikalian formation age was envisaged for parts of these rocks in early work (Jamičić 1983), it became prevailing thought later that the metamorphic evolution of the Slavonian Mountains is almost entirely Variscan (Pamić et al. 1988). The proposal for a pre-Variscan metamorphic history was recently reinforced when a monazite age of ~440 Ma was measured at Salzburg University by EMP, in a micaschist from a locality ~3 km north of Kutjevo (Balen et al. 2006). A few km southeast, at Gradište, Variscan (Carboniferous) monazite was found in an andalusite bearing St-Grt-Bt-Ms schist (Horvath et al. 2010), implying a complex polymetamorphic history for this region.

Our current research project has the goal to delineate zones of pre-Variscan and Variscan metamorphism in the Slavonian Mountains, to provide further geochronological and petrological data for both events, and to establish on that basis regional correlations with other, Variscan/pre-Variscan polymetamorphic basement terranes of Central Europe. Preliminary results are as follows: By means of electron microprobe monazite dating, Ordovician metamorphism could be documented in several localities along an east-west trending zone north of Kutjevo. We suggest the name Kutjevo Zone (KZ) for this Ordovician crystalline zone, which is at least 12 km long and 3.5 km wide. The KZ exposes Grt-Bt-Ms±Chl schists with small intercalations of amphibolites and metagranitoids in its southern lower part, and a Grt-Chl-Ms schist along its northern hangingwall termination. The Ordovician P-T evolution is of the Barrowian type. It reaches ~10 kbar/600 °C in Grt-Bt-Ms±Chl schists and ~9 kbar/550 °C in Grt-Chl-Ms schist according to empirical thermobarometry and thermodynamic modelling. In the latter, the presence of Chl instead of Bt is due to an Al-rich pelitic protolith composition. From the Grt-Chl-Ms schist we have obtained a Lu-Hf garnet age of 466.0 ± 2.3 Ma (isochron age from 3 garnet fractions plus whole rock), interpreted as the integrated time of prograde garnet formation. EMP monazite ages in the KZ also cluster around ~470 Ma. Judging from the well defined Lu-Hf garnet isochron and the presence of exclusively Ordovician monazite, the entire high-T metamorphic evolution of the KZ should have taken place during the Ordovician. Variscan and Alpine overprints are at best low-T and of subordinate importance. To the north, the KZ abuts low-grade metamorphic rocks (chlorite schists) with an Alpine metamorphic age. Towards the south, the KZ borders a Variscan amphibolite facies metamorphic series with mylonitic contacts. This Variscan metamorphic series (mainly staurolite and garnet bearing metapelites) seems to occupy the entire southern flank of the Slavonian Mountains. It must be clearly distinguished from the KZ and, following Jamičić (1983), shall be referred to as the Psunj metamorphic complex

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Precambrian metabasic relicts in the Ograzhdenian supercomplex, Gorna Ribnitsa Village, Serbo-Macedonian massif, Southwest Bulgaria

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Abstract

A gabbro-norite body in the Ograzhdenian supercomplex bears traces of several phases of zircon formation. TIMS and LA-ICP-MS zircon age dating yielded a considerable number of ancient zircon crystals scattering between c. 2600 Ma and 565 Ma. Discordant xenocrysts cannot define a single perfect Discordia line although an upper intercept of a reference Discordia corresponds to about 2.7 Ga, and a lower intercept may be inferred at about 1.0 Ga. Concordant zircons are situated between c. 850 Ma and 450 Ma. The data obtained are interpreted as indicative of a Neoproterozoic basic intrusion (or amalgamated mantle material) contaminated with Neoarchean to Palaeoproterozoic zircon xenocrysts. The major Ordovician metamorphic event is well defined at 454.2 +/-2.1 Ma.

Key words: *Cadomian metabasites, Ordovician*

The Ograzhdenian metamorphic supercomplex is subdivided into two metamorphic complexes of predominantly amphibolitic (Troskovo complex) and gneissic (Maleshevska complex) composition. It builds the Ograzhden unit (Fig. 1) of the Serbo-Macedonian massif on Bulgarian and Macedonian territories. The Maleshevska complex occupies the greatest part of the unit, and consists of two-mica and biotite gneisses and mica schists, some of them bearing graphite, garnet, kyanite, sillimanite and tourmaline. The protoliths of these rocks are considered to be mostly of terrigeneous (pelitic and psammitic) sedimentary origin. Packets of amphibolite layers are present, most of them probably originating from basic metavolcanic protoliths. Rootless lenticular bodies of metaultrabasites to metabasites are also observed. The Ograzhdenian supercomplex underwent a polydeformational and polymetamorphic evolution (Zagorchev 1976,

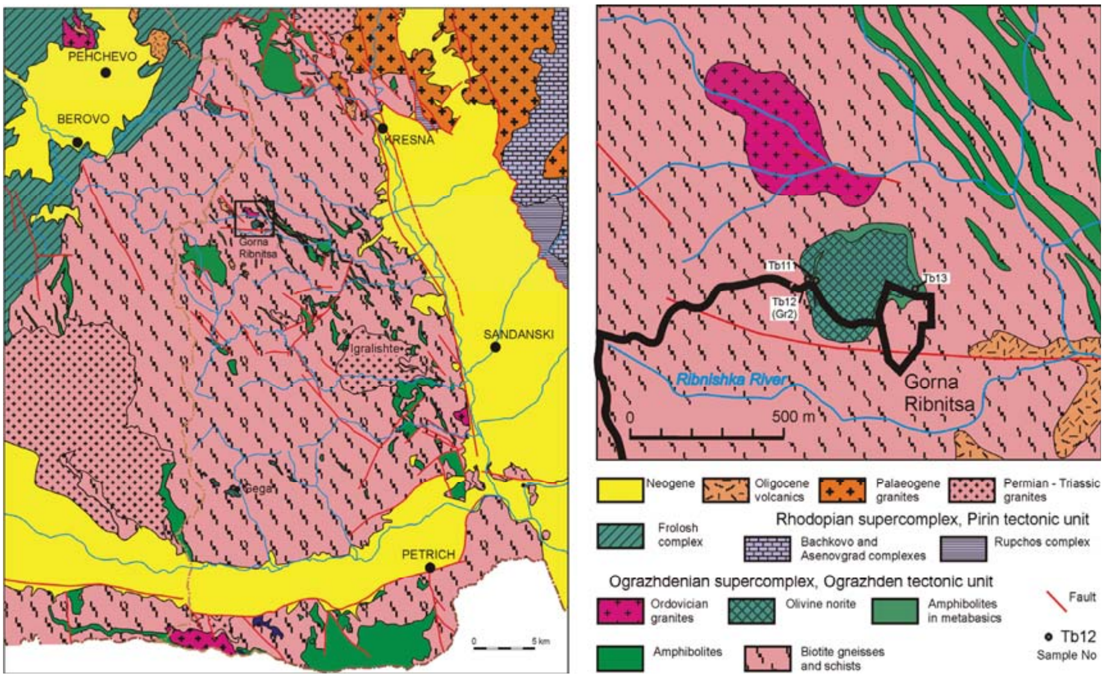

Figure 1. Geological map of the Ograzhden unit (left) and the area of the village of Gorna Ribnitsa (right). After different sources, with revisions.

2008; Zagorchev and Milovanović 2006), the most important metamorphic events being of Cadomian (Lilov et al. 1983) and Ordovician (450-460 Ma – Zagorchev et al. 2012) age.

A body of olivine gabbronorite to norite has been mapped (Zagorchev et al. 1971) in and around the village of Gorna Ribnitsa (Fig. 1). The core of the lens-shaped body has well-preserved primary structure consisting of olivine (Fo71-72 Fa28-29), rhombic pyroxene (altered bronzite or hypersthene), hornblende, garnet, and spinel, all forming zoned clusters included into the plagioclase mass. The latter consists of labradorite-bytownite to bytownite-anortite (An70-89), often in large twinned zonal laths. Late small grains of oligoclase (An13-15) are observed as nest-like clusters. The mafic aggregates usually exhibit corona structures, with subisometric olivine crystal (up to 1.0 mm) in the center, surrounded by thin (0.1 mm) zone of finely-prismatic enstatite. Towards the periphery there follows a thinner spinel zone, an almandine-type (Alm43-60, Sp0.5-1.0, Pyr11-27, Grs28-31) garnet zone, and an outer thin (0.1-0.3 mm) rim built of fine crystal to fibrous Mg-hornblende to edenite.

The chemical whole-rock composition corresponds to high-Mg and high-Ti tholeiite-type gabbro.

The gabbro-norites are transformed at the peripheral parts of the body into gabbro-amphibolites and amphibolites with distinct layering and schistosity. Gabbro-pegmatitic dykes and lenses are observed as well as rare dykes of aplites. The amphibolites at the periphery and along shear zones within the gabbro-norites are moderately migmatized. Nenova and Zidarov (2008) reported rare thin (about 5 cm) dyke bodies of amphibolitized eclogites. They are built of omphacite, zoned garnet (almandine type), rutile, late pyroxene (diopside and augite), hornblende and plagioclase. Banded eclogites built of the same minerals, and quartz, zoisite, clinozoisite, sphene and magnetite, have been also reported but only in separate boulders. The alkaline pyroxene of the banded eclogites has a varying jadeite content – from 8.56 to 22.89 % Jd.

The gabbro-norite contains at least two types of zircons (Fig. 2). The first variety forms translucent crystals of hyacinth type ({100}+{110}+{111}), with adamantine lustre, intact non-corroded surface, rhythmic zoning (parallel to the crystal contours), rarely with sector zoning. Opaque and gas-fluid inclusions are present. The average dimensions are 0.175 x 0.1 mm, Ky = 1.7. The second variety forms dark-pink prismatic crystals with unclear crystal faces and corroded surface. The crystals are semi-translucent, with adamantine lustre, often fractured. The rhythmic zoning is parallel to the crystal contours and not very well observable. The average dimensions are 0.2 x 0.1 mm, Ky = 2.

The isotopic U-Pb studies on single zircon grains

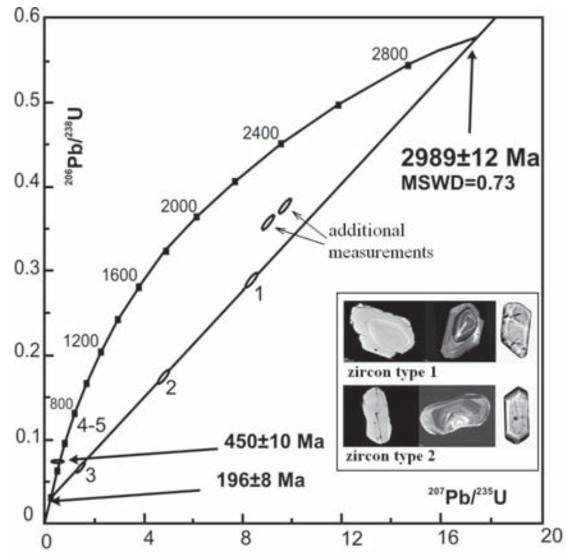

Figure 2. Two types of zircons (inset) and TIMS data.

have been made at the facilities of the Geological Institute of the Kola Center of the Russian Academy of Sciences by T. B. Bayanova according to the method described by Corfu et al. (2011), and at the Laser Chron facility, Department of Geosciences, University of Arizona, by C. Balica (LA-ICP-MS).

Both the TIMS and LA-ICP-MS analyses yielded a considerable number of ancient zircon crystals scattering between c. 2600 Ma and 565 Ma. The TIMS analyses (Fig. 2) show imperfect Discordia lines with upper intercepts at 3000-2800 Ma and lower intercepts with strongly varying values: from c. 900 Ma in some cases, to about 200 Ma, in others. Another sample yielded an upper intercept of about 1.56 Ga and lower intercept at c. 460 Ma. Two crystals from the migmatized amphibolite formed at the periphery of the body give concordant points with 500 and 460 Ma, respectively.

Similar data are obtained by the LA-ICP-MS studies (Fig. 3). Discordant xenocrysts cannot define a single perfect Discordia line although an upper intercept of a reference Discordia corresponds to about 2.7 Ga, and a lower intercept may be inferred at about 1.0 Ga. Concordant zircons are situated between c. 850 Ma and 450 Ma. The best fit of concordant zircons corresponds to 454.0 +/- 2.1 Ma, MSWD = 1.5. The interpretation of the data obtained meets no difficulties in respect of the concordant values (only nine data points!) between 460 and 450 Ma. Intrusive granitoids in the Ograzhdenian supercomplex near the village of Ribnik have been dated (Zagorchev et al. 2012) at c. 460 Ma, whereas concordant zircons from samples of the host migmatites throughout the Ograzhden unit define ages in the interval between 483.6 ± 1.1 and 433.0 ± 1.5 Ma. All these ages clearly indicate that major granitoid igneous activity and coeval and slightly later metamorphism are constrained to the Ordovician Period.

Explanations to the numerous older zircon data from the olivine gabbro-norites and their amphibolite rim are much more difficult to give. Eight zircon grains are considerably scattered and correspond to $^{206}Pb/^{207}Pb$ apparent ages between 2611.7 and 1584.6 Ma, and one grain situated near the Concordia, to 1125.1 Ma; these data points define an imperfect Discordia with upper intercept at c. 2700 Ma and lower intercept, at c. 1000 Ma. These zircons may be inherited as xenocrysts of subducted crust provenance during the mantle evolution. Twenty-two data points are situated over the Concordia or near it, and cover the interval between 877.5 and 503.0 Ma. They may correspond to a Neoproterozoic protolith with culminating Ediacaran-Cambrian (Cadomian) emplacement and cooling.

The data obtained and discussed are interpreted as indicative of a late Neoproterozoic basic intrusion (or amalgamated mantle material) contaminated with Neoarchean to Palaeoproterozoic zircon xenocrysts. Similar cases are known also from the Central and Eastern Rhodope.

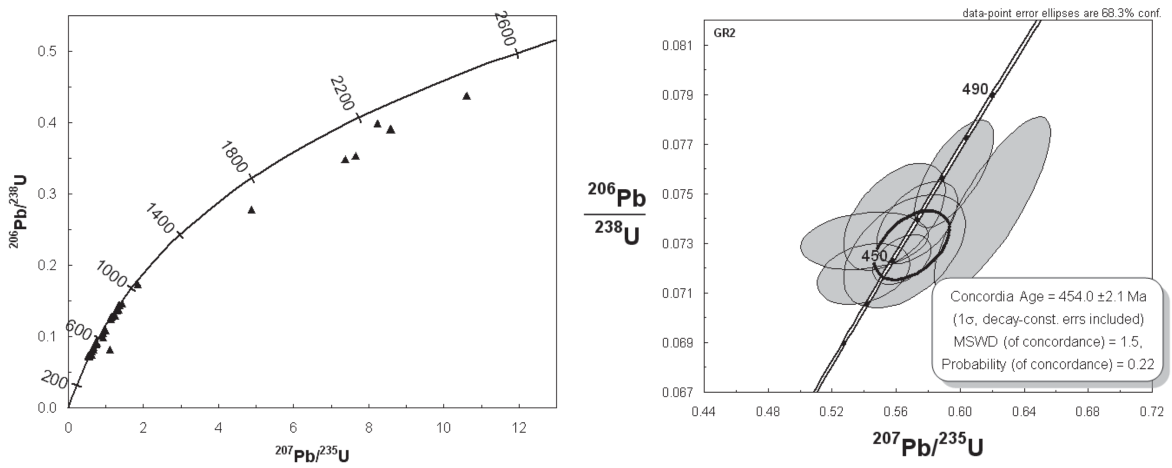

Figure 3. LA-ICP-MS data for the Gorna Ribnitsa gabbro-norite.

Several important conclusions may be drawn. First of all, basic rocks are considerably more resistant to recrystallization (inclusively of zircons), thus containing important evidence of earlier igneous and metamorphic events. As Yoshida (2007) noted, “Major problems (in zircon geochronology, our note) are (i) the lowering of closure temperatures under deformational and/or fluid-rich conditions. (ii) the weighted mean U-Pb concordant ages. (iii) the disappearance of an earlier discordia in the polymetamorphism, (iv) diversity in the interpretation of zonal structure of zircons, (v) general lack of discussion on the formative process of the dated zircons and (vi) the practical difficulty in zircon geochronology for providing evidence of the absence of earlier events superposed by a later high-grade event. It is stressed that it is difficult for zircon geochronology to provide robust evidence for eliminating the possibility of the existence of earlier tectonothermal events superimposed by later high-grade events.” This is probably the case of the Ograzhdenian supercomplex: Precambrian amalgamation of mantle and crustal material, and a polymetamorphic and polydeformational evolution with culmination of metamorphism and anatexis in Ordovician times.

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The Ciomadul volcano revisited: combined U-Pb, U-Th and (U-Th)/He zircon dating for eruption ages and magma residence time

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Abstract

The Ciomadul is the youngest volcano in the Carpathian-Pannonian region. There are number of observations indicating that rejuvenation of the volcanic activity cannot be excluded and thus, a thorough investigation of the past volcanic events and the present status of the volcano are crucial. Here, we provide results of new zircon dating to constrain the temporal evolution of the volcano and to infer the magma residence time. The eruption ages are determined by (U-Th)/He zircon dating corrected by the disequilibrium for the U-decay chain. On the other hand, the U-Pb and U-Th ages imply the zircon crystallization dates. Former views on the volcanic activity were based primarily on K/Ar dating and considered an initial sporadic lava dome effusive phase (Haramul Mic and Balvanyos) at 900-1000 ka, followed by a more extensive volcanic stage that formed the Ciomadul volcanic complex between 600 ka and 30 ka. Our new zircon dating suggests, however, that the volcano is much younger than previously thought.

One of the oldest lava domes is thought to be the Balvanyos. In contrast to the K/Ar age, we determined the eruption age as 580 ka based on the corrected (U-Th)/He zircon date. The U-Pb age data are in the range from 1100 to 700 ka and this implies that a prolonged crystallization in the magma storage preceded the volcanic eruption. Furthermore, the magma chamber is inferred to have become in a low temperature (ca. 750 ^{o}C) crystal mush state >100 ka before the eruption, when presumably no more zircon crystallization occurred. The Ciomadul volcano is also proved to be much younger than the K/Ar age data indicate. The oldest identified lava dome rocks are found north of the explosive twin-craters and have eruption ages around 150 ka. The next eruptive phase resulted in further lava domes about 100-120 ka. The oldest explosive volcanic product has a corrected (U-Th)/He zircon age of 57 ka. Repeated explosive volcanic eruptions with intermittent lava dome extrusions took place up to 32 ka. The Sf. Ana crater could have formed by a large sub-plinian explosive eruption at ca 37 ka, whereas the age of the Mohos crater is still unknown. Nevertheless, lacustrine sedimentary beds at the eastern Mohos crater outlet are underlain by a 34 ka old thick pumiceous pyroclastic flow deposit. This implies that the widening of the lake in the Mohos crater could have possibly followed the last volcanic event. The 32 ka eruption age, yielded both by zircon and radiocarbon dating, is the youngest one in the Ciomadul. In summary, the volcanism of Ciomadul is characterized by intermittent eruption events possibly with several 10's ka repose times. So far, the active volcanic phase is constrained between 160 and 32 ka.

The U-Pb and U-Th zircon age data determined for crystal rims and interiors provide important information on the lifetime of the magma storage. There are only a few relatively old zircon ages in the range of 380-700 ka, however, the dominant zircon crystallization commenced at 350 ka, i.e. at least 200 ka before the onset of the volcanic activity. Remarkably, zircons of the youngest eruption products show the widest crystallization age, indicating a continuous, long lifetime of the silicic magma chamber. However, there are only sporadic zircon crystallization dates after 100 ka. The stop of zircon crystallization several 10's ka before the eruptions is corroborated by the depth profiling data from the outermost 5 micrometres of the crystals. Thus, a long-lived magma storage is inferred beneath Ciomadul. Effective remobilization of the low-temperature silicic crystal mush could have occurred due to intrusion of hot mafic magma. An important implication is that until a melt-bearing crystal mush body exists beneath the volcano, it can be considered being in a potentially active status, even after several 10's ka quiescence period.

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Geochronology of the basalt maars in the northern Pannonian Basin revisited: a new approach by combined U/Pb and (U-Th)/He geochronometry

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Abstract

Reliable dating of mafic volcanic rocks is often complicated due to the scarcity of minerals accumulating radiogenic elements. Consequently, the Ar/Ar and K/Ar whole-rock or isochron dating of basalts and their K-rich minerals are often the only viable methods. However, even these methods may be limited by open-system behaviour of radioactive parent-daughter pairs such as mobility of K and Ar, extraneous ^{40}Ar or the presence of xenocrysts that can produce erroneous results. In this study, we demonstrate on the example of Neogene-Quaternary alkalibasalts from the South Slovakian Volcanic Field (northern Pannonian Basin), that the age of basaltic eruptions can be accurately determined by targeting apatite- and zircon-bearing magmatic xenoliths with a combination of U/Pb and (U–Th)/He dating methods.

We applied a combination of zircon U/Pb, zircon (U–Th)/He and apatite (U–Th)/He dating techniques to a total of six maar structures and diatremes in the South Slovakian Volcanic Field (Hurai et al. 2013). Our new ages differ in majority of cases from the ages inferred from indirect geological, geochronological (K/Ar data on adjacent lava flows) and geomorphological constraints. The new data allowed us to redefine the volcanic geochronology of the area and conclude the following: Two isolated maars (Hodejov and Fiľakovo) in SE part of the study area, which have been indirectly dated by geomorphologic constraints to Late Pleistocene, yielded Pliocene (2.8 ± 0.2 Ma) and Late Miocene (5.5 ± 0.6 Ma) ages, respectively. In contrast, two maars (Jelšovec and Pinciná) in NW part of the study area are of Late Pliocene age (4.1 ± 0.4 and 5.2–5.4 Ma), that is clearly younger than the Late Miocene age (~6.5 Ma) inferred previously from K/Ar data on the proximal basaltic lava flows. These maars therefore belong to the so called second volcanic phase that was previously identified only in SE part of South Slovakian Volcanic Field. Hajnáčka diatreme is dated by our approach at 2.1 ± 0.2 Ma, which is in agreement with the K/Arage of intersecting basalt dyke (2.4-3.2 Ma, Vass et al. 2000, 2007). The maar near Gemerské Dechtáre village age is dated 3.1 ± 0.1 Ma using apatite (U–Th)/He technique, which overlaps the U/Pb age of associated zircon (3.19 ± 0.3 Ma). In the light of the new geochronologic data, it seems to be likely that the Pliocene phreatomagmatic eruptions may have occurred along extension-related, NW- and NE-trending orthogonal faults. This study demonstrates the potential of the combined U/Pb and (U–Th)/He geochronometry of zircon and apatite for accurate dating of mafic volcanic rocks.

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Dome-building volcanic activity in the Oaş-Gutâi Neogene volcanic area, Eastern Carpathians, Romania

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Abstract

A complex dome-building volcanic activity developed during a 5 Myr time interval (13.2-8.0 Ma) in Oaş-Gutâi Mts., associated to the intermediate volcanism of the Oaş-Gutâi Neogene volcanic area (OG). Numerous domes were built up in the entire volcanic region also triggering both non-explosive and explosive fragmentation volcanic processes. The volcanic forms consist of extrusive domes, lava domes and dome-flows/coulées and cryptodomes predominantly as solitary domes, or compound domes and dome complexes. The domes are comprised of andesites, dacites and rhyolites (acid andesites and dacites are prevalent). The volcanic rocks show a calc-alkaline and medium to high-K character and typical subduction-zone geochemical signatures. Overall, either subaerial or subaqueous, the dome growth and collapse associated with fragmental explosive or non-explosive processes, was dominantly responsible for most of the volcanic products. Dome emplacement in submarine setting is commonly associated with marginal auto-brecciation, much subordinated explosive events and subsequent resedimentation. Overall, the dome-building volcanic activity in OG is recorded to a monogenetic-type of volcanism. The series of dome-building events which were triggered and controlled by magma-mixing and -mingling processes developed from time to time in different locations of OG.

Keywords: *Neogene, calc-alkaline volcanism, domes, dacites, volcaniclastics*

Introduction

The Oaş-Gutâi Neogene volcanic area (OG) forms the north-western segment of the Romanian Eastern Carpathians volcanic arc, which has been built up in connection with the post-collisional magmatism related to the Miocene subduction of the European Plate beneath the two, Alcapa and Tisza-Dacia microplates (Csontos 1995). The OG volcanic activity took place in Miocene (15.4-7.0 Ma, Pécskay et al. 2006) and comprised two types of calc-alkaline volcanism: an acidic/felsic, extensional-type volcanism of explosive origin and an intermediate volcanism of extrusive and intrusive origin (Kovacs and Fülöp 2003). The dominant intermediate calc-alkaline volcanic rocks, represented by a series of rocks ranging from basalts to rhyolites (andesites are prevalent) overlap the previous, felsic calc-alkaline volcanic rocks (rhyolitic ignimbrites). A complex dome-building volcanic activity developed in OG associated to the intermediate volcanism. The shape and morphology, as well as the distribution of the specific co-genetic fragmental counter-parts and the relationships with the hosted formations revealed the processes involved in the evolution of each of the edifices. Previous data about the dome-building activity in OG are published by Fülöp and Kovacs (1999, 2006), Kovacs and Fülöp (2002, 2005), Lexa et al. (2010), Kovacs et al. (2013). This paper aims to integrate all the available geomorphological, volcanological, sedimentological, petrological and geochronological data on the dome-building volcanism from OG.

General features of the domes

Space and time distribution. The domes are prevalent in Oaş Mts. where they preferentially locate in the western part of the volcanic area along specific alignments (possibly tectonically-controlled fissures) oriented parallel to the volcanic arc. In Gutâi Mts., the domes are common in the southern and central part of the mountains where they inter-finger with the complex, predominant effusive volcanic structures of the area (Fig. 1). Overall, the dome-building volcanic activity in OG took place during a 5 Myr time interval (13.2-8.0 Ma, Fig. 2A), which was a shorter time interval comparative with the OG intermediate volcanism (approx. 6.5 Myr) and with the entire volcanic activity in OG (around 8 Myr). In Oaş Mts., the dome-building volcanism was shorter (11.0-9.5 Ma) than the corresponding volcanism in Gutâi Mts. (Fig. 2A).

Morphometrical features. The volcanic forms attributed to the dome-building activity are dominantly solitary volcanoes located adjacent to the main volcanic area and surrounded by Neogene-Quaternary sedimentary deposits in Oaş Mts. In Gutâi Mts., the domes mainly located within the main volcanic area inter-finger with the complex, polygenetic structures. Overall, the domes are subround or elongate (circular to quasi-circular, or ellipsoid map-outline), conical or flat-topped, with steep or shallow slopes. The morphologies suggest simple extrusive domes like lava domes, dome coulées, cryptodomes. More complex shapes and morphologies suggest compound domes and dome complexes. The sizes vary from 300 m (e.g. Turulung dome-Oaş Mts., 5 in Fig. 1) to 5 km (e.g. Oraşu Nou dome-coulée from Oaş Mts., 9 in Fig. 1, Gutin cumulodome from Gutâi Mts., 17 in Fig. 1) with the common 1-2 km in length/diameter. The actual height of the volcanic edifices (in respect to the surrounding geological formations, either sedimentary or volcanic rocks from the adjacent volcanic structures) varies from tens of meters (e.g. 40 m Turulung small dome) up to 400 m (e.g. Batarci dome in Oaş Mts., 3 in Fig. 1, Gutin cumulodome-Gutâi Mts.).

Petrographical and geochemical data. The domes are comprised of andesites, dacites and rhyolites. The acid andesites and dacites are prevalent. Most of the domes show a remarkable petrographic homogeneity, comprising a single rock-type. Subordinately, two or several different rock-types (e.g. andesite and dacite) were identified in some of the compound domes.

Major, trace element and isotope geochemistry revealed the geochemical features of the volcanic rocks from the OG domes with indications about their source magmas. The calc-alkaline and medium to high-K character and typical subduction-zone geochemical signatures are confirmed for all the volcanic rocks. Crustal assimilation processes involved in the evolution of the generated magmas are constrained by the high Sr ratios (0.7063-0.7083). Besides the main AFC petrogenetic process, magma-mixing and mingling processes were also involved in the evolution of the magmas responsible for the

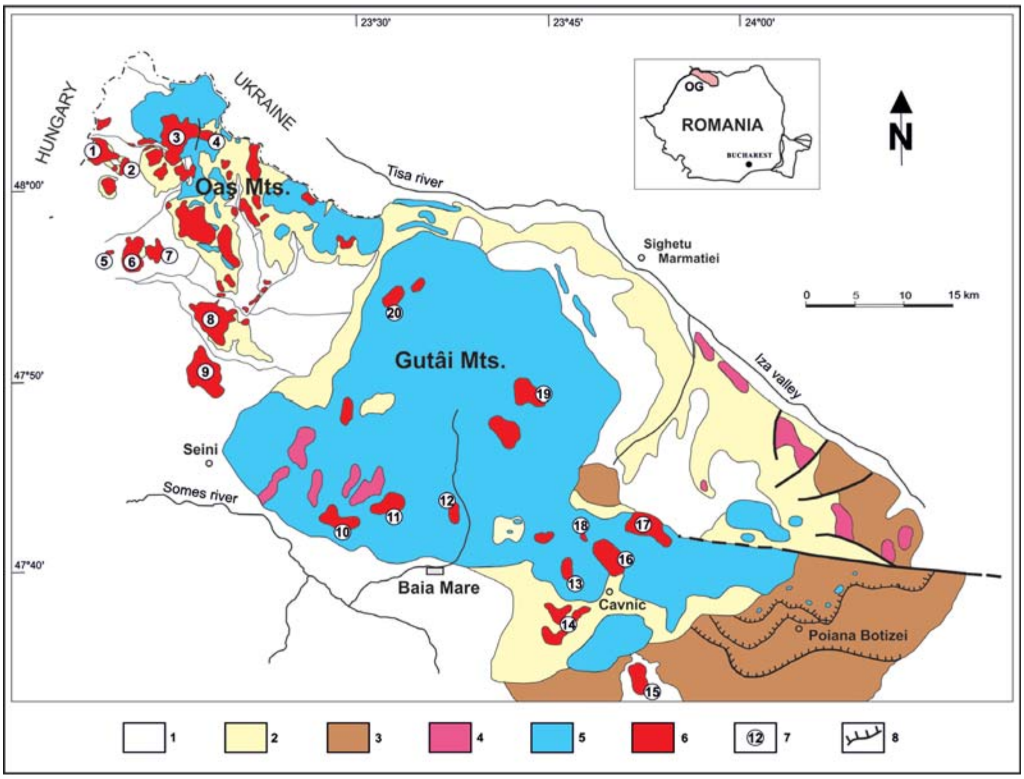

Figure1. Simplified geological map of the Oaş-Gutâi Neogene volcanic area (OG) with the location of the domes.
1. Quaternary sedimentary deposits; 2. Neogene sedimentary deposits; 3. Paleogene sedimentary deposits; 4. Felsic volcanic rocks; 5. Intermediate volcanic rocks; 6. Domes; 7. Numbers allocated to the described domes; 8. Overthrust.

dome-building volcanism. With this respect, the mineralogical and textural features of the dacite domes strongly constrain these processes (e.g. the large-sized embayed sanidine crystals coexisting with high Mg# (85-90) chromian-diopside, large-sized sieve-textured or strongly reverse zoned plagioclases, high amount of gabbroic-type mafic microgranular enclaves/MME).

Volcanic and petrogenetic processes.

The investigations conducted on the main domes of OG enabled the reconstruction of the dome-forming extrusive processes, often complex because of additional non-explosive or explosive fragmentation events. Subaerial or subaqueous setting could also be assigned to the main domes. Lava domes, dome coulées and cryptodomes form the dominant group which does not suggest subsequent fragmentation: e.g. Penigara (7 in Fig. 1) and Colnic (2 in Fig. 1) in Oaş Mts., Pleşca Mare (19 in Fig. 1) and Hircea (12 in Fig. 1) in Gutâi Mts. lava domes; Hatu Lung (1 in Fig. 1) in Oaş Mts. dome coulée, Ghezuri (4 in Fig. 1) in Oaş Mts. and Ulmoasa (11 in Fig. 1) in Gutâi Mts. cryptodomes. However, a non-explosive type of fragmentation was common during dome growing due to auto-brecciation /quench fragmentation and overload-driven gravitational collapse**:** extrusive domes with hyaloclastic and autoclastic shells (e.g. Pusta Heghii-6 in Fig. 1 and Jeleznic-8 in Fig. 1 in Oaş Mts., Şatra-15 in Fig. 1 and Vezău-20 in Fig. 1 in Gutâi Mts.) and talus breccias (e.g. Gutin-17 in Fig. 1 in Gutâi Mts.), respectively. Less common but more complex, a second group of solitary domes and dome complexes (single or multiple interconnected edifices) were investigated with respect to the magma source, the growing process, and the role played by explosive processes in their evolution history. Some examples of this group are: in Gutâi Mts. Şindileu dacitic solitary lava-dome (10 in Fig. 1) shows a large portion of the dome comprised by block and ash flow deposits suggesting subaerial emplacement; in Oaş Mts., Turulung dacitic lava-dome develops *in situ* and resedimented phreatomagmatic volcaniclastics at its margins, indicative of subaqueous setting. Large dome complexes such as Batarci which occupies a large area in the north western part of Oaş Mts. comprise thick piles of lavas and wide spread pumice-and-ash flow deposits which testify for the dome growth co-genetic subaerial explosive activity. Two interconnected and subaqueously emplaced lava domes, Dăneşti and Piatra Roşie (14 in Fig. 1) located in the southern part of Gutâi Mts. comprise of coherent lavas and *in situ* and resedimented hyaloclastites with co-genetic primary and reworked phreatomagmatic volcaniclastics.

Overall, either subaerial or subaqueous, the explosive or non-explosive dome growth and collapse-related fragmental processes, seem to be dominantly responsible for most of the volcaniclastic products. Dome emplacement in submarine setting commonly conducted to marginal quench fragmentation, subordinate rootless explosive events and subsequent resedimentation.

The petrological features of the volcanic domes from OG suggest different extrusion-controlling genetic magmatic processes. The petrographic and geochemical homogeneity of the majority of the OG volcanic domes correlated with the morphologic features (solitary, simple-shape, small volume of magma volcanoes) suggest a likely monogenetic volcanism. Less common, some domes show petrographic complexity and at least two petrographic rock-types generated by magma-mixing and mingling processes in the same open-magmatic system: e.g. Laleaua Albă dome (18 in Fig. 1) with a core of macroporphyric sanidine dacite (8.42 ± 0.33 Ma) surrounded by an envelope of aphyric andesite (8.47 ± 0.42 Ma); Pleşca Mare large-sized dome (19 in Fig. 1) comprised of a well-developed biotite dacite core, partially bordered by a biotite andesite. Hereby, extrusion was controlled by magma-mixing and mingling processes during at least two distinct magmatic events: the formation of the hybrid andesitic rocks of the envelope and the subsequent generation of the dacitic rocks within the core. Building of several other domes in OG was triggered and controlled by the mixing of two compositional different magmas (Fig. 2B) which generated hybrid rocks: a basaltic magma and a silicic magma. Hybrid rocks (acidic andesites and dacites) are considered to be common in OG domes.

Conclusions

Dome-building volcanic activity (13.2-8.0 Ma) represents a significant part of the CA intermediate volcanism in the Oaş-Gutâi Neogene volcanic area (OG). Numerous domes were built up in the entire

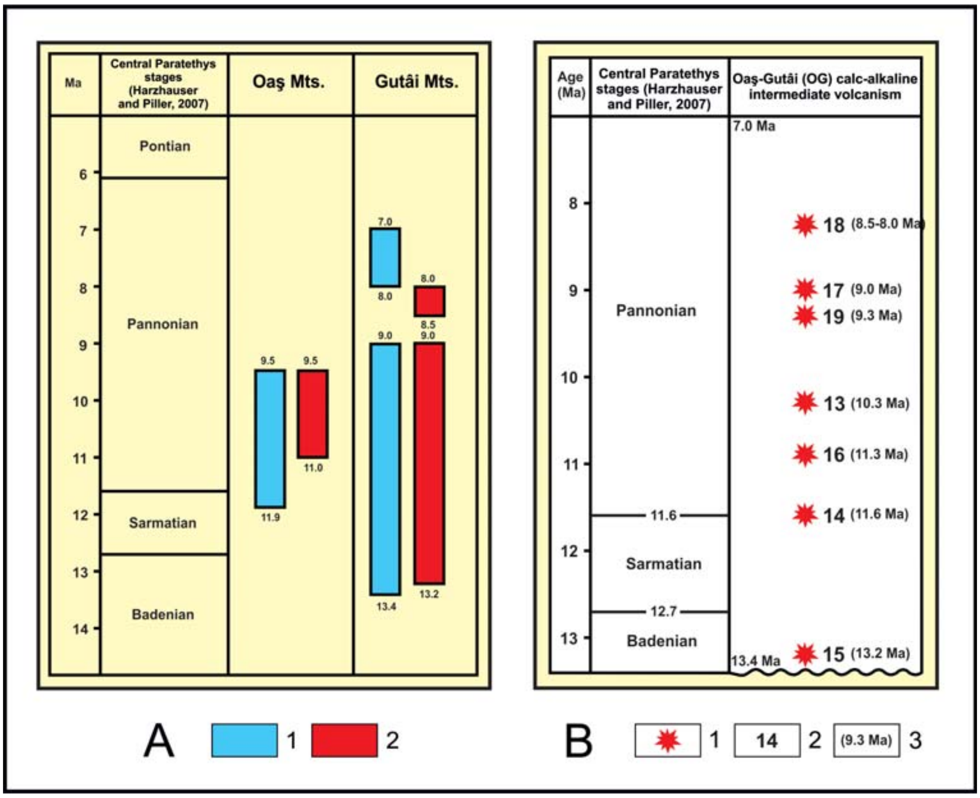

Figure 2.

A. Temporal evolution of the dome-building volcanic activity in Oaş Mts. and Gutâi Mts. 1. Intermediate volcanism; 2. Dome-building volcanism.

B. Dome-building events triggered and controlled by magma-mixing and -mingling processes. 1. Volcanic events; 2. Examples of domes (numbers according to Fig. 1): 15-Şatra; 14-Dăneşti-Piatra Roşie; 16-Poiana Cremenii-Şuior; 13-Valea Morii-Mogoşa; 19-Pleşca Mare; 17-Gutin; 18-Laleaua Albă. 3. K-Ar ages.

volcanic region and fragmentation by both non-explosive and explosive volcanic processes related to the dome growth is very common. The majority of domes grew up in subaqueous setting. The acidic volcanic phases of the OG intermediate volcanism are strictly associated to the dome-building volcanism. Overall, the dome-building volcanic activity in OG is assigned to a monogenetic-type of volcanism. To a small extent, dome-building events were triggered and controlled by repeated magma-mixing and -mingling processes.

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Evolution of monogenetic rhyolite volcanoes: Viničky, Eastern Slovakia

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Abstract

Four essential volcanic units have been recognized in the late Middle Miocene rhyolite complex at the southern side of the Zemplín horst next to the village Viničky. A succession of ash/pumice flow, surge and fall deposits separated by horizons of eolian dust and paleosoil in total thickness >15 m forms the lower unit. It represents distal facies deposits of subplinian/plinian/phreatoplinian type eruptions at unidentified centers. The second unit rests upon the lower one with unconformity marking a period of erosion. It consists of coarse phreatic/phreatomagmatic pyroclastic rocks with fragments of basement rocks and glassy dacite/rhyodacite. They represent proximal facies of a phreatomagmatic pyroclastic ring. Both units are truncated by a rhyolite extrusive dome, formed of perlite and perlitic breccias at its margin. Emplacement of the dome concluded activity of local centers northwest of Viničky. An extensive rhyolite coulee represents the fourth, uppermost volcanic unit. It is 40 – 70 m thick, formed of felsitic rhyolite with perlite and perlitic breccia at the base. Orientation of flow banding implies that the Borsuk extrusive dome 1 km northeast of Viničky was a source of the coulee. The dome and coulee form together one rhyolite body of the dome-flow type. With exception of the distal facies tuffs at the base the rhyolite complex represents most probably products of three overlapping monogenetic volcanoes.

Keywords: *phreatomagmatic eruption, cryptodome, dome-flow, coulée, rhyolite tuffs, perlite*

Introduction

Rhyolite volcanic fields are often monogenetic as their basaltic counterparts. They are composed of many individual volcanoes, each one having its own specific form, lithology and history. While a given rhyolite volcanic field may cover a quite short time interval, individual volcanoes are not strictly contemporaneous and their products mutually overlap. One of such fields of rhyolite monogenetic volcanoes of the Middle Miocene to early Late Miocene (Late Badenian to Early Pannonian) age extends in the area of highlands Tokaj, Zemplín, Beregovo, Oas in northeastern Hungary, eastern Slovakia, Transcarpathia of SW Ukraine and northern Romania. It includes a complex of rhyolites and related volcanoclastic rocks in surroundings of the village Viničky in eastern Slovakia (Fig. 1) that represents remnants of three overlapping monogenetic volcanoes. Natural outcrops, several abandoned quarries and excellent outcrops in walls of a wine cellar (830 m of galleries) excavated in a succession of phreatomagmatic pyroclastic rocks allow for a paleovolcanic reconstruction of events that created the volcanoes.

Geological setting

The Middle Miocene Tokaj-Zemplín-Beregovo-Oas field of monogenetic rhyolite volcanoes is an integral part of the Middle/Late Miocene bimodal andesite-rhyolite volcanics associated with a system of horsts and grabens south of the Transcarpathian Basin – a segment in the Carpathian volcanic arc (Lexa et al. 2010). Episodes of rhyolite volcanic activity alternated with activity of andesites and dacites that have given rise to mostly solitary small stratovolcanoes, effusive complexes and extrusive domes. K/Ar ages of andesites, dacites and rhyolites overlap in the interval 13.8-9.5 Ma (Pécskay et al. 2006; Pécskay unpublished data). The formation of the horst and grabens, as well as the volcanism were related to the interplay of subduction, delamination and back-arc extension (Seghedi and Downes 2011). The bimodal andesite-rhyolite volcanic association is interpreted as contemporaneous partial melting of metasomatized lithospheric mantle and crustal source materials as a result of the related tectono-thermal reactivation. Peraluminous rhyolites are of anatectic origin, later affected to various extent by mixing with mafic mantle source magmas and lower pressure AFC processes (Konečný et al. 2010).

Rhyolites of the volcanic field appear as clusters or solitary extrusive domes, dome-flows/coulées and related pyroclastic and epiclastic volcanic rocks that evolved in terrestrial and/or shallow marine environment (Lexa et al. 2010). In the area of the Zemplín horst (southern part of Eastern Slovakia) rhyodacite/rhyolite extrusive domes/coulées and related volcanoclastic rocks occur along marginal faults of the horst. The horst represents an uplifted block of basement rocks including Late Paleozoic conglomerates, sandstones and shales and Triassic sandstones, limestones and dolomites. Rhyodacites/rhyolites belong to two episodes of volcanic activity. Solitary rhyodacite/rhyolite extrusive domes along the northeastern and eastern sides of the horst and reworked rhyolite pumice tuffs interbedded with the Late Badenian sedimentary rocks at the southwestern side of the horst belong to the first stage age in the interval 13.2-12.2 Ma (Pécskay, unpublished data). Rhyolite extrusive dome/coulée (dome-flow) and underlying breccias and tuffs around the village Viničky at the southern side of the horst (the Viničky volcanoes) represent the younger second stage of the Sarmatian age. The age is not well constrained K-Ar dating of felsitic rhyolite, obsidian and perlite whole rock samples provided results in a broad interval 13.3 – 9.7 Ma (Bagdasarjan et al. 1971; Merlich and Spitkovskaya 1974; Uhlík et al. 2002; Pécskay unpublished data). Apparently the results on whole rock samples are variably affected by the presence of tiny basement inclusions, excess argon in plagioclase phenocrysts and/or loss of radiogenic argon by unstable glass.

Geology and lithology of the volcanoes

Rhyolites, breccias and tuffs of the Viničky volcanoes rest mostly on rocks of the pre-Tertiary basement. Permian conglomerates, sandstones and shales extend bellow most of the volcanoes, while overlying Triassic sandstones and dolomites occur underneath their northern and south-eastern parts (Bačo et al. 2012). It is probable that locally there are bellow the volcanoes preserved also remnants of Upper Badenian tuffaceous sedimentary rocks. Four essential units are distinguished in the overlying complex of rhyolitic rocks. At its base there is a succession of distal facies rhyolite tuffs in thickness >15 m, well-exposed in walls of the wine cellar. The Viničky volcanoes itself are represented by overlapping products of three volcanic centers. Early phreatic/ phreatomagmatic activity created a pyroclastic ring with a center northwest of Viničky. Subsequently an extrusion of glassy rhyolite took place at the center closer to the village. Corresponding proximal facies pyroclastic rocks and glassy rhyolites are exposed in the vine cellar above the tuffs. Both units exposed in the wine cellar are covered by extensive rhyolite coulee (dome-flow) with extrusive center about 1 km northeastward in the area of the hill Borsuk (Fig. 1).

The lower unit of tuffs is exposed in the thickness 15 m. Their extent bellow the lowermost horizon of the cellar is not known. Exposed succession starts with unsorted ash-flow tuff horizon grading upward into 1.5 m thick brownish paleosoil horizon with variable eolian dust admixture. The succession continues by three eruption cycles of total thickness 4.5 m, each starting with sorted crystal-rich fall tuff or less sorted coarser fall/surge pumice tuffs followed by unsorted ash-flow tuffs and concluded by ochre to brown color poorly developed dusty paleosoil horizons of smaller thickness. Next 3.5 m is dominated by thick layers of sorted (fall) and poorly sorted (surge/flow) coarse pumice tuffs interbedded with horizons of sorted fine to medium grained tuffs and ochre to brown fine dusty horizons. Lamination and normal or reversed grading has been observed in fall type deposits. Following a period of erosion the succession continues with poorly sorted ochre to brown color pumice tuffs with substantial dust component in fine matrix that grade upward into fine tuffaceous paleosoil of reddish-brown color with variable eolian dust admixture. Paleosoil is enriched in smectite and iron hydroxides and contains tiny remnants of plant roots. The described succession of tuffs was affected by normal faulting and once more eroded before the deposition of phreatic/phreatomagmatic pyroclastic rocks of the middle unit.

Succession of poorly to well-sorted pyroclastic breccias, lapilli tuffs and tuffs of the middle unit with overall thickness >15 m starts with sorted tuffaceous sandy deposits rich in nonvolcanic

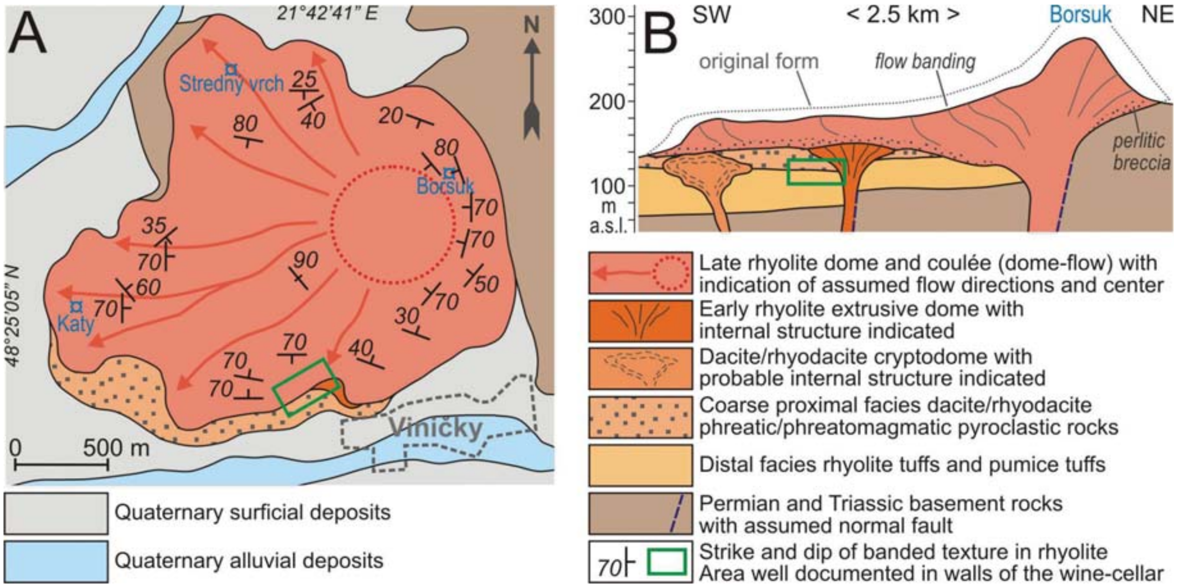

Figure 1. Structural scheme of the Viničky rhyolite volcanoes.

components of quartz and mica grains and clay minerals. Characteristic are also plant remnants and leaf imprints. Contact with underlying fine tuffs is sharp, paleosoil is missing. Most of the succession is formed of alternating beds of variable grain-size from fine tuffs to coarse lapilli tuffs. Only few beds are coarse enough to be classified as pyroclastic breccia. Especially in coarse beds there are frequent blocks, rarely up to 1 m diameter. Some blocks created impact structures. Basement rocks dominate among angular blocks and lapilli, juvenile dark glassy dacites/ rhyodacites are less frequent. Rare deformed fragments of underlying tuffs have also been observed. Tuffaceous matrix, as well as fine to coarse tuff beds, is rich in nonvolcanic material too. At the top of the exposed succession beds of lapilli tuffs are thinner, better sorted and of finer grain-size. Juvenile fragments are less frequent. Lapilli tuffs here alternate with horizons of brown fine dusty tuffs, often with numerous accretionary lapilli.

Drilling 800 m west of the wine cellar evidenced a dacite intrusive body emplaced in rhyolite pyroclastic rocks (Bačo et al. 2012). The margin of the dacite body is glassy and brecciated. Apparently it can be interpreted as a cryptodome.

At the eastern side of the wine cellar the successions of tuffs and phreatic/phreatomagmatic pyroclastic rocks is truncated by marginal parts of rhyolite extrusive dome. Rhyolite is glassy, perlitic, locally with small remnants of obsidian as cores of perlite blocks (marekanite). Its color varies from almost black to pale gray, often in alternating bands of pronounced flow bending dipping 40°-50° eastward. Perlitic breccias occur locally close to the contact with tuffs.

The three units exposed in walls of galleries in the wine cellar are buried by extensive rhyolite coulee passing northeastward into the source extrusive dome forming together a dome-flow (Fig. 1). Its primary morphology is still preserved in the morphology of the ridge north and northwest of Viničky. Rhyolite is felsitic, pale and slightly porous. It shows blocky to platy jointing, locally with well pronounced flow banding expressed as alternation of dark massive bands and pale porous bands. Figure 1, shows orientation of flow banding that fits well the assumption of the dome passing westward and northwestward into coulee. Thickness of the coulee is 40-70 m, originally perhaps up to 100 m. At the base and margins felsitic rhyolite grades into perlitic rhyolite and perlitic breccias. Basal perlitic breccias of the coulee are well exposed in the northern part of the wine cellar, where they rest on eroded surface of tuffs and phreatic/phreatomagmatic pyroclastic rocks. Breccias are formed of angular blocks of dark to pale perlites up to 3 m in diameter, often with pronounced flow banding, in pinkish matrix of grounded perlitic material. Underlying tuffs are locally deformed and mixed with perlite blocks into peperitic breccia.

Discussion and conclusions

A detail lithological analysis of natural outcrops and walls of the wine cellar has brought evidence that what appeared before as a single rhyolite volcano in reality represents four overlapping essential volcanic units inferred to be parts of monogenetic rhyolite volcanoes with different volcanic centers. Lower unit of alternating ash and pumice flow and fall tuffs with eolian dust and paleosoil horizons implies intermittent plinian type eruptions at distal volcanic centers. Such centers, represented by rhyolite domes of roughly the same age, are known from the northern part of the Tokaj mountain range 15-20 km west and northwest of Viničky. Erosion and thick soil horizon at the top of the lower unit correspond to a longer lasting break in volcanic activity.

The overlying unit of dacite/rhyodacite phreatic/phreatomagmatic pyroclastic rocks shows many aspects characteristic of the proximal deposits forming a pyroclastic ring, including ballistic block impacts and coarse pyroclastic surge/fall deposits. Locally low proportion of juvenile glassy fragments implies transition among phreatomagmatic and phreatic types of eruptions. Such eruptions are usually initiated by rising magma coming close to the surface and subsequently forming a dome in the crater (e.g. Panum dome in Mono Craters, California). We have no evidence of the exact position of the crater and hypothetical dome. However, the same type of magma appears close by as the cryptodome (Fig. 1).

Despite a petrographic similarity the steep intrusive contact of perlitic rhyolite in the eastern part of the wine cellar with older pyroclastic rocks rules out a possibility, that it represents a part of the overlying rhyolite coulee. Instead we assume the form of a small extrusive dome (Fig. 1).

Morphology and orientation of flow banding in the youngest rhyolite coulee unquestionably point to the source dome in the area of the hill Borsuk 1 km northeast of Viničky, with dome root situated on one of the Zemplín horst marginal faults indicated by basement displacement (Fig. 1).

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New zircon U-Pb geochronological data for constraining the age of the Miocene ignimbrite flare-up episode in the Pannonian Basin

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Abstract

In the Carpathian-Pannonian region, an ignimbrite flare-up episode occurred during the Miocene within a timespan of about 7 Myr. This volcanism was fed by large volume dacitic to rhyolitic magmas and was coeval with the formation of the Pannonian basin by major lithospheric stretching. So far, the age of the ignimbrite-forming eruptions was determined based on K/Ar radiometric dating, stratigraphic considerations, and fossil contents of the associated sediments. Palaeomagnetic rotation data add further constrains on the age of the volcanic formations since two major block-rotation events were identified in this area contemporaneously with the silicic volcanism. However, the precision (+/-1-2 Ma) of the determined K/Ar ages does not allow a rigorous evaluation of the temporal evolution of the volcanism. The Bükkalja Volcanic Field (BVF; Northern Hungary) provides an exceptionally good opportunity to study the deposits of the Early to Middle Miocene ignimbrite flare-up period since the BVF contains several well-preserved outcrops. According to the former K/Ar age dating the volcanism occurred between 21-13.5 Ma and within this interval three main eruption events were distinguished: 21.0-18.5 Ma; 17.5-16.0 Ma; 14.5-13.5 Ma, respectively. In order to better characterize the silicic volcanism, we performed high-precision in-situ zircon U/Pb dating by LA-ICP-MS. Fort this, we selected samples from continuous stratigraphic sections, which include deposits of both the second and third main volcanic events (outcrops at Tibolddaróc, eastern part of the BVF and drilling cores of the Szv3 borehole at Tard). The U/Pb zircon age dating was carried out for deposits formed by pyroclastic flow and fall events. In the Szv3 borehole three petrographically distinguishable pyroclastic units between 160 and 601 m depths were recognized below Sarmatian and Pannonian sedimentary formations. The volcanic deposits of the two stratigraphic sections can be well correlated based on the U/Pb age data. Two main zircon crystallization periods can be distinguished which roughly correspond with the second and third eruption phases suggested by the K/Ar dating. The first one has a mean age of around 16.2 Ma, whereas the second one could occur after a significant, approximately 2 Myr-long quiescence period. The second active stage comprises at least two eruption events with mean ages of around 14.1 and 14.6 Ma, respectively. The new U/Pb zircon crystallization age data characterize the magma evolution with a much better precision and resolution (i.e. errors are <2-300000 years) and it shed new light concerning the nature of the volcanic activity. The zircon U/Pb zircon age data related to the older volcanic event do not show differences on the resolution of our age determinations and comprises at least 340 m thick deposits. This could be consistent with a larger caldera forming volcanic eruption or series of eruptions within a short period (i.e. <200 000 years). This was followed by an eruption gap presumably with limited sedimentation. Rejuvenation of the silicic volcanism occurred with repeated eruptions resulting at least 100 m thick pyroclastic deposit. Furthermore, our results show that the 16.2 Ma volcanism produced initially at least 260 m thick high-silicic, crystal-poor, rhyolitic unwelded ignimbrite and followed by eruption of crystal-rich rhyolitic-dacitic magmas resulting in welded and unwelded mixed pyroclastic flow deposits.

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Geoheritage values of intracontinental volcanic fields of Saudi Arabia

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Abstract

Western Saudi Arabia is a region where long-lived dispersed alkaline basaltic intracontinental volcanic activity has produced numerous volcanic fields in the past 10 My. Four distinct volcanic fields, spanning a North to South axis over 1000 km in length, represent continental rift-related dispersed volcanism. The rich geological architecture of these volcanic regions can be evaluated to assess their uniqueness and geoheritage value and the usefulness of developing volcanic geoparks around them, with associated geoeducational programs.
Keywords: *geoheritage, geopark, monogenetic volcanic field, maar, scoria cone*

Introduction

The term geoheritage derives from the word heritage, which means something that has been transmitted from the past, or has been handed down by tradition. To evaluate geoheritage, three factors should be taken in to account: 1) the scale, 2) the scope, and 3) the significance of the site (Brocx and Semeniuk 2007). The uniqueness of a site is dependent on the scale in which it is measured, eg. individual rocks vs whole landforms. Expressing the geoheritage value of a site also needs an appreciation of its scope, for example, does the site represent causal processes (eg. process-oriented features) and/or does it offer insights for historically reconstructing the Earth's development (eg. product-oriented) (Brocx and Semeniuk 2007). Geoheritage sites can be further graded by separating the 1) international, 2) state or 3) regional significance of the sites (Brocx and Semeniuk 2007).

Small-volume volcanoes (tuff rings, maar-diatremes and tuff cones) are commonly defined as monogenetic, which is a reflection of (a) their short-lived eruption styles that are commonly associated with the arrival of a single magma batch to the surface and (b) their generally small volcanic edifices (~0.001-0.1 km^3) (Kereszturi and Németh 2012). The small size of these volcanoes makes them easy to access; their eruptive products are on a "*human scale*" and, therefore, they can be used to demonstrate volcanic processes without major challenges for educators or visitors. Volcanic fields can carry great geoheritage value if: a) their historic eruptions strongly influenced human societies, b) they have high aesthetic value, or c) they are used as reference areas to describe volcanic processes typical and characteristic of volcanic fields. Saudi Arabia is the home of superbly exposed and accessible volcanic fields, offering itself as a global hub of geoheritage sites showing features of volcanic fields.

Volcanic fields of Western Saudi Arabia and their geoheritage values

Harrat Rahat is one of the largest volcanic fields in the Arabian Peninsula (Fig. 1). The northern part of Harrat Rahat, the Harrat Al Madinah, is located near the city of Al Madinah. Harrat Al Madinah has numerous volcanic geosites relevant to our understanding of the evolution of volcanic fields dominated by Hawaiian and Strombolian style volcanic cones and lava fields (Moufti and Németh 2013) (Fig. 2A). The region also hosts older, superbly exposed trachytic lava domes and explosion craters at its southern edge (Fig. 2B). The region includes the location of the last historically erupted volcanoes in the Arabian Peninsula that created lava spatter and scoria cones during a 52 day eruption in 1256 AD just 10 km SE of Al Madinah city (Camp et al. 1987) (Fig. 2A). This eruption site is scientifically significant due to the evidence of fissure-dominated eruptions, cone rafting, and a variety of lava flow types (Camp et al. 1987) (Fig. 2A). The location is culturally and historically rich, being formed in the early years of the birth of Islam (Camp et al. 1987). Al Madinah city now has extended into the northern parts of the Harrat and the lava flow fields became an extinct landscape of Al Madina. Regarding the historic eruption itself, it was a frightening experience for the inhabitants of Al Madinah city and the eruption became part of both oral and written traditions. In addition Harrat Al Madinah contains numerous archaeological sites, historic

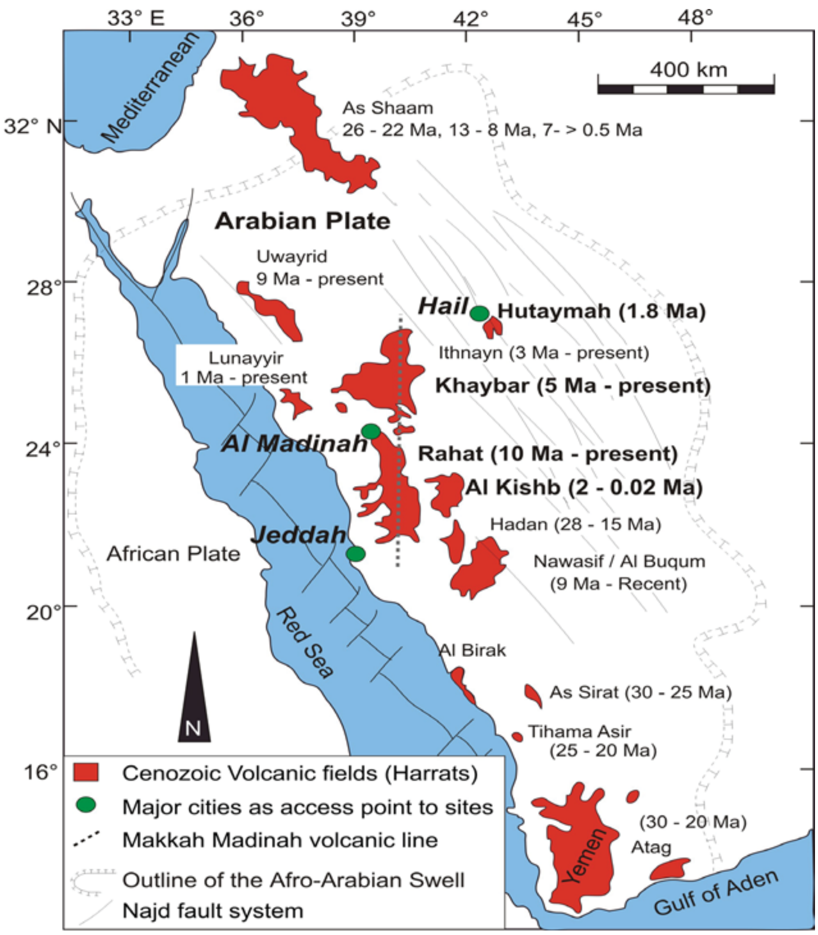

Figure 1. Overview map of the western part of the Arabian Peninsula showing major harrats (intracontinental volcanic fields with extensive lava fields).

dams and relicts of Ottoman fortresses enforcing the historic significance of this volcanic region. The site also carries high aesthetic value as a perfectly exposed and fresh chain of cones easily accessible (Fig. 2A). The trachytic lava domes and explosion craters located in the south of Harrat Rahat (Moufti and Németh 2013) are scientifically significant sites for understanding magma genesis in intracontinental settings (Fig. 2B).

Harrat Kishb (Fig. 1) is a bimodal volcanic field and has been active since 2 Ma, having its latest eruptions 4.5-2 ka (Camp et al. 1992). Harrat Kishb mainly consists of scoria cones and spatter cones associated with pahoehoe to transitional lava flows (Camp et al. 1992). Two geoheritage sites have high scores for their scientific, cultural or aesthetic values. Al Wahbah is a maar crater cut ~250 m into the crystalline basement rock (Fig. 2C). The maar crater formed shortly after the growth of a fissure-aligned spatter cone and a scoria cone, which have both been cut through by the growing maar crater, and, therefore, it is a scientifically significant site to understand such eruption history (Fig. 2C). The Al Wahbah crater is also an important site for local people, who utilize its sheltered location for terraced agriculture in its upper crater wall, and thus it bears a significant cultural value. Aslaj volcanic complex in the northern part of Harrat Kishb is a scoria cone complex with pit craters and lava outflows. The central cone in this complex was disrupted and "*blown off*" in a paroxysmal eruption that initiated base surges and, potentially, a high eruption plume that formed an ash plain, making this site scientifically important. The location is important in local Bedouin communities; however, its cultural value is probably not as high as Al Wahbah crater, but it bears high aesthetic value.

Harrat Hutaymah in the North is a monogenetic volcanic field located about 70 km to the SE of Hail city (Fig. 1). The abundance of tuff rings and maars makes Harrat Hutaymah different from other harrats. The age of Harrat Hutaymah is poorly constrained, but it is probably in the range of 2 to 1 My (Pallister 1985). Harrat Hutaymah is located today in an arid region, thus evidence of magma-water interaction driven volcanism in its past can form the basis of a geoeducational program to demonstrate the dramatic climatic and hydrogeological changes a region can go through (Fig. 2D). Harrat Hutaymah maar has

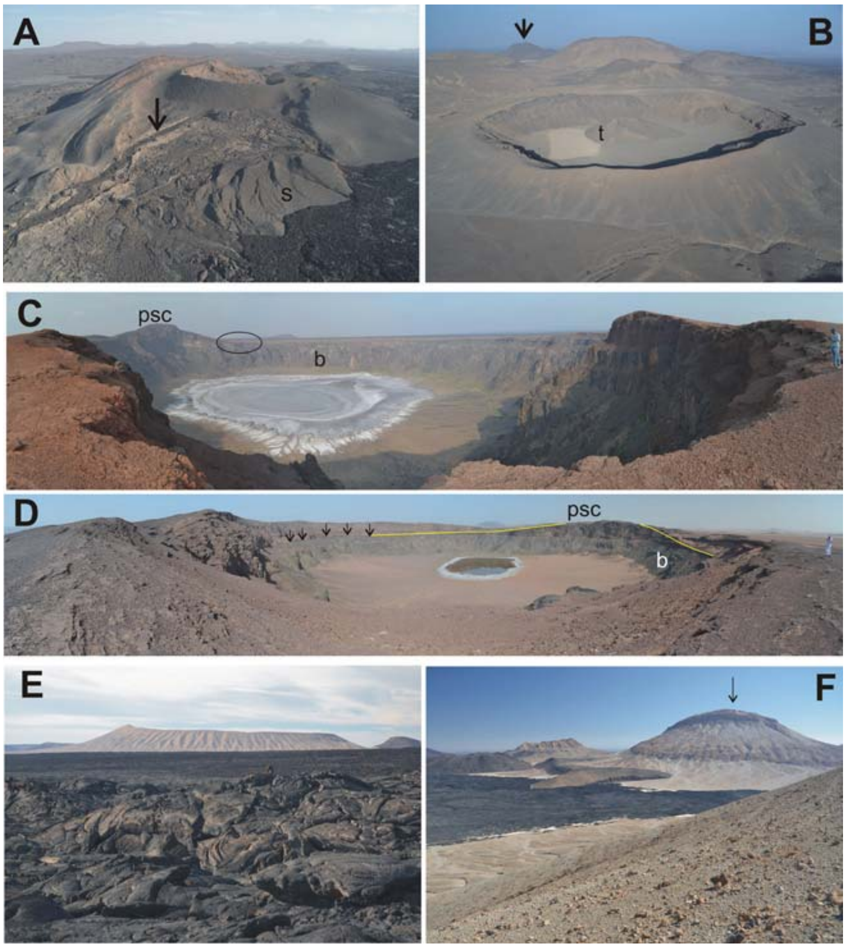

Figure 2.

A) NW side of the fissure aligned voclanic cones of the 1256 AD Al Madinah eruption site as a major geotope of Harrat Rahat. Arrow points to an open channel lava flow emitted from the centrl cone flank. S refers to a faulted and displaced scoria cone edifice fragment.

B) Gura 3 maar crater in the centre of the Harrat Al Madinah as a major geotouristic attraction to demonstrate explosive volcanic eruptive processes and their resulting landforms. In the centre of the crater a small toloid can be seen (t). Arrow points to a trachytic lava dome in the distance.

C) Dramatic "hole-in-the ground" landform of the Al Wahbah maar crater. In the maar crater wall the basement is exposed (b) in its lower part that is coverred by extensive pre-maar lava flows. The crater wall exposes a half-section of a pre-maar scoria cone inferred to be active immediately prior the maar forming phreatomagmatic explosive eruptions. The contact betweer the pre-maar scoria cone and the tuff ring around the maar (circle) is an important geosite where base surge beds can be studied.

D) Harrat Hutaymah maar is similar to Al Wahbah maar but its diameter is about half as Al Wahbah's. A pre-maar scoria cone also half-sectioned in its crater wall (psc) that is sitting on basement crystalline rocks and pre-maar older lava flows (arrows). The tuff ring base surge dominated successions sit unconformable over the pre-maar scoria fall beds (line).

E) Jebel Bayda is a comenditic tuff ring that is surrounded by slabby and normal pahoehoe lava flows of Jebel Quids.

F) Jebel Abyad is a comenditic lava dome with a small explosion crater on top (arrow). The lava dome exposes dark short, but thick obsidian lava flows as well as small run-out distance block-and-ash flow deposits. This volcanic facies architecture and its high aesthetic value with its easy to access nature make this site a perfect geotope.

similar scientific significance to Al Wahbah crater in respect to its dramatic "*hole-in-the-ground*" architecture and half-sectioned scoria cones in its crater wall (Fig. 2C,D). The Harrat Hutaymah maar crater is culturally significant due to the nearby archaeological evidence recording early water management systems of the region. Another volcanic crater is located to the west, near Taba village. This crater is filled with debris and exposed basement crystalline rocks, and small spatter cones are exposed in its southern edge, reflecting that the crater formed on the edge of an older fissure. Scientifically Taba crater is a significant site, because of its large size, evidence of the dramatic changes in the crater infill and crater morphology over time, and the abundance of base surge bed-forms exposed in the retreated crater walls. The Taba crater is culturally important, as it hosted the old Taba village that was relocated due to subsidence in the past decades. Such change can be considered to have a significant effect on the local community, and therefore, the site can be used to demonstrate the vulnerability of humanity even if the volcano has not erupted in a long time.

Harrat Khaybar is a volcanic field located north of Al Madinah city. Harrat Khayber was somehow accessible in the past, but the new sealed road makes it more accessible. Harrat Khaybar is a young volcanic field, having at least two sites suspected to be as young as a few thousands of years (Camp et al. 1991). Jebel Quidr in the centre of the field is a large lava shield with a cone on top. Its base is composed of numerous lava flows that show pahoehoe surface textures (Fig. 2E) and convoluted lava tubes. This location is a globally unique example to show that larger volcanoes can exist in a monogenetic volcanic field that was likely formed over a long period of time. Harrat Khaybar is also the home of the so called "*White Mountains*": Jebel Bayda (Fig. 2E) and Jebel Abyad (Fig. 2F). Both Arabic names mean "*White Mountain*", with Bayda a feminine and Abyad a masculine form of white in Arabic. Jebel Bayda is a near perfect circular tuff ring with a shallow crater (Fig. 2E), while Jebel Abyad is a comenditic lava dome complex (Fig. 2F). While felsic lava domes and tuff rings exist elsewhere (Austin-Erickson et al. 2011), the scientific significance of the felsic intracontinental volcanism of the Arabian Peninsula is great in terms of understanding the evolution of magma rising to the surface through thick continental crust.

Conclusion

Dispersed volcanoes that form volcanic fields over large (100s km^2) areas are common on Earth. However, volcanic fields that expose young volcanoes uncovered and in their authentic environment are relatively rare. Here, we have provided some examples to awaken the awareness of the community to the global geoheritage and geoeducation value of the volcanic fields in Saudi Arabia, and have shown their high scientific, cultural and aesthetic value, which can be used to develop regional and global geoparks and associated geoeducation programs.

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The Pleistocene Jabal Akwa Al Yamaniah maar/tuff ring – scoria cone complex as an analogy for future phreatomagmatic to magmatic explosive eruption scenarios in the Jizan region, SW Saudi Arabia

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Abstract

A complex of phreatomagmatic volcanoes has been identified for the first time in the southernmost portion of the Al Birk volcanic field in SW Saudi Arabia. The newly identified accidental lithic clast-rich tuff and lapilli tuff succession is partially covered by aeolian sand and wadi deposits, with abundant mantle- and deep crustal-derived xenoliths in the southern margin. This pyroclastic succession of the Jabal Akwa Al Yamaniah volcanic cone complex is typical of a volcano that had phreatomagmatic explosive eruptions in its initial eruptive stage. The large volume of accidental lithics in this basal pyroclastic succession indicates that this volcano is a maar-diatreme and its eruption was triggered by the explosive interaction of rising magma and ground water in a thick gravelly alluvial plain cross-cut by wadi networks. The young age (<1 Ma) of the Al Birk volcanic field in general puts this discovery in the spotlight, as it provides firm evidence that phreatomagmatism cannot be neglected, at least in the initial stage of any future eruptions – especially those that occur over thick alluvial fans in the coastal regions of Jizan – and should be viewed as a potentially destructive and highly unpredictable, high impact volcanic hazard.

Keywords: *monogenetic volcanic field, maar, scoria cone, tuff ring*

Introduction

The Al Birk volcanic field in SW Saudi Arabia is a young intracontinental volcanic field that formed alkaline basaltic volcanoes that are dominated by scoria and spatter cones, extensive lava fields and lava domes/dome coulees (Arno et al. 1980; Brown et al. 1989). The main part (the northern part by Coleman et al. 1983) of the Al Birk volcanic field (Fig. 1) spreads over an area 100 km in length and 50 km in width along the Red Sea coast in SW Saudi Arabia (from lat 18°45’ to lat 17°45’ N) and comprises over 200 individual eruptive centres (Coleman et al. 1983; Brown et al. 1989). The main part of the volcanic field is located about 100 km north from the city of Jizan (Fig. 1), where a dorsal ridge of older basal lava flows form the base of younger scoria and spatter cones with younger lava flows. Scatterred small volcanic regions in the south are separated by the Ad Darb transform fault from the main volcanic region of Harrat Al Birk (Fig. 1) are commonly referred to as the harrat of the coastal plain of Asir region, the harrat of Tihamat Asir (Coleman et al. 1983). Some work group these volcanic regions as part of the broader Harrat Al Birk, however they are clearly distinct indivudal scatterred volcanic fields (Arno et al. 1980; Coleman et al. 1983; Brown et al. 1989). While older ages have been reported for the basal lava flows (e.g. as old as 12.4 Ma), some renewed dates have put the age of the volcanic field at less than 2 Ma, with the majority of the eruptions being younger than 1 Ma (Coleman and Gregory 1983; Brown et al. 1989). Some reports have described historic eruptions taking place in the eastern margin of the field, such as Jabal Ba’a and Jabal al Qishr (Fig. 1), where isolated patches of black scoriaceous ash on the steep mountain slopes near the volcanic vent appear very fresh and may represent eruptions during the last century (Coleman and Gregory 1983; Brown et al. 1989). Similarly, in the southern part of Harrat Al Birk (after Coleman et al. 1983), commonly referred to as the harrat of Tihamat Asir - the coastal plain of Asir (Vincent 2008), an eruption in the last century was reported in an area called the Harrat Gar’atain (Jiratan) (Fig. 1) (Neumann Van Padang 1963). These reported (but only loosely confirmed) young volcanic eruptions of the Harrat Al Birk and the Harrat of Tihamat Asir are associated with volcanic cones that appear to be very youthful in their morphology, vegetation cover, and erosion level, indicating that this region in SW Saudi Arabia is a potentially active volcanic area, and therefore detailed study of these young volcanoes is essential to shed light on potential future volcanic eruption scenarios with which the region may be faced. The general view of the volcanoes formed in the past 1 Ma in Harrat Al Birk and the Harrat of Tihamat Asir is that the harrat is largely dominated by scoria and spatter cones associated

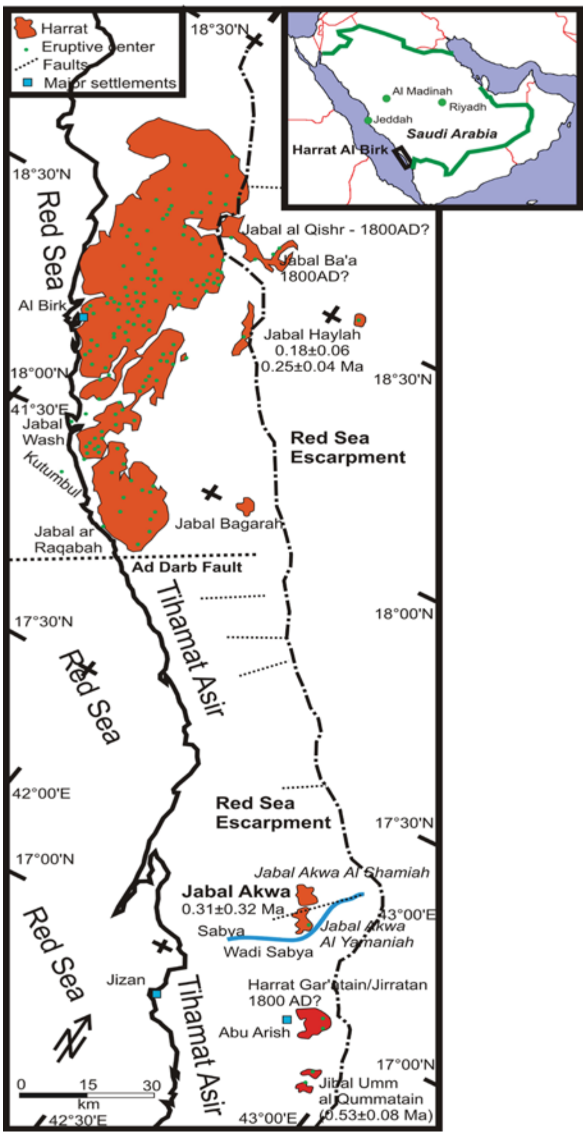

Figure 1. Volcanic regions of SW Saudi Arabia (Brown et al. 1989) generally defined as Harrat Al Birk or Al Birk volcanic field (Coleman et al. 1983; Brown et al. 1989) that has two well-distinguished northern and southern zone.

with extensive lava flows. Identification of any evidence of phreatomagmatic explosive eruptions in the recent history of this volcanic field is critical in terms of defining volcanic hazards that are considered to be fast, destructive and highly unpredictable.

Jibal Akwa or Akwa cones

South of the main body of Harrat Al Birk, just NE from Jizan city, near the city of Sabya (Fig.1), two well-distinguished large scoria cones and associated lava fields dominate the landscape: Jabal Akwa Al Shamiah in the north (Fig. 2A) and Jabal Akwa Al Yamaniah in the south (Fig. 2B). Both volcanoes (called Akwa cones in English, or Jibal Akwa in Arabic) are composed of a large (about 100 m high) scoria cone with a breached crater toward the west, an extensive lava field and some mounds that are inferred to be rafted cone pieces or distal lava flow fronts, which stalled and formed piles of lava about 3 km from their sources. Both cones are covered by aeolian deposits that make the identification of their volcanic facies difficult. The northern cone complex, Jabal Akwa Al Shamiah has a complex morphology with at least two well-distinguished craters, each breached toward the west and composed of steeply dipping lava spatter and spindle-bomb rich proximal edifice-building pyroclastic units. The inner crater wall has been preserved in a few places and is defined by agglutinated spatter that forms an erosion-resistant collar on the lip of the crater, indicating that, at least in the final stage of the volcanic activity, this cone had lava fountain dominated eruptions. In contrast, the main edifice is composed of black and red scoria lapilli and ash, which forms a well-developed cone edifice that is gradually transforming into an inter-cone ash plain traceable over 3 km from the cone. The scoriaceous ash and lapilli is angular, moderately to highly vesicular and the clasts are primarily isometric, but more flattened clasts are also known, indicating fluctuation between normal Strombolian style eruptions and lava fountaining. Large chunks of former cone flanks form a mound zone on a lava field spread isometrically toward the western side of the cone, suggesting that the cone erupted in a gentle westward dipping coastal plain. In the south, another cone complex is known. Jabal Akwa Al Yamaniah is a similar size to Jabal Akwa Al Shamiah; however, this cone is more eroded in its northern flank, forming a steep and evenly spaced gully network. The cone is surrounded by two circular lava flows. An upper lava field, which has a flow front in the west, reaches about 3 km from the cone, while the other lava field spread about 6 km from the cone and formed a lava surface about 50 m below the other lava field. The cone has a large breach toward the west, and the upper lava flow front and the cone area is covered by a thick aeolian Quaternary succession. In addition, the gently westward-dipping, Quaternary sedimentary cover hosts numerous archaeological sites with pottery remains and grinding stones, suggesting that this volcano has hosted a village in the past.

Jabal Akwa Al Yamaniah maar/tuff ring –scoria cone complex

Undescribed tuff deposits have been noted below the Pleistocene lava flows intercalated with fluvial terrace and aeolian deposits in the south of Jabal

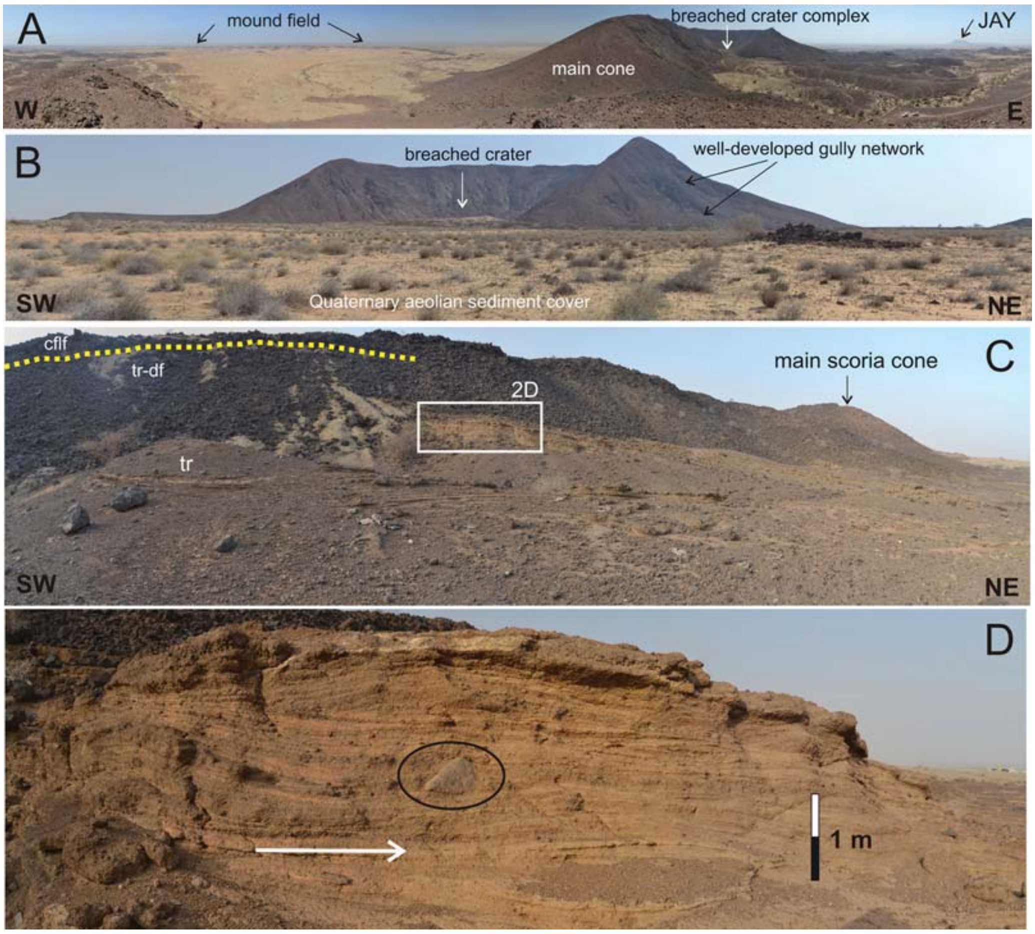

Figure 2.

A) Overview of the Jabal Akwa al Shamiah scoria cone complex (JAY – Jabal Akwa Al Yamaniah volcano).
B) Overview of the main scoria cone of the Jabal Akwa Al Yamaniah maar/tuff ring – scoria cone complex.
C) Preserved tuff ring rim coverred by a thin lava flow that flow over the crater rim (yellow dashed line marks the boundary betweent he tuff ring and the lva flow). The base surge dominated pyroclastic succession shown on Fig. 2D is marked by a white rectangular field in the middle of the view.
D) Typical base surge succession with dune bedded accidental lithic-rich lapilli tuff and tuff beds forming the upper part of the preserved tuff ring of the Jabal Akwa Al Yamaniah volcano. Note the large mudstone lithic fragments in the succession (circle). White arrow shows the inferred flow direction based on flow indicators of the pyroclastic beds.

Akwa Al Yamaniah, along the Wadi Sabya; however, their origin was not known (Dabbagh et al. 1984). An accidental lithic rich tuff and lapilli tuff succession has been identified in the southern and eastern margin of the thick upper lava flow fronts of Jabal Akwa Al Yamaniah. The tuff and lapilli tuff deposits dip about 15-20 degrees away from the cone, forming the well-defined remains of a former gently sloping volcanic edifice in these sectors of the volcano (Fig. 2C). The pyroclastic succession is composed of angular glassy pyroclasts (lapilli and ash sized), with a majority being partially or completely altered, red to brown palagonite, abundant various sizes of accidental lithics of known crustal rock types, and mantle-derived nodules. The pyroclastic succession shows a general trend of fining upward, having a lapilli tuff succession that is more lithic-dominated at its base, which gradually transforms to a better sorted, finer grained and more juvenile pyroclast-rich, coarse-fine succession at the top of the section (Fig. 2D). The accidental lithic fragments are commonly well-rounded gravels, while silts and mud-stones are common among the large angular lithics. The upper part of the succession is more dune and cross-bedded with abundant features recording the deposition from horizontal moving pyroclastic density currents and the microtopography of the depositional surface (Fig. 2D). The total thickness of this pyroclastic succession is about 40 m in the SE.

Interpretation

The abundant glassy to palagonitized, low vesicularity juvenile pyroclasts indicate fast chilling of the fragmented magma, which is consistent with magma-water interaction triggered explosive fragmentation (White and Ross 2011). The abundance of a great variety of country rocks as accidental lithics in the pyroclastic units indicates that the explosions excavated a significant proportion of the bed rocks, suggesting that the magma and water interaction took place below the syn-eruptive surface, such as in the case of a maar-forming volcanic eruption (White and Ross 2011). The dune-bedded and unsorted nature of the majority of the pyroclastic succession is consistent with an origin from a base surge dominated eruption (White and Ross 2011). The at least 40 m thick pyroclastic succession is inferred to be part of a former tuff ring that is today partially engulfed by post-eruptive, Quaternary aeolian and fluvial terrace deposits. The tuff ring formed a barrier to the intra-crater lava flows emitted from the spatter cones that were formed in the crater of the initial phreatomagmatic volcano. The accidental lithic-dominated pyroclastic deposits suggest that the explosive eruptions must have excavated a significant portion of country rocks and formed a maar volcano that is surrounded by its tuff ring in the ancestral Wadi Sabya. A crater was carved in the wadi deposit and subsequently functioned as a depocentre, collecting lava flows emitted from the scoria and spatter cones in the maar crater. By the complete exhaustion of the available ground-water supply, the initial phreatomagmatic explosive eruptions led to the formation of a scoria cone similar to common trends associated with monogenetic volcanoes elsewhere (Kereszturi and Németh 2012), probably on the syn-eruptive surface outside of the maar, on its northern side. The large size and complex stratigraphy of the scoria cone indicates that it was erupted over a prolonged period of time.

Conclusion

Jabal Akwa Al Yamaniah is the first volcano where a phreatomagmatic pyroclastic succession has been identified in SW Saudi Arabia. It records a complex volcanic eruptive history that started with a violent explosive eruptive phase, when rising magma interacted with ground-water and formed a deeply excavated crater: a maar surrounded by a tuff ring. Mapping indicates that the tuff ring was probably thicker in the SE and absent in the northern sector of the volcano. The circular distribution of the lava flows and spatter mounds of Jabal Akwa Al Yamaniah is the direct result of the lava flows being controlled by the crater rim of the initial phreatomagmatic volcano, capturing and collecting post-maar eruptive products in a broad maar crater. The identification of the basal maar volcano in this location reveals for the first time that the explosive interaction between magma and water needs to be evaluated seriously in this region as a potential high consequence volcanic hazard similarly to other coastal regions elsewhere (Németh et al. 2012). Alluvial fans, wadi deposits or deep faults, especially along the coastal escarpment, can host significant volumes of water (particularly in the rainy season) and this is capable of dramatically changing the volcanic eruption style of the rising magma, making it more destructive and hazardous.

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Paleomagnetic constraints for the timing of volcanism from the Gurghiu, Harghita and Perşani Mountains (East Carpathians)

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Abstract

We present recent paleomagnetic results obtained from the volcanic rocks from the Gurghiu, Harghita and Perşani Mountains (East Carpathians, Romania). This volcanic chain is around 120 km long and, according to the K-Ar ages, the volcanic activity gradually migrated to the south between the Miocene (~9 Ma) and the Quaternary (~0.2 Ma). The high number of sampling sites (over 300) and their geographic distribution has allow us to refine the time model for the evolution of the volcanic activity in the last 9 Ma in the East Carpathians. The areal distribution of sites with normal and reversed polarities is in general agreement with geographic and time distribution of volcanism and the magnetic polarity time scale. Starting with the southern volcanic structures from the Gurghiu Mountains, the polarities distribution highlights the fact that in most volcanic structures, the main eruption period lasted for less than 1 Ma usually a shorter time interval than the one inferred from K-Ar age determinations. The time of volcanic activity of the main volcanic structures can be correlated with the magnetic polarity time scale as follows: 1) the Seaca-Tătarca, Borzonţ, Sumuleu and Ciumani-Fierăstraie volcanic structures (Gurghiu), with dominant normal poalrities, has erupted during chron C3An (6.7-6.0 Ma); 2) the Ivo–Cocoizaş and Ostoroş volcanic strutures (North Harghita), with only reversed polarity, has erupted during chron C3r (6.0-5.2 Ma); 3) the Vârghiş volcanic structure (North Harghita), with mixed polarities, has erupted during chron C3n (5.2-4.1 Ma); 4) the Luci-Lazu volcanic structure (South Harghita), with dominant reversed polarities, has erupted during chron C2Ar (4.2-3.6 Ma); 5) the Cucu volcanic structure (South Harghita), with dominantnormal polarities, has erupted during chron C2An (3.6-2.5 Ma); 6) the Pilişca volcanic structure (South Harghita), with dominant reversed polarities, has erupted during chron C2r (2.5-1.9 Ma) and partially during chron C1r (until 1.6 Ma according to the K-Ar ages); 7) the Malnaş and Bixad subvolcanic domes (South Harghita), both with normal polarity, can be correlated according to K-Ages with chron C2n (1.9-1.7 Ma); 8) Some parts from the Balvanyos extrusive dome (South Harghita) has erupted during chron C1r1n (1.07-0.98 Ma); 9) Ciomadu volcanic structures (South Harghita) has erupted during chron C1n (0.78-0 Ma); 10) The basalts from the Perşani Mountains has erupted in short episodes between 1.2-06 Ma which correspond to chron C1r (Racoş – 12 Ma, Turzun and Comana volcanic structures), C1r1n (Măguricea and Gruiu volcanic structures), C1r1r (Bărc – Bogata upper lavas) and C1n (Dâlma and Mateiaşi volcanic strutures). Overall, the results are consistent with the currently accepted model of a progressive migration of the volcanic activity from North to the South, in time steps of around 1 Ma or less according to the magnetic polarity data.

Investigation of explosive volcanic structures by combined geological and geophysical surveys of Na-alkalic basaltic field in the Perşani Mts., Romania

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Abstract

The Pleistocene volcanic field of the Perşani Mts. (active in 5 cycles between 1.2-0.6 Ma) includes 21 identified monogenetic centers disposed at fault intersections in a NE-SW oriented area of about 22 km in length and 6 km in width. Most of them are complex structures formed by interplay of up to three different eruptive mechanisms (phreatomagmatic, scoria cone building and effusive). One single structure seems to be formed during just one eruptive phase (phreatomagmatic). The Gruiu volcanic edifice is entirely a result of magmatic processes (scoria cone building and effusive); all the other structures involve initial Na-alkalic magma – groundwater interactions that resulted in phreatomagmatic activity. According to the lithic clasts excavated by the explosions, the aquifers seem to have been hosted by Cretaceous-Jurassic limestones, conglomerates, sandstones and Lower Miocene siliciclastic sediments and rhyolitic tuffs. The excavated craters (with variable diameters from less than 700 m up to about 2.5 km) provide well-preserved exposures of marginal or intra-craterial deposits. Their lithology provides critical geologic constraints regarding the vertical and lateral facies changes that occur proximal to the vent. Several volcanic facies providing temporal information about processes and interactions that occur within and adjacent to the vent during a phreatomagmatic eruption have been described.

They are characterized by the prevalence of ash, juvenile lapilli, blocks and clasts of country rock that were dispersed away from the vent by a combination of base surges or fallout mechanism. In most cases, after using up the available groundwater, the initial phreatomagmatic turned to purely magmatic, producing lapilli, bombs and scoria deposits that filled in or evolved marginally in the craters. Typical scoria cone structures have been built up, sometimes followed by lava effusions that breach through the base of the cones. One of the main issues however, remains that of the nature of the initial phreatomagmatic structures (tuff rings or maar-diatremes). The morphological characteristics of the craterial area, including crater floors above or beneath the presumed pre-eruptive topography, lava ponding and others allowed for volcanological interpretations concerning the type of the craters. However, due to the high degree of syn- and post-eruptive destruction processes, these interpretations are only tentative.

Gravity and magnetic surveys were performed in order to better understand the overall and local tectonic setting, the crater structures and to test morphometric interpretations. Based on the revealed pattern of the gravity and geomagnetic field, along with rock-physics determinations (density and magnetization) of the main geological formations occurring in the study area, 2D geophysical interpretative models were performed. The obtained results succeeded to provide additional information on the feeding system configuration of the craterial structures.

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Time-space evolution and volcanological features of the Late Miocene-Quaternary Călimani-Gurghiu-Harghita volcanic range, East Carpathians, Romania. A review.

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Abstract

The Carpathian-Pannonian Region (CPR) hosts one of the major Cainozoic volcanic provinces of Europe extending in space over 6 eastern European countries.The lithospheric evolution of this large area governed by large-scale asthenospheric processes is recorded by products of volcanic activity occurred during a time interval of more than 21 million years. According to their surface occurrence areas, ages and composition the Neogene volcanics of CPR were systematized in three main groups: 1) mostly explosive products of felsic magmas generated at the beginning of volcanism in the whole CPR and in their particular occurrence areas (21-12 Ma) developed in the actual intra-Carpathian Pannonian Basin, 2) mostly intermediate calc-alkaline rocks emplaced in both the intra-Carpathian areas and along the arcuate Carpathian fold-and-thrust belt, and 3) Na- and K-alkaline and ultra-alkaline products clustered in a number of monogenetic volcanic fields across the whole intra-Carpathian realm developed in the final stages of volcanic activity of the CPR as a whole and of their particular occurrence areas. The ca. 160 km long Călimani-Gurghiu-Harghita volcanic range (CGH) developed as part of the intermediate calc-alkaline volcanism closely related in space with the fold-and-thrust belt of the Carpathians, representing the south-eastern segment of the CPR. Although its map view and general petrochemical and volcanological characteristics are quite similar with those of other segments of the orogene belt-tied calc-alkaline volcanic segments, at a closer look CGH displays a number of unique features. The time-space evolution of CGH is particular not only in that it is the youngest (10.5 to < 0.05 Ma) dominantly calc-alkaline segment in CPR but also it shows a transient character. Unlike other segments along which volcanism occurred simultaneously forming true subduction-related 400 to 800 km long volcanic fronts which were stable in time for millions of year, in CGH volcanic activity migrated continuously along the range from NW to SE. So, during any given 1 Ma time interval active volcanism was restricted to very limited areas and to just a few active volcanic centers. The along-range shift of volcanic foci was concurrent with progressively lower volumes of magma erupted and decreasing magma output rates. As a result, gradually lower-volume and less complex volcanic edifices were built up. Moreover, at the range-ending and youngest South Harghita sub-segment, magma compositions gradually changed from normal calc-alkaline to high-K calc-alkaline and shoshonitic, and adakitic features emerged at the end of volcanic activity, after a time gap of 0.5 Ma. This marks a major geodynamic event in the development of the East Carpathians themselves. During the transient volcanism of CGH, edifices of varying volume and complexity were built up forming a row of tightly-packed adjoining stratovolcanoes/composite volcanoes whose peripheral volcaniclastic aprons complexly juxtaposed, overlapped and merged with each other. The largest ones (Călimani caldera, and Fâncel-Lăpuşna) developed until caldera stage. Some of them (Rusca-Tihu in the Călimani Mts., Vârghiş in the North Harghita Mts.) became unstable during their growth and collapsed, generating widespread large-volume debris avalanche deposits. Edifice instability was solved by volcano-basement interaction processes, such as volcano spreading, at some large-volume volcanoes (in particular those in the Gurghiu Mts.). Volcano typology changed at the smaller-volume constructs toward the southeastern terminus of the range in the South Harghita Mts. from typical large stratovolcanoes to smaller composite volcanoes, dome clusters and isolated domes and simpler internal structures. As a whole, CGH displays an extremely particular evolutionary pattern strongly suggesting a transient character and decreasing to extinguishing volcanic activity along its length from NW to SE.

Volcanology of a Miocene lava dome field, Tokaj Mountains, Hungary

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Abstract

Telkibánya Lava Dome Field (TLDF) was evolved at the northern part of the Tokaj – Slanske Mountains in the Carpathian Volcanic Arc. The subaerial lava dome and flow complex connected to a long lived (13.9-11.2 Ma) silicic reservoir and multi cycle caldera structure as the youngest silicic event between 11.7 to 11.2 Ma. The proximal and distal lithofacies characteristics were defined by field mapping, borehole stratigraphy revising, combined with textural and geochemical studies. The extrusions contributed to the NNW-SSE and perpendicular fracture network and generated 2 extrusion levels in a thickness of about 500 m and 8 km^3 in volume. The volcanic succession ranges in composition from andesite to high-silica rhyolite (58–78 wt.% SiO_2). Chemical characteristics include enrichment in K_2O (>3.5 wt.%), Al_2O_3 and large-ion lithophile elements (Rb, K and light rare-earth elements), and depletion in high field strength elements (Ti, Nb).

Keywords: *caldera, lava dome, flow, rhyolite, perlite*

Introduction

Variable volumes of highly differentiated rhyolitic magmas erupt periodically from the long lived large silicic magmatic systems through the thick ash flow sheets and minor lava extrusions. Lava domes form high-viscosity felsic magma piles up above and around a vent. Their emplacement connected to collapse or explosion calderas, developed during pre- and/or post-caldera stages (Fink 1987; Heumann and Davies 2007). Today focused interest is the consequence of their potential hazards (Mt. Saint Helens 1980-1986, Mt. Unzen 1991, Sinabung 2013-14). The study of dome-forming extrusions gives important information about the longevity and the regeneration rate of large silicic volcanic systems (Heumann and Davies 1997).

The caldera structures may host substantial precious and base metal ore deposits. The older eroded structures in the Carpathian-Pannonian Region (CPR) are also well-defined examples of caldera-related resurgence and accompanying late stage dome activity and epithermal mineralization such as the Stiavnica stratovolcano (Konecny et al. 2013), Telkibánya caldera (Kiss and Zelenka 2009) and Beregovo caldera (Vytik et al. 1994).

Regional geology

The Tokaj-Slanske Mountains (TSM) located in the central-northern part of the CPR and comprises an Upper Badenian-Pannonian, thick (1.5 to 3 km), compositionally and texturally diverse succession of calc-alkaline volcanic and sedimentary rocks that record a transition from a shallow submarine to subaerial setting. TLDF located in the middle part of TSM (Fig 1.) and probably connected to a larger caldera structure. As the youngest silicic extrusion event was active for approximately half a million years (Table 1). The extrusion of viscous melts was conforming to regional basement fault and fracture system rejuvenated by the subsidence of the ash flow center. The direction of dome vents and the dissecting valleys is verifying the dominance of the NW-SE and the perpendicular striking fault system.

The rocks of explosive-extrusive acid cycle in space and time were overlapped also the multi-stage intermediate effusions (Fig. 1). The older, northern andesite bodies suffered low-sulphide alteration with potassium enrichment (Kiss and Zelenka 2009). Younger andesite flow remnants settled down on the eroded Sarmatian rhyolite surface (SW peak region of the Ósva watershed).

Materials and Methods

The new volcano-stratigraphic framework is based on the lithofacies characteristics defined by field mapping, borehole stratigraphy revising, combined with textural and geochemical studies. The eruptive volume of TLDF and associated domes and flows (Table 4) were determined by

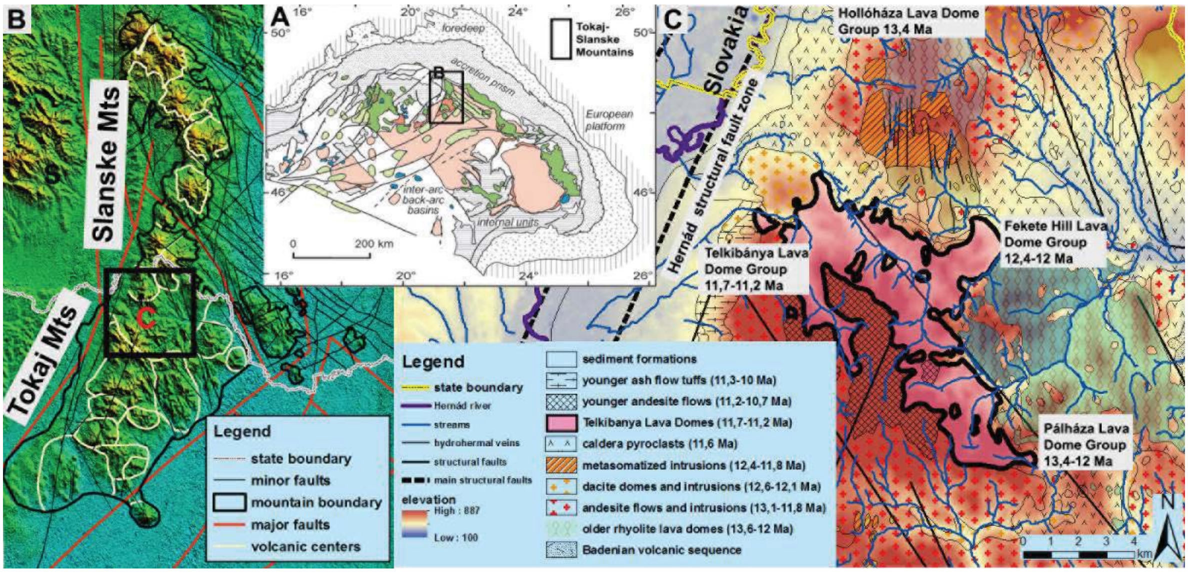

Figure 1. Regional geology of Tokaj Mountains and the Telkibánya Lava Dome Field. A) Position of the Tokaj Mountains in the Carpathian-Pannonian region (pink: felsic volcanics, green: andesite volcanics based on Chernyshev et al. 2013) B) The main volcanic centers of Tokaj-Slanske Mountains) C) Geological sketch of Telkibánya Lava Dome Field and surroundings K-Ar ages from Pécskay et al. (1987), Pécskay and Molnár (2002).

using ArcGIS analytical tools, the lateral resolution of the digital elevation models were 30 and 10 m, based on a 1:50,000 scale. For geochemical correlations (20 samples) the major, trace and rare earth element concentrations were measured at the Hungarian Geological and Geophysical institute (ICP-AES, ICP-MS, Bartha et al. 2004).

Results and Discussion

The volcanic facies associations have genetic significance with respect to volcano type, eruption style, proximity to source and emplacement processes. The facies associations (Table 1) were defined on the basis of systematic field mapping and borehole revising. The caldera related succession became more precisely dismembered than previous work (Perlaki 1972; Kiss and Zelenka 2009). The substantial textural zonation in felsic lavas were developed by variation in cooling rate, degassing, and syn-emplacement ductile and/or brittle deformation (Fink 1987).

The extrusions contributed to the NNW-SSE and perpendicular fracture network and generated 2 extrusion levels in a thickness of about 500 m and 8 km^3 in volume. The distal (clast-supported autobreccias) and medial (coherent perlite) lava dome facies zones characteristic of lower extrusion levels. The near-vent microcrystalline zones formed eroded necks at the upper level. The subvertical textural arrangements of the domes were in accordance with the endogenous growth model. The breccia enveloped lava lobes verified another, exogenous accumulations style of the viscous melt. Some of the coherent dome material might have been destroyed by explosive vent activity. Dome-derived block and ash flow and pyroclastic density current deposits were identified partially around the extrusion units. The rhyolite volcanic activity was contemporaneous with a subvolcanic intrusion that was caused resurgence and epithermal mineralization (low sulphidation type gold-silver deposit Fig. 1). The secondary mineralization of the domes is usually limited to minor silicification, quartz, tridimite and opal (precious, vax, milk) fillings of lithophysae.

The geochemistry was used to refine the field-based subdivisions and not for petrogenetic interpretations. The dataset was in good consistency with the last geochemical review (Kiss et al. 2010). The fine grained (groundmass > 90%) quartz-plagioclase (biotite) phyric rhyolites, and perlites belongs to high K part of the calc-alkaline series.

The distal breccias and medial coherent perlites suffered post genetic hydration (1-5 wt.% H_2O), which coupled with significant Na_2O leaching (0.5-0.8 %) and supported by the quench fragmentation generated micro-crack network. The Fe_2O_3/FeO ratios were shifted by the brecciation (distal zones) and low temperature devitrification (dome and flow interior) processes. The LREEs show overall enrichment over the HREEs (Fig. 2A,

Table 1. Summary of the main volcanic and sedimentary facies in the acid succession of the Telkibanya Lava Dome Field

units	age	spatial connections	proximal facies associations		distal facies associations		volume
			facies	texture	facies	texture	
upper lava domes and flows	11.2±0,7	eroded dome necks, younger andesite flow covered thicker successions (~ 50-70m)	columnar jointed, massive or flow banded, weakly vesicular coherent perlite:, coherent: rhyolite	porphyritic (<10%) plag+q+ bi (am), variable devitrified (felsitic, micropoikilitic), spherulitic and hydrated, perlitic groundmass	clast supported monomict perlite breccia (in situ autobreccia) with gradational contact toward the coherent perlite	non stratified minor matrix, jigsaw-fit and clast rotated texture clasts: blocky to polyhedral (Ø ≤0,5m), perlitic, pumiceous matrix: minor q+plg+bi phyric perlitic clasts, crystal, and glass fragments	1,3 km^3
lower domes and flows	11.5±0,4 11.7±0,5	less eroded part of lava bodies along the valley (Csenkő, Gönci) floors (50-100 m)					5,4 km^3
(partly) dome derived pyro-clasts	not dated	valley filled block and ash-flow, pyroclastic density current deposits around the domes (m-10 m)	non-welded poorly sorted clast or matrix supported redeposited autobreccia	lithic: angular subangular pumiceous, perlitic clasts, matrix: minor clasts, crystal and glass fragments	massive poorly sorted, fine to coarse ash, with sometimes inversely graded lithic and pumice lapilli rich layers	lapilli: plg+q+ +bi phyric pumice, obsidian and fluidal perlite clasts (Ø ≤0,3m) ash: glass shards, crystal fragments	<0,5km^3
ash-flow deposits	11.6±0,4	series of thick ignimbrite sheets, erosional contact with sediment and coarse grained pyroclastic units	poorly sorted, non welded, sometimes lithic and crystal rich ash flow deposits. Clasts: pumice ≤ 5 cm, minor obsidian (cm) degassing pipes, matrix:coarse shards of vesicular tube pumice, crystal fragments (q, plag)				~ 30km^3
sediment formations	Sarmatian nano fauna	scattered outcrops or layers of intra caldera sedimentation	shallow marine, lagunar, normally graded, planar stratified silicified sandstone-conglomerate, bed thickness: 10-50 cm components: broken crystals, perlite, rhyolite and metamorphic clasts (≤cm) grey tuffitic clay, sandy clay with brackish fauna of central Parathetys				-

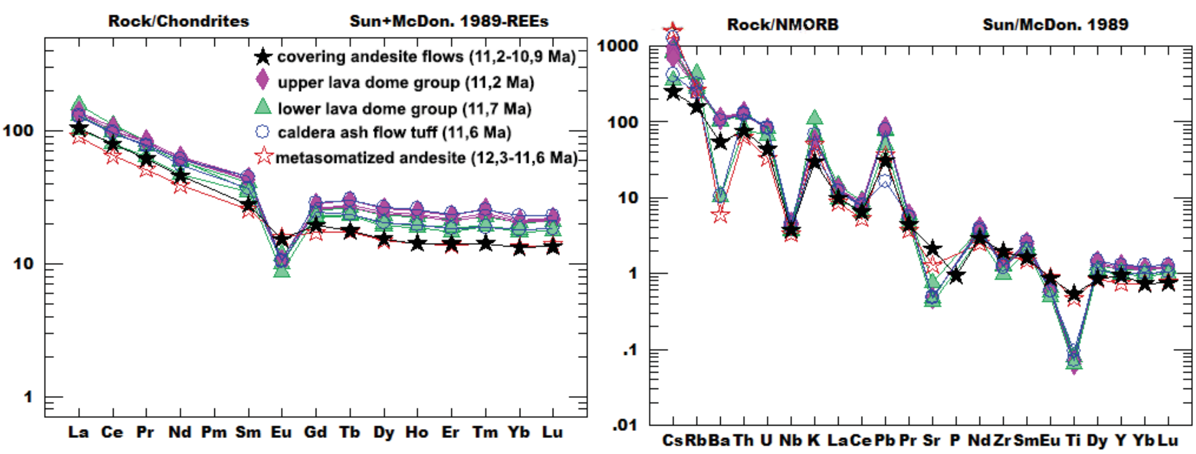

Figure 2. Chondrite (A) and NMORB normalized multi element diagrams of the succession (both reference values from Sun and McDonough, radiometric ages from Pécskay (1987), Pécskay and Molnár 2002).

La/Yb_N: 5.2-8.4) with slight increase toward younger upper dome series. However the Sr and Eu anomaly is much more pronounced in the case of acid succession, lower than southern part of the mountains. The NMORB-normalized diagram (Fig. 4B) shows a similar pattern as the subduction-related volcanic rocks, where the incompatible trace elements show hundred to thousand fold enrichment (Kiss et al. 2010). Comparing the andesites to rhyolites well-defined negative anomalies occur for Ti and Sr. The Ba shows a less well-expressed negative anomaly except the hydrothermally altered samples. The rhyolite lavas had highest Th, U and Pb concentrations expressly in the upper dome samples.

Conclusions

Felsic lava dome and flow edifices are important components in the Miocene succession of Tokaj-Slanske Mountains Facies and textural examinations were essential to define the main stratigraphic units and their emplacement mechanisms. The location of source calderas has not been defined precisely at this stage and it requires further fieldwork, geochemical and geochronological (zircon U/Pb) studies.

In addition, the regional transport direction and lenghts of the first defined dome-derived pyroclastic units need to be constrained by detailed grains size measurements.

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Management of Tourist Potential of the Natural and Cultural Monuments along with the new Tirana - Elbasan Road

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Abstract

This presentation is a compilation about the natural monuments found along the new road axis from Tirana to Elbasani, the last one , being one of the ancient and oldest cultural cities in Albania. The construction of this new road started in 2008 and itsmost important and interesting aspect is Qafe Krraba tunnel with a length mora than 2 kilometres crossing the thick sandstone formation of Tortonian age. Before the construction of this new road, an the old axis crossed the Qafe Krraba hills. Now, the new axis crosses a field area, along Erzeni River in Tirana District and Kusha River Valley, in Elbasani District and some localities such as: Lundër, Petrelë, Bërxhitë, Krrabë, Gracen and Bradashesh.

The new roadwill highlight some natural and historical monuments, which are of interest to visitors who can pass in this new road or can spend some time watching on both sides of the road.

Traveling on the road from Tirana to Elbasani, the geological-geomorphologic landscapes and geological sites can attract the attention in terms of geotourist aspect.

From Tirana to Krraba tunnel on both sides we can observe molassic formations belonging to Tirana Depression. Here there are seen erosion landscapes of escelon form, as result of differences against erosion between sandstone packages and clayey-marl formations. A lot of beds containing fossils can be observed in Krraba area, which geological sites of paleontological interest. On the eastern side of the road, far away, within the limestones and dolomites the karst phenomena and river erosion processes such as: Erzeni Canyon and Erzeni Gorge, with the Black (Pellumbasi) Cave and Myrdhari Canyon in Krraba represent real tourist attractions. On the right side of the road, on the Lithothamniom limestone package rises Petrela Castle, an important historical monument and very interesting tourist place.

Coming out of the tunnel, the road to Elbasani passes along the Kusha River. On both sides we can observe very nice and large outcrops of Burdigalian marls having different colors, predominantly blue, of Burdigalian age. On this road, amongst the Petrela Castle, there are other important cultural monuments such as Monastery of Shijon, Ad Quitum, Basilica of Tepes and Elbasan Castle etc.

The road from Tirana to Elbasani will bring the development of several municipalities and marginalization of some others. It should be noted the further developments that will bring the construction of this new axis.

Construction of the new axis will make an assessment of tourism potential which will have economic impact. Setting consecutive these natural and historical monuments along the cultural axis will affect the management of potential developments in the area. It will be the need for the creation of a guide to develop a new element, which would include territories on both sides of the road.

In this work will be emphasized the development potential of this regiondrag the in terms of tourism and provide suggestions on how to make the Tirana - Elbasan attractive to visitors.

The touristic objectives located along this road Tirana-Elbasani and representing a natural and cultural heritage will be presented in a guide with a map created using GIS technology.

Key words: *Tirana-Elbasan road, natural and cultural heritage, tourist guide, GIS*

Morphologic Features and Dynamic Changes of Coastline Shkumbin, Seman and Vjosa River Deltas

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Abstract

The Adriatic coastline constitutes the most dynamic area of the Albanian territory, especially the section between the Shkumbin and Vjosa river mouths. The distinct dynamic of motion and enormous morphologic changes, there are reflected in the complex evolution of river deltas of Shkumbin, Seman, and Vjosa. These changes there are reflected in the sizes and features of morphological elements, coastline instability, in general, and the volatility of estuaries, in particular.

The sedimentation of the alluvial deposits has been dominant not only at the mouth of the rivers, but also in their area of influence, on both sides, therefore the coast has been continuously aggraded at a rate of 20 m/year at the Vjosa mouth, 35 m/year at the Seman mouth, and 45 m/year at the Shkumbin mouth. That has lead to the increase of land at the expense of sea, while the intermediate sectors or abandoned deltas have been heavily affected by erosion reaching the rate of 10-40 m/year.

The most interesting is Shkumbini River delta. Because of long sandy barrier along the seaside, the river has turned from west direction of the flow to the south, just parallel to seaside for some kilometers, displacing his mouth south, near to the Divjaka sandy beach. Alluvium material of Shkumbini River and sandy grains are of different content: mixed carbonate material with magmatic grains and flysch material.

Semani River delta during last periods shows the trends of the displacement to the north. At the seaside of the Semani delta, there are formed high and long sandy dunes, which are displaced year by year. Sandy dunes and the transgression of the sea towards the earth, it is explained not only by the sea activity. The most important role here, are playing new tectonic movement and especially the depression activity of this territory. Sandy grains and alluvium material in Semani delta are constituted by carbonate and flysch material.

Vjosa River delta it is interesting because of the lot of meanders of the river at his mouth. In spite of the meanders, river flows northwest direction, through sandy dunes. Sandy dunes show that river mouth has been south before, and has changed gradually to the north. Any way, it is the most stable delta in comparison with above mentioned Semani and Shkumbini rivers. Concerning the alluvium sediments and sandy grains, in Vjosa delta predominate carbonate material and grains.

The degree of deposition and erosion varies in time and space, but over the last 20 years of deposition have declined in inverse proportion to erosion, which is linked to human intervention into the riverbeds and coastline itself.

The paper has been prepared by applying the method of comparing 1:25,000 topographic maps of different years, as well as comparing satellite images of recent years. So as to better reflect the evolution of today's river deltas of Shkumbin, Seman, and Vjosa, we have also taken into account the morphological evolution of this coastal sector during the Holocene and historical period.

The article aims at public and private institutions having an interest in the field of Dynamic Geomorphology, and in this framework, it is valuable to construction, tourism, and environment designers etc.

Keywords: *Vjosa, Semani, Shkumbini rivers, coastline, morphologic evolution, delta*

Geoheritage in Kosovo

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Abstract

Kosovo with its complex geological, geomorphologic and lithological features structure is characterized by large geo-heritage values which have not yet been inventoried. Therefore this paper represents a modest (initial) contribution in terms of presentation (inventory) of the geo-heritage in Kosovo.

In the past, the geological development in the territory of Kosovo has differentiated a considerable number of geotectonic units with complex geological interweaving and geodiversity. In a relatively small space it can be observed a variety of magmatic and volcanic massifs of different geological ages. The composition of diverse geological units is manifested with exceptional dynamic contour, represented by a lot of geomorphologic diverse forms.

So far, the access on promotion and evidence of the geoheritage in Kosovo is developed within the Kosovo Institute for Nature Protection (1974) and ProGEO - Kosovo (2009). ProGEO - The European Association for the Conservation of the Geological Heritage, mainly regarding the legal protection.

The inventory and sustainable management of geo-heritage will precede the development of geotourism as a potential of overall economic development. Among the most important values of geoheritage in Kosovo can be distinguished: Minerals in the Crystal's Museum, Watershed sea "Watershed of Dermani (1359 m), Bifurcation of Nerodime River, Canyon of Mirusha, Gadime Cave, Pashtriku (1986 m), Oshlaku (2212 m) Lumebardhi Canyon in Prizren, Rugova Canyon, the Water Spring and Caves of Drini i Bardh (White Drini River), etc.

All these geosites have national and International values which represent geological, geomorphologic, hydrological, and educational and tourist scientific values.

Keywords: *Kosovo, geoheritage, geology, caves, inventory*

Bifurcation of Nerodime River – hydro-morphological phenomenon

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Abstract

The Bifurcation of Nerodime River is located in southern Kosovo. It is created from the merger of several small water flows stemming from Jezerc Mountains (1655 m). Nerodime River, in Kaçanik, discharges into Lepenc River. The total area of the basin is 228 km^2. The geographical position of the upper flow of Nerodime River is particularly important for its morphological and hydrographical aspect. Maritime watershed is located at the top of Dermani (1,364 m), where the waters flow towards the three different sea catchments: Adriatic, Aegean and Black Sea. This is a rare morphological - hydrological phenomenon, not only in Kosovo but also in the Balkan Peninsula. The wide area of Nerodime river, is almost entirely attributable to the massif known as the Vardar Zone, while only a small part of south - west belongs to Sharr (Jezerc Mountain) geotectonic zone. The wide area of Nerodime River is composed of a variety of geological formations of Palaeozoic age, and by Triassic, Tertiary, Quaternary formations, as well by magmatic rocks. At the middle flow of Nerodime River (in Ferizaj), from relieve specific morphology, is created the bifurcation which is a unique hydro-morphological phenomenon in Kosovo and Europe, which discharges its waters into two seas. Through Lepenc and Vardar River into the Aegean Sea and through the Sazlia flow to the river Sitnica, Ibër, Morava and Danube into the Black Sea.

It is estimated that the bifurcation is created by favourable morphological - natural conditions.

There were a large number of mills in Nerodime River flow such as: (Mullini i Nikës, Mullini i Kukës, Mullini i Madh, etc.), which used the Nerodime River waters to grind grains. First it was used as ditch for mills and then deepening the river bed has become a permanent flow and thus has resulted in a bifurcation phenomenon, which is the only one in Europe.

The Bifurcation phenomenon has been mentioned for the first time in the documents of 1321.

Dermani watershed and bifurcation of Nerodime River as rare natural phenomena also present important and tourist potentials. The fact that Dermani watershed and Nerodime bifurcation (hydro-morphological unique phenomena) are near tourist areas such as: Gadime Cave, National Park "Sharri" (Brezovica ski centre, Prevalla), Gryka e Kaçanikut, Blinaja, etc., increase even more the values and tourist potential of the Bifurcation geological site.

The following measures should be undertaken in order to improve the situation and increase the tourist flux in Nerodime River bifurcation: preparation of a strategy for sustainable management of bifurcation, continuous monitoring of the situation; placing information boards along the main roads, etc.

Undertaking these measures will not only increase the number of tourists and the local community benefits from the bifurcation of the Neodime River, but at the same time, will turn the Bifurcation into an important tourist site for Kosovo and the region. The Bifurcation of Nerodime river is the first hydro facility protected in Kosovo (1979) declared as special natural reserve (first category according to IUCN), with an area of 13 ha. The Bifurcation of Nerodime River is a hydro-morphological phenomenon, with rare hydrological, geomorphologic, educational and tourist values.

Keywords: *Nerodime River, Kosovo, bifurcation, hydro-morphological site*

Can a widespread lithofacies unit become a local geosite, if enhanced by cultural and historical values? Kliwa Sandstone Formation, Buzău Land, Romania: a keeper of two stories.

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Abstract

A geosite, according to the ProGEO (www.progeo.se) "represents a key locality or an area showing geological features of intrinsic scientific interest that allows us to understand the key stages in the evolution of the Earth". Practically, a geosite is the structural unit of geoconservation, such as endangered species and rare habitats are for bioconservation. By contrast however, geoconservation is an emerging field of applied research, and as a result of its novelty, the limits of its definitions and rules can be tested and can still be improved. For example, there are no widely accepted criterions for quantitatively ranking and discerning amongst the importance of various geosites. Also, although geoconservation and geopark development are interdisciplinary areas, the above mentioned definition of a geosite is strictly given in geological terms. Although the answer to this seems rather trivial, we wish to explore the possibility of enlarging the definition of a geosite by answering two key questions that have risen while developing the aspiring Buzău Land Geopark, from Romania. Can a widespread lithofacies unit become a geosite only in a limited, well defined area of its extent? Can cultural and historical heritage make and co-define a geosite by adding to the intrinsic value of a geological element? In order to explore these two questions we will refer to the Kliwa lithofacies, which are specific for its outcrops from the Carpathian Bend Area, in Buzău Land.

The Kliwa lithofacies is found in the Eastern Carpathian fold and thrust belt, with outcrops occurring from Poland to Romania. It forms monotonous stratigraphic units, characterized by alternating strata of bituminous shales and Kliwa quartz sandstone. This alternation is indicative of the bituminous anoxic facies of the Oligocene paleobasins and of the periodicity of turbidity currents. Although the shales usually contain fish fossils, the sandstones conserve very few animal remains and sometimes scarce green-schist lithoclasts, indicative of the source region of terrigenous material. The Lower Kliwa Formation is known to host at least one amber rich bed, and although scarce amber occurrences have been described in different locations along its extent, amber deposits seem to be concentrated in the relatively small area of the Carpathian Bend. A unique species of amber (i.e. rumanite) has been described here, and it occurs in a ~1m thick bed and in many organic-rich nodules (also containing coal fragments) that are hosted as lithoclasts by the Kliwa sandstone. This increases the scientific and tourist importance of the Kliwa lithofacies, as it is not only recording the story (i.e. history) of the Oligocene bituminous basins, but also the story of amber. This is true however only for this limited area that makes up for less than 5 % of the total length of the lithofacies' extent. From a cultural point of view, amber and its host rock represent very important elements in the life of the locals from the Carpathian Bend Area. Amber has been and continues to be used as a good luck charm and in manufacturing jewels, while the Kliwa sandstone is being used for sharpening tools as well as a carving material for various items (i.e. crosses). Moreover, since late antiquity people have been carving rock-hewn settlements in the Kliwa sandstone outcrops, with about 20 known locations in the discussed area. The most important of them is the Alunis complex, a rupestral settlement consisting of 3 ruined and 4 intact shelters, of which 2 were never finished. Although in the medieval ages they were used by the religious clergy, our work sheds a new light on their ancient origins based on the presence of 2 inscriptions. They are carved in sandstone and represent a unique, yet undeciphered alphabet which resembles the Anatolian Lydian, Lycian and Carian alphabets. Practically, the Kliwa sandstone is the only reminder and conserver of this endemic alphabet, which has not been identified anywhere else. Due to its specific geological and cultural features from the Carpathian Bend Area, a limited extent of the Lower Kliwa Sandstone Formation can be promoted as a geosite. Moreover, we consider that when defining a geosite, the cultural-historical value should also be quantified because it adds up to the intrinsic value of the geosite while also increasing its tourist appeal. A geosite can record not only events in Earth's geological history, but also in the history of humans.

Geomonuments of Gramsh district (Albania)

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Abstract

Geological sites (Geomonuments) are an important source of information for all geographers, geologists and geoscientists. They represent physical – geographical phenomena which have happened before or are actually happening to the land. Gramshi District is situated in the southern part of our country. Within a small geographical space the nature has created many various shapes. One of the factors which have conditioned the creation of the geological sites in this territory is the type of rocks which compose the landscape of the study area. Physical – geographical space of Gramshi region shows a variety of natural landforms of great, scientific, touristic and cultural value. These natural objects are taken on the focus of different studies. Gramsh area is rich in natural monuments, with a different origin of formation, with beautiful, attractive, strange, and amazing shapes, which make the essence of the tourism development. The identification and the description of geological sites of Gramsh District is the object of this study. The aim of this study is that all these assets should be identified and exploited, serving as a base for geotourism development, as a good chance for the stable development of the district. This work will help all those who study in this field, to the explorers of the nature, but even to the local and foreigner investors. At the end of this work there are given some conclusions about geosites of Gramsh District.

Key words: *Gramshi, geological site, geology, geomorphology, glacier, karst*

Introduction

Many tourists are especially interested in geological sites. Gramsh town is located in old alluvium terraces on the right of the Devoll River, opposite the Tomorri Saint Mountain. Within these limits, the district has a surface of 695 km^2, nearly 2.4 % of the total surface of our country. According to administrative viewpoint, Gramsh district consists of one municipality and nine communes, where are included 95 special villages (Bollobani, 2007). There is a population of 39,799 inhabitants.

Territory of this district is included in the inner tectonic zones of southern Albanides. Gramshi district it is located between Kruja and Krasta tectonic zones. Sedimentary rocks there are presented by carbonate, terregenous, flysch formations of Upper Miocen and Pliocene (Xhelili, 2004).

Gramsh landscape is diverse from the morphological viewpoint and is mainly hilly mountain. This region begins from quotes of 120 metres in Devolli Valley up to 2373 m above sea level in Valamare Mountain, having huge hypsometric amplitude (2253 m).

Literature and methods

The materials which are exploited for the compilation of this paper are the references set in the inner part and at the end of the paper, even scientific magazines inside and outside the country. The methods which are used in completing this study are:

The method of collecting and processing of the written information with the same thematic used.

The method of observation with the topic of Devoll canyons, Sotira waterfall, Dushkulake, Black Lake, Valamara –Lenie – Sogora mountains and Devolli River Valley.

The method of interviewing and discussing with environmental specialized people (like Dr. Mahmut Xhelili, representatives of the local government, etc.).

Results

Geomonuments (Geological sites) of Gramsh district

1. Geomonuments created by hydrographical shapes

Black Lake and the Cold Water Spring. The lake is set at the end of the circus with glacial origin and filled with water resulted by the ice melting

(Marishta 2003). It has a surface about 2 Ha and lies at the height of 1684 m above the sea level. The water of this lake freezes during the winter. In the east of the lake is found a cold water spring with the flow of about 2 l/sec and with a stable regime.

Dushku Lake. It is situated in the north – western slope of Komjan Mountain at a height of 1105 m above the sea level and has a surface of about 22 ha (Xhelili 2004). It has a cavity shape over placed in the shape of the glacial. In summer is populated by white lilies which create an amazing view. Gramsh – Dushku's lake is 28 km long.

Photo 1. Dushku's lake (Photo by Elvira Bollobani).

Waterfall and Sotira water springs. The springs emerge out from the tectonic contact of the limestone rock with the flysch. The largest spring is that of the waterfall, where the water emerge according to limestone lining cracks and fall in the range of rock with a height of 15 m (Marishta, 2003). The road Gramsh – Sotire is 13 km long, whilst from Sotira village up to waterfall is about 3 km on foot.

Photo 2. Waterfall and Sotira's springs (Photo by Elvira Bollobani).

Kerpica springs. The water emerges in the surface Mountain, near the village with the same name, which is situated 20 km far away from Gramshi city. The sources in Xhepexhia's neighbourhood of this village are sulphur mineral waters with increased concentrations of sulphhydric gas which is located inside the Oligocene sedimentary rocks of Kruja zone (Marishta 2003).

Holta springs. They are situated on the left side of Holta's gorge. The emerge in the surface is done by powerful tectonic fault line with general flows of 100 l/sec with a regime almost stable. The water has the characteristic smell of sulphhydric gas and a whitemilky colour. Holta and Xhepexhinjve springs have approximate physical and chemical features to thermo mineral springs of Elbasan, Mamuras, Fushe – Kruje (Marishta 2003).

2. Geomonuments created by geological shapes

Tervol creasing structure. This structure crop-outalong the Ridge of Tervol Mountain, which belongs to the tectonic zone of Kruja, represented by anticline structure (Marishta 2003).

Tomorr Mountain. By its geographical position Tomorri Mountain lies between Dardha's neck in the North and Kulmaku's neck in the South. It is represented by a folded anticline structure with a tectonic origin formed by Alpine orogenesis and it is mainly constructed by limestone rocks of the Upper Cretaceous and Palaeogene flysch (Gruda 2003).

Mountain ridge Valamare-Lenie-Sogore-Koshnice. The tectonic cover of Valamare – Lenie – Sogore – Koshnice has been unique, but later in geological times in the space of Lenie – Kurate are covered autochthonous of Valamare and Lenie mountains. They are often visited by different naturalists, who come to the Black Lake.

The pervasive gorge of Kopace rock. The river of Grabova forms a narrow canyon with a width of 400 m and a height of 1371 above the sea level. The forming of this pervasive valley is helped by a tectonic longitudinal demolition in the gorge entrance and it is of an antecedent type (Gruda 2003).

Devoll and Holta canyons. Devoll canyon with a length of 8 km begins growing the hanging bridge beside Zerec village near Bratila. The river has broken strong and stabile ultrabasic rocks, toward erosion with a depth of 300 m up to 1500 m with a bigger length of 30 m (Bollobani 2007).

Holta canyon has got a smaller length about 2 km and the bed of this valley is not breached in rapids and waterfalls with a width up to 10 m (Bollobani 2007).

The cave of Kabash. This cave is located near

Photo 3. Devoll canyon (Photo by Elvira Bollobani).

Photo 4. Holta canyon (Photo by Elvira Bollobani).

the village with the same name. It has a rare and attractive beauty, the strange microforms of the stalactites and stalagmites, which gather in the interior of the cave (Bollobani 2007).

Griba's haystack. The largest residue with the shape of a haystack has a height of 3 m, with a diameter which keeps growing from up and down, until reaching 3 m in the base. It was done by the water and wind with clear and interesting features.

"The frozen intermarry" on the top of Lisec. The mountain of Lisec it is located between Kukur and Holtas with a height of 1883 m. It is made of limestone rock and it belongs to the Krasta tectonic sub zone. The rocks under the top are carved and well eroded, uniformly, whilst the rocks on the top are strong and resistant toward erosion, reconditioned not everywhere the same (Marishta 2003). Consequently, there are created high carver strings which look like statues, related to a legend about the frozen intermarries of Lisec.

The intermarry legend. During the winter, too many years ago in this mountain were walking through intermarries who had taken as their bride, a girl from Pogradec. On the top of the mountain began blowing a strong wind and a snowstorm. One of the two boys of her tribe, who were accompanying the bride, pinched her and she cursed them. The intermarries, the bridemaids and she herself were frozen. It is said that the stones on the top of Lisec are the frozen intermarries (according to an interview with one of the inhabitants of this area, 100 years old).

Discussion

By the natural objects created in Gramshi District the most distinguished are:

1. The springs of thermal water in Kerpica and Holta
2. The springs of the cold water in the Lenia Village.

According to the specialists it is supposed that the water springs in Xhepexhia's neighbourhood of Kerpica village and Holta water springs are thermal waters, which are curative for rheumatic illnesses. Some doctors and some specialists are of the opinion that the cold water springs at the east of the Black Lake in Lenie are of curative attributes for rheumatic illnesses.

Conclusions and recommendations

- The description and the evaluation of the geological sites of Gramsh District compose the base of tourism development in this area, which is important to emphasise that is rich even in cultural monuments.
- High tourist values have the following natural

monuments: The Black Lake in the cold water spring, the Valamare – Morasses Mountain of Grabova, Dushku's Lake, Kabash Cave, Holta canyons and Holta water springs, Devoll Canyon along the road Gramsh – Korça, Sotira waterfall, Kerpica springs and Tomorr Mountain.

Recommendations

- These objects should be preserved and well contained by the local inhabitants.
- The construction of the road infrastructure, the establishment of the hotels and local services, even the support of the state institutions a central and local level, will enable the use of these rare natural monuments also unique to our country.

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Geotourism in Durresi district

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Abstract

A new trend of tourism is geo-tourism. It is recognized as part of natural tourism. Its object is sustainable development of tourism on the base of geological heritage. It is based on the landscape of nature, mainly in morphological-tectonical structures and geological formation of each area. Geo-tourism or "geological tourism", helps to maintain the geo-diversity, promote geosites and for understanding the Earth sciences. Geo-tourism it is related to geo-monuments and geosites, through the use of geo-trails, observation points and tourist tours. This event attracts people who want to contact to the land in order to recognize and evaluate it. Education about geomorphologic structures of relief and the interpretation of deposits are a good way to create fun and real tourist experience.

Durresi district offers a good perspective on the development of geotourism. Durres City is located in the Adriatic Seaside, in Pre-Adriatic Depression, in the center of the external Albanides, where tectonic activity is very active. The territory where the Durres district is located consists of terrigenous formation, quaternary alluvium, marine deposits (sands and surers) and lagoon-swamp deposits. Relief of Durres district is mainly plain, dominates the field of Durres. The climate is Mediterranean central plains. The capricious character of Mediterranean climate, expressed in elements of climate (such as temperature, rainfall and winds) has influenced the modeling of relief forms, even giving the specific scientific value.

The activity of the Adriatic Sea and the alluvium sands of Ishem and Erzen rivers have created unique beaches. Internal movements and the impact of climatic and hydrographic factors have created a variety of special forms with scientific, educational and tourism values, that are recognized as geological sites. Their complexity values have international, national and local importance.

Geological sites (Geomonuments) are part of protected areas. According to the IUCN classification. They are part of the third category "natural monuments". Some of the geological sites of Durresi Region are included in the attached list of DCM Nr. 676, dt. 20.12.2002, as "Protected areas as natural monuments of Albanian Nature", and in the First Inventory, and in the Map of the Geological Sites of Albania (Serjani A et al. 1998).

The most important geological sites and landscapes of Durresi Region there are located along with the Adriatic Coast such as: Shen Pjetri (Saint Peter), Kallmi, and Currila beaches. Along with Durresi Bay it is one of the most visited during the summer Durresi Beach.

The best geological sites we consider the very nice landscapes of Rodoni and Faleza capsand Lalesi Bay, north of Durresi.

Just above the Durresi Beach, it is risen Kavaja Rock, a geological site, described in the First Inventory of Geological Sites of Albania, full of sediment logical forms, interesting structures and textures, macrofossils and erosion forms. Another one interesting and important geosite it is located in Miocene clays northeast of Currila Beach. Here, as result of rain erosion there are formed a lot of spherical landscapes of very regular form.

The lack of the information and tourist tours has hindered the development of geotourism as part of tourism. Promoting the geotourism in general, requires maximal commitment from the actors in charge of management. The action of responsible institutions, the implementation of legislation, the financing and use of appropriate technology are very important.

Recognition of scientific values of geosites, emphasizing their importance, creating and managing tourist itineraries are the main achievements of this paper.

Key words: *geotourism, geology, geological site, management, geotours*

Banjat Thermal, Sulfur, Water Spring in Peshkopi (Albania)

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Abstract

Albania is rich country in thermal water springs, which have high curative values due to their content and high temperature. This presentation it is about the thermal, sulfur, water spring of Banjat, in Peshkopi City. Banjat thermal spring is getting out just at the western contact of Bellova Evaporate Dome with the Paleogene flysch. Banjat-Bellova salt dome of huge sizesis located in northeastern Albania, in Korabi tectonic zone, of about 3km east of Peshkopi City and 170 km from Tirana. Thermal spring gets up to the surface on the northern slope of Banjat torrent. In Banjat valley, there is narrow of about 100m wide, with gypsum rocky slopes, especially on the southern slope.

Banjat-Bellova salt dome has a surface 15 km^2 and a thicknes more than 1000 m. According to the Strontium isotopic analisis, The the age of Lower Permian (F. Diamanti 2004). Gypsum-anhydrites outcrops on the surface at heights of 700-800 m above the sea level in the western side, where the thermal spring flows and up to 1800-1900 m above the sea level, in the eastern side.

On the southern slope of Banjat torrent we can observe some tectonic faults of thrusted character from west to the east.

Banjat-Bellova salt dome has a rounded form. In eastern part, east of Bellova Village, there is a large, white gypsum-anhydrite deposit, representing a geological site of regional importance and which is included in the First Inventory of Geological Sites of Albania (Serjani A. et al. 1998). At the foot of this rock, there is a small sulfur spring which is included in the list of protected areas of Peshkopi District, as monument of Albanian nature (DCM Nr. 676, dt. 20.12.2002).

Gypsum-anhydrite rocks have massive and crystalline structure, In most part predominate white gypsum-alabaster with some clay and dolomite mixtures. Chemical content of gypsum it is as following:

CaO = 32.21 wt.%, H_2O = 19.80-20.49 wt.%, SO_3 = 46.17-46.52 wt.%. The content of $CaSiO_4$ = 92-96 wt.%.

Banjat thermal, sulfur water springs and Banjat Hospital of Peshkopi there are well known, not only in Albania, but in neighboring countries as well. Thermal water has a temperature of 43 °C, and a considerable H_2S content, which can be noted by their smell even if we are far from the spring A curative and medical resort is situated next to the thermal spring and consists by 44 individual cabins and some therapeutic cabinets. Some hotels there were built during the last years, especially after the change of the social system. Thermal waters are used since ancient times to cure a wide range of diseases, especially rheumatism and skin disease. Their presence in addition to several diseases healing capabilities, has changed the surrounding area to a small town with many new buildings.

Amongst the thermal water baths, here are used at the same time clay baths. Clay is obtained as sediment of the thermal water.

This curative center of thermal water springs, together with Banjat-Bellova large salt dome and some specific geological sites have all capacities to be turned in a most tourist and geotourist center of Albania.

Banjat Thermal Water Spring, according DCM, Nr. 898, dt. 21.12.2011 it is included in the Korab-Koritnik "Natural Park", proclaimed as mountainous natural ecosystem.

The income generation to the local population from the efficient use of these resources, current situation and prospects of further development of curative tourism constitute the contents of this presentation. The previous publications and field works, some interviews with the visitors of this center, were some of the methods used to come to some tentative conclusions about their economic assessment and their impact to the sustainable development of the area close by.

Keywords: *Peshkopi, Thermal water spring, gypsum dome, curative tourism*

Geoinformation of the waterfalls of Albania

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Abstract

Among the beautiful and wonderful landforms of Albania, waterfalls of different types are very impressive and unforgettable. The scenic beauty, the cataracts, the altitude of the falling water, the sound of the fall and the landscape around, make these waterfalls special tourist attractions. The most interesting waterfalls in Albania are already included in the list of the protected areas in the third category as "Monuments of nature". This list includes the waterfalls of Duriçi, Kryeziu, Kardhikaqi, Pocestë, Progonati, Ramicë, Sotirë, Sopoti, Rehovë and Thethi.

Some of these waterfalls are included in the touristic itineraries, but most of them are still unknown. The fact that they are situated far from the roads, in difficult landscape, has made them almost inaccessible or even unreachable. However, these picturesque landscapes need to be promoted and included in the touristic circuits in order to increase the number of visitors and to support the local population living near.

One of the ways to inform the interested visitors about the existence of thesewaterfalls is the creation of the digital geoinformation data base by using the ArcGIS10 software. This database will include scientific, aesthetic, hydrologic informationvalues of the waterfalls together with the distance, altitudes, typical flora and fauna, itineraries, pathways, etc.

The geoinformatization of the waterfalls as geological sites will not only inform the tourists about their values, but also will provide geotours information based on scientific knowledge. This digital information will be updated periodically based on the continuous professional information provided by the geologists, geographers, hydrologists, biologists, etc.

Keywords: *Waterfall, monuments of nature, geoinformation, database, itineraries*

Geosites and their Geotourist Values in Arrën Region, Albania

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Abstract

Arrnit municipality is located in the southwestern part of Kukes District, at an altitude from 350 m up to 1987 m above sea level. It has an area of about 64.7 km² and five villages (Walnut, Verrijn, Lien, Arrëz, and Tejmallë). Located in a mountainous area, this municipality has some specific potential for tourism development, especially mountainous geotourism. Arrnit municipality area is constituted mainly by carbonate rocks Upper Triassic-Lower Jurassic and Lower Cretaceous-Upper Cretaceous. In limestone rock there are developed karst processes causing the formation of many geological sites, especially karst geological sites. Some wonderful relief landscapes are formed as well. Karst processes have been developed especially in Cretaceous limestone.

Karst was developed in two main periods. The first period was continued until the Pliocene and the second, from the Pliocene to the present day. Karst development is conditioned by rapid increases and strong fragmentation of the territory of large soluble rocks.

Arrën Plateau. In the northeastern part of Zepa Mountain, is located the Arrën Plateau of the area of 25 km², situated at the height 1000-1100 m above sea level. In this plateau are intensivelly developed karst processes, forming different karst forms such as: wells, hoppers, dolinas, caves. This karst landscape in this plateau is favored by carbonate rocks. An important role have played, some major tectonic faults such as: Komi tectonic fault, cutting deep tektonical-erosion of the Lura and Bene Neck tectonic fault.

The important factor in formation of karst landscapes in this area, we consider a large amounts of precipitations during the year in form of rains and snow. In Arren carbonate plateau are formed a lot of hinks, which are the most characteristic and the most widespread karst landscapes, formed by chemical and mechanical activity of water. Their diameter ranges from 2-3 m up to several meters and depth of 2-3 m, small hopper, while large hopper reach 12-15 m diameter. In the area there are formed some dolinas as well. They are greater than the hopper and flat bottom. All karst forms landscapes there are distributed especially in Arrën area. Wells as underground karst forms are formed as well. Karst forms in Arrni area there are associated with hydrographic processes such as karst water springs. These water springs are especially numerous in Arrën municipality. The biggest karst water spring is that of Postëvirra water spring.

In Arren region there are formed some canyons, which represent geological sites. The biggest canyon of this area it is Skavica Canyon, formed in carbonate, mainly limestone rock of Upper Triassic-Lower Jurassic. Here are situated Postvirra weaterfall, and Skanderbeg, Docit, Skupulancitand Pigeon caves.

As conclusion, Arrnit Region has a special potential tourist activities such as: geotourism, ecotourism, winter tourism and some types of sports like hiking, hipism hunting, speleology. In this paper, we will also presentsuggestions on how this place to become the most visited by tourists, explorers and geotourists, This area also has cultural potential, which combined with natural heritage, can helps to a great opportunity for the development of tourist activities.

Key words: *Arrni Region, karst geosites, landscapes, geotourism*

Geoheritage of Tirana Region and its Tourist Values

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Abstract

The region of Tirana, shows arich geodiversity and biodiversity representing a unique location, where are included the areas Internal and the External Albanides. Tirana is built in molassic deposits belonging to the Pre Adriatic Depression (DPA).

East of Tirana Depression is located Kruja tectonic zone (Dajti Mountain), thrusting on molasses, while to the east are located Krasta and Mirdita tectonic zones. Geographical features of the region with mountainous landscapes east and lowlands to the west, are reflected in biodiversity, in flora and fauna, creating some ecosystems, in the panoramas and in general, in its geoheritage.

East of Tirana, since the Linza village, up to the east of Dajti Mountain is located the Dajti Forest Park with a surface of 2,957 Ha, proclaimed by DCM as National Forest Park since 1966. In 1994, by DCM, the surface of the protected area was widened up to 10,269 Ha, including Priska and Brari mountains. The accomplished studies have shown Tirana's geoecoheritage values and have enabled the status taken as geomonuments and biomonuments on the Decision of Council of Ministers No. 676, dt. 20.12.2002 "Proclaimed protected areas as monuments of the Albanian Nature". As geological sites, there are defined shapes and landscapes of karst, erosion processes, river canyons and gorges, macrofossil beds in molasse etc. On the other hand, biomonuments are woods and groups at early aged woods or connected with special historic events and special habitats.

In some cases, geological sites are linked with cultural heritage, especially in the case of some castles, which are built just on the tops of erosion remains and on the nice high landscapes.

Some of the most important geological sites of Tirana region there are presented below:

Mali me Gropa ("Honey Comb Mountain") east of Tirana. It represents a miraculous landscape of karst processes in carbonate rocks. Karst forms at 1500–1800 m above the sea level, on gentle slopes of mountain are of interesting views, similar as honey comb. Karst holes, wells, cones, valleys of different sizes there are placed with a strange regularity.

The known karst caves there are: Black Cave (Pellumbasi Cave) in Erzeni Gorge, Vali Cave in Mali me Gropa, Shutre Cave, and Tujani Cave. The deep canyons and gorges are formed by rivers and torrents which cross the Dajti mountain ridge. Here we can note: Shkalla e Tujanit Gorge at northeast of Tirana, Skorani Canyon in Erzeni River and Myrdhari Gorge south, in Krraba. A lot of geological sites containing Tortonian macrofossils are formed in the molassic depositsin Linza, and Krraba sections. The most interesting are outcrops in Tujani that contain macrofossils, next to the contact of the molassic deposits with limestonesand in Vrapi village. Some of biomonuments there are: Bokërrimat Mustafa Koci, and Mner, Priska Plane tree, Ndroqi Plane tree, Krane Plane tree, and Bab Myslymi Nut.

Geological sites and biomonuments in Tirana Region are an important part of the spiritual world of local inhabitants. Their tourist values are correlated with the beauties which they have to offer, lots of opportunities for different sports, associated by the didactic values, scientific and ecological.

The management of the values that offers Tirana's geoheritage, highlighting of protection routs and scientific use to a stable development today and in the future, plan's strategy preparing, and to save their values are some of our objectives in our study.

The promotion of geoecotourist values of Tirana Region will enable to turn the tourist development to an important economical source, in a traditional activity for the local residents living, on the creation of a contemporary environment for the scientific researchers and especially for young specialists. Inclusion of geobioheritage in tourist guides it is minimal, that is the reason why geosites are not known as they should by the tourists, and even the tourist infrastructure needs rapid urge to further improvements.

Key word: *geoheritage, geosite, biomonuments, geoecotourism*

Geopark Orliakas: a Proposed Addition to the Global Geoparks Network from Greece

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Abstract

The proposed Geopark Orliakas encompasses an area of about 500 km^2 in Northern Greece, on the eastern front of the Northern Pindos Mountain Range. Geopark Orliakas is the product of 700 million years of tectonic evolution, where the collision of the African and European plates thrust fragments of an ancient ocean floor upward, exposing a wide variety of rock types which are the basis, in turn, for a multitude of unique soils and ecosystems. Thus Orliakas Geopark is an area of great biodiversity. It is known for its pristine environmental resources including endemic plants, mushrooms, and an important habitat for bears, lynx, wolves, and migratory and predatory birds. In addition to its geological and biological interest, the rich cultural heritage of the area can be seen in its many traditional villages and works of stone architecture, especially its stone bridges, as well as its many archeological sites dating as far back as the Neolithic. Moreover, Mt. Orliakas has been recommended to host an astronomical observatory in the near future.

The proposed Geopark will be overseen by Geowonders Greece, a non-profit consortium of public and private sector partners working to promote interpretive planning programs such as information centers, academic conferences, interactive exhibits, geotourist excursions, guide books, applications and souvenirs, among others. Geowonders Greece will also oversee funding, publicity and responsible management of the resources of the Geopark. An assortment of partners in our organization, from government, private enterprise, and various fields of scientific research, will work toward these goals and contribute strategically to the implementation of programs.

In order to ensure the viability of this project in the currently depressed economy of Greece, Geopark Orliakas must become a self-sustaining enterprise, within a relatively short time frame.

With that goal in mind, Geowonders Greece will operate on a collaborative, business-oriented framework which will use revenue from multiple sources to support its initiatives.

One priority of Geowonders Greece will be to operate with minimal disruption to the landscape, therefore it will utilize existing infrastructure for its activities, wherever possible. It will make use of currently unused buildings for its interpretive centers and other activities. Many of these buildings were created through previous development initiatives by other organizations which, for various reasons such as overreliance on governmental support, were not successful in the long term. Our strategy of making use of available infrastructure and supporting ourselves through various fundraising endeavors will enable Geowonders Greece to remain viable throughout the fluctuating economic climate.

Our application to UNESCO for status as a Geopark is founded on a high estimation of this region's geological, ecological and cultural value, both for its own sake and as a means to revive the local economy and reawaken the spirit of cooperation, innovation and environmental stewardship.

Dumrea Geopark and its Karstic Lakes as a Beauty of Nature on the Surface of Evaporites

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Abstract

The big geopark of Dumrea and its karstic lakes is located between Lushnja and Elbasani cities, on the surface of Dumrea salt diapir that is the largest diapir in Albania. It has a surface of about 270 km^2 and is characterized by an intensive development of karst processes. In this aspect, Dumrea salt diapir can be considered as rare example of a "Natural karst Museum in evaporite Rocks".

Dumrea region is placed in central part of Albania and represents an evaporate diaper of salt and gypsum, covered, in most part, by "cap rock" of 200-300 m thick and represents a hilly plateau of evaporate rocks situated between Devolli (southeast) and Shkumbini (north) rivers. Above Dumrea evaporites there are a lot of different beautiful landscapes, with predomination of rounded hills, karst depressions and funnels. The underground karst is developed as well. Dumrea diapir has tectonic contacts all around with Oligocene flysch formation. On southwestern part, in Kuçova area, some oil deposits are discovered and exploited.

In evaporite rocks are developed all karst forms, on the surface and in depth. The most widespread karst forms are funnels, depressions, caves, and wells.

In Dumrea, was counted a number of 85 lakes exclusively of karstic origin exclusively being the biggest of this type in Albania. The total surface covered by these lakes is 645 Ha and represents 3% of the whole surface of Dumrea diapir. Commonly, they have rounded and ellipsoid shape and in rare cases rarely theyhave elongated shape. Their width varies from 15-20 m up to 1500 m. Most of these karstic lakes have a depth of over 10 m, while the average depth is 5 m. The deepest one is Merhoja Lake of 17.5 m average depth and with maximum depth of 61 m.

The most interesting groups of these karstic lakes are:

Belshi lakes, situated in tourist village of Belshi, Poroske-Çerraga lakes, Seferan Ndergozhda lakes, where is Seferaj lake, one of the biggest in Dumrea of surface 85.7 ha, Moçali-Çanga lakes, Zgjanç-Çestie lakes, where is the biggest Çestie lake of surface 97 ha, Dega-Merhoja lakes, where lies the deepest, Merhoja lake up to 61 m deep.

Due to their muddy appareance, some of these lakes were called by the villagers:Black Lake, Red Lake or in other cases, they wear proper or village names.The water bearing complex of evaporite rocks is widespread in this region. There are absent water springs on the surface of Dumrea. Existing springs commonly stop during the summer. The circulation of waters happened below the "cap rock".

Biodiversity of this area is specific andthere were described about 40 species of birds, some species of wild animals and fishes.

Karstic lakes together with the nice landscapes on the surface of Dumrea evaporite are rare beautiful natural phenomena. From the tops of Destora (259.0 m), Gradishta (239.2 m), Faqe Madhe (233.0 m), Sukubora (209.0 m) hills it can be watched interesting aesthetic landscapes all around. Some of them are beautiful tourist attraction such as: Belshi lakes with the beautiful village of Belshi, Seferani, Gradishta, etc.

Belshi lake area is the most populated part in Dumrea region. This is a geopark of rare beauty, due to the nice lakes rounded by specific vegetation with some interesting kinds of birds, good climate, fresh air and green grass all around.

About two centuries before, our great epresentative of National Renaissance Movement of Albania, Sami Frashëri proposed Belshi region to be capital of Albania.

Keywords: *Geopark, Dumrea, Karst Lake, diapir, evaporite*

The geosites from Danube Defile in Romania. The vulnerability to touristic activities

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Abstract

This paper aims to a better understand of the geosites of Danube Defile in Romania, from the point of view of vulnerability to touristic activities. The Iron Gates Natural Park is an important area for geoconservation in Romania, as its geological heritage is among the richest in the South Carpathians. The series of structural units, typical for the South Carpathians, crossed by the Danube, shows unique features from paleontological, structural and morphological points of view, making the Park one of the most interesting areas in geosciences, for research and education. Our introductory study of vulnerability of geological and geomorphological elements from Danube Defile is made from the geosites point of view. Geosites (term which include also the geomorphologic sites) are relief forms with a scientific, aesthetical, ecological, economical, and cultural values, in respect of human perception, that complete the total heritage of a given territory, including the biodiversity and human creation. In the last decades we assist to an increasing interest according to vulnerability studies. The specialty literature emphasizes the importance of measuring vulnerability to find new criteria and indicators to measure directly the vulnerability and the natural hazards. Geosites from Danube Defile are important geological and geomorphological elements of natural environment which start to become tourist attractions. In those conditions, it is necessary to initiate some studies regarding the vulnerability of those geosites in the local context of tourist development.

Keywords: *Danube Defile, Romania, geosites, vulnerability, touristic activities*

Introduction

On our study area several studies concerning the geology and the geomorphology were made (Grigore et al. 1963; Posea 1964; Popa, 2003, 2011; Carablaisa and Delău 2010; Grecu et al., 2011), but not any study concerning the vulnerability to natural risks of geological and geomorphological elements. Our approach aims for the geosites and geomorphosites from the Danube Defile (Iron Gates) in Romania in a particular perspective which is integrated in the large field of vulnerability and natural risks.

In the last decades we assist to an increasing interest according to vulnerability studies. The specialty literature emphasizes the importance of measuring vulnerability to find new criteria and indicators to measure directly the vulnerability and the natural hazards. Despite those contemporary researches, at this time there is no wide standard application unanimously accepted. Quantitative representation using attributes such as small vulnerability, medium vulnerability or great vulnerability always include quantitative analyses and only some times indirect assessments based on material damage and/or human loses (Grecu 2009).

Study area

The Danube Defile on the Romanian side is a valuable natural unit of a unique character along with the entire 2,875 km length of the Danube. A lithological and morphological variety of the relief, a climate with sub-Mediterranean influences, a complex biotic cover, as well as a multitude of historical, cultural and religious remains, lend the landscape an aspect of originality. Historical relics attest to thousands of years of human habitation on this territory. To the West, the boundary of the park coincides with that of Bazia village, while to the South, the limit follows the Danube watercourse downstream to the dam at Gura Vaii (Fig. 1). To the north, the boundary follows the southern flanks of the Locva Mountains, partly includes the Almăj Mountains and almost the entire area of the Mehedini Mountains (Pătroescu and Vintilă 1997). The Danube Defile in Romania is best known by the name of Iron Gates.

The Iron Gates are situated between Bazia locality and Drobeta Turnu-Severin city (Caras-Severin and Mehedinti County), for a distance of about 140 km. The name applies to the region where the Danube River cuts through the Carpathian Mountains forming a spectacular defile. Geologically and geomorphologic ally, the Iron Gates is a very complex region. The Danube valley defines here a multitude of microreliefs and reveals most of geodiversity. The geologists call this region „A museum in open air". The diversity of geology being the main characteristic of this region, characteristic which confers to the Iron Gates a great scientific potential (Fig. 2).

Results & Discussions

By field experience of the authors and by a work consisted in many discussions with other specialists of geology, geomorphology and physical geography of the analyzed region, we could identify 24 geosites in the Danube Defile. We must mention that we inventoried just the geosites which can be one way or another, touched by the tourist activities.

From the possible typology presented above and consisted in ten types of geosites we find in Danube Defile seven types of geosites vulnerable to touristic activities. The Table 1 presents all the 24 geosites and the typology consisted in seven classes, corresponding to seven morphogenetic processes.

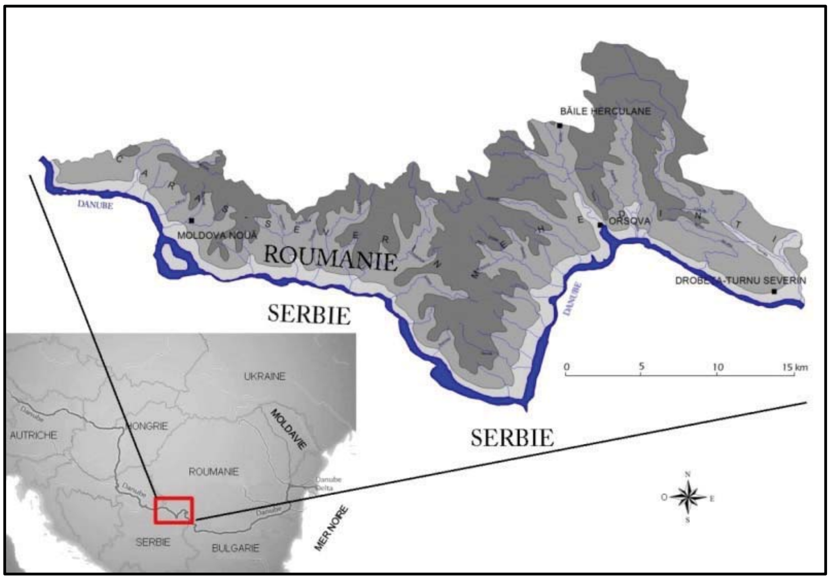

Figure 1. Localization of the Danube Defile at the south-western part of Romania's Border with Serbia.

Methodology

Geosites represent relief forms of scientific, aesthetical, ecological, economical, and cultural value, in respect of human perception, that complete the total heritage of a given territory, including the biodiversity and human creation (Panizza and Piacente 1993; Panizza 2001; Reynard and Coratza 2005, 2007; Pralong 2006; Reynard et al. 2007; Reynard 2008).

Our analysis takes in consideration the human accessibility to geosites. In this case and considering that in our region use just one single road (from Bazia to Turnu-Severin) we have split our inventoried geosites in two groups: one group which are near the road (and accessible for great public) and the second group which are far away from the main route, isolated (and inaccessible for great public). Taking these criteria to our analysis, we must mention that this study region is poorly equipped concerning the accessibility. There is just one main road, along the Danube, a national road that presents, in places, very bad sectors.

Conform to the methodology presented above, first step was to split our inventoried geosites in two groups, as we mentioned above. Fig. 2 shows the geosites that are accessible for tourists from the main road that follows the Danube valley from East to West (from Drobeta Turnu Severin to Moldova Noua and Bazias). Three of them (Ilovita fossil point, Baia Noua and Moldova Noua mines) there are not on the main road, but they are very well accessible from secondary roads. We have identified 13 geosites, which are particularly sensible to tourist activities. Those geosites cover seven types, which demonstrates that the issue of vulnerability in Danube Defile is a very significant aspect and touch important geological and geomorphological sites.

Table 1. The 40 inventoried geosites from Danube Defile and their typology.

N°	NAME OF GEOSITE	TYPE
1	Statue of King Decebalus, Baia Nouă mine, Moldova Nouă mine, Cozla's sterile deposit, Quarry	Anthropic
2	Big Cazans, Small Cazans, Karstic plateau of Ciucaru Mare, Curchia waterfall, Mraconia collapse, Liubotina landslide, Coronini fortress hill, Babacaia rock	Geomorphologic
3	Golf of Cerna, Basin of Dubova	Hydrologic
4	Saraorski valley, Ilovia fossil site, Curchia fossil limestone	Paleontological
5	Trescovă volcanic dome, Urgonian limestone-bars of Dubova, Outcrops of Selski, Permian quartzite of Stariștea, Permian tuffs of Povalina, Serpentinites of Tișovița, The Greben, Outcrops of Jeliseva	Petrographical
6	Sedimentary basin of Sirinia (Cozla), Conglomerates of ancient Zancleen delta, Moldova Veche island, Sedimentary basin of Sirinia (Munteana)	Sedimentary
7	Ponicova cave, Gaura cu Muscă cave, Veterani cave, Climente cave, Gaura Haiducească cave, Padina Matei cave, Zamonița cave, Valea Ceuca cave	Speleological
8	Cioaca Borii cuesta, Zeliște-Veligan natural amphitheatre	Structural

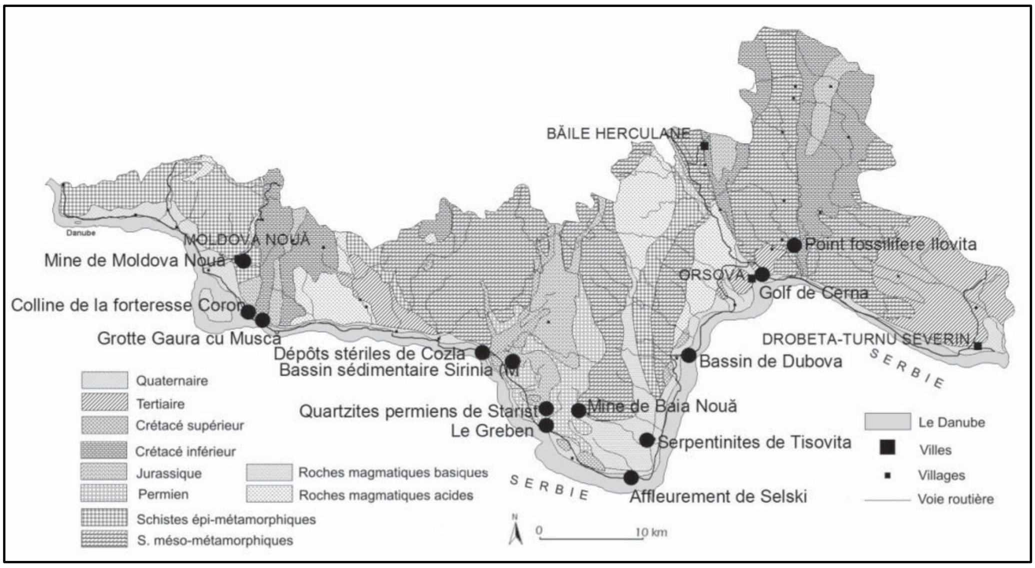

Figure 2. The geosites from Danube Defile that are accessible from the main road.

Contrary to those geosites, we have found also 11 elements that are not on the main road, but inside of the territory, far away from the tourist areas. Generally, the tourist activities are spread only along the Danube River, in the villages founding here. In the north of Danube waters, the mountain areas and the poorly accessibility made to exist few villages, bad roads and, consequently, no tourist activities in present. However, the areas situated north of Danube River are very rich in geological and geomorphological sites. Only the five types of those geosites emphasis the poorly accessibility of those areas and therefore a smaller attention from the researchers. This methodology and result are perfectly correlated with the theory that argues that the vulnerability and damage of a geological region is directly linked by his accessibility and especially by his tourist exploitation. The more a region is accessible, the higher it is exposed to human pressure.

In this second category of geosites we find important elements as the volcanic dome of Trescovat (a relevant geosites from our region, a Permian witness of Iron Gates geology), or several caves. In addition to those speleological sites, we fund another three geosites (carstic plateau of Ciucaru Mare and Curchia limestone and waterfall), which emphasis the presence of large limestone percentage in this area (Fig. 3). The limestone is a preferred rock for the Danube Defile geosites. We must also mention that some geosites integrated in this second category are not very far from the main road. It is the case of the karst plateau of Ciucaru Mare and the caves of Veterani and Ponicova. Despite the fact that they are not so far from the main road, however they present some Inaccessible features. For example, the carst plateau is at 300 m altitude just above the main route. To arrive there, the tourist must mount a slope quite inclined, in approximately one

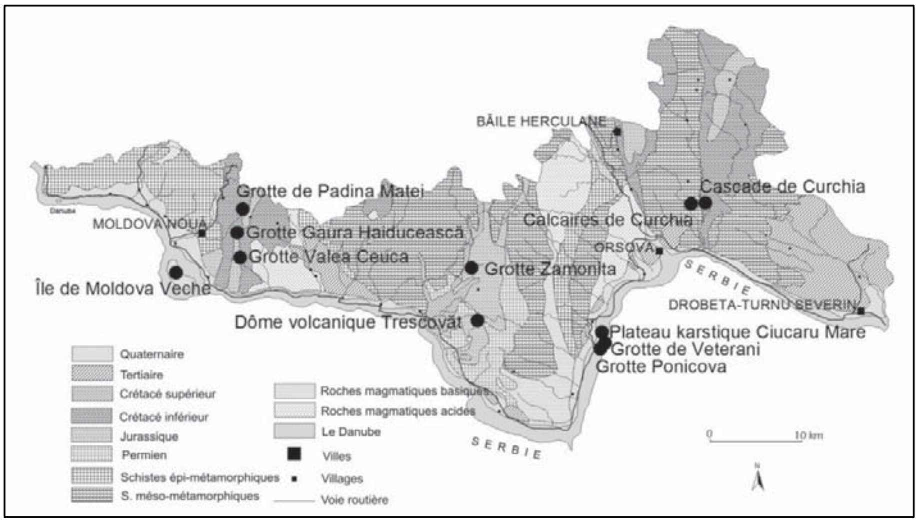

Figure 3. The geosites from Danube Defile that have no good accessibility (inland geosites).

hour. In these conditions, the geosite is practically inaccessible for the big public. The same thing with the Ponicova and Veterani caves. The Veterani cave is near the road but the entrance is made only from the Danube, in a boat. For the Ponicova cave, the tourist must follow a dry karst valley (very inaccessible because of its big limestone rocks) and then to descend several wooden stairs, also very instable. In this cases, the inaccessibility of geosites prevent the degradation of them under the touristic pressure. However, all those sites present a basic vulnerability. For example, the geosites are visited by few tourists (comparable to the first category of geosites), but we have remarked that they to a lot of damage to geosites, especially by disrupting the outcrops or the geosites microforms (e.g. disruption of the stalactites and stalagmites of the caves). The Curchia limestone and the Ilovita fossil points were very affected by the tourists sampling and removing the paleontological in situ elements.

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The Aliakmon Legacy: a project for geotouristic development in Western Macedonia, Greece

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Abstract

Aliakmon river, the longest Greek river, in the central part of its course cuts a narrow valley within one of the most studied and well known ophiolite sequences of the Alps-Himalaya range, with several outcrops, most of which with an almost one century history of studies of ophiolite sole contact, crust-mantle boundary and oceanic crust sequences. The final portion of the narrow valley was chosen as the place for building the biggest hydroelectric dam in Greece. As a consequence of completion of dam and flooding of the valley, in 2011 an artificial lake more than 20 km long now covers the valley. The Aliakmon Legacy Project brought, between 2006 and 2008, several international teams of students in earth sciences to the Central Aliakmon Valley (CAV). The teams, working in close collaboration, built a large database of the geological features of the valley for the cultural and scientific heritage of a prominent geologic site. Three teams from university of Milan, for a total of 13 students were particularly devoted to draw a detailed geologic map of the valley and surroundings, to collect representative samples of rocks, to study ore deposits and to asses the characters of the landscape.

Keywords: *geotourism, ophiolite, chromite*

Introduction

CAV is shared between Kozani and Grevena districts of Western Makedonia region, an area where tourism is little developed especially if compared with the most renown Greek tourist attractions, one of which, the Meteora district lies about 40 km to the south of CAV, in Western

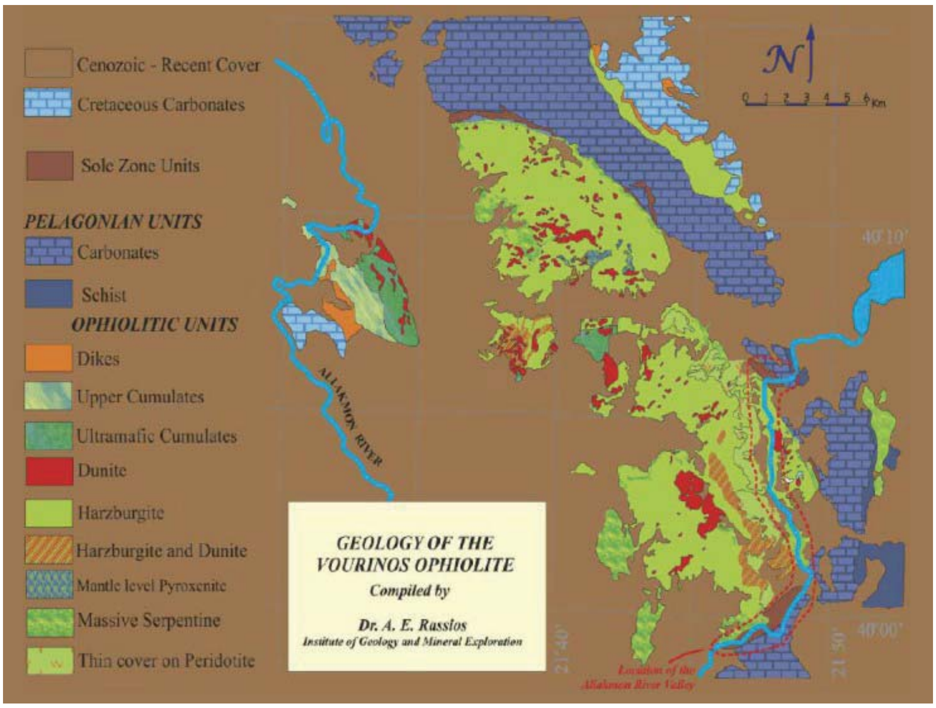

Figure 1. Geologic map of the Vourinos ophiolite. Dashed line shows the area covered by water after flooding consequent to completion of Hilarion Hep dam.

Thessaly. The high geotourist potential of Kozani and Grevena districts needs projects that can emphasize it and that can work as attractors able to offer to visitors a reason to prolong their stay to visit this region. The most prominent geotourist landmarks of the region are the Pindos and Vourinos ophiolite complexes, where some of the most studied and best preserved ophiolite sequences are exposed. Such sequences comprise easy to access outcrops of the whole magmatic sequence and especially of crust-mantle boundary and of ophiolite sole.

A second geologic and potentially geotouristic landmark of the area is the Vourinos chromite mining districts. Several chromite mines, most of which were worked underground, exploited big reserves of chromite ore, but are now abandoned and neglected. Xerolivado Mine, with about 4 million tons of ore and worked on more than 10 levels was the biggest chromite mine in Greece.

In its central valley Aliakmon river flows in a narrow canyon that cuts the western portion of the Vourinos ophiolite complex and giving rise to dramatic outcrops of rocks from the ophiolite sequence (Fig. 1). The downward exit of the canyon was chosen as the place to build Hilarion Hep the biggest dam in Greece. This dam completed in 2011 formed a lake with an area of 22 km^2 and a volume of water of 410,000,000 m^3 that now stretches along the narrow canyon.

The construction of Hilarion Hep in the last decade was a challenge for both geoheritage and geotourism. On one side a record of the geologic history of the area would be hidden underwater, on the other the lake could be a positive factor in geotourist development of the area.

Techniques

The present note describes the work carried out within the Aliakmon project by the teams from Università degli Studi di Milano (Italy). The whole project involved more than 40 students from 10 different countries working, under the guidance of one of the Authors (A. Rassios), for three years in the field (2006-2008), with laboratory and analytical work lasting till 2010.

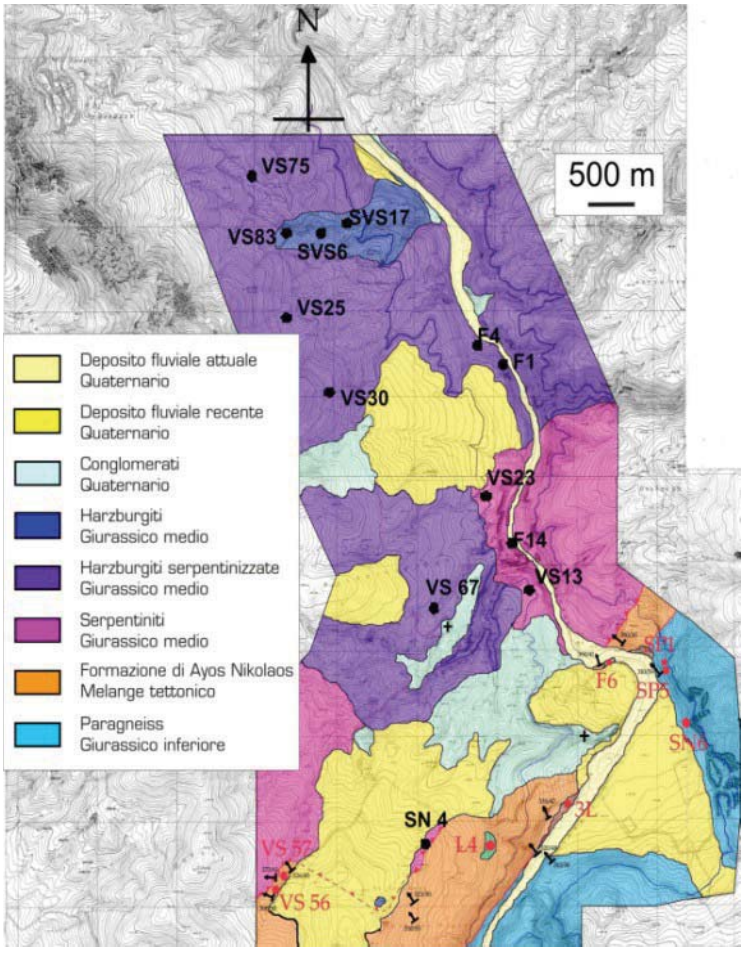

Figure 2. A portion of the 1: 5,000 geologic map compiled for the Aliakmon project, with location of sampling localities.

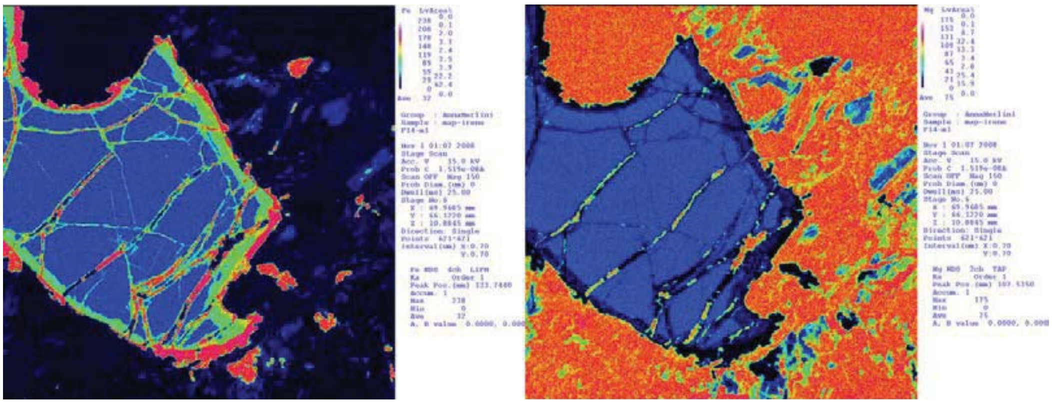

Figure 3. Atomic maps of Fe (left) and Mg (right) in a chromitite sample from Xerolivado Mine. It is visible the multistage overgrowth of ferritchromite and magnetite over chromite.

Work by teams from Università degli Studi di Milano resulted in 12 theses of bachelor in Geological Sciences degree (Pedrazzini 2006; Ferrari 2007; Lotti 2007; Pedrotti 2007; Borghesan 2008; Casartelli 2008; Fantone 2008; Ninicato 2008; Cazzaniga 2009; Colombo 2009; Broetto 2010; Molteni 2010) and one thesis of bachelor in (De Carlo 2008), all discussed at Università degli Studi di Milano.

Products comprise:

- A 1:5 000 Geological map of CAV (Fig. 2)
- The collection of more than 200 samples representative of the lithologies of CAV
- A petrographic and minerographic study of 6 abandoned chromite mines
- A landscape description of CAV and main excursion paths crossing it

Results and discussion

The first basic result of the work was the compilation of the 1:5,000 geologic map of CAV (Fig. 2) that covers and area of about 30 km^2 totally including the area flooded in 2011. It provides a description of lithologies and geological features that was missing and that will be no more possible to collect in future.

The map has also been used for the choice of sampling localities so that the sample collection is representative of all lithologies present in the area and also of their variability. Each sample of the collection has been photographed and describe at the macroscopic scale. Selected samples were chosen for a microscopic scale description in thin section. Sample collection together with collections from students from other countries was the base for the publication of a guide to rocks outcropping within CAV (Rassios et al. 2007).

The study of chromite ore was extended to mines in the CAV and in the surrounding area and comprised a total of 6 localities: 3 in open pit (Rizo, South Frourio and Potamia) and 3 in gallery (Xerolivado, North Frourio, and Aetorahes).

Minerographic, SEM and EMP studies gave important scientific results that were published in an international journal (Grieco and Merlini, 2012), but that could be of use in a possible future museum of mines. Particularly amazing are the multiple zonings that interest chromite grain from

Figure 4. CAV before (A) and after flooding (B), view of Zavordas monastery from Aliakmon river banks (C), view of hermitage before (D) and after flooding (E).

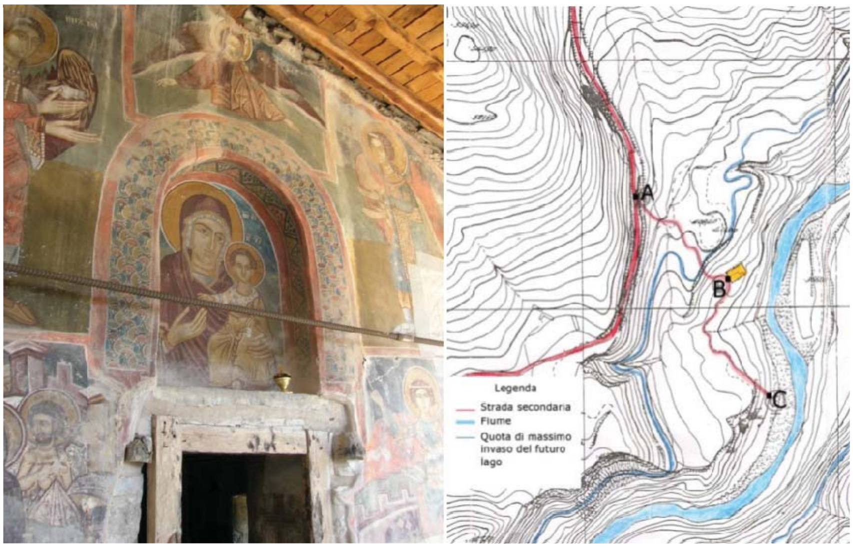

Figure 5. Frescos from the monastery of Panagia in Tornikos before flooding covered it (left) and a portion of the excursion map of CAV (right).

Xerolivado and Aetorahes ore deposits (Fig. 3).

The third product is a collection of more than 500 photos of CAV that record a landscape and a cultural heritage already disappeared forever (Fig. 4).

The fourth product is the map and description of existing excursion paths within the valley (Fig. 5).

Conclusion

The Aliakmon Project fulfilled its multiple tasks. It allowed preserving the geologic, landscape, and, partially, also the cultural heritage of the CAV for future generations and it also provided a database for the possible geotourist development of the area. Moreover it was a fertile ground were young minds from several countries, involved in the study of geology and geotourism, could interact, grow and learn from each other.

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Natural and Cultural Heritage in Berat and their Sustainable Management

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Abstract

The natural and cultural heritage represents a precious treasure for every country. Berat City is a destination known around the world, with a sustainable development of tourism, which preserves and revives its cultural and natural heritage, provides unique values, experiences and contributes to improving the quality of citizens life. Historical, cultural, ethnographical, architectural and natural heritage of the city constitute a strong basis for the development of tourism. Consequently, the development of sustainable tourism has all possibilities to help economic, social, and environmental circle. Berati has a rich natural and cultural heritage. Here we can find Castle-Quarter, Mangalem and Gorica old quarters, which constitute an important cultural legacy for our country, included in the world cultural heritage under the UNESCO protection. But even more special for this ancient museum city, is the combination of natural and cultural heritage at the same time. The neighborhoods of Gorica and Mangalem are placed on opposite flanks of the Berat anticline, divided from Osumi River, which has formed here a magnificent Gorge, representing a geological site (geomonument).To the east of Berati City rises Tomorri Mountain, with glacial moraines and circuses on the top, while on the western side to attract more regular erosion forms on the slope of Shpirag Mountain.

Identification and evaluation of natural and cultural heritage is a very important task for the propagation of the values of these elements, measures protection and their use for various purposes. Precisely, the aim of this paper is the identification and evaluation of these natural and cultural values, as a potential sustainable development of the area.

Key words: *Berati City, natural heritage, cultural heritage, sustainable development*

Introduction

Berat City it is known as a safe tourist destination with great value, characterized by a variety of unique natural and cultural sites to a global level contained within a relatively small geographic area. He is a quality destination, with a sustainable development of tourism, which preserves and revives its cultural resources and natural, offers value and unique experiences, contributing thus to improving the quality of life of citizens.

Tourism development and the achievement of sustainable development is now a global trend in which every country is making efforts with appropriate policies to achieve this objective. Developing sustainable tourism resource management supports economic, social and environmental issues in order to meet one another, while preserving the cultural integrity, aesthetic ecological processes, and biological diversity and promote social life in the area. Berati it is a good witness of the intersection in complete harmony with those natural and cultural monuments. It is unique, with a large amount of architectural, historic, cultural, natural, and ethnographic.

This paper consists in the recognition of natural and cultural heritage, reflecting an improvement of tourism image and a better management of them. So, the conversion of a quality destination in order to attract as many tourists that have interest for culture and nature. Harmonization of combining cultural and natural monuments and long-term positive impact tourism relying on the principle of sustainability represents precisely the subject of this study.

2. Material and Methods

For the research work and publications have been used so far were contacted and interviewed specialists and representatives of local and central government, are providing demographic and statistical data, plans, maps, aerial photos, information, etc., the municipality and other sources. The analysis has a descriptive focus on important aspects regarding natural resources and cultural background that has land, and the achievement of sustainable development using these resources.

Results and discussions

Natural and cultural monuments are part of the identity of a nation or a country, as well as important factors of historic, economic and social development. Berati, a City of over a thousands window, a country with a considerable wealth of natural and cultural monuments that bear witness in itself a cultural, historical and artistic life of work, expertly performed by generations of its inhabitants, he today counts:

- 11 natural monuments, from which 9 belong to biodiversity and 2 to geodiversity.

- 210 museum objects. 60 of them are monuments of the first category, while the others are of the second category.

Among these values combined well with each other, the most prominent are:

Castle - Mangalem neighborhood - Gorica neighborhood.

Berat is undoubtedly one of the most beautiful and interesting cities of Albania. Located in the southern part of the country, about 110 km from Tirana.

It is constructed on both sides of the Osumi River. Berat now counts over 2400 years of his existence and thus being one of the oldest centers of civilization in Albania. The castle was built on rocky hill in triangular shape. With its Illyrian foundations, and rebuilt several times, it is today not only one of the largest castles inhabited, but also a stone archive that

Offers varieties of styles and contributions of different eras: the Illyrian, Roman-Byzantine, Albanian and Turkish.

As it is known, neighborhoods Mangalem and Gorica, along with Berat Castle, constitute an important cultural heritage for our country, therefore, have been found in the World Cultural Heritage, under the protection of UNESCO, declared on 08.07.2008. Except for the historical castle and very specific objects of worship, very well preserved, in the citadel of Berati is also famous museum Onufri and many other items. The value of these reside consists in a very special architectural construction, of early period. They are rich in paintings. With a fanaticism worthy to be called holy, are stored in Berati manuscript evidence, which proves particularly high level of culture of the city. The most important of these testimonies is the Purple and Gold Codices. Both these codices containing parts of the Gospels written in the old Greek. Mangalem and Gorica neighborhoods with uneven architecture, inherited from the past, also constitute very important objects of large sizes. A great interest also represent Islamic facilities as “Plumb” Mosque, “Mbreti” Mosque , Bektashi monastery, which presents a wonderful honor architectural realizations of the seventeenth century and

Decorated with colorful frescoes Turkish-Arab and accompanied by a traditional Ottoman inn. Gorica Bridge with arches built also skilful since ancient times. Gorica Bridge is one of the architectural monuments and architecture symbols of Berati. But for the residents and visitors of this ancient museum-city, it is necessary to recognize the combination of natural cultural heritage with it simultaneously.

Mangalem neighborhoods (the citadel above) and Gorica placed in opposite sides of the Berati anticline, which has the Eocene limestone roof. These neighborhoods are divided by the River Osumi, who has formed a gorge as result of river erosion, representing a magnificent Geosite (Geomonument). At the entrance to the Castle is the contact between limestone and flysch formations of Eocene-Oligocene age. Meditating and resting on the landscape from the top of the castle visitors look east and see Tomorri Mountain, which is superb rises above the surrounding territory, full of glacial circuses at the top, while to the west side far away, draw the attention regular erosion forms on the slope of Shpirag Mountain.

On the top of Tomorri Mountain there are formed a lot of glacial circuses and moraines, and a wide karst field full of surface and underground karst forms. Because of interesting flora and fauns he has been declared as hunting reserve, especially for wild hare.

The beauty and features of Tomorri left indelible impressions for visitors as they become vulnerable when you are there. For each year, in August, near the Kulmaka Tekke located on this mountain celebrates pilgrimage of Bektashi believers.

Since 1996, an area of 4,000 hectares of Tomorri Mountain was declared a National Park. From here the view to offer from all directions is magnificent impressive. Perhaps this has done great poet A.Z. Cajupi considered Mount Tomorri as "with their heads in the sky, king of heaven, the Church of Albania and the throne of God."

Some of the natural monuments declared under the protection according DCM 676, DT. 20.12.2002, in Berati district there are: The Oak of Çesma of Prokopise, located in Paftal. Is a tree with stump and special crown (cylindrical) over 300 years old. Kapinove Cave, located near the Kapinovo Village. It is a carst cave formed at the junction of tectonic fault, in Mesozoic limestones. The cave has several galleries with multiple concretions.

Pashalli Oak: Situated in the village of Mimas. Is a tree with stump and special crown (umbrella).

Plane of Lybeshe: Situated in the village Lybeshë, about 800 m above sea level. Constitutes a forked tree trunk and with special crown (umbrella).

Plane of Fountain, Paftal: Constitutes a tree with special stem

Forest Kulajve, Velcan: Located in the village Velcan. Constitutes a forest (0.5 ha) of mixed Hazelnut, Juniper, etc.

Plane of Zhitom: Situated in the village Zhitom, about 700 m above sea level. Constitutes a forked tree trunk and with special crown (umbrella). It is over 85 years old.

The Olive of Drobonik: Located in Palikesh village. Constitutes a forked tree trunk and with special crown (umbrella). It is over 500 years old.

It should be emphasized that these monuments and many others have numerous scientific value (biological and ecological), cultural, didactic and geoecotourist values.

As it is seen Berati has a rich natural and cultural heritage. Tourism is one of the most promising directions of economic development. In some areas of the district can develop mountainous tourism with many aspects within it, as well as hunting. Already noted that the community is aware of the sensitive scale for these values, but still found ways are not appropriate for the rapid introduction of these resources efficiently. There is much to be done in terms of restoration of heritage conservation values, in providing necessary infrastructure and promoting tourist urban area.

Results

As a conclusion we can say that tourism in Berati City is one of the great economic potentials. Once it is an area with a substantial premium important potentials cultural-historical and tourism development. Improving infrastructure in tourism as hotel services, roads and transport, tourism and family support would be key ways that could lead to the development of a genuine tourism. Construction of road Berat-Permet-Three Bridges-Greece will positively influence the development of this region.

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Geomonuments (Geological Sites) of Rare Scientific Values in Dibra District, Albania

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Abstract

In Dibra district there are widespread a lot of natural, geological, geomorphological, glacial, karst, erosion, hydrographic monuments (geological sites) with unique values. The most important are: Grama Allochtone, Evaporite, diapir dome of Mali i Bardhë (White Mountain), Fusha e Panaireve glacial lakes of Korabi mountainous areas, Gorges of Grama, etc.

Glacial lakes of Korabi mountainous area are of clean and cold water. They are located at heights from 1465 up to 2000 m above sea level and are characterized by specific geological, geomorphologic, hydrological, biological and ecological features (see Fig. 1).

Figure 1. Glacial lake, Stanet e Preshit, Korab.

Mali i Bardhë (White Mountain) is a rare geological site, with special metalogenic features and economic interest. It is located at the heights from 1600 up to 1966 m above sea level. It represents a tectonically-structural geosite, an evaporate diapir, in form of very big dome, of large isometric dimensions and the apparent tectonic contacts with the surrounding formations. Evaporates primarily consist of gypsum, anhydrite and selenite with white to gray intercalations of organic matter, dolomite, limestone, etc. In most part, this dome is surrounded by flysch formation of Eocene – Oligocene age. It has scientific, didactic, economic, geotourist value (see Fig. 2).

Figure 2. View of Evaporites, Mali i Bardhe

Fusha e Panairit is located in Korabi Highland areas; at the height of about 2150 m above the sea level. It has the shape form of a large intermountain area. It is similar to a giant amphitheater with flat bottom (800 x 230 m) and steep slopes (over 500 m). It is a large complex of glacial cirque located on Devonian limestones, schists of Silurian – Devonian age and serpentines. Its erosion, karst, glacial, neotectonic phenomena are representing a rare, nice mountainous landscape of scientific, geological, geomorphologic, didactic, ecological, tourist and cultural values. Karst waters that are accumulated in its glacial deposits lose in northern marginal karst caverns and over thrust planes, to re-appear again after 5-6 km as a large water spring in Izviri area (see Fig. 3).

Figure 3. Fusha e Panairit (Large complex glacial cirque).

Allochtone of Grama. It is a rare phenomenon of over thrust, a geological site of unique and worldwide values. There is an excellent cover location of effusive - sedimentary series of Grame - Tomini area. In excellent order, it can be observed the placement of the effusive - sedimentary coverage series of Grama - sedimentary Tomini on top of Eocene flysch and Permian - Triassic evaporates. Vertical section of allochtone is over 800 m (see Fig. 4).

Erosion karst phenomena are developed mainly in

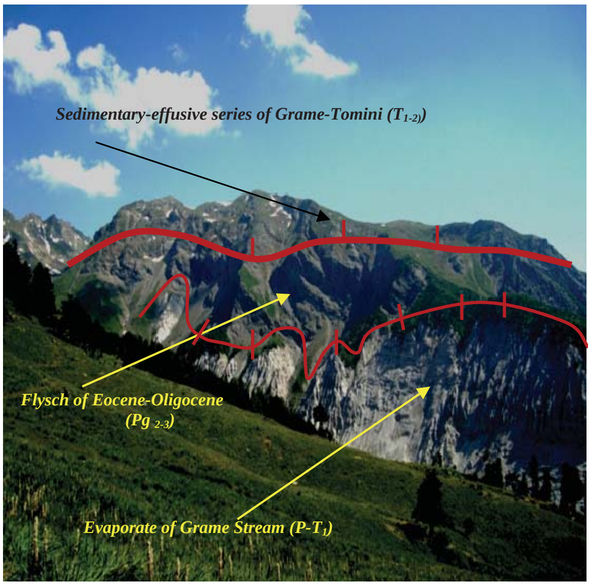

Figure 4. Allochtone of Grama, a rare overthrust phenomena, a Geo-Monument with unique world values.

Figure 5. Erosional phenomena in Evaporites, Përroi i Gramës.

evaporite outcrops of Gradishte e vogël, Veleshica and Grama stream, partly on its northern slope, up to Maja e Pelpanikut, where exit the evaporate small stream and the river Veleshica Grama, mainly on its northern slope, near up the top of Pelpaniku. Such phenomena are observed also in carbonate rocks. They have magnificent views (see Figs. 5, 6 and 7).

Figure 6. Karst phenomena in Evaporites, Vrenjt.

Figure 7. Karst phenomena in carbonatic rocks.

Key words: *Dibra District, Geomonument (geological site), glacial lakes, evaporate domes*

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Divjaka-Karavasta Geopark (Albania)

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Abstract

Divjakë-Karavasta geopark is situated in the central part of Western Region along with Adriatic Sea coast, between Shkumbini River mouth north, and Semani River mouth south, of about 40 km west of Lushnja City. The Divjakë-Karavasta geopark with a surface of 22,230.2 Ha, is the largest costal complex in Albania, made of four lagoons with a total surface of approximately 5,000 ha of sandy dunes, river delta and Mediterranean Pine forests. Karavasta Lagoon and Divjaka Pine Forest constitute the most interesting ecosystem of our country and one of the most important ecosystems all over Mediterranean. They were proclaimed under the protection since 1958 by Albanian Government, while on 1975, Karavasta Lagoon together with Divjaka forest were included in Ramsar Convention, and proclaimed as ecosystems of specific importance because of its colony of globally threatened Dalmatian pelicans.

On 22 August 1994, according the Decision Nr. 413 of the CM, the ecosystem of Karavasta Lagoon and Divjaka Park were declared as a site to be included in “The List of Wetlands of International Importance” established by the Ramsar Convention. By acceding to the Convention on Wetlands of International Importance especially as Waterfowl Habitat, Albania agreed to maintain the ecological character of this site.

Divjakë-Karavasta lagoon and pine forest provide the special conditions for accommodation of a number of plant communities and animal species, among which many of them are at risk of extinction in the world. We can mention here Dalmatian Pelican (Pelecanus crispus). The lagoons provide living conditions and breeding sites above the 5% of the world population of this bird. The islands in the lagoon are one of the most important features of the area for the conservation of birds. Although in the past, the Dalmatian pelicans have nested in other parts of the lagoon, now they only nest on these islands, owning to disturbance elsewhere. In addition, many of the other important breeding birds of the lagoon nest on the island because they are safe from predators and human disturbance. These include Collared Pratincole (Glareola pratincola) and Little Tern (Sterna albifrons).

The coastal temporary water bodies and permanent lagoons are surrounded by open salt marshes and dune grasslands of different type, representing different early stages in the vegetation succession from bare sandy beaches to reed beds, scrub and woodland. These transition zones provide the habitat for several bird species (more than 200), including Stone Curlew (Burhinus oedicnemus), Collared Pratincole (Glareola pratincola), Pygmy comorant (Phalacroocorax pygmaeus), Kentish Plover (Charadrius alexandrinus), Calandra Lark (Melanocorypha calandra), Yellow Wagtail (Motacilla flava feldeggi) and the occasional observation of individual Otters (Lutra lutra). The most notable fauna species living in the forest habitats are, for their rarity or restricted distribution, Roe Deer (Capreolus europaeus), Horseshoe Bat (Rhinolophus ferrumequinum), European Nightjar (Caprimulgus europaeus), Syrian Woodpecker (Dendrocopos syriacus), and Herrmann’s Tortoise (Testudo hemanni).

The Divjakë-Karavasta area is also well known for the presence of a number of geological sites of national importance. Geological sites are very important for birds nesting. Along with the sea coast and inside the lagoon there are formed a lot of fiords, sea bays, small island and peninsula, where are living colonies of different kinds of birds and flows. We can mention here Pelican Island and Kulari Island. Some other geosites there are Divjaka sandy dunes, Oasis and the new Karavasta Lagoon Littoral Braid. The presence of these geological sites of national importance is a reason why we are of the opinion that Karavasta Lagoon and Divjakas Forest represent an important geopark.

Karavasta Lagoon and Divjaka Forest are visited every year by a lot of explorers, mainly biologists, geographers, geoscientists, while during the summer, the Divjaka beach, becomes a resort.

Keywords: *geopark, gelogical site, biodiversity, geotourism*

Glacial Lakes of Bulqiza and Lura ultramafic massifs, an impressive natural heritage

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Abstract

The lacustrine system is one of the most important elements of the hydrographic network of Albania. There are more than 247 natural lakes of different types and sizes, distributed all over the territory of the country. In Albania, the total area occupied by the lakes is of about 460 km^2. Based on genetic criterion, these lakes can be divided in four groups: tectonic, glacial, karstic, and fluvial lakes.
The glacial lakes in Albania were formed during the glacial period of WURM, when the glaciers, descending slowly on the slopes of the high mountains have created the glacial circuses. This has been more evident for the northernmost areas of Albania where most of the glacial lakes occur. The geology of the areas where glacial lakes lie consists of magmatic, ophiolite rocks. In Albania there are known 134 glacial lakesthat occur as individual groups consisting of 10 to 22 lakes, at the heights 1600-1800 m above the sea level. Generally, glacial lakes are of small sizes and are very similar to each other. The glacial lakes of Bulqiza and Lura ultramafic massif are among the most beautiful ones.
These glacial lakes lie on the glacial deposits that cover the ultramafic rocks of Bulqiza and Lura massifs.
The erosional-denudation relief predominates t the elevations up to 1600-1700 m and the frozen glacial lake lakeat highest elevations. The glacial deposits consists of coarse clastic deposits of ultramafic rocks of size up to several m^3, highly rounded within a silty-gravel matrix. These deposits are 10-20 m thick. They are easily percolated by ground and underground waters, shown by numerous watersprings that flow underneath their bottom and within them.
Bulqiza and Lura glacial lakes are located at the elevations from 1650 m to 1900 m above the sea level. Balgjaj Mountain has the highest number of glacial circuses and lakes in Albania. There are 5 big circuses with diameter 2 km to 2.5 km, where 22 glacial lakes lie. A part of them is full of water during all the seasons of the year. Liqeni i Zi (Black Lake), at the northern flank of Lopa mountain, at 1800 m above the sea level, of surface 45 ha, is another glacial lake within a complex circus 400m long, 200 m wide and 60 m deep. It is surrounded by pine and beech forests.
The group of the glacial lakes placed on Lura ultramafic massif are known under the term “Liqenjte e Lures” (“Lura lakes”). Lura lakes are a group of glacial lakes that lie on the eastern slope of Kunora e Lures mountain, about 1500-1600 m above the sea level. In total,they occupy an area of about 100 ha: Liqeni i Madh is of about 32 ha, 425 m long and 300 m wide, being the biggest lake in this area.
The glacial lakes of Bulqiza and Lura are distinguished for their cold waters and their high clearness, blue and dark color. They are surrounded by pine and beech forests having various fauna and flora and offer a picturesque landscape of a distinguished natural beauty. Numerous torrents flow from the circuses and lakes running through the mountains slopes being continuously fed by the waters of these lakes. The regime of these lakes is of Alpine type with slight frequencies of their level during the different months of the year. The water of these lakes is supplied by snowfall, rainfall, ices and underground waters during the winter that percolate the fissures of the ultramafic rocks. These lakes are of scientific, hydrogeological, biological, ecological, aesthetical, didactic and geotourist values. All these lakes are accessible by roads.

Key words: *Glacial lakes, Bulqiza and Lura ultramafic massifs*

Guri i Gradinës – Geomonument with natural value

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Abstract

Drenas Municipality territory is located in the central part of Republic of Kosovo and is rich in metallic ores and non-metallic mineral resources, but the geo-heritage of this area has not attracted too much the interest of the experts or institutions. The Municipal Assembly of Drenas according to the proposal of the Ministry of Environment and Spatial Planning dated 23.02.2006 with No. 14/2006, accepted the decision to protect the facilities of the natural values in the territory of Drenas Municipality on date 09.05.2006. Guri i Gradinës (Gradina Stone) is also included in this decision.

The Guri i Gradinës it is located in the surrounding environment of Llapushnik Village. and due to its strategic position on the top of a very sharp hill it can be easily protected. Guri i Gradinës in the southeast, east, north and northwest parts is surrounded by Drenica plane. It is connected by a mountain neck with the southwest part with Drenica Mountains. The toponymy shows names as as: Gradina or Town prison, named after the place where it was assumed that once was the prison of a castle, Kroni i Gradinës, Oda e Gradinës, Rrezja e Gradinës, Shkëmbi i Gradinës etc. 300 meters away is is situated the placed called Kulla, where foundations of old houses still exist. The position, form and size of Guri i Gradinës give it a magnificent and very attractive view.

Except natural values, this complex is also known also for its archaeological and historical values.

According to historical records, Guri i Gradinës was an ancient Illyrian fortress, the bronze coins, different vessels and tools testify this fact. . Also today, some parts of Guri i Gradinës have special denominations such as: Oda, Sofra, etc.

Historical values of Guri i Gradinës are closely related with the Kosovo Liberation Army war. Since the beginning of the war in Kosovo, Guri Gradinës was a fortification and a very important strategic point of Kosovo Liberation Army. During 1999, where 100 thousand inhabitants from different places of Kosovo were sheltered in Berisha Mountain, many battles have occurred in Guri i Gradinës to protect this strategic point. Five martyrs have died heroically and many members of KLA were wounded to protect this position.

Guri i Gradinës is over 30 m height and over 100 m wide.

Perhaps there is no risk for the natural framework of Guri i Gradines, but the historical and archaeological values may be in danger.

Key words: *Kosovo, Guri Gadines (Gadine Stone)*

Narta Wetlands and its Ecotourist Potentials

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Abstract

Vlora region is well known for its underwater riches. Part of this region is Narta wetland, which is placed in the southernmost point of the coastal lowland, near Vlora City. The coast of Vlora Bay is characterized by a unique ecosystem of different species of plants and animals, which represent a special reserve for the Adriatic and Ionian Seas. Narta Lagoon and Zvereci beach are placed in southernmost part of the Adriatic Sea. Narta Lagoon is formed north of Narta Village and continues north up to the Vjosa River mouth. In Narta Lagoon is situated the Zverneci Island covered by a nice pine forest. Here there are two old monasteries. The traces of this old settlement are recorded since the first century BC. Narta lagoon during the winter connect with the sea, while during the dry summers, in the southern part, is going to be dry, outcropping its clay bottom. This lagoon is rounded by vegetation, the high pine forest and the monastery on the top, are giving an aesthetic view. The whole landscape creates a beautiful natural ensemble, full of contrasts, where we can find beauty, harmony and peace. The whole area with the wetland and the sea make up an attractive and interesting ecosystem for the tourists. Narta Lagoon is an important fishing centre in Albania. In the waters of this wetland there are found different kinds of sea fish like mullets, skates etc.

Next to Narta Lagoon, in Adriatic seaside it is located Zverneci site. Here, outcrops molassic formation of Miocene age, full of sedimentological features Sandstone beds, more resistand against sea waves have formed typically ridges along the seaside. Amongst the sedimentologial features, just as footprints, there are seen a lot of concretions of rounded form. This geosite has complex scientific and didactic values. The above sandstone landscape, is located just at the foot of Zverneci native, sandy beach.

The dunes have scientific, geomorphologic, aesthetic, tourist and economical values. Of great interest for a visit are the Narta Dunes situated in the western part of the wetland in the sandy part, which separates the lagoon from the sea. The length of this system of dunes reaches some km up to Poro. With all these specific hydrological characteristics in more than one case it has problems with the pollution. The salinity of its waters is determined by the climatic regime of the area and its reaches even higher values in the eastern, northern and southern regions.

Narta Lagoon and Zverneci geosites constitute together an interesting seaside geopark.

The aim of this study is the evaluation of the quality of the waters and the environmental condition of the Narta wetland and the surroundings.

To preserve this area and its natural wealth a special interest has to be shown from the central and local government as well as different environmental organizations and the local community.

According DCM Nr. 680, dt. 22.10.2004 the coast area from Vjosa mouth north up to soda forest south (19,738 ha), is proclaimed under the protection in A1 Group of protected areas.

Keywords: *Vlora, Narta Wetland, ecotourist potential, ecosystem*

Management and tourism development of monuments of nature along the coastal area in Albania

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Abstract

Albanian coastline with a length of 427 km is washed the waters of the Adriatic and Ionian seas, which are distinguished for a variety of physical and geographical features.In particular, this coastal area also shows a variety of: geomonuments (Geological sites), hydromonuments and biomonuments having high scientific, aesthetic, economic and tourist values. Along these coasts, were counted 75 different entities, or 10 %, of the total of the total inventory of the Albanian natural monuments.

Along the coastal area, among the most important monuments of tourist and economic values we can mention:

The General's Beach, in Kavaja region, which is featured for having the highest values, not only for balneary tourism, this spectacular beach offering facilities for diving sports enthusiasts. It should be noted that this is the only habitat of water turtles in.

The Pelican Island is another monument of nature of great importance and is located in Karavasta Lagoon, next to Divjaka pine Forest, of about 0.5 m above the sea level. It is an interesting island created by the accumulation of organic waste and represents an important and interesting geoecosystem which is distinguished by a rich world of herbaceous plants and by the presence of te curly pelican, that make this place special and unique not only in Divjaka, but along the whole coastal area.

Also of special importance is the Pirates Cave, a natural monument of great turist value situated in the Ionian rocky seaside. In the case of this geological site, the crucial role is played by the karst process that created this cave.

The presence of above mentioned natural monuments and many others also adds to the coastal area more tourists values and enriches tourist guides and tours.

The natural, scientific, educational and cultural values of these monuments of the coastal zone are still unknown and not frequented by many tourists and this is due to a poor promotion of their values and a poor infrastructure. Despite this, the list of monuments of nature has been increasing year by year, and a part of them is being damaged in recent years, as a result of indiscriminate and uncontrolled intervention of human being.

The purpose of this paper is to identify scientific and tourist values of these natural monuments in the Albanian coastal area, as well as their involvement in any tourist guide through an effective management.

Keywords: *Management, coastal area, natural monument, geoecotourism, tourist guide*

Geotourism in the Prespa-Ohrid Cross-Border Region – it's potential for development on the Albanian part

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Abstract

The Prespa-Ohrid area is stretched out across the border between Macedonia, Greece and Albania. On the Albanian side of the border, the region is divided naturally into two distinct parts:
-The National Park of Prespa; -Protected Landscape around Ohrid-Pogradeci Lake, in accordance with the legislation on protected areas in Albania.
The heritage value of these areas consists in both, their geodiversity and biological diversity, and in the many cultural sites in the region. These protected areas are also remarkable for their impressive geological sites the processes of geomorphologic evolution, karst processes and the spectacular lakes. The geological sites have been duly identified and classified as a distinct category in the overall list of features that constitute the natural heritage of the region. However, they do not feature prominently on tourist guides and are barely mentioned in the course of daily transactions.
The aim of this presentatiom is to explore the potential of the geological sites in serving as a basis for the promotion of geotourism in the Prespa-Ohrid region. While the protected status of these areas is conducive to the development of tourist activities, the geosites, whether located in the center of the region or in the outlying periphery, can become a very interesting attraction for tourists. It is incumbent in a country that has chosen the development of tourism as a national priority to fully exploit the commercial value of all its resources, including geoheritage. The geological sites of the Prespa-Ohrid region, situated in a cross-border region, represent a rich complexity of values which no strategy aiming at the development of tourism in Albania can afford to ignore.
The conclusions presented here are based on our scientific argumentation of their tourist values and on the results of a questionnaire on the knowledge and expectations that the members of the local community have about the geological sites in their region.
We have also made use of special interviews with specialists in GIS for their gjeoinformation.
Besides serving to heighten the awareness of tourists and large community on the value of geological sites, it is hoped that the results presented in this study will be of some use to the local authorities in drawing up their plans for the development of the Prespa-Ohrid region.
They could also be used by tour operators as a sound reliable basis for the marketing of their services.

Key words: *Prespa-Ohrid Cross-border region, geological sites, geotourism, sustainable development*

Komani Area, a Spectacular Geological and Historical Site of Northern Albania

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Abstract

Komani area is located in the middle part of Drini River Valley; just at the foot of the Albanian Alps. The following features make this area very interesting:

Landscapes, canyons, gorges, clean waters, diversity of geological formations with different types and very well expressed folds, dams constructed in very mountainous terrains, artificial lakes, hospitality of people living in this region, mineral and water recourses, specific biodiversity, historic values of this region etc.

From the geological point of view, in this area outcrop formations of both Mirdita tectonic unit, composed of ophiolite complex and Krasta-Cukali tectonic unit, composed by carbonate and flysch formations. The Krasta-Cukali formations display spectacular mosaics created by the alternation of variable colors of thin bedded limestone, cherts and flysch formations, which in addition are intensively folded. Such mosaics are really fascinating in Komani village. Just close to Komani passes a very important regional tectonic zone, known as Shkoder-Peja (Scutari-Pec) lineament. Several mineralizations including rare ones as dawsonite are encountered through this tectonic lineament in Komani area.

Not far from Komani is located Kçira holotype of Ammonites with five families, nine genera and forty nine new species discovered for the first time by great geologist Franz Nopcsa in the first quarter of twentieth century.

Three dams constructed one by one at a distance of not more than 60 km (Vau i Dejes, Komani and Fierza, respectively 58 m, 131 m and 180 m high), have created three artificial lakes. Artificial lakes (Vau i Dejes, Komani and Fierza) occupy respectively 27.4 km^2, 14 km^2 and 73 km^2 and containing respectively about 580 million m^3, 450 million m^3 and 2,5 billion m^3 water.

Except for the important impact of these lakes for improving of the natural equilibrium, three hydropower stations related to these lakes are of a great importance for economy of Albania. They produce over than 80% of the total electrical energy of Albania. Komani hydropower station, the biggest in Albania is constructed just at the narrowest gorge of Drini River and just here the best rock mosaics, rarely seen another place, are exposed.

Komani area is at the same time very specific concerning the history.

The archeological objects discovered in the Komani tumes, belonging the 6th –7th century, were not found at any other place, so scientists named the Komani old civilization ruins as the Komani Culture. Here are also the ruins of Dalmatian castle.

Only about 7 km west of Komani, Shurdhahu castle built during the Middle Ages is located in a small island of Vau i Dejes Lake. Shurdhahu sector is also known as the place of one hundred churches and one hundred crosses.

Several caves as Cukali, Levrushku Buzhala etc., were shelters for Christians during ottoman occupation in medieval time. Those caves have specific names as Cave of Christian, Cave of Kolika, and Cave of Friars etc.

Unified inventory of geomonuments in Albania

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Abstract

Fossils, rocks, mining sources or geomorphology are an integral part of nature that's why they require the attention of the community as a whole, but in a particular way, it requires the attention of geologists who are closer to these objects or phenomena.

Similar to archives in a library which keep the human history documentation, geological sites (geomonuments) are natural "documents" that need to be safeguarded, protected and inherited to the future generations, in order for them to know and understand the way of the Earth, where they live, is formed.

Many studies on geomonuments are made from different authors in Albania, among them Albanian Geological Survey (AGS) and ProGEO – Albania is played an important role. Until now, only an official document exists: DCM no 676, 20.12.2002, which lists in total 669 areas considered as natural monuments of Albania. In this list, in comparison to the first inventory of geological sites of Albania (Serjani A., et al.), only a few of them are included as natural monuments. Also, this document does not contain the classification of the natural monuments (biodiversity and geodiversity), there is not an assessment on the scale of importance which they represent and not for all the protected areas are defined boundaries with coordinates. The UNESCO resolution of Barcelona Congress (October, 2008) underlines that geodiversity should be listed together with the biodiversity. Starting from this resolution, besides the biodiversity, the efforts toward the official recognition and geodiversity protection should be materialized.

Within the context of sustainable management of natural resources, has been proposed a project aiming the reassessment of geological heritage in compliance with the European directives and guidelines, as part of general management of natural resources as well as the set-up of the unified inventory, officially recognized by the relevant state authorities. For this reason, the new lists of geomonuments divided by districts are being revised and reformulated with reference to the existing lists; new previously unidentified geomonuments are being listed in addition, as well as maps of geological sites of 1:100,000 for each district are being prepared.

In Albania, several forest parks are declared as national as well as some biodiversity reserves. Generally, national parks and reserves are proclaimed based on the criterion of rarity of forests, flora, fauna, thus of the biodiversity. We have tried to take in consideration the formation and geomorphology aspect of the proclaimed park, because in the majority of cases forest parks have a picturesque geomorphology, which constitute geological site. At the same time, we have considered the fact that inside of forest parks are "hidden" important geomonuments, of extraordinary value, and we are aiming that the concept of "geo-park" to be included as a term in the environmental legislation.

Natural heritage, geomonuments and geoparks, have begun to be active with the development of geotourism in Valbona, Thethi, Dajti, Llogara, Çajupi etc. In some areas, they are being integrated with the cultural heritage of the country. With the support of central and local state authorities, some of the geoparks of the country could be prepared, in order to be completed with management plans and infrastructure with the goal of their integration in European Geoparks Network.

Based on the genetic classification and the values group of geotourism, didactical and historical, for each district, has been made the classification and grouping in regional and international geosites. Starting from this classification and grouping, the lists of geo-monuments and geoparks are compiled, and also their digital inventory has been integrated in a database. Another objective of this project has been also the creation of an interface to facilitate the geosites data capture and the digital inventory creation. It is indispensable to put geotourist signs nest to geosites and in geoparks. Besides in Vlora, Tropoja, Bulqiza, Tirana that will be a good initiative to establish so called "Open Geomuseum", as an efficient way for encouragement and promote geoecotourism.

Keywords: *geomonument (geological site), inventory, geopark*

Geotopes - Geoparks in Greece, Contribution to the Sustainable development

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Abstract

The geotopes compose the geological history of each region. The geotopes are the "books of the Earth". In every area of our planet are geological sites, named "geotopes", which inform us the story of Earth in the mentioned region.

Perhaps here the question arises how many sites are characterized as "geotopes" that we must maintain sites which consist "geological heritage" forming the geological history of each one of these sites, telling a small snapshot or greater than the long history of the earth. The geotopes is a dynamic concept and it is the educational, informative material. The interpretation thus is a crucial concept to showcase geotopes, conservation and management.

Something similar happens with Geoparks, under some further conditions, which will analyze the definition of Geoparks. In other words, geotopes and geoparks include in their definition, not only the geological and geomorphological element found in nature, but also the interpretation, for protecting and conserving them.

Our country due to its location, in the convergence space of two tectonic plates have a variety of geological formations, landforms, geological processes of past or "nascent" threat are of particular scientific or educational interest. On the other hand many of them have high cultural and tourist value. So both need to record and preserve the scientific, educational, environmental value, secondly to highlight many areas with conditions and potential for creation and promotion geotrails, thematic networks, geotopes alternative proposals for tourism, and geoparks. The interpretation of the geological history of each is related to development and the environmental, tourism and cultural affairs.

The Registry of geotopes currently under construction will function as a source of information for every use: Public or private sector projects in national and international level, for the development, planning and conservation of nature, environmental education, and for tourism and geotourism.

Development and management proposals for geoparks in selected areas could be implemented by the local councils or other relevant entities, providing social and economic benefits to local communities.

Creating the right products will result in the designation of the geological heritage and the establishment of new forms of alternative geotourism, a modern tourism trend for the social and economic development of each region.

Designating geotopes will also have a positive impact on the awareness and knowledge of geological history at all levels of education, in our country and internationally.

Karst geosystems in Hasi transboundary region and their Geotourist Values

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Abstract

In Hasi transboundary region, the presence of the limestone and the development of the karst processes have made possible the formation of the karts geo-ecosystems. In this region there are shown in the initial forms karst caves, furrows, grooves up to uvala with different dimensions. The under ground karst geoecosystems are widespread in form of tunnels, galleries and karst caves. Amongst the karst caves we can name here the Pigeons cave, the cave with the yard, the cave that sounds. All above mentioned caves there are considered as natural monuments (geological sites). Karst ecosystems are interesting and vary along with their components, carrying a range of scientific, practical and touristic values. The presence of the karst geoecosystems in the Hasi transboundary region composes a very important potential for the development of geoecotourism.

Key words: *Hasi Region, karst geoecosystems, carbonates formation, geoecotourism*

1. Geology

In the Hasi area, the karst geoecosystems are associated with the presence of carbonate formations of the Lower Cretaceous age). Carbonate rocks cover the entire plateau of Hasi ranging from the White Drin River in the south, to the northeast village of Cahan and continuing beyond to the territory of Kosovo. In the limestone rocks of Hasi-Kruma Mountain, there are developed surface and underground karst geoecosystems. All carbonate massif is placed on the ultra basic rocks. Their thickness varies, reaching the greater thickness on the top of Pashtrik Mountain (1989 m), where it increases from 400 to 500 m SW to 800-1000 m to NE.

The large developing of karst processes in this region is related to the new tectonic movements, to the tectonic faults of White Drini and Kruma, and by the syncline structure of carbonate rocks. Surrounding magmatic rocks, serve as a screen for water retention, which resulted in intensive development of karst phenomena and formation of geological sites of karst origin.

2. Karst and karst geoecosystems of the region

The karst in this plateau is generally young and has generated some interesting contrasts in relief. Karst phenomena have led to the formation of a myriad of forms to the size of uvala. Karst forms between the tip of Tregtan, Domaj and town (southwest half of the plateau) have rich forest cover of oak and beech which gives to it a unique natural beauty.

There are also historical and cultural values, as in the top of the citadel, where are traces of an ancient settlement. While in the hinterland, the plateau is characterized by steep slopes, constituted by limestone rocks, and associated with tectonic faults. The largest development of the karst landscape in this sector is among the top of the Kruma Mountain and the Pashtriku Mountain. Karst forms primarily, there are created by the dissolution. In karst forms predominate funnel ellipse - shaped of 25-60 m in diameter and 2-7 m in depth, while the dolina are 80-200 m in diameter and 20-35 m in depth. The Dolina and funnel groups that do extend between the top of the citadel and Domaj form a typically elliptical Uvala with a length up to 4.7 km and 1.5 km wide. In the north plateau and the top of the citadel extends a typical landscape in the evolution of which has affected the Gjinaj and Leshnica rivers.

The largest development of the karst landscape may be found in between the top of the citadel and Pashtrik. The funnels and the dolinas here are grouped into two major Uvalas, the one of Kruma Mountain and Cahan. The last one is at the same time the largest and most developed uvala of the karst plateau of Hasi.

In the entire surface of carbonate rocks there are formed some karst geological sites, which fully form a karst geo-ecosystem of considerable size. Besides the largest karst area in the upper level, there are formed many caves and karst water springs, some of which will be described in the following paragraph.

3. Description of the karst geo monuments of Has

The karst field and the top of the Coast plateau (1 308 m) to the east of Cahan

Geomorphologic geosite of karst origin. Karst is an elongated area from south to north in the shallow water Lower Cretaceous limestone. In this area, except karst forms of small size, there are also formed many karst pits and hoppers of large size up to 1km length and width of 300-500 m. They have an oval shape.

The pigeons cave Karst geological site

Situated at an altitude above 1,300 m, near the border crossing of White Stone in the Pashtrik Mountain. it belongs to Vlahën village, Golaj comune and Hasi district. It constitutes a karst cave formed in the upper limestone on the Ridge. It is of about 30 m long, up to 11 m wide, and 5 m high. Different birds spend the night in, but more wild pigeons, according whom it are named. The cave has numerous concretions of scientific values: geological, geomorphologic, didactic, ecological and cultural. It can be visited following the rural road from the town of Kruma – Vlahën village - border points of White Stone.

The cave with the yard

It is situated in the Kruma affinities, Has district, of about 700 m above the sea level. It constitutes a karst cave formed in the upper limestone of Ridge. It continues with galleries over 40 m long, up to 5 m wide and 10 m high. The cave is not yet fully explored. It has multiple concretions of scientific values. It can be visited following the rural road from Kukes to the town of Kruma.

The cave that sounds

It is situated in the village of Vranisht, the municipality of Fajzë in the district of Has, up to 600 m above the sea level. It constitutes a karst cave formed in the upper limestone of Ridge. It begins with a well in which sound the stones thrown inside it. Then it continues with the galleries over 50 m long, up to 20 m wide and 15 m high. The cave is not yet fully explored. It has multiple concretions of scientific value. It can be visited following the rural road from the town of Kruma - Village Vranisht.

Vranishti fountain is damaged as it is cemented and has lost its values.

Kruma water spring (Hydro monument)

It is situated in the southeastern part of the city of Krumë, at height 480 m above the sea level. It constitutes the major water source of karstic origin, which appears in the contact, between the Upper Cretaceous limestone Ridge and the Quaternary cover. The feeds are of 600 l/sec, and waters clear and cold. It creates a more attractive environment. It can be easily visited following the itinerary from the city of Kukes - the town of Kruma.

Domajve water fountain. (Hydro monument)

It is situated near the village of the same name, the Gjinaj municipality of Has district, at 400 m height above the sea level. It constitutes a huge source of karst, resulting in tectonic contact - karst limestone and terrigenous ridge. There are feeds over 300 l/sec of clean and cold water. It creates a more attractive environment. It can be visited following the rural road from the town of Kruma - Village Domaj.

The Brudi springs

They are occupied by the waters of the artificial lake of Fierza.

Conclusions and recommendations

The karst ecosystems are interesting and vary along with their components carrying a variety of scientific geo tourist and practice values.

The karst geoecosystems are rich in monuments and form special landscapes. They are attractive, with particular forms of relief and living world making different the nature of the region.

They offer great opportunities for building an attractive tourism infrastructure, regarding this should be carried out more detailed geological and geo morphological studies as in this region are quite incomplete.

The underground karst geoecosystems (caves, galleries) have a set of values not only natural, but they have served as dwellings of our ancestors (Pigeon Cave) with great historical value and quite attractive. The multiple forms of stalactites and stalagmites as caves, columns, and walls veils etc. surprises and amazes with their rare beauty posing a tourist attraction.

More detailed studies for detection of geo karst ecosystems since most of them are still unexplored (Dajani caves, Shepherd's well etc.).

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Geotourism potential in Slovenian Istria (SW Slovenia) – introducing rock shelters in the area as potential geosites

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Abstract

The most impressive landforms (caves, canyons, waterfalls etc.) will always be attractive to visitors. That is why they can play an important role in development of geotourism in areas where they are located. As geotourism follows a concept of sustainable tourism, it encourages synergy between tourist development and conservation of valuable natural features. Slovenian Istria is known for being a region where rock shelters (or abris) occur. These are shallow cave-like openings, formed mostly in the lower parts of rockwalls/cliffs. Rock shelters are for most of the people impressive landforms, therefore, our aim is, by means of more detailed research of rock shelters, to attach greater importance to them so they can be recognized not only as valuable natural features but also as geosites in a geomorphological and structural aspect. As geosites they can play a role in development of geotourism in Slovenian Istria.

Most of the rock shelters are a part of a larger area Kraški rob (Karst Edge), which represents an area with more than 40 limestone rockwalls. Rockwalls, where rock shelters occur (Veli Badin, Štrkljevica and Mišja peč), are just some of them. Kraški rob is unique in Slovenia by its geomorphological, geological, and biological characteristics. It is also in a process to become a protected natural area. For now, it is defined only as an important ecological area. Limestone rockwalls, where rock shelters occur, were already recognized among environmental authorities as a part of natural heritage. Veli Badin and Štrkljevica are classified on the list of valuable natural features as of national importance and therefore protected by the national authorities. There is also one valuable natural feature of local importance protected by local community – a rock shelter in Mišja peč. Despite the fact limestone rockwalls are important because of their geological and geomorphological value, the emphasis of protection is given on habitats of different animal and plant species (southern part of Kraški rob is also Natura 2000 area). The same is with another example – the limestone hill with rock shelter Stena in Dragonja Valley which is classified as a natural monument, but its values are again not recognized as geological or geomorphological but only as botanical and zoological.

Besides the importance of limestone rockwalls and rock shelters as habitats for protected species, there are many reasons why rock shelters should be identified as geosites and can be promoted in the field of geotourism. Their formation is related to geological events which had a great impact on the area on a larger scale. Most of the rock shelters occur in the contact betweenAdriatic-Apulian foreland and External Dinarides. Subthrusting of the Adriatic-Apulian foreland underneath External Dinarides resulted in a specific landscape (a series of geomorphological steps) where weathering more resistant Eocene alveoline-numulite limestones are thrust on less resistant Eocene flysch. Rock shelters occur on the contact of two limestone layers. The research of exact mechanisms of their formation is still in progress, but main factors seem to be lithologic and tectonic features (small thrust, fold) of limestone rock, which is transformed by geomorphological processes, e.g. freeze-thaw weathering and corrosion. Another thing that makes rock shelters in Slovenian Istria special are numerous tufa formations on their inner walls and roofs. Because of their shape they were mistakenly described as speleothems (stalactites, flowstone ribs, draperies) by many researchers in the past. Detailed research of tufa formations is currently underway and the results will also be used for raising awareness of rock shelters' importance as geosites among people. And there are other positive results new discoveries about rock shelters will bring – they will encourage environmental authorities to revive previous efforts for establishing protected areas in Slovenian Istria.

A Possible Stratotype of the Oligocene-Middle Miocene Molasse of the Albanian-Thessalian Basin in Drenove Geopark.

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Abstract

The Oligocene-Middle Miocene molassic sediments of the Morave Mt. represent the complete and the best continouosly exposed stratigraphic section belonging to Rupelian and Langhian stages within the Albanian-Thessalian Basin, an intramontane marine basin of very high subsidance and strongly controlled by tectonic activity. These sediments holds several geological-morphological units as the Oligocene erosional cyrcus, Aquitanian formations of Guri i Capit, Burdigalian Lithothamnium limestones, Langhian blue marls that may represents a particular stratigraphical and geomorphological sites of regional importance located in Drenove Geopark.

Key words: *Oligocene-Middle Miocene, Albanian-Thessalian Basin, Albania*

Introduction

In the Morave Mountain area, the very thick section of approximately 3700 m represented by mostly Oligocene-Middle Miocene marine molasses was formed in the Albanian-Thessalian Basin (ATHB), a prolongated narrow of an intramontane marine piggyback basin trending NW-SE from southeastern Albania to the Thessalian Plain in Greece. At beginning of the Eocene, the Albanian-Thessalian Basin has been part of Tethys, a Paleogene – Miocene relatively vast isolated ocean basin having its own paleogeographic and sedimentologic conditions, characterized by extensive *coral reefs*, *mollusks*, large *foraminifera*. This basin was spread from Paris Basin through the Alps, Northern Italy, and Albania and from Greece to Iran and Pakistan. It was controlled by a strong tectonic activity and characterized by a very high subsidence that continued up to Langhian time. Having an important economic potential because of lignite seams, the biostratigraphy of the Oligocene-Early Miocene molasses has been subject of detailed and advanced studies, mostly conducted during the late 20 century: Bourcart (1922; mollusks and corals), Pasko et al. (1973) and Pasko (1977) (mollusks and foraminifera), Kumati et al. (1995; foraminifera and nannoplancton), Marku (2000; mollusks and corals), Kleinholter (2004; plant fossils). Four cross-sections have been studied in the Morave Mountain, the stratigraphic sections representing the most outstanding and continouosly exposed Rupelian-Langhian sequences and holds several sites with high geological value. The main morphological unit is represented by the Oligocene erosional cirque with Rupelian coral reefal limestones, Aquitanian deposits belonging to Guri i Capit, Burdigalian Lithothamnium limestones and Langhian bluish marls, representing particular stratigraphical and geomorphological sites of regional importance, located in Drenove Leopard.

Description of the section

Oligocene-Lower Miocene molasses cycle. Oligocene. The Oligocene sequence has a thickness of about 650 m and transgresively lies on the ophiolitic basement. According to the macro- and micro fauna content represented by *mollusks*, *foraminifera* and *nannoplancton*, were dated the Rupelian and Chattian stages.

The **Rupelian stage** consists of a thick litho logically remarkable sedimentary sequence of about 345 m in thickness, rich in *mollusks*, *corals*, *echinoderms*, small and large *foraminifera*. This sequence can be divided into several formations.

Mborje Conglomerate Formation represents a continental basal conglomerate (fan deposits) up to 25 m in thickness and consists of ofiolitic conglomerates and coarse-grained sandstones. To Mali i Kuq, this formation is characterized by the appearance of a limestone pebble within redish sandstones reaching a thickness up to 80-90 m.

Drenove Lignite Formation represents a coastal brackish-shallow marine sequence (Mangrove facies) of about 86 m thick and consists of intercalations of grey marls, dolomite strata and up to five lignite or coal clayey-marly seams. In the

Drenica section, the lower part of this formation starts with grey marls and siltstones of about 22 m thick with intercalations of dolomite strata (0.2-0.3 m) and two lignite seams, (B of 0.9 and A of 2 m, respectively). The macrofauna content is represented by *Cyrena sirena strangulata*, *Ostrea cyathula* and plant fossils. This sequence is followed by a succesion of about 65m of marls with intercalattions of dolomite strata (0.2-0.3 m) and scarce lignite seams (C lignite layers) that is overlied by a 0.5 m of greyish-blueish laminated limestone with *Dreissena sp.*, and rich in brackish species as *Melanopsis impressa* and marine eurihaline molluscs as *Potamides stampinensis, Pirenella plicata galeoti*, *Tympanotonus margaritaceus, Ampullinopsis crassatina, Cordiopsis incrassata, Cyrena sirena strangulata, Barbatia albanica*, *Ostrea cyathula* etc. In the uppermost part of succession, the nannoplankton data show the *Sphenolithus distentus* Zone

Drenice Coral Formation represented by shallow marine sediments of 178-200 m in thickness, rich in marine mollusks and coral and mainly consisting of massive sandstones, occasionally calcareous, grey marls, conglomeratic lenses and horizons with corals, coral reefs or reefal limestones from 4-5 m to 50-70 m thick. The sequence begins with a succession of 50.5 m of sandstone and conglomerate lenses and is very abundant in shallow marine mollusks: *Turritella magnasperula*, *T. conofasciata, Tympanotonos margaritaceus, A. crassatina, Cyrena sirena strangulata,* corals and echinoderms and followed by carbonaceous sandstones and limestones laterraly passing onto coral reef facies. It also contain two horizons with *Nummulites fichteli* and is covered by a thick gray massive sandstone of about 82 m in thickness, with conglomerate lenses and a rich macro fauna represented by marine mollusks such as *Tectus lucasianus*, *Cerithium pupoides*, *Turritella strangulata*, *T. magnasperula, Natica auriculata, Strombus radix, Ficus conditus, Athleta ficulina, Conus ineditus, Megaxinus deperditus, Cardium fallax, Laevicardium anomalum, Venus aglaurae, Pecten hofmanni, Pholadomya puschi, Panope menardi, Corbula carinata oligolaevis, Nautilus decipiens* etc., irregular echinoderms and *Juglans* (fruits). It was signaled a scarce micro fauna with micro foraminifera, larger foraminifera (*Lepidocyclina)* and nannoplankton belonging to *Sphenolithus distentus* Zone. The sandstones and sandy clays of about 345 m thick from the uppermost part of the formation are rich in *Corbula carinata oligolaevis*, *Operculina complanata* and pass onto massive sandstones (6 m thickness) with scarce specimens of *A. crassatina, Cardium fallax, Pitar beyrichi*. The dominating macro- and micro fauna is typical to littoral-shallow sub littoral settings, indicating tropical-subtropical conditions.

The **Chattian** deposits up to 300 m thick are representated by *Chama* Marls, and Plase Fm.

The *Chama* Marls are represented by grey to blueish marls with a thickness ranging from 50 m to more than 90 m. In detail, this section contains a marly sequence of 28 m thick which is particularly fossiliferous (*Coquina* horizons) with large foraminifera as *Lepidocyclina* (*Eulepidina*) *dilatata, Operculina complanata, Amphistegina sp* and abundant mollusks as *Chama granulose, Crassatella carcarensis*, *Ch. hausmanni exlaevigata*, *Dentalium kickxii*. This sequence is followed by a high fossiliferous thick intercalation of 22-23 m, a grey to blueish marly package of 2.5-3.5 m thick and a fine-grained sandstones of 5-25 cm thick, mostly in upper part of the section and containing different larger foraminifera and mollusks as *Chama granulosa*, *Ch. tongriana*, *Crassatella gigantea*, C. *sulcata*, *Pecten arcuatus, Chlamys hausmanni exlaevigata, Spondylus cisalpinus*, etc.

Plase Formation that mostly consists of stratified and thick massive fine-medium grained sandstones with alternances of gray-blue marls rich in marine mollusks and large foraminifera. This formation reaches about 300 m in thickness. The lower part of sequence of about 114 m thick consists of thin interbeded, mostly fine and medium-grained gray and yellow sandstones (0.5-1.8 m thick) with fossil leaves, *Clupea* scales and some meters of fossiliferous grey-blue marls with marine mollusks as *Haustator strangulata*, *H. magnasperula, Conus ineditus, Crassatella carcarensis, Cardita arduini corbuloides* etc. and large foraminifera as *Lepidocyclina* and passes onto a 76m thick stratified, laterally massive (4-12 m thick) sandstones with several horizons of 10-20 cm thickness that are rich in thin specimens of *Lepidocyclina,* that increase the carbonate content of the sandstones, and grey sandy-marls with marine mollusks particularly represented by pectinids*:Pecten arcuatus*, *P. cf. hofmanni, Chlamys hausmanni, Ch. exlaevigata, Costellamussiopecten deleta*, *Ch. oligosquamosa.* Below the massive sandstones are found horizons with boreholes of the *Kuphus*, a mainly shallow marine bivalve.

Towards the north, within the shallow marine sandstone and grey marls with *Lepidocyclina* and *Operculina* and marine molluscs are found two horizons of 0.3-0.9 m thick scarce lignite seams with brackish mollusks as *Agapilia picta* and *Dreissena basteroti.*

Lower Miocene. Aquitanian consists of a sequence up to 750 m in thickness, containing marine fauna.

The **Bozdoveci Formation** has a thickness of 240 m and consists of marine clays deposits starting with a succession of 50-120 m of grey and blue clays and marls, interbeded by thin sandstone strata (0.2-0.5 m to 1.0 m thickness) and containing fossil horizons with *Lepidocyclina morgani* and mollusks as *Turritella desmarestiana substrangulata*, *T. tricarinata, Crassatella carcarensis*, *Pecten vezzanensis*, *Chlamys northamptoni*, *Spondylus concentricus*, echinoderms as *Clypeaster rostriformis, Scutella cf. subrotundaeformis,* subsequently passing onto a 60 m thick flishoid series. The upermost part is characterized by grey clays about 120 m thick with conglomeratic beds up to 25 m in thickness, rich in plan tonic foraminifera: *Globigerinoides trilobus*, *Globigerina bulloides*, *G. concinna*, *G. dissimilis* etc.

Guri i Capit Formation is represented by a succession of up to 490 m consisting of marine deposits that start with 40-70 m of conglomerate overlie by a sequence of 380 m grey clays with sandstone strata. The uppermost part of this sequence consists of 85m thick of strong conglomerates and sandstones (Guri i Capit), covered by grey-blue sandy marls with thickness ranging from 10-20 m to 120 m. The macro fauna is represented by marine mollusks as *Turritella desmarestiana, Flabellipecten burdigalensis*, *Chlamys northamptoni, Ch. haueri*, *Lutraria lutrari*, *Glycymeris insubricus* and echinoderms as *Clypeaster sp.*

The Lower-Middle Miocene Molasse Cycle of about 2290 m thickness is characterized by the limestone with Lithothamnium of Burdigalian age and characteristic Mediterranean deep marine blueish marls of Langhian age.

The **Burdigalian** sequence up to 410 m thick is mostly represented by Lithothamnium limestone beds, marls, sandstones and thin conglomerates rich in planctonic foraminifera: *Globigerinoides trilobus-Gl. bisphaericus* Zones, large foraminifera as *Lepidocyclina, Operculina*, *Miogypsina* and nannoplankton belonging to *Helicosphaera carteri–H. ampliaperta* Zones, as well as marine mollusks and echinoderms.

The Morave Formation represented by deposits of about 156 m in thickness starts with a package of 15-16 m thick redish-yelowish sandstone, 3 m of conglomerate limestone and is followed by the Lithothamnium limestone up to 137 m thick that build-up the top of the Morave Mt., sandstones, grey-bluish marls and fossil horizons with large foraminifera as *Lepidocyclina elephantina, Miogypsina globulina etc.,* molluscs: *Flabellipecten burdigalensis, Chlamys martelli, Laevicardium discrepans, Pitar incrassata, Tapes vetulus* and echinoderms: *Clypeaster latirostris*, *Cl. crassus, Scutella sp*., *Echinolampas sp.*

The Bradvica Formation of 240-250 m in thickness, starts with intercalation of calcareous sandstones and grey-blue marls and is overlie by intercalations of grey sandy marls, fine-grained sandstones and fine conglomeratic horizons. The lower part of the sequence consists of sandstones and micro-conglomerates following the grey marls, of about 50-70 m in thickness. The marls are rich in plan tonic foraminifera: *Globigerinoides bisphaericus* Zone.

The **Langhian** is built-up of deposits of 1870 m in thickness, well dated by *Praeorbulina* Zone, *Sphenolithus heteromorphus* Zone and mollusks represented by many *Pectinidae*, planctonic mollusks and corals.

Sinica Formation consists of about 1120 m of blue marls starting with fine stratified sandstones and Lithothamnium limestones that are passing onto massive sandstones. A basal package of about 40 m thick of blue marls is followed by 460 m of fine intercalation of marls and sandstones with some massive sandy-limestones (3-4 m thick) and micro-conglomeratic lenses. The upper part consists of up to 90 m of thick blue marls that pass onto 530 m of interbeded blue marls with sandstones, rich in planctonic foraminifera: *Praeorbulina* Zone, mollusks, many deep water pectinids: *Flabellipecten burdigalensis, Amussium cristatum, A. denudatum, Propeamussium anconitanum,* and *Cuspidaria cuspidate, Solecurtua antiquatus,* particulary planctonic mollusks *Clio aff.* s*turani, Cavolina bellardi, C. aff. triplicata, Vaginella austriaca*, *V. rotundata, V. lapugyensis*, *V. callandrelli, V. oligostoma*, *V.*

testudinaria, corals.

The Miras Formation is built-up of sequence about 760 m thick representing the upermost part of the marine molasse and consists of massive, concretionary sandstones followed by stratified sandstones and gray clays with mollusks: *Cerithium sp*., *Ostrea sp*., *Cordiopsis islandicoides* and foraminifera. At the end of Langhian, a short compressive event results in the rapid uplift and marine regression in the Albanian-Thessalian Basin and the the passage into a fresh-water, lacustrine and fluviatile with lignite sedimentations.

Conclusions

The molasses sequences of the Albanian-Thessalian Basin consist of the Oligocene-Lower Miocene (Aquitanian) and Lower-Middle Miocene cycles and represent a continuously exposed Rupelian-Langhian outstanding stratigraphic sequence, characterized by a rich fossil fauna mainly consisting of mollusks, corals and coral reefs, foraminifera, echinoderms, leaf flora. Several morphological units represent extremely particular geosites of regional importance, such as Oligocene erosional circus, Aquitanian Guri i Capit, Burdigalian limestones etc.

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Geoinformation of the geological sites of Dibra district

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Abstract

Dibra district with an area of about 2500.42 km^2, lies in northeastern Albania.

Natural conditions (geology, landforms, climate, soils and biodiversity) have defined diversified landscapes. In this district are present four of the six protected areas categories classified by Albania according to IUCN categorization. In the third category of Protected areas are included natural monuments, which are geological sites, hydro monuments and biomonuments. Geological sites are formed as result of physical and geographical processes (different rocks, various landforms, geomorphologic evolution of the area, as well as external factors influence such as rainfall, winds, etc.). In this district there are declared 25 geological sites, based on their geological formation periods, scientific and aesthetic values.

In Dibra district there are defined geological sites of the following genetically groups: stratigraphical sections of Paleozoic formations in Albania, tectonically-structural salt domes, complex geosites, where are included geomorphologic sites of erosion, river erosion, karst, glacial and of neotectonic origins, hydro geological geosite, geosites of the magmatic, metamorphic and sedimentary complexes, unique ore deposits etc.

In Dibra region it is located Lura National Park, proclaimed by special DCM of Albania since 1966. Placed at an altitude of 1300 m above the sea level, Lura represents a geopark showing the most interesting virgin ecosystem, and offering a unique diversity of natural attraction. In Lura mountain chain 12 glacial lakes, a lot of moraines and circus of Wurm Glacial Period are preserved.

The most important geological sites of Dibra district of regional (international) values there are:

Muhurr-Bulac stratigraphical section of Silurian-Devonian formations, Gurre Lura metamorphic sequence at the bottom of the Mirdita ophiolite, compared with such outcrops in Oman, gigantic evaporate domes of Mali Bardhe (White Mountain) and Bellova, Banjat Thermal Water Spring, Lura glacial lakes, Korabi glacial landscapes and lakes, Skavica Canyon in Black Drini River.

As national geosites we can name Kercishta unique sulfur deposit in Albania, *ammonitico rosso* outcrops in Muher-Bufl, Seta gorge, Pocesta waterfall and karst caves: Guri Kuq, Rusi, Qyteza, Sopaniku and Ice (Bulaci). Beautiful glacial landscapes are formed in Korabi Highland, where is located the highest Albanian peak, Korabi Mountain, 2764 m above the sea level, Black glacial lake of Radomira and cold water springs of Vlesha and Kercini.

Some of geological sites of local importance there are as following: White Mountain Karst in evaporate, Kasnia Lakes, Grama Reflections, Panairi Holes, Kercini Rock, Bellova springs, Big Gorge in Lura, Fushe Lura moraines, Kunoira e Lures Cirques, Money Hill in Bllice, Mare's field in Lura etc.

Geoinformation of the geological sites of Dibra district is a digital database of all known natural monuments. In this study there are determined: location of every geological site, genetic group (type) of geosite, geological setting, geographical-physical features, accessibility, etc. Geoinformation will help to inform the tourists and all interested people about natural monuments of Dibra Region. Geoinformation of geological sites of Dibra Districtis created with the help of ArcGIS10 software, which is a computer based system for storing and analyzing different format data, which can be updated based on continuous monitoring of geologists, geographers, geoscientists etc.

Geoinformation of the geological sites of Dibra district will inform explorers of nature, tourists, students, pupils, about their values, providing itineraries to reach them.

GI will also support central and local authorities to the effective management and protection of geomonuments and commonly natural monuments of the district.

However, although these geological sites have significant values they are poorly visited by both native and foreign visitors, mainly due to lack of information, lack of infrastructure, and difficult terrains.

Keywords: *Dibra District, geological sites, geoinformation, database*

From rock to geosite: what can an ultra-distal volcanic fall-out tell us about the history of an Early Miocene Paleobasin?

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Abstract

Geoconservation is an applied research field developed in a modern, pragmatic world and in order to be credible and accepted by today's society, it must bring social and economic benefits. Thus, although the geosite must have intrinsic scientific value as a pre-requisite, it should also have esthetic and educational appeal, important characteristics in promoting geotourism. In this case, choosing a geosite is more than just science, as it also becomes an issue of integrating the visual and/or cultural ambiance. This combination of science-education-aesthetics (SEE) provides a seed for sustainable economic development and it brought a global success to the UNESCO Geopark concept, which is currently implemented in 32 countries. As part of the working team for the aspiring Buzău Land Geopark (Romania, Carpathian Bend Area) we have encountered geological elements of important scientific value, but with almost no cultural and no aesthetic prospects. The question was how can a culturally decoupled and visually monotonous but scientifically interesting site become a landmark for geotourism and contribute to the profit of the Geopark? Our experience has shown that a good "story" (science interpreted for the general audience) can overcome these issues. This is the case of the so called "dry stones" of Coli Valley, which after a careful petrographic and mineralogical study have improved the picture of the Lower Miocene (Aquitanian) history of the SE Carpathian paleobasins.

The "dry stones" are part of the Lower Miocene Menilite Formation of the Carpathian fold and thrust belt and are found in extended outcrops as cm-to-dm thick, white-to-grey homogeneous beds, with comprised thicknesses of at least 30 m. They are variably silicified (diagenesis) and sometimes separated by thin (mm-thick) paper shales. A close inspection reveals that they are mostly consisted of diatomaceous material (frustules belonging to the *Actinocyclus* genre and to *Aulacoseira praegranulata*), variable amounts of siliceous sponge spicules, chalcedony micro-nodules and accidental, well-rounded terrigenous quartz (200-400 μm diameter). Their most remarkable characteristic is the presence in different lithostratigraphic beds of about 4-7% volcaniclastic material, consisted of highly cuspate and acicular glass shards and fragments of quartz, sanidine, oligoclase, biotite, zircon, titanite and apatite. The volcaniclasts are ~100μm long and the crystal fragments are highly angular. Under BSE and SE they show highly cuspate contours, microfissures, deformation bends and crystal splinters. It is interesting to note that the same type of volcaniclastic material is also observed in certain lithostratigraphic levels of a diatomite deposit found nearby, which is interpreted to be a part of the same unit, which has not been so strongly silicified. The mineralogical characteristics of the volcaniclasts and their morphometry are suggestive of a highly explosive eruption of rhyolitic composition, and their very fine sorting indicates their fall-out origin. Different lithostratigraphic beds contain both primary fall-out and reworked volcaniclasts. However, their small sizes and reduced frequency mean that they have been deposited in an ultra-distal environment, with the source located probably hundreds of kilometers away. Their association with siliceous sponge and diatom fossils is not coincidental, as the chalcedony nodules suggest the water-sediment interface was suprasaturated in silica. This suprasaturation is due to the hydrolysis of volcanic glass, which releases silicic acid. This is taken up by diatoms, as a pre-requisite for developing their siliceous frustules, and thus promotes their bloom. However, the dissolved silica from the suprasaturated water-sediment interface has to be transported to the photic zone, and so upwelling currents are required as a mean of disseminating the nutrient. The meroplanktonic *Aulacoseira preagranulata* (analyst Dr. Simona Saint-Martin) affirms this supposition, as the colonial diatoms lose their ability to float and require constant upwelling movements in order to be kept in the photic and oxygenized water layers. The two genres of diatoms are characteristic for marine (*Actinocyclus*) and freshwater (*Aulacoseira*) environments, and their association indicates a brackish shelf environment, developed during the Aquitanian. All of these are new data that are available only because volcanic particles were carried by the wind in the past. Once it entered the marine environment, the volcanic ash triggered bio-chemical changes that lead to the formation of the "dry stones" which allow us today to understand a moment of the basin's history.

Regional geological sites of Albania

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Abstract

Albania is the country of special geological interest, representing the most suitable territory for the observation of important geological phenomena, which represent geological sites of regional (international) importance. The main goal of this abstract it is the definitionand the selection of the regional geological sites, in a regional, Balkan and Mediterranean context. Unique gelogical sites, and the first findings are determined much wider, in European context. The finalisation of the this study was the compilation of regional list of geological sites. Since the first paper on Geological heritage conservation in Albania, presented in ProGEO Meeting, in Sofia, on May 1995 (Serjani and Cara 1996), there are done a lot of works, studies, inventories, publication on geosites, geoparks and geotourism. The most important act for the protection of geosites as natural monuments was the D.C.M. of Albania Nr. 676, dt. 20.12.2002. Last years, for the first time in Albania, the concept of geo-eco-systems appeared (Serjani 2011; Serjani and Dollma 2012). According this concept the special areas, where are located together, geodiversity and biodiversity can be defined and named as geo-eco-systems. Since the 2011 the study on the "Unique Inventory of Geological sites" begun. An important work for digitalisation of geological sites and geoparks is going in GSA. As framework for the selection were accepted the general geological features of the geology of Albania, which are conditioned by its geographical position in Alpine, Mediterranean Belt and by the evolution during past geological periodes, together with neighbouring countries, with which it has shared the continuation of tectogenesis, structures, paleogeography and sedimentary sequences, magmatic and metamorphic processes. There are determined and listed 582 geological sites of local, national and regional importance. From the above mentioned list were selected 60 regional (International) geosites.

Key words: *Albania, regional geological sites*

Introduction

Although its small area, Albania is the country of special geological interest regarding its complicated structure. Since the first presentation in Subregional Meeting of ProGEO held in Sofia on 1995 up to now, in our country there are done a lot of intensive steps in field of Geological Heritage Conservation.

The most part of the geological sites of Albania are of local and national parameters, while some of them are of regional (international) value. This study is dedicated to these geosites. Firstly, it is presented the current situation of geological Heritage in Albania.The main goal of the study was the determination of the most important frameworks/topics for our country for the definition of the regional geological sites of Albania. That is done in context of Balkan Peninsola, SE and Mediterranean Region. Some unique gelogical sites, and the first findings, are determined in an European context.

In second part, it is done the way of selection of regional geological sites. The comparative selection is done in framework of the main regional geological units. Based on comparative documentation, and on geological studies and publications of our region, we have done the selection of the most important, regional geosites of Albania. Commonly, the activity on geological heritage conservation and geotourism in Albania, is done in framework of the ProGEO strategy.

The finalisation of the this study is the compilation of regional (international) list of geological sites. There are determined sixty regional geosites included in the attached list.

Current Situation of the Geological Heritage Conservation in Albania

Since the first papers on Geological Heritage Conservation in Albania, presented in ProGEO Meeting, in Sofia, Bulgaria, on May 1995 (Serjani and Cara 1996, Serjani 1996), there are done a lot of works, studies, inventories and publication on Geosites, geoparks and geotourism.

The first Project supported by GSAwas finalised with compilation of the First Inventory of geological sites (1999), and the Map of Geological Geosites (2001). In the first inventory there were defined and listed 350 geological sites of local, national and regional (international) importance. In the framework of Southeastern Europe ProGEO Working Group it was compiled the list of the regional geological sites of Albania, included in Balkan list and presented in Dublin (Drandaki

2002).

The most important act for the protection of geosites as natural monuments was the DCM of Albania Nr. 676, Date 20.12.2002 on "Protected Areas as Natural Monuments of Albanian Nature". The book on Geological Heritage Conservation in Albania, in both Albanian and English versions (Serjani et al. 2003) and the Geotourist Map of Albania were published.

Last years, for the first time in Albania appears the concept of geo-eco-systems (Serjani 2011; Serjani and Dollma 2012). According to this concept, the special areas where are located together geodiversity and biodiversity can be defined and named as geo-eco-systems.

Since the 2011 started the study on the "Unique Inventory of Geological sites and Geoparks in Albania". This official study is undertaked by Geological Survey of Albania and Ministery of Environment. Many papers on geological sites and geotourism were presented last years, on November 2012, in a special session during the International Conference, dedicated to the 90-Aniversary of the GSA. An important work for digitalisation of geological sites and geoparks is initiated as well.

Special Elements of Geology of Albania in a Regional Context (as a Framework)

The definition of the regional geological sites of Albania is done in the context of Balkan Peninsula, Southeastern Europe and Mediterranean regional geology. Some unique gelogical sitesand the first findings are determined much wider, in European context.

The general geological features of the geology of Albania are conditioned by its geographical position in Alpine, Mediterranean Belt and by the evolution during past geological periodes, together with neighbouring countries, with which it has shared the continuation of tectogenesis, structures, paleogeography and sedimentary sequences, magmatic and metamorphic processes. In geological aspect, Albania is part of the folded "Mediterranean Alpine Chain", in Dinarides-Albaniades-Hellenides Arc, part of the western part of Eastern Mediterranean (Peza 1967) .

At the most southwestern part of Albanian territory is located Sazani tectonic zone which represents eastern slope of African Plate, Adria Microplate.

The oldest deposits in Albania are represented by metamorphic rocks of Ordovician-Silurian age in Korabi (Pelagonian) zone. The region during these old periods was yet part of Gondwana Continent. Carboniferus is not known in Albania. Permian sequences in Korabi and Albanian Alps zone, which coincide in time with the division of Pangea by Hercynian Appallacian System, there are detrmined as the oldest geosites in Albania. Traces of Hercynian Tectogenesis during late Paleozoic are found in Korabi and Gashi zones.

During Late Triassic and Lower Jurassic, the Albanian territory together with neighbouring countries was located just at the division contact of Pangea, between two orogenic belts. During this period were sedimentated all over nowadays Mediterranean Sea, thick limestone sequences in so-called Tethys Ocean. A lot of amonite fossils there were found there for the first time in 1911 by F. Nopcsa, as is the collection of Triassic Ammonites in Kcira, Puka region. Spiteni condensed section is a rare phenomenon characterizing this period.

During these geological periods appeared the Cimmerian Orogeny, which continued up to the Early Cretaceous. Cimmerian stage of Dogger-Malm it is expressed in two main phases (Shallo et al. 1983): Intraoceanic, characterised by intraoceanic subduction (or intraoceanic charriage) which was accompanyied by the widenning of the eastern ophiolites and Marginal phase, characterised by the plunging of the oceanic edges down, underneath the oceanic formations. Mirdita ophiolite show a classical stratification. Mantel harzburgite-dunite of the Eastern Belt are rich in chromite ore, where are prospected and exploited chromite deposits in Bulqiza area, a unique concerning the morphology of folded ore body.

In the framework of above geological evolution, in Mirdita ophiolite zone there are determined some regional geosites such as: Gzhiq-Shenp-Shenmeri regional geosite of Mirdita oceanic spreding, Gjegjan-Kalimash-Runa petrologic sequences of ultrabasic rocks, one of best sections of ophiolites among the Mediterranean and Alpine chains from Pyreneans to Pamir and Hymmalay (Serjani 1967), Bregu Bibes as a typically paragenetical association of PGE and Fe-Ni-Cu-Cr, Kaçinar-Munella-Domgjon sheeted dyke complex, which represents rare phenomena of worldwide importance, Derveni eclogites, very interesting and important, which can be compared with similar outcrops in Algeria and Marocco, Gziqi-Shenpal site, a very good outcrop of radiolarite beds of oceanic crustwhich represents the top (cover) of the ophiolite activity.

During Alpine Cycle happened continental riftings, break up of the continental crust and oceanic widenning, closing of the oceanic basin up to nowadays geological structures (Kodra et al. 2003).

It is the place to remember here about some other geological opinions and interpretations:

Acording to Kici (2013) Mirdita Ophiolite Belt represents a sedimentary basin with intensively magmatism and the Mirdita ophiolites there are formed in a trough (in a behind intracontinental arc, marginal basin). Shehu based on the the Mirdita Opening since the Verucano serie of Permo-Triassic distributed in Korabi and Gashi zones, integrated his vieus appeared in successive editions of his book: The developing Earth (Tirana, Albania, 1988), in The Growing and Developing Earth (USA, 2005).

Alpine tectogenesis, beginning since the Early Neogene, is represented and documentated widely in Inner and external Albanides, in all territory of Albania. Mollases of Pre Adriatic Depression (PAD) and inner depressions forming big coalbearing basins are a rare example all over Mediterranean. There are a lot of full mollasse structures and section, representing stratotypes in regional context, and with good preservation of fossil beds. Evaporate domes in Peshkopi region and salt diapirs of Ionian zone, as rare geological phenpmena are formed as well.

The red outcrops of ‘’Terra rossa’’ Pliocen-Quaterrnary lake sediments are the best all over Mediterranean countries as well. Transgressions accompanied by bauxite mineralisation in Albanian Alps and Kruja zones, and the under ground Jurassic break in sedimentation “Hard Ground” type in Ionian Zone, are of special interest in palaeoenvironment aspect.

Deep seismogenic, transform faults and thrusts of tectonic units (discribed some times as “tectonic nappes”) of Albania are of regional, Mediterranean scale. If it is known that around Meditarranean there are formed huge vortex structures (Lee 1973), Dinaride-Albaniade-Hellenice folded Belt represents a long orogenic system divided by submeridional deep faults in huge long blocks. Dinarides-Albanides-Helenides Belt was compressed between Balkanides east and Apulian microplate west. The font of African foreland outcrops just in Llogara, where is the contact between African Plate (Adria microplate) and Orogen, while in central and north Albania there are documentated some regional overthrust tectonics. Clearly this system of overthrusts is expressed in Droja valley. Thrust tectonic system was discovered for the first time by S. Zuber and supported later by Albanian geologists V. Liko, V. Melo, A. Qirinxhi and others.

Submeridional Geological structures there are crossed by two long and deep seismogenic fault: Shkoder-Peja (Scutari-Pec) fault, which divided Dinarides north from Albanides-Helenides south and Vlora-Elbasan-Oher-Skopie seismogenic fault. Shkoder–Peja fault was discovered by F. Nopcsa (1910) and it is supposed to go far northeast up to the Carpathian Arc. It is thought to have been formed since the Kimmerian phase of folding. Its role as structural boundary between Dinarides and Hellenides was defined by Cvijic since the 1901.

It is discoverd the clockwise rotation of the Albanide domain opposite to Shkoder-Peja (Scutari-Pec) transform fault (Kissel 1985; Bushati et al. 1990). According to paleomagnetic data of last years south of the “Scutari-Pec Transverse” was twice clockwise rotated by a total of about 45 to 50 degrees (Marovic1995). By the influence of compression and above mentioned rotation, on both sides of the Shkoder–Peja fault, huge foldings in Cukali Zone north (Komani tectonical-structural geosite), and Kabashi ophiolite massif south, were originated.

In late tectonic evolution and neotectonics there are included late uplifting movements which caused the formation of Pliocene-Quaternary relief. Albanian relief was formed mainly during Pliocen-Quaternary. First uplifting movements were since the Middle-Upper Miocene. Inner tectonic units during the late tectonic stage and during neotectonics were under the influence of widenning and horizontal movements. In external zones, especially in Ionian zone, horiontal movements in widenning happened since the Liassic, causing formation of a lot of tectonic blocks, horsts, grabens and breaks in sedimentation. Inner depressions on Mirdita zone were formed mainly during Pliocene and Pliocene-Quaternary.

Late tectonic and neotectonic have played main role in uplifting and relief formation of Albania. Albanian relief was formed since the Middle-Upper Miocene, continuating intensively during Pliocene and Quaternary. There are distinguished four main geomorphologic cycles:

1. The areas of early (young) cycle: Albanian Alps, Eastern-Central and Southern mountainous geographical units. As result of glacial, erosion, structural-erosion, karstic processes high mountainous chains, ridges, horsts and depressions are formed, presenting severe, but specific, aesthetic geological sites and landscapes. As result of new tectonic-karst depressions were formed Shkodra, Ohri, Big Prespa, Small Prespa, the largest natural lakes in Albania.

2. The areas of wide river valleys between mountainous chains belonging to the middle stage or to the maturity stage. River-erosion processes have caused the formation of deep narrow canyons, gorges, and aesthetic valleys, which served as the best places for the prehistoric human settlements.

3. The areas in late maturity stage, where belong hilly regions of PAD and some wide river valleys with predomination of the erosion-denudation processes forming smoothly landscapes.

4.The western field areas of Adriatic coast and lagoons belonging to the last, old geomorphologic stage. Along with Adriatic and Ionian sea coasts there are placed Patoku, Karavasta, Narta, Orikumi and Butrinti lagoons, which represent important ecosystems all over Mediterranean. Divjaka-Karavasta Lagoon it is included in Ramsar Convention. Butrinti lake-lagoon and Butrinti archeological site is included in world heritage under the UNESCO protection, while the Ksamili Islands located not so far from Butrinti represent a pearl of Ionian Rivera.

Selection of the Regional Sites in a Regional Geological Units and Neighborous Countries context

For comparison and selection of geological sites of Albania there are used many publications on Balkan geology, and on Eastern Mediterranean. The attemps for choosing "unique" and the "best sites" for the European list of geosites are done some years before. As initial and base materials have served the main publications, declarations, resolutions and reports such as: A First attempt at a Gesites framework for European IUGS initiative to support recognition of WH and European Geodiversity presented in Belogradchik Workshop (1998), Balkan Framework list of the Geological Heritage–a first attempt (with contribution from Albania, Bulgaria, Greece, Bosnia, Serbia, Romania, Turkey, and Bosnia and Herzegovina), List presented at the Florence IGC, The First Inventory of geological sites of Albania, district's lists attached to the DCM of Albania Nr. 676, date 20.12.2002 etc.

Based on comparative documentation for each geosite, on geological studies and publications of our region we have done the selection of the most important geosites of Albania. Concerning the criteria of comparison we are based on the following regions and regional geological–geomorphologic-geographical units: Selection of geosites through comparison in framework of SE Europe Region. Selection of geological-geomorphological sites and seaside lagoons in comparison to the East Mediterranean region.

Comparison with similar geosites in Dinaride-Albanide-Hellenide–Taurides. Comparison of geosite with similar in East Mediterranean Alpine chain. Bulqiza chromite deposits and Selenica asphalt deposit are unique all over the Europe. Amongst the system classification published in Geologica Balcanica (Wimbledon et al. 1998) we have add some systems proposed later, and have done the division in subsystems in case of the common list of geological sites of Albania, where are included local, national and regional (international) geosites. In this list there are in total 582 geological sites, from which there are selected 60 geological sites of regional (international) importance.

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Geodiversity of Rila Mountain, Bulgaria

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Abstract

Rila-Rhodopean Massive in southwest Bulgaria, the Balkan's oldest land, is composed of predominantly metamorphic and igneous rocks. Rila is the highest mountain in the Balkans (2925 m). It is believed that the oldest rocks in Rila Mountain are the Precambrian metamorphites of the Ograzhden (Praerhodopean) Supergroup. Initially under this name were united different types of metamorphic rocks in Rila-Rhodopean Massive: granite-gneisses, biotite and amphibole-biotite gneisses, aplitic gneisses, migmatitic biotite and two-mica gneisses, migmatites, gneiss schists, amphibolites, serpentinized ultrabasites, eclogites, etc. Later this unit is subdivided into metamorphic complexes and lithotectonic units: Maleshevtsi and Troskovo Metamorphic Complexes, Plana Gneiss Complex, Ograzhden, Malyovitsa and Thracian lithotectonic units. They contain orthometamorphic bodies of amphibolite, metaserpentinite, gneiss-granite, metadiorite and metagabbro. The younger Rhodopean Supergroup is composed of Neoproterozoic metamorphites belonging to the Rupchos and Predela Metamorphic Complexes (Malyovitsa lithotectonic unit), composed of biotite gneisses, gneiss schists, distene-sillimanite and kyanite schists, amphibolites and marbles, and Sitovo Metamorphic Complex (Assenitsa, Thracian and Chepinska lithotectonic units), composed of biotite and two-mica gneisses, muscovite-albite gneisses, migmatitic gneisses, gneiss schists, amphibolites, biotite and two-mica leptynites, and marbles.

Neoproterozoic-Lower Paleozoic rocks are low-grade metamorphic rocks belonging to the Frolosh Metamorphic Complex (green and actinolite schists, phyllites and metadiabases) and Struma Diorite Complex (diorite, gabbrodiorite, gabbro, peridotite and olivine pyroxenite). Another Neoproterozoic - Lower Paleozoic metamorphites belong to the Plana Gneiss Complex (gneisses and migmatites) and the Prazinite Complex (metabazites, amphibolites, amphibole and green schists). All these rocks are intruded by granitoids of the Rila-West Rhodopean batholith. It was formerly referred to the Late Paleozoic "South Bulgarian Granites" but recent radiometric dating proved Late Cretaceous age for the igneous bodies of the 1st phase, and Tertiary age for the surrounding igneous bodies of the 2nd phase.

The Upper Cretaceous intrusive bodies in North Rila and Plana Mountain represent an exceptional diverse range of intrusive igneous rocks. The Upper Cretaceous Plana Pluton is composed of biotite and amphibole-biotite granite, amphibole-biotite granodiorite, quartz diorite, monzonite, quartz monzonite, quartz monzodiorite, gabbro diorite, gabbro, pyroxenite, gabbro pyroxenite, diorite porphyry, monzodiorite porphyry, pegmatite, aplite, etc.

The oldest sedimentary rocks are the Carboniferous - Permian conglomerates, sandstones, siltstones and shales.

The Mesozoic is represented only by Lower Triassic sandstones of the Buntsandstein facies belonging to the Marvodol Formation.

The Tertiary includes Oligocene conglomerate, sandstones, siltstones and shales, and several Neogene terrigenous units: German Formation (Meotian-Pontian), Barakovo Formation (Pontian), Alino Formation (Pontian-Dacian) and Relyovo Formation (Dacian-Romanian). Plio-Pleistocene glacial and fluvial-proluvial clastic debris are deposited in the surrounding grabens, forming attractive rock pinnacles due to the recent erosion. The youngest deposits are the result of the Pleistocene glacial activity, responsible for the formation of spectacular glacial valleys, cirques and numerous glacial lakes and moraine debris.

This remarkable geodiversity makes Rila Mountain one of the most perspective areas for Geopark development in Bulgaria and South East Europe.

The Geoecotourism Potential and Management of the Sazan-Karaburun National Marine Park

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Abstract

Vlora District is a well known area for its natural and geographical assets. On October 28th 2010 by the proposal of Environmental, Forests and Water Administration Ministry, with the rule Nr. 289 Karaburun-Sazan zone was proclaimed "Protected National Marine Park" in Albania. The area of Sazan Island and Karaburun Peninsula is under the protection because of the high geodiversity, biodiversity and natural values of the habitat. The rocky coast built by the limestones of Karaburun peninsula has various sights, with unreachable rocks, caves, and small bays.

Karaborun Peninsula is of about 16 km long and 4 km wide. The slopes of the western side are very steep in some places, on the shores, seasonal steams have created deep canyons which rarely end into sandy beaches. These rocks are eroded and crossed by a large number of caves, most of them being under water. Among them we can mention the following karstic caves: the Cave of Haxhi Ali, the Cave of Duk Gjoni, the Cave of Gjon Gjin Leka, and the Cave of Doves etc.

Sazan Island has a prolongation shape in north-northwest-south-southeast direction, with length of approximately 4.8 km, maximal width of 2 km and a total surface of 5.7 km². The western slope of the island is characterized by rocks that rise vertically, interrupted from deep canyons that extend from the caves, mainly underwater. In this slope, the erosion has formed the Ravine of Xhehenemi and the seasonal activity of the stream of Xhehenemi. The ravine ends into sea, in the Bay of Xhehenemi, a geosite which is created upon the impact of the sea waves. The Ravine- Bay with a tough view, with the slope that falls sharply into the sea. It has served many times to anchor of the ships during stormy weather.

The western side of the Sazan-Karaburun area is known as a priority area from many documents of environmental policies of the Albanian Government. On the southwestern coast of Karaburun is situated Grama Bay, once a famous harbour since thousands of years before. On the rocks of Grama Bay were found a lot of inscriptions in Ancien Greek and Latin language, dating back 2000 years before, which has made this bay to be considered as the most rich ″rocky dairy″ in the Mediterranean.

This area carries precious archaeological, historic and cultural values. In the southern part of Karaburun Peninsula is is located the antique city of Orikum (once called Orik), one of the most important Illyrian harbours which was built in the 5th century BC and is mentioned as being an important economical and cultural centre in the Mediterranean during the Ancien Greek and Roman periods and until the Middle-Age. The lagoon has a surface of about 150 hectares and a depth of approximately 3m. Despite the vegetation of the characteristic poultry, it is also distinguished for the karst phenomena occurring within the limestones. In the slopes of this wetland landscape are also built cult and historic buildings.

The interesting underwater topography, with caves and various microhabitats together with the the presence of sunken ships, gives to this area a lot of special geoecotourist values appreciated by diving enthusiastsIt is very difficult to reach this zonebecause of the road infrastructure and rocky seaside, which has naturally protected the natural habitats. In the recent 20 years, the ground and coastal areas have been widely used in our country, so it has lost many of its biodiversity values, the causes being the uncontrollable development of urban tourism, the high number of population, deforestation, erosion, the lack of law protecting these areas and the failure to comply with rules.In Vlora Bay, in the eastern part of Sazan-Karaburuni Park is foreseen to have an energetic wind development that will affect this part, and which is in contradiction with the law of protection status. We thinkthat for elimination, the conflict through the multiple usages and the protection of the biodiversity and geodiversity must do their efforts local government, researchers of the academic centers, environmental societies etc.

Key words: *Protected area, biodiversity, geoecotourism, management*

How the Mesozoic Apulian platform shaped the outer Hellenide fold-and-thrust belt

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Abstract

The front of the W-verging Hellenide fold-and-thrust belt and its adjacent Adriatic foreland have been investigated using a grid of seismic reflection profiles, purposely acquired in the Southern Adriatic Sea. Along this convergent margin the continental collision observed in Albania and north-western Greece passes to oceanic subduction south of Kefalonia. The structural style of the external part of the fold-and-thrust belt and the evolution of the related foredeep basin are strongly controlled by the nature of the Mesozoic paleogeographic units that are progressively accreted to the belt. Where the thick Apulian carbonate platform is accreted (souther Albania and north-western Greece) the frontal mountain range presents a high topography, whereas the foredeep basin is relatively shallow. Where the Ionian basinal domain is accreted (northern Albania), the topography of the fold-and-thrust belt is subdue, whereas the foredeep basin is remarkably deep. South of Kefalonia, at the north-western tip of the Eastern Mediterranean oceanic subduction, the Apulian limestones are stacked within the Hellenic accretionary prism. The Apulian platform limestones show different amount of deformation along the Hellenide thrust front, with deformation being larger south of Kefalonia. This result has palaeogeographic implications that have relevance for the build up of the whole Hellenides.

Keywords: *Hellenide thrust front, southern Adriatic basin, foredeep basin, palaeogeography*

Introduction and Geological Setting

Along strike variations in structural style occur at all scales, from outcrops to Fold-and-Thrust Belts (FTBs), because strength heterogeneity and anisotropy of the rock units affect the shape and size of thrust faults (Price 1988). The front of the W-verging Hellenide fold-and-thrust belt and its adjacent foreland (Fig. 1) have been investigated using a grid of seismic reflection profiles, purposely acquired in the Southern Adriatic Sea (Fig. 2). This contribution aims at showing that the size and width of the Apulian carbonate platform domain has greatly affected the evolution of the thrust front. The Apulian platform and Ionian basinal domains are involved in thrusting at the front of the Hellenides, where a marked along-strike change in structural style has been observed. It can be shown that the change in structural style is closely related to the nature of the Mesozoic domain, either platform or basin, which the thrust front impinges onto. It results, therefore, that the style of accretion of the Apulian units gives some hints on the Mesozoic palaeogeography.

Two are the chief geological elements in the region: the Adria domain and the Hellenide thrust front (Fig. 1).

Adria. The continental extension that caused the opening of the Tethyan ocean, during the early Mesozoic, gave rise to a system of epicontinental pelagic basins and carbonate platforms (e.g., Zappaterra 1994). Most of the sediments belonging to these depositional settings are now stacked within the Alpine-Mediterranean FTBs, from the Betic cordillera to Turkey. This system of platforms and basins typically characterises the southern Tethyan margin (Biju-Duval et al. 1977; Dercourt et al. 1993). Relatively undeformed portions of this Tethyan margin crop out at Present in the Adriatic Promontory, of which the Apulian Platform is an outstanding example. In the region comprised between the southern Adriatic Sea and Ionian Sea the original relationships between the Apulian Platform and its adjacent basins are still preserved and can be investigated through geophysical surveys.

Hellenides. The W-verging Hellenides FTB runs along the eastern boundary of Adriatic Promontory, from Albania to the Peloponnesos (Fig. 1). In western Greece the outer Hellenides are characterized by the Ionian basinal unit overthrusting the margin of the Apulian platform which i deformed in various ways (Karakitsios 2013), whereas over most of Albania the thrust front involves only basinal units (Argnani 2013). The intense seismic activity and compressional

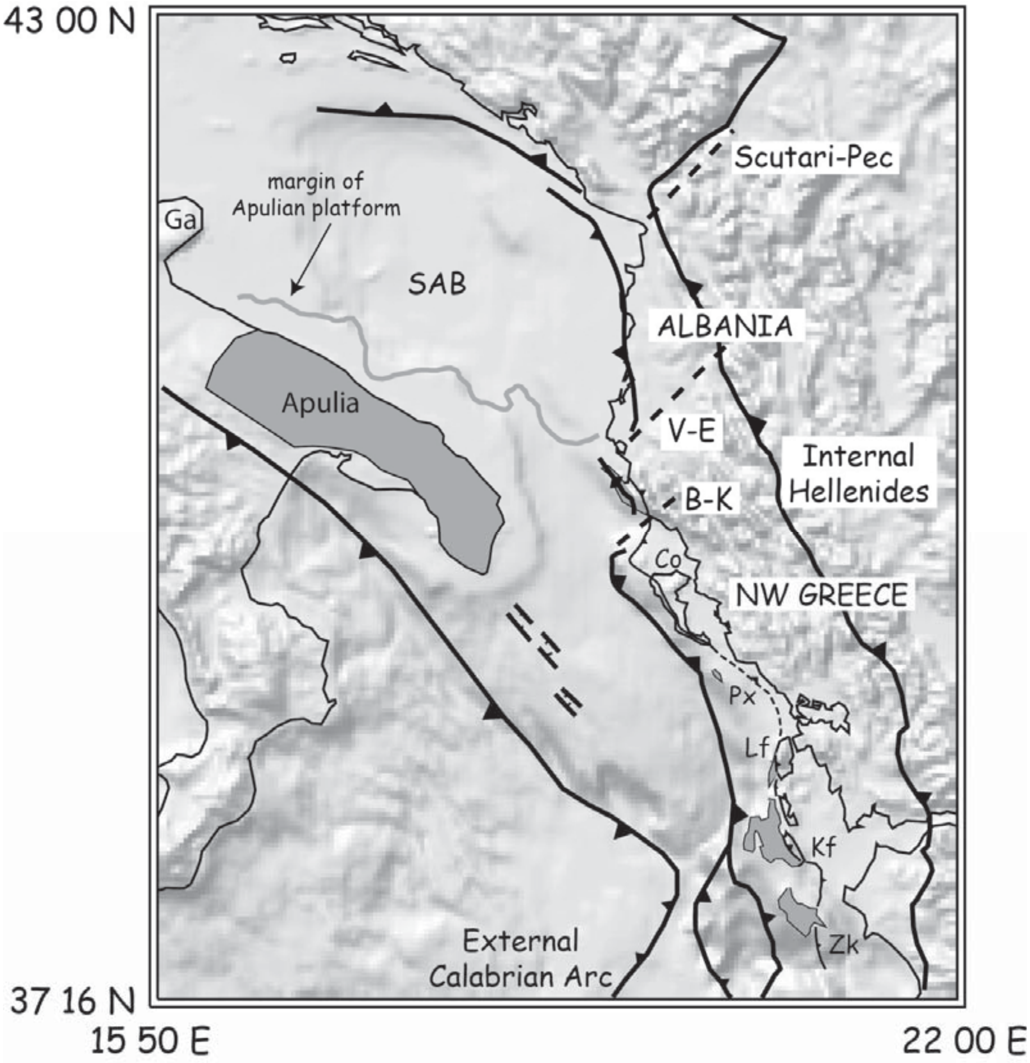

Figure 1. Shaded topography of the south-eastern Adriatic with the main morphological and tectonic features indicated. The outcrops of Apulian units are indicated with dark gray. Co-Corfu, Px-Paxos, Lf-Lefkas, Kf-Kephalonia, Zk-Zakintos, SAB- Southern Adriatic Basin, Ga-Gargano promontory. Dashed lines represent the main transversal structures: V-E-Vlore-Elbassan, B-K Borsh-Khardhiqit.

focal mechanisms indicate that this fold-and-thrust belt is currently deforming (e.g., Vannucci et al. 2004). Paleomagnetic data from the thrusted terranes of the Hellenides indicate a 40-45 degrees clockwise rotation since early Miocene (e.g., Van Hinsbergen et al. 2005).

Data Set

A grid of seismic profiles (Fig. 2) has been specifically acquired between 1991 and 1998, in several cruises (Argnani et al. 1993, 1994, 1996), in order to better characterise the tectonics of the southern Adriatic basin (Fig. 1). Data acquisition during the various surveys has been carried out using a 24 to 48-channel Teledyne streamer (25 to 12.5 m group interval, respectively) and 1 or 2 Sodera G.I. gun in harmonic mode (105 + 105 c.i.). Shot interval was usually 50 m, except in one survey where the interval was 25 m. Data coverage was typically 6-fold. Seismic data were digitized and recorded by a Geometric's Stratavisor seismograph, with sampling rate of 1 msec and record length varying from 8 to 12 s. Finally, the seismic data were processed using a standard sequence (Yilmaz 1987) up to time migration, using the software Disco/Focus by Paradigm Inc.

Results and Conclusions

The Hellenide thrust front presents a marked variation in structural style from Albania to Kefalonia. Major differences are due to the Mesozoic paleogeographic setting of the Adria

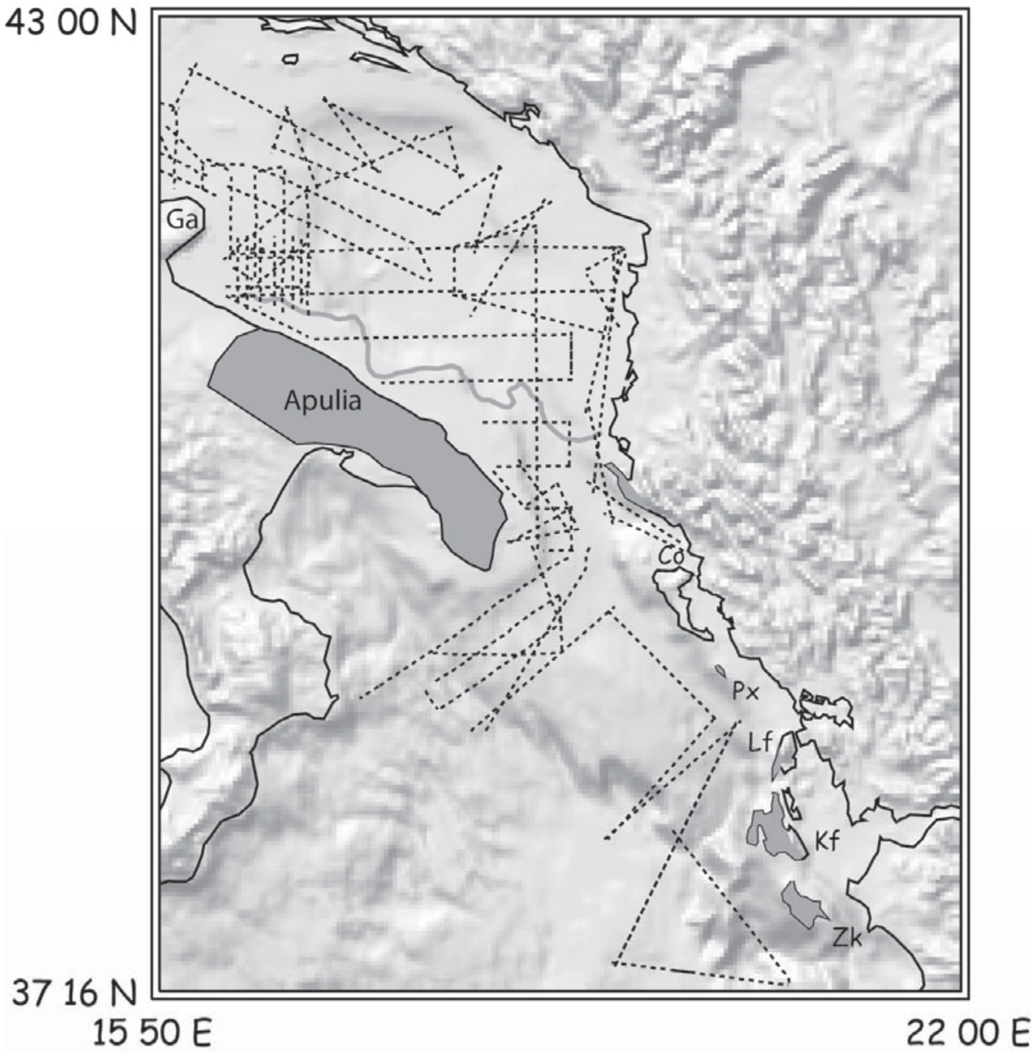

Figure 2. Shaded topography of the south-eastern Adriatic with the location of multichannel seismic profiles. Co - Corfu, Px - Paxos, Lf - Lefkas, Kf - Kephalonia, Zk - Zakintos, Ga - Gargano promontory.

region, namely by the different topographic expression of the Apulian platform and Ionian basin, both deposited on continental crust thinned during the Tethyan ocean opening. In northern Albania, where the basinal Ionian domain is accreted, the topography of the FTB is subdued whereas the Neogene foredeep basin is remarkably deep. In southern Albania and NW Greece, where the Apulian platform unit is accreted, the topography of the FTB is elevated close to the coastline. On the other hand, the foredeep clastic sediments are rather thin in this area when compared to the northern portion of the foredeep. In the southern part of the study area (Kefalonia and Zakintos) a major role is played by the occurrence of the oceanic substrate (present-day Ionian Sea) which is currently subducted. Here the Apulian platform carbonates are sheared off their continental substrate and stacked in the eastern Mediterranean accretionary wedge (see also Pearce et al. 2012). The Apulian platform is resting on a continental crust substrate and its width decreases to the SE. The width of this continental paleogeographic domain controls the evolution of the rolling back subduction in the NW corner of the Eastern Mediterranean. Slab retreat occurred only where the continental substrate is narrow enough to be scraped off without jamming the subduction.

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How far can the magma-poor rifted margin concept be used to explain the Mesozoic Peri-Alpine rift systems in eastern Europe?

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Abstract

The study of the plate tectonics of the Peri-Alpine region (i.e. Pyrenees, Alps, Apennines, Carpathians, Dinarides systems) usually consists in identifying plate boundaries with oceanic domains that will be recorded as sutures in the orogens. However, the progressive overprint of subsequent deformation phases during the orogenic cycle makes their reconstruction very complex and debatable. Nevertheless, in the last 15 years, the access to new seismic datasets on modern margins allowed to introduce new concepts on the evolution of magma-poor rifted margins. This approach has also been tested inside orogens and especially in the Alps, where clear evidence of hyperextension and subcontinental mantle exhumation along extensional detachments faults has been demonstrated. For what concerns their primary features, these observations can be tentatively extended to the whole Western Peri-Alpine region (Alps, Pyrenees, Apennines, Corsica). In fact, from the Late Permian to Late Jurassic, its paleogeographic evolution was strongly controlled by the formation of magma-poor rift systems. If these rift systems were the result of a single, long-lasting rifting event or if they were generated by distinct rift pulses is still a matter of debate. Nevertheless major incertitude arises on the interpretations of the older rifting events, due to the successive orogenic overprint related to the formation of the Alpine belt and of the Western Mediterranean domain. The aim of this work is to apply the actual knowledge on this margin-type to the whole Peri-Alpine region using both the vast existing literature and own observations. The challenge is to test if the basic configuration of magma-poor rifting can be applied to the eastern European system and, if it is the case, to understand if some hyperextended domains eventually evolved into true oceans. From the theoretical model, which just benefits of the Alpine and Pyrenees benchmarks, we know that magma-poor rift system generates margins with major discrete features that follows a precise evolutionary history and lead to well defined first-order characters in the geological record.

Especially, these systems account for an upper and a lower plate sensu rifting (i.e. footwall and hangingwall in respect to the exhumation fault) that show markedly-different characters in their structural evolution and sediment supply/accumulation. The lower plate is characterized by the juxtaposition of exhumed crustal material (including prerift granulites) with hydrated mantle rocks, draped by deep marine sediments, which may account for a peculiar distribution and composition depending on the source-areas migration during rifting. They can feature a “mixed” composition (mafic+continental clasts) deposited by the reworked material from the exhumation surface and by the shedding from the Upper plate. This last accounts for a particular subsidence history during rifting, when the margin becomes very differentiated in a large uplifted domain that underwent sediment starvation or subaerial erosion (H-Block) and in a drowned and more distal domain in which paleodephts reached up to several thousand meters. In the Upper plate domain, the evaporitic successions, the onset of thick carbonate platforms, their demise or drowning, the iron-manganese hardground sedimentation, may correspond to correlatable and mappable residues of large-scale rift events that can be recognized in the Peri-Alpine stratigraphic record. This account for a process which is not strictly related to a “facies belts” approach in the paleogeographic reconstruction but better to a more selective process in which the stratigraphic record is sifted in search for primary hyperextension-related features. In particular, the lack of a layer-cake stratigraphy may be diagnostic for the reconnaissance of hyperextended realms; the top of pre-rift basement and the base of postrift key-levels embrace a synrift succession that, as a result of the crustal thinning, laterally terminate or evolve inside complex domains that experienced exhumation. The asymmetric characters of magma poor margins, their peculiar isostatic history and their thermal evolution may offer a framework that, if reduced to the essential, has a strong “portability” character. Applying it to the Peri-Alpine region may offer a new view on the tectonic shaping of this area introducing geometrical constrains on the rifted margins (i.e. plate polarity sensu rifting).

Age and composition of meta-ophiolite from the Rhodope Middle Allochthon (Satovcha, Bulgaria): a test for the maximum-allochthony hypothesis of the Hellenides

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Abstract

The metamorphosed thrust stack of the Rhodopes comprises a level with ophiolites (Middle Allochthon) under and overlain by continent-derived allochthons. The Upper Allochthon represents the European margin, but the origin of the Lower Allochthon remains controversial, with suggestions that it may be derived from an inferred microcontinent (Drama) or from the margin of Adria. Trace element compositions and Sr and Nd isotope ratios of metagabbroic amphibolites and enclosed meta-plagiogranites from the Satovcha Ophiolite, Middle Allochthon, show that they are cogenetic and represent supra-subduction-zone ophiolites. U-Pb dating using LA-SF-ICP-MS of zircons from two meta-plagiogranites and a metagabbro yielded identical Jurassic ages (160 ± 1 Ma, 160.6 ± 1.8 Ma, and 160 ± 1 Ma, respectively). In addition, older zircons were found in one of the two meta-plagiogranites, clustering at 610 to 589 Ma (Proterozoic), 472 to 470 Ma (Ordovician), and 348 to 262 Ma (Carboniferous andPermian). The Jurassic ages are similar to ophiolites in the eastern Vardar Zone bordering the Rhodopes to the SW. The trace element patterns also closely resemble those of the Vardar ophiolites, and the association with Late Jurassic arc-type granitoids is another feature that applies both to eastern Vardar and Satovcha. This strongly suggests that the Middle Allochthon comprises the metamorphosed northeastward continuation of the Vardar zone. The Jurassic age of the Satovcha ophiolite contradicts the hypothesis of Early Jurassic suturing between Europe (Upper Allochthon) and the assumed Drama microcontinent (Lower Allochthon) but is in line with the "maximum allochthony hypothesis", i.e. the assumption that the Lower Allochthon represents Adria and that the entire internal Hellenides including the Vardar Zone represent an allochthon rooted at the NE boundary of the Rhodopes.

Although the total width of the overthrust mass from the thrust front of the Internal Hellenides to the suture at the northeastern slopes of the Rhodopes is about 500 km, the original thrusting distance has probably been much less. A significant fraction of the 500 km was produced by Paleogene and Neogene rollback-related extension. One implication of the maximum-allochthony hypothesis is that it reduces the number of microcontinents and oceanic branches involved in the Eastern Mediterranean Alpine orogen. If Drama/Pangeon/Thracia was not a microcontinent but part of Adria, and if the Paikon continental basement in the Vardar Zone also represents a tectonic window instead of a continental ribbon, there remains only one ocean between Europe and Pelagonia in Jurassic times. A second, small (?) oceanic basin may have existed between Pelagonia and Adria during the LateCretaceous, represented by ophiolites in the Cyclades. Our results are in accordance with recent proposals that subduction and collision tectonics in the Rhodopes lasted up to the Eocene.

Geodynamics and paleogeography of the Silesian Ridge in the Outer Carpathians

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Abstract

The complex Mesozoic and Cenozoic tectonics of the Outer Carpathians produced series of ridges separating deep water basins.The Silesian Ridge existed since from Jurassic till Oligocene times. Today this ridge is destroyed totally and is known only from olistoliths and exotic pebbles in the Outer Carpathian flysch. It separated the proto-Silesian Basin from the Alpine Tethysduring Jurassic-Early Cretaceous times.The carbonate platform was initially developed on this submarine ridge providing excellent conditions for organic life, represented by calcareous algae, sponges, corals, bryozans, brachiopods, bivalves, ammonites and crinoids. The Late Cretaceous uplift of the Silesian Ridge produced a tremendous amount of clastic material.The submarine fragments of the Silesian Ridge provided favorable conditions for development of shallow banks with the carbonate platform sedimentation during Paleocene-Eocene times. Shallow water, probably narrow shelf locally was dominated by Paleocene and Eocene reefs built of red algae together withbryozoans, brachiopods, sometimes corals and foraminifers. Patchily distribution of these faunas is confirmed by local occurrence of redeposited organic limestones within siliciclastic material. The accretionary prism of Outer Carpathians reached the Silesian Ridge during latest Eocene-Early Miocene. The uplifted part of the nappes produced big olistoliths, which glided down into the adjacent, more distal basins. Finally, the ridge collapsed as a result of the lithosphere flexure in the southern part of the Silesian basin and was destroyed during Neogene times.

Keywords: *Carpathians, Paleogeography, plate tectonics, flysch, carbonates*

Introduction

The complex Mesozoic and Cenozoic tectonics of the Outer Carpathians produced series of ridges separating deep water basins. These ridges were providing favorable conditions for development of shallow banks with the carbonate platform sedimentation. The orogenic processes in the Northern Outer Carpathians produced an enormous amount of the clastic material that started to fill the basins. The material was derived from the northern and southern margins as well as from the inner ridges and swells. The present authors investigated geodynamics and paleogeography of the most prominent elevated area – the Silesian Ridge, which existed since from Jurassic till Oligocene times. Today this ridge is destroyed totally (collapsed during subduction processes) and is known only from olistoliths and exotic pebbles in the Outer Carpathian flysch (Cieszkowski et al. 2009, 2012 and references therein).

Methods

The assessment of the Outer Carpathian paleogeography was based on evaluation of existing published and archive data, plate tectonic analysis, and correlation of lithostratigraphic units with the global sequence stratigraphy scheme. The plate tectonic model used (PLATES and PALEOMAP software) incorporates the relative motions between approximately 300 global and about 20 Circum–Carpathian plates and terranes (Golonka et al. 2006). Information from several general and regional paleogeographic papers was assessed and utilized. The calculated paleolatitudes and paleolongitudes were used to generate computer maps in the Microstation design format using the equal area Molweide projection. The arrangement of the lithostratigraphic units is related to their paleogeographic position within the original basins. It is partially based on previously published papers (Golonka et al. 2008; Waskowskaet al. 2009; Golonka 2011).

Geological setting

The Northern Carpathians are subdivided into an older range known as the Inner Carpathians and the younger one, known as the Outer or Flysch Carpathians. The Outer Carpathians are built up of a stack of nappes and thrust-sheets showing a different lithostratigraphy and tectonic structures. From the South they are: the Magura Nappe, Fore-Magura Group of nappes, the Dukla Silesian, Subsilesian and Skolenappes (Ślączka et al. 2006; Golonk 2011 and references therein). Each Outer Carpathian nappe represented separate or partly-separate sedimentary subbasin. The enormous continuous sequence of flysch type sediments were deposited in these subbasins, their thickness locally exceeds 6 km. The sedimentation spanned the time between Late Jurassic and Early Miocene. During the folding and overthrusting sedimentary sequences were uprooted and generally only sediments from the central parts of basins are preserved (Ślączka et al. 2006). The Outer Carpathians nappes thrust over each other and over the North European Platform, a large continental plate amalgamated during Precambrian-Paleozoic time. Proterozoic and Paleozoic fragments could be distinguished within the folded and metamorphosed basement of this plate. The sedimentary cover consist of the autochthonous Upper Paleozoic, Mesozoic and Cenozoic sequences covered by the allochthonous Jurassic-Neogene rocks. The Inner Carpathians are built of the continental crust of Variscan Late Paleozoic age and Mesozoic-Cenozoic sedimentary cover. The uppermost Paleozoic-Mesozoic continental and shallow marine sedimentary sequences of this plate are folded and thrust into a series of nappes (Ślączka et al. 2006).

Origin of the Silesian Ridge

The Outer Carpathian rift (proto-Silesian Basin) had developed with the beginning of the Uppermost Jurassic-Lower Cretaceous calcareous flysch sedimentation. The Jurassic-Early Cretaceous Silesian Ridge (Książkiewicz 1962; Golonka et al. 2005; Golonka 2011) originated as a result of the fragmentation of the European platform in this area. The proto-Silesian basin was formed during the synrift process with a strong strike-slip component. The complex system of rotated block was born. The emerged fragment of these blocks supplied material to the basin. The opening of the basin is related to the propagation of the Atlantic rift system (Golonka et al. 2005). The Silesian Ridge separated the proto-Silesianbasin from the Alpine Tethys (Fig. 1). A part of the clastic source area for the proto-Silesianbasin was situated on the islands at the southern margin of this basin and related to the northern margins of the Silesian Ridge (Książkiewicz 1962; Ślączka et al. 2006; Cieszkowski et al. 2012). The carbonate platform was initially developed on this submarine ridgeproviding excellent conditions for organic life, represented by calcareous algae, sponges, corals, bryozans, brachiopods, bivalves, ammonites and crinoids. The debris-flow uppermost Jurassic-lowermost Cretaceous sediments include clasts of bioclastic limestones. The existence of coarse-grained facies of the Upper Cieszyn Limestones as well as the appearance of mass-movement debris-flow deposits indicate the significant vertical movements during the Neo-Cimmerian activity. The Early Cretaceous development of the proto-Silesian Basin, perhaps from rifting into spreading phase, as suggested by the presence of teschenitic magmatism was probably another effect of this Neo-Cimmerian activity. The carbonate facies within the proto-Silesian Basin were replaced by clastic deposits (Golonka et al. 2005).

The Cretaceous reorganization

During the Cenomanian and Turonian, compression embraced the Inner Carpathians and several nappes with northward polarity developed. In the Outer Carpathians during this stage several ridges have been uplifted as an effect of the orogenic process. These ridges distinctly separated several subbasins, namely Magura, Dukla-Fore-Magura, Silesian, Charnahora-Audia, Skole-Tarcausubbasins. More outer subbasins (Skole, Silesian, Dukla-Fore Magura) reached diagonally the northern margin of the Outer Carpathians and successively terminated towards the west. From uplifted areas, situated within the Outer Carpathian realm as well as along its northern margin, enormous amount of clastic material was transported by various turbidity currents.The sedimentation and subsidence rate in the Silesian Basin and were accompanied by a continuous uplifting. The uplift of the Silesian Ridge produced a tremendous amount of clastic material. Sedimentation started during the Late Turonian-Early Coniacian and lasted up to the Early Eocene in the Silesian Basin being mainly represented by thick bedded, coarse-grained turbidites and fluxoturbidites (Ślączka et al. 2006; Golonka 2011). The submarine fragments of the Silesian Ridge provided favorable conditions for development of shallow banks with the carbonate

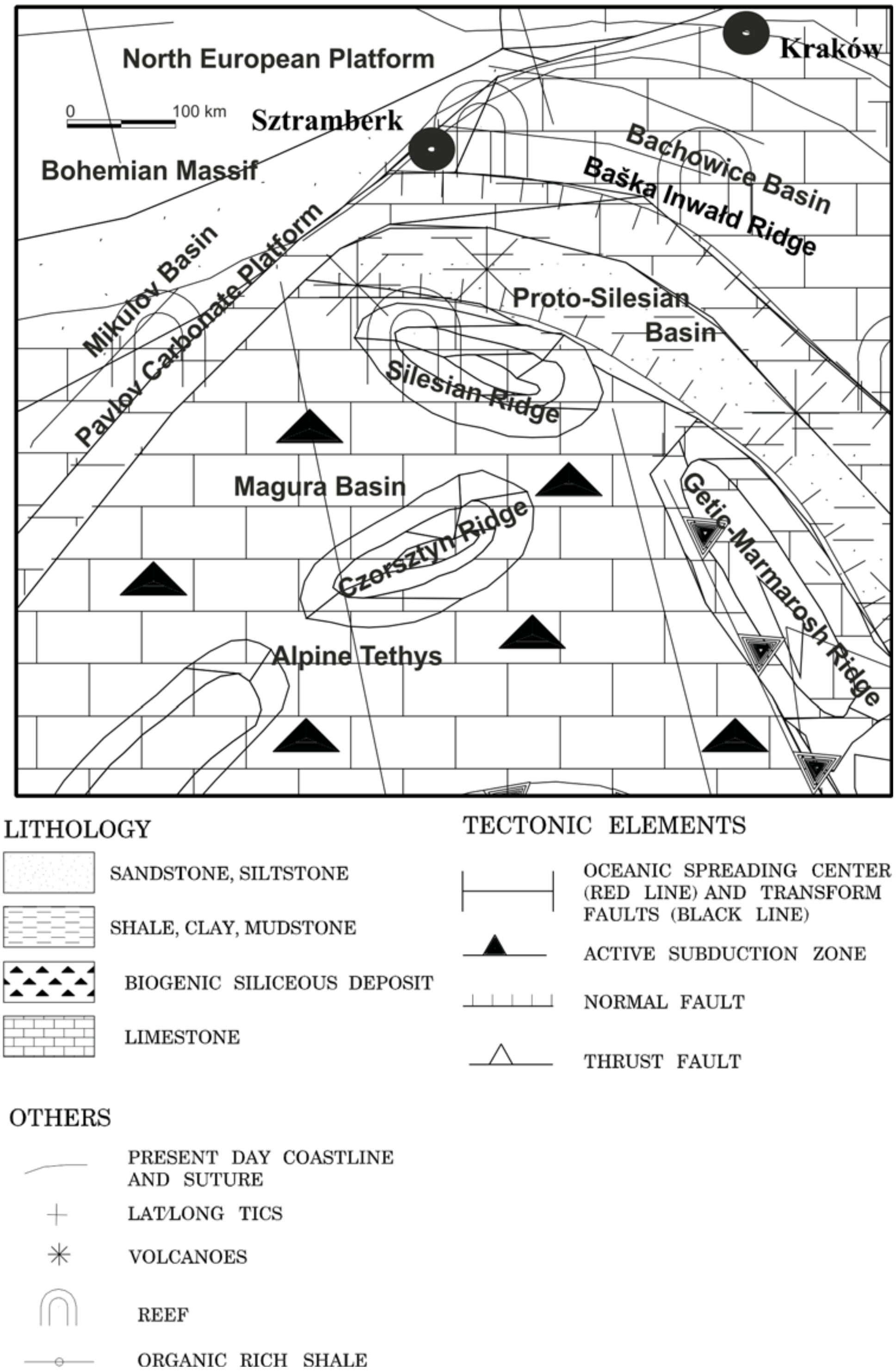

Figure 1. Paleolithofacies with main paleogeographical element of the West Carpathians and adjacent areas during the latest Jurassic – Early Cretaceous (from Golonka 2011, modified). Plate position 140 Ma.

platform sedimentation during Paleocene-Eocene times. Shallow water, probably narrow shelf locally was dominated by Paleocene and Eocene reefs built of red Corallinaceae algae Lithothamnium. Lithophyllum, Arhaeolithothamnium, Paleothamnium, Ethelia, together with bryozoans, brachiopods, sometimes corals and foraminifers. Patchily distribution of these faunas is confirmed by local occurrence of redeposited organic limestones within siliciclastic material.

The destruction of the Silesian Ridge

The oblique collision of the Inner Carpathian terranes with the North European Plate led to the farther development of the accretionary prism of Outer Carpathians during latest Eocene-

Early Miocene times.The front of the overriding Magura Nappe reached the Silesian Ridge, which collapsed as a result of the lithosphere flexure and in southern part of the Silesian Basin, in front of the advancing nappe huge olistoliths were deposited. The Silesian Ridge was destroyed totally and is known only from olistoliths and exotic pebbles in the Outer Carpathian flysch (Cieszkowski 2012 and references therein). They destruction is related to the advance of the accretionary prism. The outer, marginal part of the advanced nappes was uplifted during overthrusting. Big olistoliths glided downfrom the uplifted part of the nappes into the adjacent, more distal basins. The nappes became detached from the basement and were thrust northward in the west and eastward onto the North European platform with its Miocene cover. The Outer Carpathian allochthonous rocks, as result of Miocene tectonic movements, have been thrust over the platform for a distance of 50 to more than 100 km. The olistostromes formed during the final collisional and postcollisional stages are known from outcrops as well from numerous wells in the marginal part of the Northern Carpathians. Tectonic movements caused final folding and the Carpathian nappes became uprooted from the basement. The allochthonous flysch nappes were trust over the North European platform for the distance of 50 km to more than 100 km. Overthrusting movements migrated along the Carpathians from the West towards the East. The inner part of the platform, in the eastern part also with the marginal part of the flysch basin started to downwarp in front of the advancing Carpathians nappes and tectonic depression formed during the Early Miocene times. That basin became overthrust by the Carpathians. At the end of Burdigalian and a new, more external one, developed. Clastic and fine-grained sedimentation of the Carpathian and foreland provenance prevailed with a break during the Late Langhian to Early Serravallian, when younger evaporate basin developed. In the west, sedimentation terminated already in Langhian and in the east lasted till Pliocene. These events mark the postcollisional stage in the Outer Carpathian (Golonka et al. 2006; Ślączka et al. 2006).

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Structural and U/Pb zircon age data from Rila and Vlachina Mountains: implications for tectonic correlations of basement units from SW Bulgaria

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Abstract

The high-grade basement of Southwest Bulgaria is classically interpreted as parts of two separate Precambrian blocks, namely the Rhodope and the Serbo-Macedonian massifs that did not suffer Alpine metamorphism. The modern tectonic and regional geology interpretations consider the two massifs as parts of the Rhodope Metamorphic Complex, an Alpine syn-metamorphic nape stack which was formed during subduction and collision processes in the northern Thetian margin from Jurassic to Late Eocene times. The region of upper Struma River valley, Rila and Vlahina mountains are considered as an area where the boundaries between different tectonic zones of the internal parts of the Alpine Orogen of Balkan Peninsula can be observed. This is namely the Gabrov dol Fault that has been interpreted as a major detachment fault, a boundary between the Rhodope Massif in the foot-wall and the Kraishte Zone in the hanging wall. However, the tectonic affiliation of the high-grade metamorphic rocks that comprise the pre-Late Eocene basement of parts of Southwest Bulgaria and namely Northwest Rila and Vlahina mountains yet remains poorly understood. Here we present a combined structural and U/Pb zircon age study of high-grade metamorphic rocks constituting parts of the pre-Late Eocene basement of Northwest Rila and Vlahina Mountains and namely Kabul and Troskovo units. We are also trying to set the data in a regional tectonic frame and thus making an attempt for larger scale tectonic correlations. The high-grade basement of Northwest Rila and Vlahina mountains consists of lithotectonic units that underwent different as a grade and time tectono-metamorphic evolution. The highest part of the tectono-metamorphic pile consists of migmatized in Variscan time gneisses which are traditionally correlated with the Ograzhden (Vertiskos) type of basement that did not suffer Alpine metamorphism. Everywhere in the field this type of basement tectonically overlies the middle part of the metamorphic pile with a Late Eocene-Early Oligocene extensional low-angle shear zones (detachment faults). The middle part of the section (Kabul Unit in Northwest Rila Mountain and Troskovo Unit in Vlahina Mountain), which is an aim of this study consists of formerly migmatized variegated section (garnet bearing amphibolites, orthogneisses and schists) which in the deeper parts and away of the detachment faults have preserved their earlier penetrative high-grade foliation and stretching lineation and related top-to-the north-northwest tectonic transport. The U/Pb zircon age data from unaffected by the detachments deeper parts of both units show that they consist of similar in protolith age (~527 Ma) meta-igneous rocks (amphibolites and orthogneisses). In several samples, especially from Northwest Rila the metamorphic rims of the zircons show ages between 115 and 98 Ma and thus pointing to an amphibolite facies metamorphism in the Latest Early Cretaceous time. Kabul and Troskovo units overlie tectonically units of a typical Rhodope affinity. The latter is clearer in Northwest Rila Mountains where the contact between Kabul and underlying Maliovitsa Unit (Middle Allochthon) represents a top-to-the southeast synmetamorphic thrust, namely Dodov vrah Shear Zone. The shear zone is interpreted as a thrust since it is juxtaposing higher grade rocks in the hanging wall against lower grade ones in the foot wall. Dodov vrah Shear Zone overprints the penetrative high-grade foliation in Kabul Unit and was later affected by the Eocene-Oligocene extensional shear zones. The isoclinal folds pattern in Kabul Unit is most probably related to the thrusting along Dodov vrah Shear Zone. Top-to-the north sense of shear and the Early Cretaceous metamorphism in Kabul and Troskovo units differ significantly from the typical for the Rhodopes top-to-the south Late Alpine tectonic transport. However we interpret both units as an upper part of the Rhodope Metamorphic Complex (Upper Allochthon), which tectono-metamorphic evolution is similar to the evolution of the high-grade basement of Kraishte Zone. That poses a question on the Gabrov dol Fault as an upper boundary of the Rhodope Metamorphic Complex and enables correlations of tectonic units beyond the presently known boundaries of the complex.

Lithological, sedimentological and petrographical approach to understanding the origin of marls in the Outer Carpathian region

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Abstract

Measurement and sampling was carried out in the outcrops considered as the type localities. The marls selected represent 15 complexes of different age (Upper Jurassic-Oligocene) and location in the Outer Carpathian Basin (Skole, Sub-Silesian, Silesian, Magura and Dukla Units). Marls from the Outer Carpathians show variation in field appearance, therefore the description of these rocks has been standardized and the marls were grouped into four lithotypes on the basis of field characteristics: (1) limestone-like, (2) shale/claystone-like, (3) chert-like, and (4) mudstone-like. These marl lithotypes can be found in a variety of colours such as variegated and red, light and dark brown, greenish and bluish gray, and black. The marls form mono- or polilithic complexes with thicknesses of 5 to 500 m, and up to 2000 m, respectively. The marls are considered as sediments redeposited from shelf-related areas to the deeper parts of the basin. On the basis of Ghibaudo's (1992) facies interpretation, the marls are inferred to have formed under fluctuating depositional conditions marked by periods of current activity (traction transport and reworking of sediments by bottom currents), alternating with periods of suspension settling. Some of the marls studied were redeposited from shallow-water areas as olistoliths. The lithology of marls is a record of similar depositional processes operating repetitively at various periods with varying intensity in different portions of the Outer Carpathian Basin. In the marls wackestone textures prevail. The matrix of all samples studied is composed of coccoliths debris altered to various degree, clay, nano-quartz, occasionally opal CT, and calcite authigenic in appearance (mostly overgrowths on coccolith shields), which serve as cementing agents. The high resolution petrography (FESEM/BS) reveals that the most constituents of the Outer Carpathian marls have been modified or produced by diagenetic processes. The thin-section petrography reveals that the alteration processes attributed to the eogenetic stage of diagenesis were enhanced by reworking and redeposition of unconsolidated starting material for the rock studied. The primary components of the Outer Carpathian marls were calcareous bioclasts (mostly nanofossils with minor microfossils), siliceous fossils (mostly sponge spicules), and clastic material, mostly volcanic in origin. The mode of occurrence of some clay aggregates suggest them to be formed by alteration of volcanic glass shards disseminated within minute bioclastic material. The occurrence of quartz grains that are wedge-, splinter- and cuspate in shape and of volcanogenic indices minerals (euhedral biotite, apatite and zircon) in the marls studied is natural tracer of primary presence of pyroclastic material within starting sediments for these rocks. This paper argues that: (1) marls deposited at various time and accumulated in various parts of the Outer Carpathians basin are in general similar in microscopic images; (2) this has shown that the provenance of clastic components for marls studied was similar and cannot be tied to a particular source area; (3) initially petrogenetically similar material, both bioclastic and clastic in origin, were transported to starved basins and deposited under similar sedimentary conditions; (4) original sediments for the marls were mostly composed of coccoliths debris with various amounts of admixed pyroclasts and scarce terrigenous particles; (5) based on the provenance studies, the marls from the Outer Carpathians are referred to as dirty chalk deposits, which contain various amounts of non-calcareous material; (6) the marls underwent pervasive diagenetic alteration; (7) non-calcareous constituents of the marls such as clay and silica originate mostly from the alteration of volcanic glass; (8) the composition and fabric of the marls make them important as indicators of past depositional conditions favorable for deposition of dirty chalk facies in the Outer Carpathian region; these were formed in starved sub-basins under conditions of volcanic and tectonic activity related to the opening, reconstitution and closing stage of the Outer Carpathian Basin.

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The paleotectonic significance of the Cretaceous ophiolitic mélange and blueschists in the Turkish Thrace

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Abstract

Ophiolitic mélange and blueschists, representing a Cretaceous subduction-accretion complex, crop out in southern Thrace along the North Anatolian Fault. They are unconformably covered by the Eocene-Oligocene sediments of the Thrace basin. The ophiolitic mélange and blueschists were interpreted as representing the Intra-Pontide suture, which separates the İstanbul and Sakarya zones. However, they are located between four major terranes: the Rhodope Massif, the Strandja Massif, the Istanbul Zone and the Sakarya Zone, and it is not clear, as to which Cretaceous ocean they initially belonged.

Our studies in the southern part of the Thrace basin, have shown that the Upper Eocene basinal sediments rest unconformably over two types of basement: ***(1)*** Slate, dark limestone and phyllite crop out in small inliers under the Upper Eocene (?) conglomerates and Upper Priabonian limestones in the Mecidiye region north of Saros Bay. These low-grade metamorphic rocks form the eastern extension of the Circum-Rhodope Belt of Greece. ***(2)*** In the Şarköy region south of the Ganos Fault a tectonically uplifted basement consisting of serpentinite, metadiabase and Upper Cretaceous blueschists is unconformably overlain by Upper Eocene (Lower Priabonian) limestones. The blueschist metamorphism has affected oceanic lithologies and occurred in an oceanic subduction zone. Both Rb-Sr phengite-whole rock and incremental ^{40}Ar-^{39}Ar phengite dating from the blueschists consistently yielded age values of ~86 Ma, indicating that the blueschist-facies metamorphism took place during Late Cretaceous (Coniacian-Santonian), and there is a time lag of ~45 Ma between the blueschist-facies metamorphism and the overlying sandstone-shale sequence. Hydrocarbon wells south of the Ganos Fault have also encountered a basement of ophiolitic mélange under the Eocene siliciclastic rocks or limestones. The Ganos Fault, the segment of the North Anatolian Fault in Thrace, forms the boundary between the two basement types. During the Late Palaeocene - Early Eocene the ophiolitic mélange was tectonically emplaced northward over the low-grade metamorphic rocks of the Circum-Rhodope belt. The ophiolitic mélange is overlain by Upper Eocene limestones and flysch sequence including debris flows and olistostromes. The clasts in the flysch sequence include Eocene (Ypresian, Bartonian and lower Priabonian) shallow-marine limestone, Cretaceous and Palaeocene pelagic limestone, serpentinite, basalt, gabbro, greywacke, quartz-diorite and greenschist. They range in size from sand grains to olistoliths up to one kilometre wide. Some of the olistoliths are composite and include pelagic limestone or basalt unconformably overlain by Upper Eocene (Priabonian) limestone. The Upper Eocene mass flows were formed in an extensional setting and were derived from the south from the flanks of large normal faults related to the opening of the southern Thrace basin. Although the basement of the southern margin of the Thrace basin consists of an ophiolitic mélange, regional tectonostratigraphy indicates that the Intra-Pontide suture passes through the Biga peninsula. The Sakarya Zone terminates in the centre of the Biga peninsula and sequences to the west of the Cetmi ophiolitic mélange belong to the Rhodopes.

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Triassic radiolarians from the "Ophiolite mélanges": implications for the geodynamic evolution of the north-western part of the early Mesozoic Neotethyan subbasins

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Abstract

The Ophiolite mélanges of the Balkan Peninsula provide one of the most important clue for reconstruction of the geodynamic evolution of the Mesozoic Neotethys. This geological unit can be followed through eight different countries (Greece, Albania, Former Yugoslav Republic of Macedonia, Bosnia, Serbia, Croatia, Hungary and Slovakia). In addition, comparable units (although in several dissimilar aspects) are exposed in the Internal Western Vardar Ophiolite Belt which were referred to under a variety of names in the former literature such the Vardar Zone Western Belt or Inner Dinaridic ophiolite belt etc. The difficulty is that this belt connected to the External Western Vardar Ophiolite Belt (Dinaride Ophiolite Belt), geographically while it preferably relates in the lithology, in the age of metamorphic sole, in the geochemical composition and several other to the Eastern Vardar Ophiolitic Unit (Main Vardar Zone or Central Vardar Subzone). The presence of the isolated Jadar – Drina-Ivanjica – Korabi-Pelagonian zone within the Internal Western Vardar Ophiolite Belt spawned two significantly different geodynamic models: a single Mesozoic Tethyan ocean vs. multiple oceanic basins with microcontinents. Radiolarian micropaleontologic investigation has proven that this group is particularly useful for biostratigraphic dating in such sequences where the deep-sea sedimentary units are connected with volcanics. In most geodynamic reconstructions suggested onset of ocean seafloor spreading from Middle–Late Triassic time. New radiolarian biostratigraphical data from several localities of Dinaride Ophiolite Belt (DOB) from Serbia and its equivalent, but dismembered DOB unit from Hungary (Darnó and Szarvaskő Complex) and from a single locality of Vardar Zone Western Belt is presented. In all investigated area, the radiolarites connected, overlain directed or intercalated with ocean-ridge related basalts. The samples from radiolarite localities in the Darnó and Szarvaskő Complex contains Middle (Illyrian to Longobardian) and Upper (Carnian) Triassic fairly poor preserved radiolarian assemblages, simultaneously. The investigated radiolarite samples from Dinaride Ophiolite Belt and from Vardar Zone Western Belt yielded Upper Triassic (Carnian-?Norian) poorly preserved radiolarians. Co-occurences of Middle and Upper Triassic radiolarian specimens in Darnó and Szarvaskő Complex presumes the resedimentation during the Carnian time or posteriorly. The radiolarian biostratigraphic data confirm that Neotethyan rifting started in the Anisian (Illyrian) in the western ophiolite belt of Balkan Peninsula (Maliak-Mirdita-Dinaridic Ophiolite Belt) and its dismembered units (Kalnik-Darnó and Szarvaskő-Meliata), as well. However, each of the remnants of Triassic oceanic crust (from early-rift related through rift/ocean transition to MOR-type) are preserved in a mélange blocks, presumably those formed in a continuous belt from Greece to the dismembered Darnó-Szarvaskő Complex – Meliata units. This supposes a single Triassic Ocean (since Anisian) between the Adriatic – Dinaridic and Jadar – Drina-Ivanjica – Korabi-Pelagonian zone. The Middle and Late Triassic period is characterized by the closure of Paleotethys and the westward opening of Neotethys by rifting/initial spreding and the first radiolarites appereances from Illyrian (Anisian, Middle Triassic). During the Middle Triassic (from Illyrian to Longobardian) kept on the radiolarites deposition associated with MORB-type oceanic crust forming. Tectono-sedimentary mélange formed from the Middle Jurassic time including olistholites as the Lower and Middle Jurassic continental fragments from Adriatic-Dinaridic carbonate platform, the Middle and Upper Jurassic allodapic limestones with radiolarite intercalations and the Middle and Upper Triassic oceanic crust fragments, set in a siliciclastic matrix. Ultrmafics, gabbros, diabases and basalts intruded into this tectonosedimentary mélange from Middle Jurassic (probably Bajocian) that can be interpreted as suprasubduction complex. In the Late Jurassic-Early Cretaceous the closuring continued with strong deformation/metamorphism which attests synsedimentary thrusting of ophiolite complex (Szarvaskő unit) onto the continental fragment (Bükk Parautochthonous Unit), although there is no direct evidence for their boundary. The present-day situation of the Darnó and Szarvaskő Complex evolved by strike-slip movements along the Mid-Hungarian Zone during the ?Cretaceous and Tertiary.

Subduction polarity in the Hellenides

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Abstract

Subduction of oceanic and continental lithosphere has been a major geodynamic process throughout the Meso-Cenozoic history of the Hellenides. It is well known that the general asymmetry of the Hellenides has been the eastward subduction of the African/Tethyan plate below the European/Hellenic plate, which gave rise to the development of orogenic arcs in the active European continental margin including fore-arc basins, island arcs, back-arc basins and volcanic arcs. Additionally, fold and thrust belts with westward asymmetry were developed along the frontal zone of the upper plate including the obducted ophiolites during the microcollision events. However, based mainly on the internal structure of some ophiolite belts in the Hellenides, opposite westward subductions and tectonic emplacement of ophiolites have been proposed by some authors especially for Late Jurassic events involving the Pelagonian realm. Taking into account the existence or absence of orogenic arcs to the west or to the east of the assumed subduction in each case/period, we can conclude that only orogenic systems with eastward subduction can be detected along the history of the Hellenides. The polarity obtained from the fold and thrust belts during Late Jurassic – Early Cretaceous shows tectonic vergence either to the west or to the south-southeast as observed in the cases of Lesvos, Southern Vermion Mt and Viotia. Post-emplacement rotations of large blocks due to strike-slip movements during the Tertiary may have reoriented these early Mesozoic structures anticlockwise by 30-50^o. In any case, the interpretation of the seismic tomographic data across the Hellenides orogenic belt show that a steady northeastward subduction polarity can be detected at least for the Late Cretaceous-Present period and possibly also extending for the Jurassic-Early Cretaceous period.

The independent post-Attican evolution of the Pannonian Basin inside the Paratethys area

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Abstract

The independent evolution of the Pannonian Basin inside the Paratethys area began during the Attican phase and it is distinguished by the individualisation of two endorheic stages separated by a non-endorheic one, corresponding to the Portaferrian (Middle Pontian) of the regional stratigraphic chart of the Dacian Basin. The first endorheic stage corresponds to the Pannonian (narrow sense) and the second to the Pliocene, but it starts before it and ends during the Pleistocene (in Pasadenian phase). The non-endorheic stage was preceded by intermittent paleogeographic links, which do not descent below to the lower limit of the Pontian, and this was followed by ties of the same type until the middle of the Upper Pontian (Bosphorian). The links with the Dacian Basin during the Pontian justifies the use of a local stratigraphic chart for the Pannonian Basin, based on the regional chart of this neighbouring basin. The independent evolution of the Pannonian Basin was also marked by the eustatic effects of the Valach (Wallachian) climatic cycle (Țicleanu et al. 1998). The non-endorheic stage coincided with a warm phase of this cycle and ended during a new cold phase of the Valach cycle by the end of Pontian. During the second endorheic stage, i.e. during the Pliocene warm phase of this cycle, the links with the eastern basins have not been resumed and a new cold phase (Quaternary glaciations) favoured also this isolation. But, finally, he was reinstated in the hydrographic basin of the Black Sea through successive captures of rivers from the direction of the Dacian Basin. However, a relict Pannonian Lake maintained in the SE part of this basin until the end of the Pleistocene, with a severe limitation at the beginning of the Holocene. So, the hydrographic network of the Middle Danube Depression was completed only in Upper Holocene.

Keywords: *isolation, endorheic basin, Pannonian (Malvensian), paleogeographic links, Pontian*

Introduction

The reassessment of the geological data regarding the Mio-Pliocene deposits from the eastern part of the Pannonian Depression allows us to reconsider the period of independent evolution of the Pannonian Basin in relation to the Paratethys area, subsequent to the Attican phase (11.48 ma). This approach takes into account a new temporal perspective on the Neogene tectonic phases (Țicleanu 2013), but also on the climatic phases (with eustatic implications) of a cycle (4.1 ma period) that marked the Neogene from all points of view (Valach climatic cycle, Țicleanu et al. 1998, 2005). The independent evolution of this basin, marked by the succession of two endorheic stages, justifies the acceptance of an own stratigraphic local chart proposed by several authors (among them Papaianopol et al. 1995), scheme based on the connections with Dacian Basin. In this context the last moments of this basin whose endorheic character seems to have remained until the Pasadenian phase (1.23 ma), seem very interesting. These last moments (Upper Pleistocene and Lower Holocene) may also interfere with old mythical information (as Plato's Atlantis).

Stratigraphic considerations

Thanks to the secure links with the Dacian Basin in Upper Miocene (in Pontian) it is useful to use a specific stratigraphic local chart for the Pannonian Basin, conceived in relation to the regional stratigraphic chart of the eastern Mio-Pliocene basins of the Paratethys. In relation to the latter chart is important to note that the isolation of the Pannonian Basin, as a consequence of the Attican phase, occurred during the Middle Sarmatian (in Bassarabian). In relation to this reality the post-Badenien deposits of this basin, accumulated before Attican phase, may be reported to the stratigraphic interval Volhynian–Lower Bassarabian, corresponding to the Suess's Sarmatian. More deposits are separated, which are reported to the Pannonian (narrow sense) corresponding to the interval Upper Bassarabian-

Kersonian-Meotian. This interval is designated also with a stratigraphic equivalent term, Malvensian, proposed by Motaş and Marinescu (1972). The Pannonian (Malvensian) includes the bio-zones A-E (Papp), defined in Vienna Basin, respectively the Slavonian ones, corresponding to the bio-zones A-D, and the Serbian one (bio-zone E). The resumption of the links with the Dacian Basin at the end of Pannonian let us separate the Pontian stage (pro parte), in Pannonian facies. This is not entirely equivalent to the Pontian of the Dacian Basin because it lacks the final part, namely the upper part of the Bosphorian. The Pontian of the Pannonian Basin would include the sub-stages Novorossian (equivalent to the Odessian), Portaferrian and Viminacian (equivalent to the lower part of the Bosphorian). Over the Pontian deposits there are disposed, often concordant, the Paludines Beds corresponding basically to the Pliocene in Pannonian facies. However it includes the terminal Pontian of the eastern basins and this corresponds to the interval Upper Bosphorian-Dacian and Romanian of the Dacian Basin. Over the Pliocene deposits it could be separated Quaternary ones, accumulated in a proper endorheic basin at least till the Pasadenian phase (1.23 ma) when practically started the gradually draining of the Pannonian Lake from the former Dacian Basin.

The first endorheic stage of the Pannonian Basin (Upper Miocene)

This stage begins with the Attican phase (Middle Sarmatian) and was caused by tectonic factors. This moment is confirmed by Borgh et al. (2012), proposing the isolation in two steps (at 11.6 and 11.3 ma). In relation to the Valach cycle this moment of isolation occurs in the middle of a warm phase, favourable for positive links among the basins of the Paratethys. The most visible result of this isolation was the changing of the faunas because of the lowered salinity waters. From the Sarmatian fauna with Mactra (persisting in the eastern basins) they switched to a fauna with Congeria, accompanied by other species of sweetened waters. The next cold phase of the Valach cycle (corresponding to the Meotian, namely to the final part of the Pannonian) favoured, by eustatic way, this isolation. The Late Attican phase had not as effect the resumption of ties with the eastern basins. These links resumed, intermittently, at the beginning of the Pontian and during the Middle Pontian (Portaferrian) these links were maintained permanently. This first endorheic stage corresponds to the Pannonian and, by reference to the Dacian Basin, to the Upper Bassarabian-Kersonian-Meotian interval. It may be admitted a continuity of sedimentation after this isolation, being very unlikely the imposition of a long post-Volhynian continental period on the western edge of the Apuseni Mountains, as supposed by some authors (Paucă 1954 and Istocescu 1971).

Non-endorheic Pontian stage

Permanent secure links between the Pannonian Basin and the Dacian Basin based on species frequency (molluscs) may be accepted without reserves for the duration of the Portaferrian sub-stage. These connections culminate with the presence of the characteristic species Congeria rhomboidea over large areas in both basins (Istocescu et al. 1971). It seems that during the warm phases of the short cycle of orbital eccentricity (100,000 years period) it were allowed intermittent connections among these basins starting from the temporal level of the Meotian-Pontian limit (Pannonian–Pontian in Pannonian Basin). In all this time the waters loaded with salts of the eastern basins were compensated, in part, the freshwater intake dominant in the Pannonian areas. During the Middle Pontian the salinity of the Pannonian waters was much closer to the salinity of the waters of the eastern basins. But after this period of common evolution of the Paratethys it took place, in Bosphorian, a new isolation of the Pannonian Basin. It has mainly climatic causes: the retreat of the shores because of a new cold phase of the Valach cycle. However, it is assumed that the warm phases of the short cycles of orbital eccentricity caused temporary connections with the waters of the Dacian Basin, but to the end of the Miocene the Pannonian Basin was isolated again.

Second endorheic (Pliocene) stage of the Pannonian Basin

This new stage is somehow longer than the first one and corresponds to the interval Upper Bosphorian-Pliocene and Lower Quaternary. The imposition of this new phase may be related to climatic causes: the scrolling of a new cold phase of the Valach cycle, phase which will culminate at the temporal level of the Mio-Pliocene limit (which corresponds to the Rhodanian phase). It is important to note here that neither a new warm phase of this cycle (Pliocene phase), nor a new phase of diastrophism (intra-Pliocene, 3.28 ma) could not lead to a resumption of ties with the Dacian Basin. More than this, the Wallachian phase (2.58 ma), although far stronger, had not effect in this sense. It should be noted, however, that the coaly facies placed at the median level of the Pliocene by the last warm phase of the Valach cycle can be identified in the Dacian Basin, but also in the area of the Pannonian Basin. In relation to the Dacian Basin the interval covered by this facies is clear: Upper Dacian-Lower and Middle Romanian. Furthermore, the containment of the Pannonian Basin was seriously favoured by a last cold phase of the Valach cycle, cold phase which has imposed the Quaternary glaciations. However, before the coldest moments of this phase (dictated by the cold phases of the short cycle of orbital eccentricity) it took place the reintegration of the Pannonian Basin in the area of the eastern basins, most likely from the time of the Pasadenian phase. This reintegration was achieved gradually after the capture, tectonically facilitated, which took place along the present Gorge of the Danube in the section called Greben.

The Relict Pannonian Lake

The detailed analysis of Quaternary deposits in the eastern part of the Pannonian Depression suggested the idea of the survival of a lacustrine area until the end of the Upper Pleistocene (Ţicleanu et al. 2006, 2010a). At that moment, a lake with the shoreline at about + 100 m (called by us "Relict Pannonian Lake") can be identified in south-eastern part of the Pannonian Basin. It is assumed that during the glacial phases it were registered severe regressions of the shorelines of the Pannonian Lake, with transgressions during interglacial phases. The Pasadenian phase could mark the beginning of the reintegration of the Pannonian Basin alongside the areas of the Paratethys, reality dashed by the penetration of the Greben saddle, followed by successive captures of rivers tributaries of the Pannonian Basin. A final obstacle along the future Gorge of the Danube seems to have been connected to the karstic area Cazane (Ţicleanu et al. 2010 b). But finally the surface of the Relict Pannonian Lake declined sharply at the moment of the Pleistocene-Holocene limit.

The Pannonian Depression during Holocene

The beginning of the Holocene can be marked by the existence of a successor of the Relict Pannonian Lake with an initial elevation of the shoreline at about +85 m. Its surface was much reduced than the surface of the Relict Pannonian Lake, while the outline of the shorelines was more tortuous. Through successive transformations in swamps this successor was severely limited so that at the end of Holocene it was completed the present hydrographic network of the Pannonian Depression, marked particularly by the way of the Danube river. The last relict lake areas, with few exceptions, became swamps in historical times and the way of the Danube through the Gorge has become easier continuous, being affected also in the last centuries by human interventions.

Conclusions

The independent evolution of the Pannonian Basin inside the Paratethys area started during the Attican phase, the isolation of this basin being by orogenic nature. This period of time includes two endorheic stages, separated by a non-endorheic stage temporally centred on the Middle Pontian, defined as a stage of resumption of the ties with the Dacian Basin. The first endorheic stage corresponds to the Pannonian and the second one corresponds mainly to the Pliocene. This reality allows us to use a local own stratigraphic chart of the Pannonian Basin, having common intervals with that of the Dacian Basin, but allows also the treating of its evolution in close connection with the life of the Dacian Basin. The non-endorheic stage appears to be preceded by intermittent links with the eastern basins (ties which does not descent under the lower limit of the Pontian), but it can be imagined moments of the same type subsequent to the non-endorheic stage, which do not surpass the middle of the upper sub-stage of the Pontian (= Bosphorian). The second endorheic stage was determined by the climatic causes and most likely ended during the Pasadenian phase, at the beginning of the Quaternary glaciations. The loss, in Pleistocene, of the endorheic character of the Pannonian Basin (successive captures of rivers from the direction of the Dacian Basin), did not lead to the disappearance of the Pannonian Lake. For this reason until the end of the Upper Pleistocene in the south-eastern part of the Pannonian Basin it was possible the maintaining of a lacustrine area (Relict Pannonian Lake) that separates the present course of the Danube in two distinct segments. This relict lake was then severely limited at the beginning of the Holocene and the hydrographic network of the Middle Danube Depression was completed in Upper Holocene.

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Ophiolites: Their Magmatic Evolution and Emplacement Mechanisms

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Abstract

Ophiolites display significant variations in their internal structure, geochemical fingerprints and emplacement mechanisms. These differences are controlled by (a) the proximity of their tectonic setting of magmatic construction to plumes or trenches; (b) rates, geometry and nature of spreading; (c) mantle compositions, temperatures and fertility; and, (d) the availability of fluids in these environments. The oceanic crust preserved in ophiolites may form in any tectonic setting during the Wilson cycle evolution of ocean basins from rift-drift and seafloor spreading stages to subduction initiation and terminal closure. We classify ophiolites to the first order as subduction-related and subduction-unrelated types. Those ophiolites whose magmatic construction was not affected by subduction processes include continental margin (CM), mid-ocean ridge (MOR) and plume-type (P) ophiolites (Table 1). These types correspond to the ophiolites developed at 'normal' mid-ocean, plume-related mid-ocean, continental margin, and subducted ridges. Subduction-influenced ophiolites include suprasubduction zone (SSZ) and volcanic arc (VA) ophiolites (Table 1). The SSZ types encompass the ophiolites formed in subduction-initiation and backarc basin ridges. The occurrence of ophiolites in orogenic belts are a product of two important factors: (1) tectonic, magmatic and geochemical processes of ophiolite formation, and (2) preservation of ophiolites as a result of different emplacement mechanisms and post-emplacement processes. An ophiolite is emplaced either from a down-going oceanic lithosphere via subduction-accretion or from the upper plate of a subduction zone through trench–continent collision. Subduction zone tectonics is thus the most important factor in the igneous evolution and emplacement of ophiolites into continental margins.

Table 1. Ophiolite types and representative examples with their geochemical affinities and major mineral phases (From: Dilek and Furnes 2014, Elements 10, 2, 93-100).

Ophiolite Types & Their Tectonic Settings			Ophiolite/Modern Examples	Geochemical Affinities	Crystallization Order of Minerals
Subduction –unrelated	Continental margin type		Ligurian and Western Alpine ophiolites; Jormua (Finland)	N-MORB, E-MORB, P-MORB & C-MORB lavas	Olivine + plag + cpx
	Mid-ocean ridge types	Plume-distal MOR	Macquarie Ridge; Masirah (Oman)	N-MORB (DMM) to E-MORB lavas	Olivine + plag
		Plume-proximal MOR	Iceland	N-MORB and P-MORB lavas	Olivine + plag ± cpx
		Trench-proximal MOR	Taitao (Chile)	N-MORB, E-MORB ± C-MORB lavas	Olivine + plag + cpx
	Plume-type		Nicoya (Costa Rica); Bolivar (Colombia)	P-MORB lavas	Olivine + plag + cpx ± opx
Subduction–related	Suprasubduction zone types	Forearc	Troodos (Cyprus); Kizildag (Turkey); Semail (Oman); Betts Cove (Canada)	FAB (MORB-like), IAT to boninite lavas	Olivine + plag + cpx + opx and Olivine + cpx + plag
		Backarc (continental & oceanic)	Rocas Verdes (Chile); Solund-Stavfjord (Norway)	BABB lavas	Olivine + plag + cpx and Olivine + cpx + plag
	Volcanic arc type		Smartville (California); Itogon (Philippines)	IAT to CA lavas; middle crust with tonalite, diorite	Olivine + plag + cpx and Olivine + cpx + plag

The boninites as part of the Albanian ophiolitic magmatism

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Abstract

Boninites were first recognized as part of the Albanian ophiolitic magmatism by Shallo (1990) and later described in more detail by Shallo (1994, 1995), Manika (1994), Beccaluva et al. (1995), Gjeçi and Shallo (2006) and Gjeçi (2008). Boninites occur within the Eastern Albanian-type ophiolites as part of their volcanic sequences (e.g., at Perlat, Rrenjolle, Reps, Spaç, Koderspaç, Gurthspaç, Munelle, Letiten, Gur i Zi etj Simon-Kaçinar, Paluce, Preçaj, Helshan), and sheeted dike complexex (Reps, Spaç, Rrenjolle, Lak, Roshi-Qafe, Mali-Lajthize,Vau, Spas, Helshan). Some boninitic rocks also occur in the gabbro–plagiogranite sequence in the upper part of the Kaptena massif in the Fan-Shemri region, in the gabbro-plagiogranite massif of Shemri and very rarely in the uppermost part of ultramafic intrusions in the Western part of the Shebenik massif, between the two ophiolitic belts (Gojan and Shkoze) in the Puke region. Boninites are also found in the uppermost part of the mantle sequence in the Tropoje, Kuksi and Bulqiza massifs. Boninites and high-Mg basalts in the volcanic units are localized in the upper parts as pillow lavas, massive flows and volcaniclastites, where they are interlayered with andesitic basalts, andesites, dacites and rhyodacites. The extrusive boninites and boninitic dikes are all fine-grained rocks, gray to dark gray in color with phyric, microphyric, vitrophyric and vesicular textures. Phenocrysts are mostly clinopyroxene, with rare orthopyroxene and olivine; plagioclase phenocrysts are absent. Rare microphenocrysts of chrome spinel may also be present. The groundmass is either glassy or microcrystalline with very small grains of orthopyroxene, clinopyroxene and plagioclase, sometimes accompanied by grains of chrome spinel. The glass is commonly partly to completely altered to mixtures of chlorite, carbonate and zeolite. On the basis of their petrographic characteristics the volcanic boninites of Albanian are most similar to those of Chichi Jima, Japan. (Kuroda et al. 1996). The clinopyroxene is endiopside with compositions of $Wo_{38.5-43.6}En_{51.0-53.4}Fs_{5.12-8.69}$ with $Cr_2O_3 > 0.5$ wt.%, and the orthopyroxene is enstatite-bronzite with a composition of $Wo_{18.1}En_{80.6}Fs_{3.3}$. Whole-rock chemical compositions show very low (<0.45 wt.%) TiO_2, low CaO/Al_2O_3 ratios (average 0.5), high (>7.5 wt.%) MgO and low ∑REE contents. Boninites of the Eastern (SSZ)-type ophiolite of Albania are mainly low-Ca, according to the classification of Crawford et al. (1989). Geochemically, the boninites of eastern Albania are generally similar to those of Cape Vogel, Chichi Jima, Mariana Trench, Baja California and Cyprus, but show some differences in major oxides (Fig. 1). However, they are very similar in their trace element compositions to boninites of Cape Vogel, Chichi Jima and the Mariana Trench (Fig. 2).

Key words: *boninites, Albanian ophiolites, geochemistry*

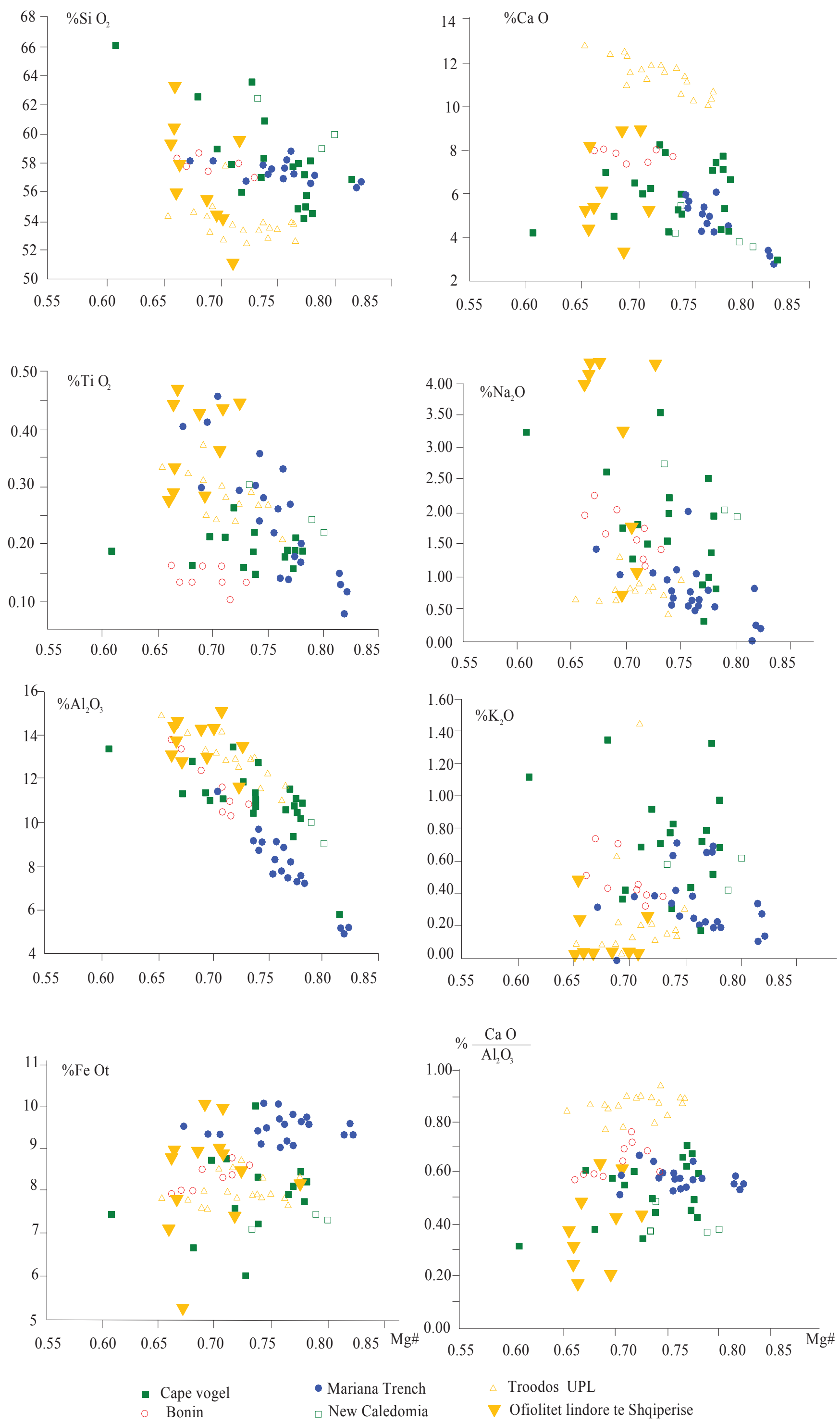

Figure 1. Major oxides vs. Mg# for boninites from the Eastern Albanian ophiolite compared with boninitic suites from Cape Vogel, Bonin islands, Mariana Trench, New Caledonia, and Troodos ophiolite, Cyprus (UPL), after Gjeçi (2006) based on data from Crawford et al. (1989); Shallo (1994, 1995); Beccaluva et al. (1989); Milushi, et al. (1990); Manika (1994).

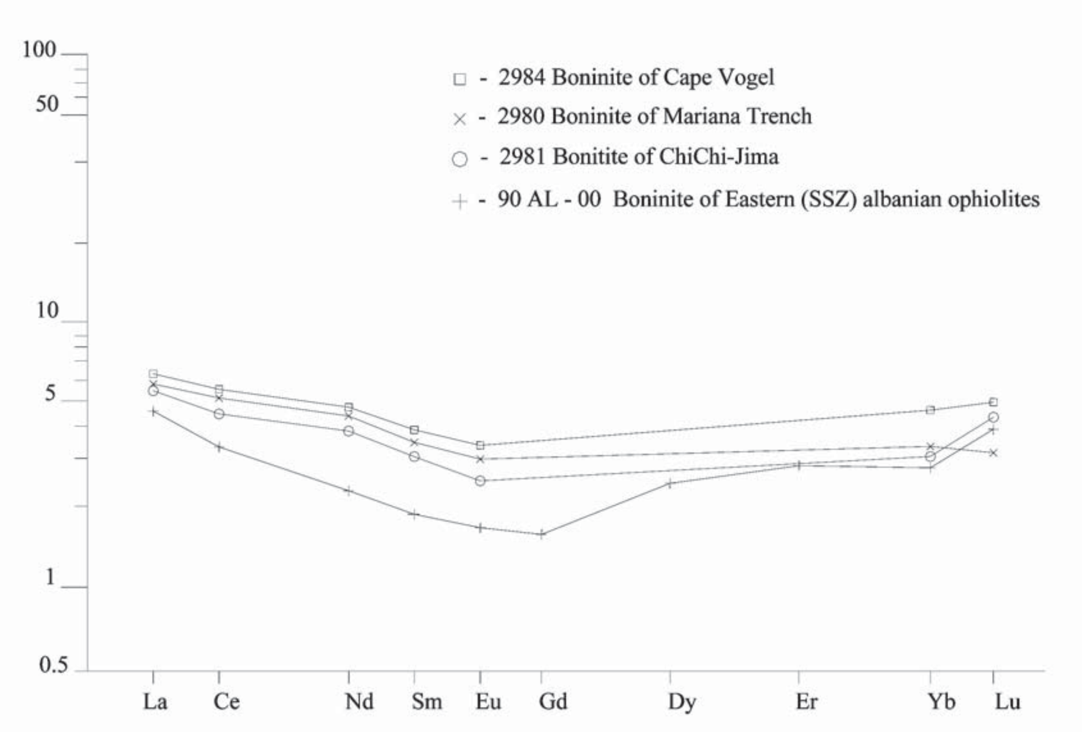

Figure 2. Chondrite-normalized, REE diagram comparing boninites of the central Mirdita ophiolite, Albania with those from Chichi Jima, Mariana Trench and Cape Vogel, after Gjeçi 2008.

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Platinum group elements mineralization in Albanian ophiolites

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Abstract

The platinum group elements (PGE) potential of ophiolites is less well known than their chromium potential. Local Pt and Pd anomalies are known in mantle or in cumulate rocks from the Philippines, Shetland Islands, Norway, Quebec, Oregon, the Urals (Siberia) and Albania.

In Albania, the Bulqiza and Tropoja massifs, which have high chromite potential, are part of the eastern ophiolitic belt that has strong similarities with immature island arcs.

Four types of PGE mineralization, two in the mantle and two in the cumulate section, are defined in these massifs according to their stratigraphic position and their geochemical and mineralogical characteristics, as follows:

1. Os, Ir and Ru mineralization in mantle rocks. This type of mineralization, with low Pt and Pd contents (<1 ppb), is related to deep-seated chromite deposits, as is usual in ophiolites.

2. Platiniferous mineralization in mantle rocks. This is associated with chromite deposits located in the upper part of the mantle in the Bulqiza massif. (Pt + Pd) contents may reach 0.8 ppm and the Pt/Pd ratio is greater than 1. Platinum group minerals (PGM) are generally included in chromites or occupy interstitial positions together with some base metal sulphides (BMS), especially pentlandite. The sulphides are later transformed locally into PGE-rich alloys. Pt- and Pd-bearing phases are sperrylite and braggite, the former indicating appreciable As activity. This kind of mineralization resembles Pt-enriched chromites from Shetland, Quebec, Norway, the Urals and Siberia

3. Palladiferous mineralization in cumulates. This is related to interstitial pentlandite in supra-Moho dunite. Base metal sulphides (BMS) and chromites lie in the layering plane. (Pt+Pd) contents are sub-economic (8.7 g/t) and the Pt/Pd ratio is always less than 1 (0.3<Pt/Pd<0.6). PGM are rare. Most of the PGE must be in the pentlandite crystals which would have PGE contents lower than the detection limit of the electron microprobe.

4. Platiniferous mineralization in cumulate rocks. This is associated with chromites precipitated at the boundary layer between the basal dunite and pyroxenites. Many pegmatitic pyroxenite and chromite dykes are associated with magmatic breccias. As in type 3, (Pt + Pd) may reach 9.1 g/t and the Pt/Pd is always high (up to 60). PGM, essentially (Pt, Fe) alloys, occur in chromite grains or in interstices where their size reaches 60 µm. Rh-rich isoferroplatinum is the high-temperature phase followed by tetraferroplatinum, becoming copper-rich with decreasing temperature of equilibrium. The latest phases are tulameenite and alloys with empirical formulae close to PtCu malanite (CuPt) and bowieite (Rh, Ir) together with sulpharsenides. In Quebec and Siberia, platiniferous mineralization in cumulates shows similar characteristics, specifically the presence of chromite breccias and (Pt, Fe) alloys, and a Pt/Pd ratio higher than in layered complexes.

An investigation of sulphide or sulphoarsenide deposits as possible sources for PGE by Neziraj showed increased values of these elements (from 0.35 in pyrites to 1.4 % in nickelites) almost in all such deposits. Most of the enrichment is due to increased values of Pt, and to a lesser extent, to Ir, Os and Pd.

PGE mineralization in the Bulqiza massif was formed at higher fS_2 than in the Tropoja massif. In the Bulqiza massif, the three types of PGE mineralization, at three stratigraphic levels, indicate PGE fractionation from the mantle to cumulates as marked by the variation of (Pt+Pd)/ (Ru+Os+Ir) and Pt/Pd ratios. The PGE mineralization was emplaced with decreasing temperature, from about 1000 °C in mantle rocks to about 500 °C in dunite.

The distribution of PGE concentrations is controlled essentially by magmatic parameters although sub economic contents in cumulates may result from magma-fluid interaction. A PGE reef may occur in the ophiolitic cumulates but its extent and content remain to be determined.

Evidence for fractionation can be found at all scales, from individual PGM grains and PGM associations to the entire ophiolitic sequence.

The compositions of the minerals mostly reflect the chemical evolution of the mineralizing system rather than secondary processes.

A common mineralizing process was responsible for PGE and sulphide concentrations and for chromite deposits. The distribution and composition of PGE concentrates are controlled by fS_2 and fO_2 variations which lead to decoupling of chromite, BMS and PGM precipitation and which emphasize along-ridge variations from the Bulqiza to the Tropoja massif.

Ophiolites which are derived from SiO_2-saturated magmas should have the highest metallogenic potential.

Keywords: *PGE mineralization, Albanian ophiolites, Bulqiza massif*

Formation environment of the Dajiweng peridotite in the western Yarlung-Zangbo ophiolitic belt: evidence from petrology, mineralogy and geochemistry

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Abstract

The Yarlung Zangbo suture zone, the youngest and southernmost suture in Tibet, separates the Lhasa Block to the north from the Indian continent to the south. Ophiolitic massifs crop out discontinuously along this ~2000 km long zone and these are interpreted as relicts of Neo-Tethyan oceanic lithosphere that separated India from Eurasia during the Mesozoic. This suture zone is typically divided into eastern (Luobusa ophiolite), central (e.g., Xigaze ophiolite) and western (e.g., Dongbo and Purang ophiolites) segments.

In the central and eastern segments, the ophiolites lie along a single lineament, whereas in the western part, the suture is divided into northern and southern branchs. The northern branch appears to be a continuation of the main suture, whereas the southern branch is marked by a tectonic mélange composed mostly of Tethyan sedimentary rocks. The Dajiweng ophiolite in the northern sub-belt is composed mainly of mantle peridotite, with some basalts and siliceous rocks. The mantle peridotites consist dominantly of harzburgite, accompanied by minor dunite and podiform chromitite. The Dajiweng harzburgite is strongly depleted, indicating a relatively high degree of partial melting and/or melt-rock reaction. Extensive melt-rock reaction in the harzburgite is indicated by its well-defined, U-shaped, chondrite-normalized REE patterns and variable contents of high field strength elements. We suggest that the Dajiweng harzburgite originated by greater than 25 % partial melting of a spinel-facies mantle source and was later modified by melts and fluids in a suprasubduction zone mantle wedge. All of the investigated ophiolites in the western segment of the suture zone have yielded microdiamonds, moissanite and other highly reduced phases from both the mantle peridotites and podiform chromitites. The presence of these minerals suggests a relatively deep mantle source for the host peridotites. However, much work remains to be done to unravel the complex processes involved in the formation of these ophiolites.

Keywords: *ophiolite, Tibet, peridotite, chromitite, melt-rock reaction, diamond*

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Petrological features of the volcano-sedimentary formation of the Bajgora area, Mitrovice, Kosovo

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Abstract

The Bajgora - Kacandoll area is situated only a few kilometers to the east of the well-known polymetallic deposit of Stanterg of Mitovica, Kosovo. It consists of magmatic and sedimentary formations, some of which are slightly to intensely metamorphosed. From the tectonic point of view, this region belongs to the West Vardar and has a complex geological structure. In this region, numerous studies have been conducted which have brought not only increasingly data and more details on the geological structure, but also a significant diversity of viewpoints on the geodynamic development of the region. Studies conducted in recent years, and surveys undertaken by Blerim Meholli, as part of his PhD studies, have brought important new data on the ages of formations in the region, identified geological formations previously unknown, and clarified the relationships between different formations and mineralization in the area.

Volcano-sedimentary strata represented by phyllite, epidote-actinolite-chlorite schist, sandstone and siltstone, with intercalated lava flows, are relatively widespread in the Bajgora-Kacandoll area. Volcanic intercalations are sparse in the lower parts of the unit but become more abundant upward and are clearly dominant close to the tectonic contact with overlying mantle formations, represented by harzburgite with very small and rare dunite lenses. This formation is considered to be Middle-Upper Triassic in age based on its similarity with other units in the region, but the age is not well constrained.

Discontinuous exposures of a newly recognized metamorphic sole occur between the mantle units and the volcano-sedimentary strata. We interpret the metamorphic sole as representing the initial emplacement of the ophiolite on a passive continental margin. In the Mirdita zone, Albania, this formation is dated as Bajocian to Callovian (161-174 Ma) and it is likely that the metamorphic sole in the Bajgora-Kacandoll area has the same age.

The upper part of the volcano-sedimentary formation is characterized by metamorphosed volcanic rocks, with rare and small lenses of

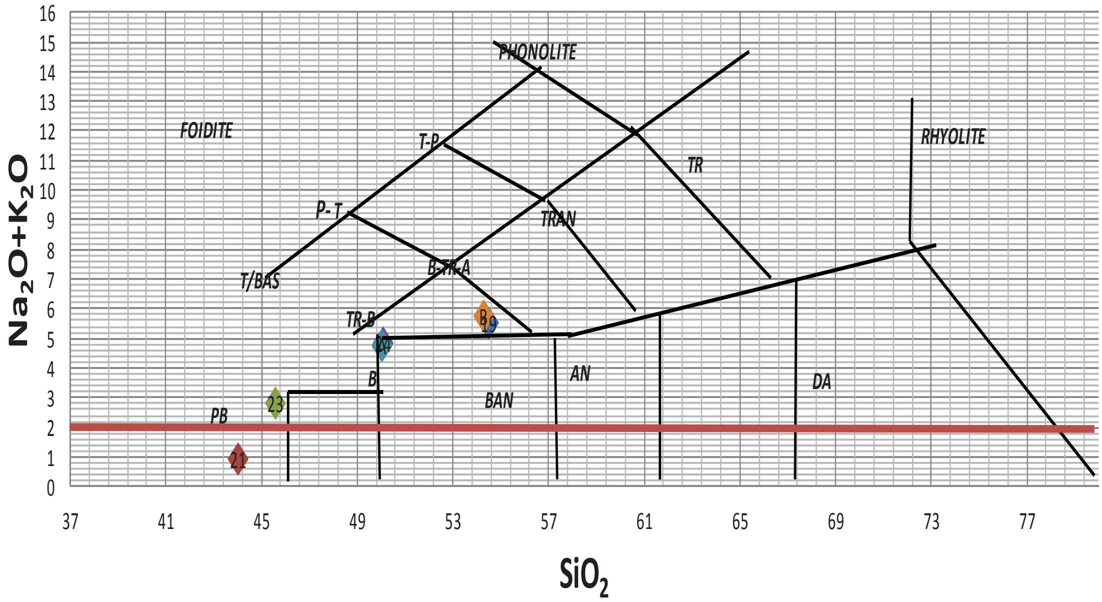

Figure 1.
TAS diagram - SiO_2 versus Na_2O+K_2O (Le Maitre et al. 2002)

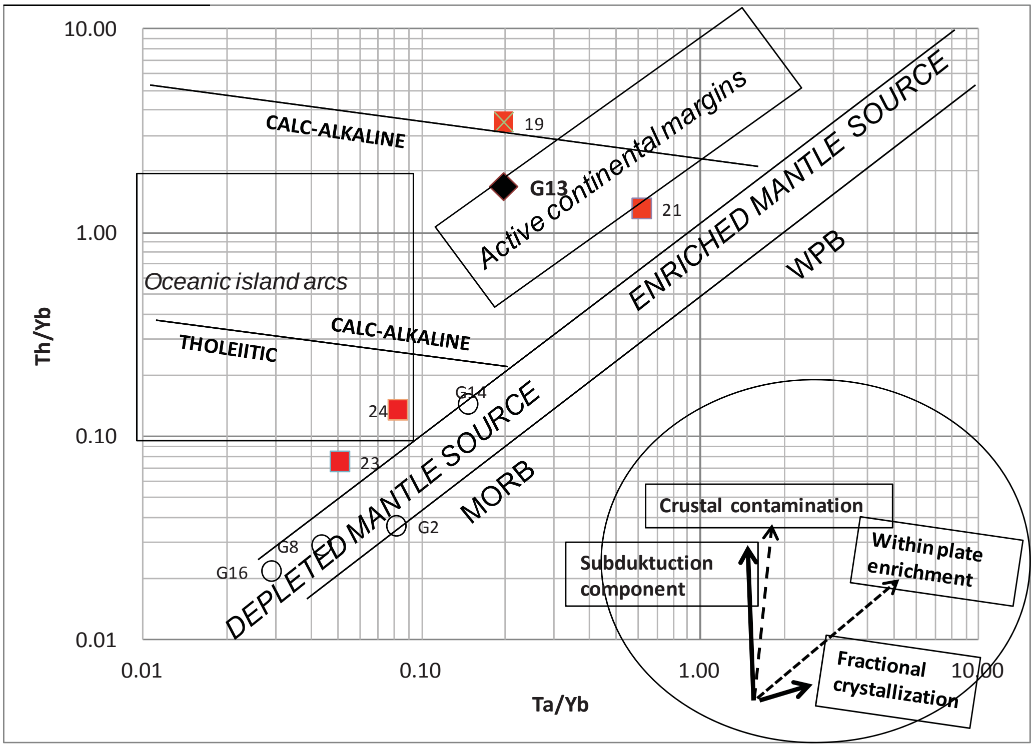

Figure 2.
Th/Yb versus Ta/Yb diagram (after Pearce, 1983). Samples 19, 21, 23 and 24 are from the Bajgore-Kacandoll area. Sample 19 is a slightly alkaline basaltic andesite; sample 21 is a picrite basalt; sample 23 is a picritic basalt; sample 24 is a basaltic andesite; and sample G13 is a Lower Triassic basaltic andesite from Livadhi i Lumes of the Korabi zone, Albania (Tashko and Mascle 2009).

radiolarian chert. Volcanic rocks (samples 19, 21, 23, 24A and B) are represented by basalt-picrobasalt, andesitic basalt and rocks that plot on the boundary of basaltic andesite-basaltic trachyandesite according to the TAS diagram (Le Maitre et al. 2002) (Fig. 1).

A plot of Th/Yb vs Ta/Yb (Fig. 2) provides some information regarding the tectonic-magmatic conditions of formation of the volcanic rocks. Most of the mafic rocks (G 2, 8, 14 and 16 plot in the field of depleted mantle, whereas samples 19 and 21 plot in the field of active continental margins and were probably derived from a mantle source enriched by continental crustal material. Samples 23 and 24 plot near the field of MORB, and were also formed from a depleted mantle source.

Based on the above, we conclude that volcanic rocks of volcano-sedimentary formation of Bajgora-Kacandoll region are highly variable in composition and that they formed during the initial phase of continental rifting, which then developed into an ocean spreading center. These volcanic rocks have similarities with volcanic rocks of volcano-sedimentary formation of the Mirdita zone and more specifically with volcanic rocks of the volcano-sedimentary formation of Ceremi, Gashi zone, north Albania.

Keywords: *volcano-sedimentary formation, Kosovo, Albania, continental rifting*

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General characteristics and the main features of chromite ore in the Albanian ophiolite

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Abstract

The Jurassic ocean lithosphere that makes up the Albanian ophiolites is divided into two distinct types with substantial differences in their chromite–bearing potential and chromite ore characteristics. The mantle sequences of the eastern ophiolite type are characterized by abundant orebodies of high-Cr chromitite of the metallurgical type with very few high-Al, refractory deposits. In contrast, the western ophiolite type, contains only small, sparse chromite showings, most of which are refractory in character.

Podiform chromite ore occurs throughout the entire ultramafic sequence, but it is heterogeneously distributed in different sequences. This heterogeneity is also reflected in the other features, such as the morphology of ore bodies, their size, quality of chromite ore, textural and structural features and types of chromium.

Keywords: *Eastern ophiolite type, western ophiolite type, chromite ore*

A short introduction to the Albanian ophiolite

The ophiolite of Albania, mostly known as the Mirdita Ophiolite, represents remnants of Neo-Tethyan ocean lithosphere, that are part of the Mediterranean alpine belt. Ophiolites in Albania crop out over an area about 250 km long and 30-50 km wide. Two distinct ophiolite types are present; a harzburgite-type (eastern ophiolite) and a lherzolite-type (western ophiolite).

The eastern ophiolite is dominated by thick, harzburgitic tectonites, overlain by dunitic and pyroxenitic cumulates, gabbros and plagiogranites, a well-developed, but not classical, sheeted dyke complex and a volcanic sequence that consists of low-Ti basalt, basaltic andesite, andesite, dacite and rhyodacite. A thin layer of radiolarian chert of Bathonian-Oxfordian age stratigraphically overlies the extrusive sequence, which in turn, is overlain by Jurassic and Lower Cretaceous mélange. A characteristic feature for the eastern ophiolite type is the presence of boninite, both as flows and dykes.

The western ophiolite is composed of harzburgitic and lherzolitic tectonites, as well as plagioclase-bearing lherzolitic and dunitic cumulates. Relatively thin and discontinuous sequences of troctolite and gabbro are directly overlain by high-Ti basalts, with only an extremely limited sheeted dyke complex. The extrusive section at the top of the ophiolite is overlain by about 5-20 m of radiolarian chert of late Bajocian-early Bathonian to late Bathonian-early Callovian age. Detachment faults linked to the formation of oceanic core complexes are present in the Krrabi and Puka massifs

General data on the chromite ore of Albania

Chromite ore is very widespread in Albania where it is generally associated with the ultramafic rocks or, in very rare cases, with troctolites. Albania is distinguished for its its abundance of high-quality chromite ore compared to other countries in the same Alpine ophiolite belt.

Many exploration and prospecting studies have been carried out over the past 40 years and hundreds of voluminous reports in the Central Archive of Geology in Tirana contain important data on the location, structural elements, morphological characteristics, mineralogy, geochemistry and other features of the chromite showings and ore deposits in the ophiolite. Generalized data, extracted from these many reports, are available in two publications (ISPGJ-IGJN 1989; Mekshiqi et al. 2007) and important data on the chromite ores of Albania have been presented in many scientific journals (e.g., Cina et al. 1986; Dobi et al. 1996; Plaku et al. 1996; Selimi et al. 1996; Premti et al. 1998; Alku et al. 1998; Mekshiqi et al. 1998; Meshi et al. 2005; Mekshiqi 2010; Cina 2012). Mining of chromite ore in Albania started in 1939, at the beginning of WWII, and by the 1980s, Albania was producing over 1 million tons of chromite ore per year, ranking third in the world. Between 1939 and the late 1990s a total of 25.7 million tons of chromite ore were extracted. The great bulk of this ore (21 million tons) were from the Bulqize massif, with about 2.5 million tons from the Kuksi massif, about 1. 6 million tons from the Tropoja massif and about 0.6 million tons from the Shebenik-Pogradec massif. Accurate statistics are not available for the last 20 years but extraction has been on the order of about 0.25 million tons per year for a total of about 5-6 million tons. Estimated reserves in the 1990s were about 36.9 million tons including measured, indicated and inferred reserves (Mekshiqi et al. 2007). Thus far in Albania 84 ore deposits with reserves of 0.01-0.1 million tons have been discovered, in addition to 37 deposits with 0.1-0.5 million tons, 8 deposits with 0.5-1 million tons 6 deposits with 1-2 million tons and 2 deposits with over than 2 million tons. The Bulqize-Bater deposit alone contained 25 million tons of high-Cr, metallurgical-type chromite with an average of 40 wt.% Cr_2O_3.

The main features of the chromite ore in Albania

Both mantle and transition zone sequences in the Mirdita ophiolite have high chromite-bearing potential, particularly in the eastern belt. Thus far, about 800 chromite showings related mainly to the ultramafic massifs of Tropoje, Kukes and Bulqize have been found in the eastern belt. Chromite in the eastern belt is mostly metallurgical grade whereas that in the western belt is typically refractory

Although chromite ore showings are widely present in the ultramafic sequences of both the eastern and western belts, they are heterogeneously distributed. This heterogeneity is also reflected in the morphology of the ore bodies, their sizes, textures, structural features and the quality of the chromite ore. According to Mekshiqi et al. (2007) and Cina, (2012), there is a close correlation between the abundance and size of ore bodies and the nature of their host rocks. For example, high-Cr chromites occur mostly in harzburgite and clinopyroxene-bearing harzburgite in the eastern ultrabasic belt, whereas in the western belt low-Cr chromite is associated with lherzolite. In the transition zone the chromite is associated with fresh harzburgite with dunite lenses and with harzburgite-dunite and massive dunite. The most important chromite ore levels, in the ultrabasic massifs of the eastern ophiolite type, occur in the middle and upper parts of the mantle section which is composed of harzburgite-dunite and dunite-harzburgite sequences, about 150-300 m (Mekshiqi et al. 2010) or 500 m (Meshi et al. 2005) below the base of the massive dunite of the transition zone.

There are three basic types of orebodies in the ophiolite: concordant, sub-concordant and discordant. The most common and most important is the sub-concordant type, which is characteristic of the Bater Bulqiza deposit. Within this framework, the orebodies exhibit a great variety of morphological types: lenticular, tabular, pencil-like, layered and disseminated (tabular or linear bands of disseminated chromite with higher concentrations in the form of schlieren, streaks, stringers, wisps, lumps, and whorls). Tabular and lenticular combinations (e.g., Bulqiza-Bater ore deposit) and pencil-like forms (e.g., Shkalla deposit) are the most common. These deposits are also characterized by a very large variety of textures and structures, including disseminated, massive, banded, nodular, antinodular, orbicular, spot-like, and irregular. Pull-apart structures are common in many ore bodies. Typically, many or all of these features may occur in a single deposit.

Another characteristic feature of many chromite deposits in Albania is the presence of well-developed folds of different sizes and types. Two spectacular examples are in the Bulqize-Bater deposit in the Bulqiza ultrabasic massif and the Dushaj showing in the Tropoja massif.

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The Archean history of the Andriamena ophiolitic chromitites, Madagascar, from ophiolite formation (3.1 Ga) to Late-Archean deformation and dismemberment

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Abstract

The story of the Andriamena chromitites is bracketed between their formation at 3.1 Ga and late metamorphic evolution in Late Archean times (≈2.5 Ga) within a greenstone belt. Re-Os analyses yield a well-constrained Re-depletion age (TRd) of 3.2 Ga. Although the exact age depends on the chosen mantle evolution curve, extraction after 3.1 Ga is excluded. An ophiolitic origin is preferred for the Andriamena chromitites. This is based on their Re-Os characteristics, which argue against crustal contamination, as well as on the PGE distribution, PGM assemblages and the presence of harzburgite, dunite and orthopyroxenite, with high Mg number for olivine (Fo_{90-92} in dunite and up to Fo_{95} in chromitite) and orthopyroxene.

Cryptic evolution of chromite reflects the major events leading to the present setting of the chromitites. The original chromite composition is essentially preserved in massive chromitites and associated ultramafic rocks, even though the present shape and size of chromite reflects strong deformation. Massive chromitites have a restricted composition, reflecting crystallization from second-stage melts derived from a depleted mantle, possibly in an island-arc environment. In layered chromitites, the composition of chromite varies from magnesio-chromite to nearly pure chromite, reflecting a more or less pronounced Fe^{2+} enrichment at nearly constant Cr# [Cr/(Cr+Al)]. This is due to chemical exchange between chromitites and the tectonically juxtaposed rocks under granulitic metamorphic conditions.

Late-stage anhedral to euhedral zircons, which occur in the interstices of chromite grains within layered chromitites, record the influence of widespread Late-Archean tectonic and metamorphic events affecting the Tsaratanana unit: a U-Pb discordia shows an upper intercept at 2.35 ± 0.16 Ga (n=33). On the other hand, magmatic charnockites injected into massive chromitites (skarn assemblage) have somewhat older U-Pb zircon ages [Concordia ages of 2475±9 Ma (n=36) and 2480±8 Ma (n=39)].

Keywords: *Ophiolitic chromitite, Madagascar, Archean, Re-Os, zircon U-Pb*

Introduction

The Andriamena chromite deposits were discovered in the 1950s and are still exploited in the open-pit of the Bemanevika mine. It remains unclear whether they are derived from a layered mafic-ultramafic complex or an ophiolite (Johan et al. 1988; BGS-USGS-GLW 2008). At the time of their discovery, the chromitites were thought to be of Archean age by BRGM geologists, but a younger age is now also considered possible due to the recognition of Neoproterozic ultramafic intrusions, (Grieco et al. 2013). Recently, a Meso-Archean age was proposed for the Andriamena chromitites on the basis of Re-Os dating (Reisberg et al. 2013), which accordingly, would suggest that they represent the traces of an Archean greenstone belt. The presence of Late-Archean zircon within two chromitites provides additional evidence for an Archean origin for these chromitites and for the Andriamena greenstone belt.

Geological overview

The Andriamena belt is one of four greenstone belts defined in the Tsaratanana unit, which structurally overlies the Antananarivo domain. The latter and the upper Tsaratanana unit form the Archean basement of Madagascar, which also includes the eastern Antongil block. The Tsaratanana unit has long been known for its high proportion of mafic granulites which coexist with acid orthogneisses and paragneisses, which were variously migmatitized at the end of the Archean. Following the high temperature granulitic metamorphism (Goncalves et al. 2004) at 2.5 Ga, two late retrogression events at 790 Ma and 500 Ma (Paquette et al. 2004) affected the Tsaratanana unit.

Nearly 600 chromite lenses of variable size have been found in the southern part of the Andriamena belt. They are juxtaposed with various lithologies, including peridotites, gabbros, pyroxenites, mafic granulites, gneiss, migmatites and magmatic charnockites. All of these rocks are plastically folded on a regional scale. Ankazotoalana and Benamevika are the largest deposits, with about 4 x 106 t estimated total reserves, followed by Telomita (7 x 105 t). Chromite from the Andriamena deposits has high Cr#s [(Cr/(Cr+Al)] and Mg#s [Mg/(Mg+Fe)], compatible with an origin either as a layered complex or an ophiolite. The PGE distribution, with Os, Ir and Ru predominant over Rh, Pt and Pd, does not provide definitive evidence concerning the origin of the chromitites (Johan et al. 1988; Grieco et al. 2014).

Materials and Methods

During fieldwork, four deposits were studied: Ankazotoalana, Benamevika, a satellite vein of the Telomita deposit and the L5b small deposit. Special attention was paid to finding contacts between chromitite and nearby rocks to determine whether their relationships were magmatic or tectonic. Chromite compositions and mineral associations were determined using optical and scanning electron microscopes and an electron microprobe (CAMECA SX100). Os isotopic compositions were determined by negative thermal ionization mass spectrometry (Finnigan MAT262) and Re by ICP-MS (Neptune) after sample digestion in a high pressure asher and Os and Re extraction. U-Th-Pb isotopic data for zircons and monazites were obtained by LA-ICPMS.

Results and discussion

Tectonic setting of the chromite deposits - In the field, chromite deposits appear either as lenses or as layers alternating with pyroxenite, gabbronorite and gneiss. The chromite lenses and the layering plane follow the regional structure of the isoclinally folded basement. Chromitites are mostly found in wedges showing a subvertical foliation, which alternate with slabs (several km wide) having a slightly inclined layering and foliation. The preferential location of chromitites in the wedge seems to result from recumbent folding, magmatic injection of massive charnockites at the end of the Archean, and/or to NW-SE to N-S shearing; all of these processes which may have contributed to exhumation of the chromite deposits.

The chromitites are all fine-grained rocks (≤ 1mm). Chromite appears as euhedral to subhedral crystals isolated in a recrystallized matrix or as clusters with closely packed grains (Fig. 1). This texture is thought to result from high temperature deformation rather than from magmatic precipitation. Recrystallization processes start with brittle failure of chromite, followed by displacement of the broken chromite pieces, and end by joining and sealing of these pieces. Inclusions of olivine, orthopyroxene and later of talc, amphibole and Mg-chlorite outline the shape of former crystals and the seals. Recrystallization processes were efficient as the resulting chromite grains are mostly unzoned. The silicate matrix is preferentially developed in low pressure areas and pull-apart veins. It hosts the same minerals found as inclusions in the chromite, as well as Mg- and Ca- carbonates, rutile, and locally zircon.

Chromite cryptic variation - Massive chromitites occupy a restricted field with high Cr#s (0.65-0.75) and Mg#s (0.32-0.47) similar to other Archean chromitites worldwide. TiO_2, MnO and Fe_2O_3 are low (TiO_2<0.25 wt.%). Such compositions are close to those found in Phanerozoic ophiolites derived from remelting of previously depleted mantle domains. Chromite in associated harzburgites, dunites and orthopyroxenites is richer in Al and Fe (0.5<Cr#<0.66), as is usual in ultramafic rocks associated with chromitites. In addition, the high Fo content of olivine from harzburgite and dunite (Fo_{90}) or in chromitite (Fo_{95}) tend to support an ophiolitic origin.

Chromitites alternating with various gneisses have high Cr#s, similar to those of the massive chromitites, but show a great variation in their Mg#s (0.86-0.12). The composition of the chromite evolves from magnesio-chromite to chromite (Ratefiarimino et al. 2009), defining a trend which mimics that resulting from fractional crystallization in layered intrusions. In Andriamena, the Fe increase in chromite may be explained by chemi-

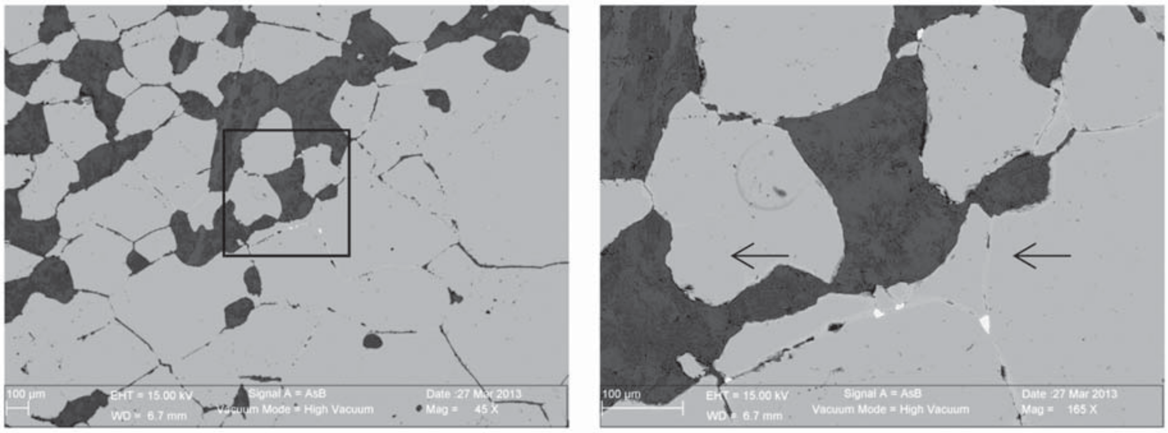

Figure 1. Metamorphic texture of the Andriamena chromitites (L5b deposit). The section to the left shows juxtaposed massive to disseminated chromitite. The enlarged area, to the right, shows 5 zircons (white spots) located in triple point boundaries (bottom of the photo), along seals joining former chromite grains, and within secondary silicates, such as talc, amphibole, Mg-and Ca-carbonates (top of the photo). Note that former sealed contacts between chromite grains (arrows) are locally marked by compositions richer in Fe and Cr than the homogeneous magnesiochromite grains.

cal exchange between chromitite and silicic gneiss during granulitic metamorphism. In addition, injection of magmatic charnockites under low fO_2 conditions within chromitites (skarn) also led to some chemical exchange: again Fe^{2+} preferentially entered the chromite grains at the expense of Mg, leading to secondary chromite rich in Fe^{2+} and Cr but with a very low Fe^{3+} content. Finally, a coupled increase in Fe^{2+} and Cr may be defined within some chromitites, illustrating a core-to-rim variation related to late-stage shear zones. In this case, the $Cr^{\#}$ variation is larger than that of the $Mg^{\#}$.

PGE and Re-Os results - Chondrite-normalized PGE spectra show depletion in PPGE (Pt and Pd) relative to IPGE (Os, Ir and Ru), typical of spectra observed in chromitites from ophiolites. Strong negative anomalies in Pt are observed in Archean samples. Coupled enrichment in Os and Ru is ubiquitous, consistent with the presence of laurite and Ru-Os-Ir alloys. Re (0.106-0.249 ppb) contents are towards the lower end of values reported for ophiolitic chromitites, whereas Os (43.6-85.7 ppb) contents plot in the middle of the range. 187Os/188Os ratios are remarkably constant among the Archean samples leading to a well-constrained, Re-depletion age of ~3.2 Ga, assuming a PMU evolution curve (Meisel et al. 2001). Use of the mantle evolution parameters of Shirey and Walker (1998) would lead to a TRD age of ~3.1 Ga.

U-Pb zircon age - The layered chromitites of the L5b and Telomita deposits host anhedral to euhedral zircons set in interstitial metamorphic silicates between chromites. Forty percent of the zircons show close contact with chromite along their prismatic or pyramidal faces. Zircons are also developed in the core of metamorphic silicate veins, thus indicating their close relationships with fluids. Thirty-three zircons have been found in sample L5b in triple-point boundaries and/or cracks between chromite grains. Their size varies between 2 and 10 μm, which is close to the laser 5μm spot-size. In spite of that, a discordia was found with an upper intercept at 2.35 ± 0.16 Ga, an age corresponding to the widespread tectonic and metamorphic events that occurred in the Late-Archean in the Tsaratanana unit. In addition, concordia ages of 2475 ± 9 Ma (n=36) and 2480 ± 8 Ma (n=39) were obtained from two samples of magmatic charnockite, thus underscoring the importance of mantle-derived magmatism and crustal remobilization during Late Archean times.

Conclusions

The ages of the Andriamena chromitites were determined by the Re-Os method to be about 3.2-3.1 Ga. This underscores the existence of mantle-derived magmatism with an age of at least 3.1 Ga in the Tsaratanana unit. The PGE distribution in the chromitites, the PGM assemblage and the magnesian character of olivine and orthopyroxene in ultramafites support an ophiolitic origin for the chromitites. Such an origin would explain the preservation of large chromite pods present in the larger deposits, otherwise encapsulated in various gneissic formations.

During Meso-Archean times, convergent margins with fore-arc or back-arc extensional basins may have been the site of original emplacement of the ophiolites generated through remelting of the previously depleted mantle wedge. It is also probable that older continents (>3.1 Ga) were present at the margins of the ophiolitic basin, as suggested also by the existence of Meso Archean ages in inherited zircons from granites.

The ages obtained by the U-Pb method on zircons, which are interstitial between chromite grains in chromitite, underline the importance of a Late Archean orogeny for the development of the Tsaratanana unit. During this orogeny, deep folding and thrusting under high temperature, granulite facies metamorphic conditions led to pervasive imbrication of the ophiolitic members with the adjacent more crustal formations. This may explain the occurrence of alternating layers of chromitite with various lithologies as well as the extent of chemical exchange with adjacent rocks recorded by the strong Fe-enrichment of some chromite in layered chromitites.

The Andriamena belt constitutes a new example of an Archean greenstone belt with a strongly dismembered ophiolitic assemblage. It contrasts with the preserved older Jamestown ophiolite (3.5 Ga) in the Barbeton area, South Africa (DeWit et al. 1987). Other greenstone belts usually comprise komatiite and related mafic ultramafic intrusions.

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The origin and significance of crustal minerals in ophiolitic mantle rocks

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Abstract

Numerous crustal minerals, such as zircon, almandine garnet, andalusite, apatite, corundum, feldspar, kyanite, rutile, titanite, feldspar have been found in mantle peridotites and podiform chromitites of the Luobusa and Dongqiao ophiolites of Tibet, the Semail ophiolite of Oman and the Ray-Iz ophiolite of the Polar Urals, Russia. These minerals coexist in these rocks with UHP minerals, such as diamond and coesite, highly reduced minerals including native elements, metal alloys and moissanite. Some of the crustal minerals occur in-situ or are attached to chromite grains, metallic alloys or rutile. Rounded grains of zircon, 50-300 microns across, with very complex internal textures, are common in all of the ophiolites. $^{206}Pb/^{208}U$ SIMS dates for the Luobusa zircons range from 549 to 1657 Ma, those from Dongqiao from 484 to 2515 Ma, and those from Semail from 84 to 1386 Ma, and are typically much older than the host ophiolites. Most of the zircons contain low-pressure mineral inclusions, including quartz, rutile, orthoclase, mica, ilmenite and apatite confirming a crustal origin. All of the zircons have REE and trace element compositions compatible with a crustal origin. The crustal minerals, combined with the morphology and age of the zircon, indicate derivation from crustal rocks subducted into the mantle where they were mixed with UHP and highly reduced phases. Preservation of these minerals may be due to their encapsulation in chromite and olivine grains. We suggest that subducted crustal material is widespread in the upper mantle and that it may account for some of the observed mantle heterogeneity.

Keywords: *Ophiolite, crustal minerals, zircon, age data*

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Unusual minerals discovered in high-Al chromitite of the Sartohay ophiolite, Xinjiang Province, Northwest China

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Abstract

Microdiamonds and highly reduced phases in ophiolites were first reported from podiform chromitites of the Luobusa massif in the eastern part of the Yarlung Zangbo suture zone (YZSZ) of southern Tibet (IGCAGS, 1981). Since that time similar minerals have been recovered from peridotites or chromitites of many ophiolitic blocks within the YZSZ, such as the Purang, Dongbo, Dangqiong, Xigaze, Zedang, and Luobusa massifs (Bai et al. 2000, 2001, 2003; Robinson et al. 2004; Yang et al. 2007, 2011, 2013; Xu et al. 2009). In addition, diamonds have also been recovered from the Dongqiao ophiolite in the Bangong-Nujiang suture zone of central Tibet, from chromitites of the Ray-Iz ophiolite of the Polar Urals, Russia and from peridotites of the Myitkyina ophiolite, Myanmar (Yang et al. 2014). The presence of all of these ultrahigh pressure minerals and reduced phases suggests formation deep within the mantle (Yang et al. 2013).

All of the above mentioned chromitites that contain diamonds and other unusual mantle minerals are

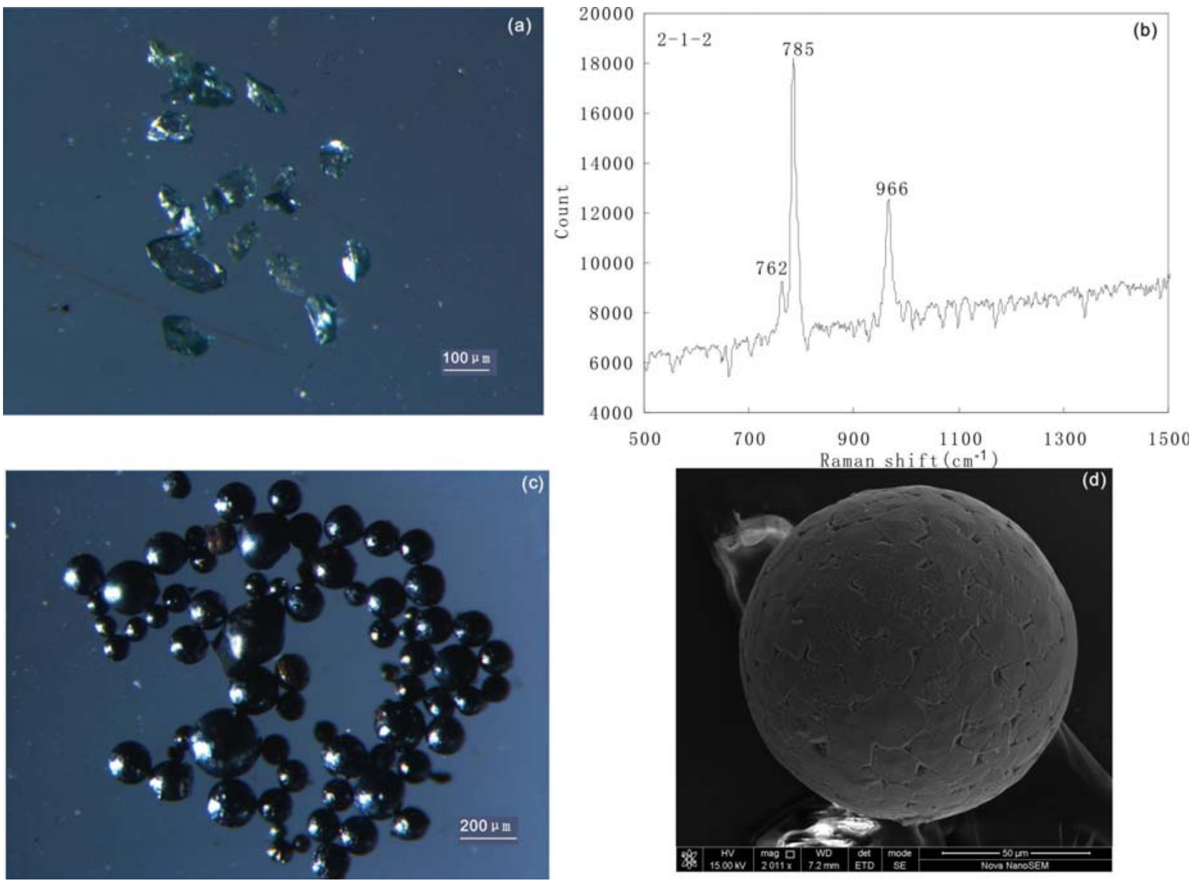

Figure 1. (a) Photograph and (b) Raman spectrum of moissanite recovered from the Sartohay chromitites; (c) photograph and (d) back-scattered image of spheres of native Fe, some of which have wüstite rims.

high-Cr varieties (Cr/Cr+Al >0.6). Thus, it is important to determine if such minerals also occur in high-Al chromitites and their host peridotites. The Sartohay ophiolite, located in the Central Asian Orogenic Belt in western China, is 20 km long and 0.1–1.5 km wide, with an outcrop area of about 20 km^2. The ophiolite consists predominantly of serpentinized peridotite, massive basalt, pillow lava and chert. The peridotites are mostly harzburgite, with lesser amounts of lherzolite and dunite, all of which have been variable altered to listwaenite (quartz + calcite + chlorite + magnetite + goethite + hematite assemblages), particularly in the southern part of the massif along the contact with early Carboniferous sedimentary rocks. The northern part of the peridotite massif is tectonically overlain by pillow lava and massive basalts, which contain a few thin bands of red chert and tuffaceous sandstone. The chromitite ores have massive, nodular and disseminated textures and are typically surrounded by dunite envelopes within harzburgite.

We collected 847 kg of relatively fresh, massive chromitite for mineral separation. Thus far, we have recovered more than 30 unusual mineral species, similar to those previously recovered from high-Cr chromitites. These include: (1) Native elements - diamonds, Cr, Si, Fe; (2) Carbides - SiC; (3) Oxides - wüstite, rutile, ilmenite, brookite, corundum, chromite, magnetite, cassiterite; (4) Silicates - olivine, enstatite, augite, diopside serpentine, chlorite, zircon, quartz, feldspar; (5) Sulfides of Fe, Ni, Pb, Zn, Cu, Mo; (6) Other minerals - fluorite, calcite, magnesite and a range of metallic alloys. More than 20 grains of diamond and moissanite have been recovered thus far from the chromitites. The moissanite occurs as angular (broken?), bright blue to dark blue crystals, mostly about 50-150 µm across (Fig. 1a). All of the grains have characteristic Raman spectra with shifts at 762 cm^{-1}, 785^{-1} and 966 cm^{-1} (Fig. 1b). These grains are accompanied by thousands of spheres of native iron, commonly with rims of wüstite (Fig. 1c-d), identical to grains from other ophiolites. The recovered diamonds occur as euhedral to anhedral crystals, 100-200 µm across, that display a variety of colors, from colorless to pale yellow, tangerine and rose red (Fig. 2a-f.). All of the recovered grains have characteristic Raman spectra with shifts at 1331.51 cm^{-1}or 1326.96 cm^{-1} (Fig. 2g-h). Zircons from the chromitites also have a variety of colors and morphologies.

All of the UHP, highly-reduced and crustally-derived minerals found thus far in the Sartohay high-Al chromitites are quite similar to those reported from the Luobusa and Ray-Iz ophiolites, suggesting that high-Al and high-Cr chromitite have similar origins.

Keywords: *Sartohay ophiolite, China, diamond, high-Al chromitite, peridotite*

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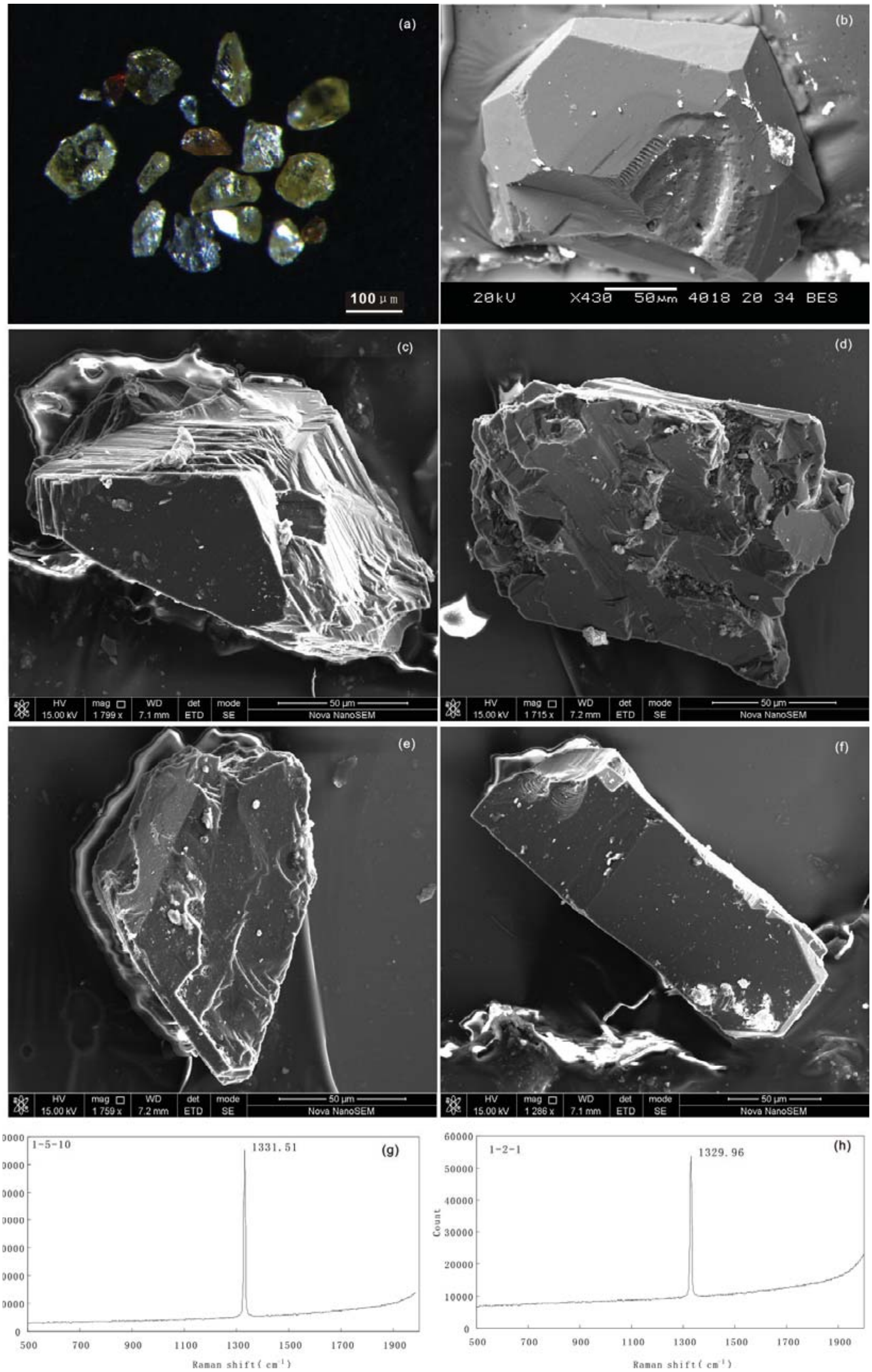

Figure 2. (a) Photograph and (b-f) BSE images of diamonds recovered from the Sartohay chromitites; (g-h) Raman spectra showing characteristic patterns for diamonds.

Mineral deposits and occurrences of the Puka ophiolite massif, Albania

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Abstract

The Puka ophiolite massif occurs in the northern part of the western belt of the Mirdita ophiolite in Albania (Fig. 1). The geology of the Puka massif has been a focus of geological mapping projects (Vukzaj et al. 1995), mineral prospecting (Gjoni and Pjetri 1990; Vukzaj and Gjoni 2000) and other petrologic and economic geology thematic studies (Shallo 1985; Pjetri 1998; Nicolas et al. 1999; Vukzaj 2000, 2006, 2009, 2010).

These studies have provided a wealth of data on the geology and metallogeny of the Puka massif. The massif contains mineralizations of chromite, nickel sulfur and platinum group elements (PGE), as well as deposits and occurrences of nonmetallic materials, such as asbestos, kaolinite, magnesite and decorative stone. In addition, some copper and titanomagnetit ore deposits occur in the periphery of the massif.

The mantle sequence (tectonites) of the Puka massif consists of lherzolite, dunite and harzburgite (Fig. 2). The cumulate sequence is composed of ultramafic cumulates (plagioclase lherzolite, plagioclase dunite, etc.) and mafic cumulates (amphibolite, olivine gabbro, gabbro, microdiorite). Pyroxenite ultramafic intrusions occur within the mafic cumulates and in the transition zone between the mantle sequence and the mafic cumulates. Farther up in the ophiolite section, a volcanic sequence consists of high-Ti MORB basalts. Radiolarian cherts of Middle-Upper Jurassic age lie on top of the volcanic rocks.

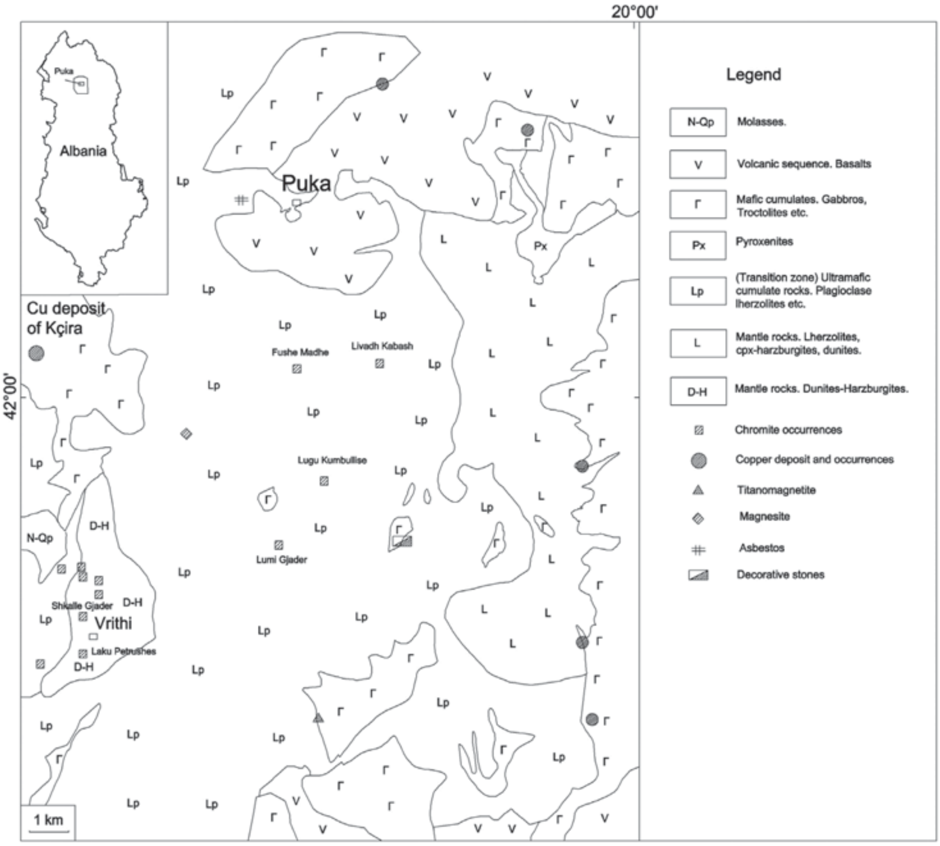

Figure 1. Schematic lithological map of the Puka ophiolite massif and the location of some of the most important mineral deposits and occurrences associated with it.

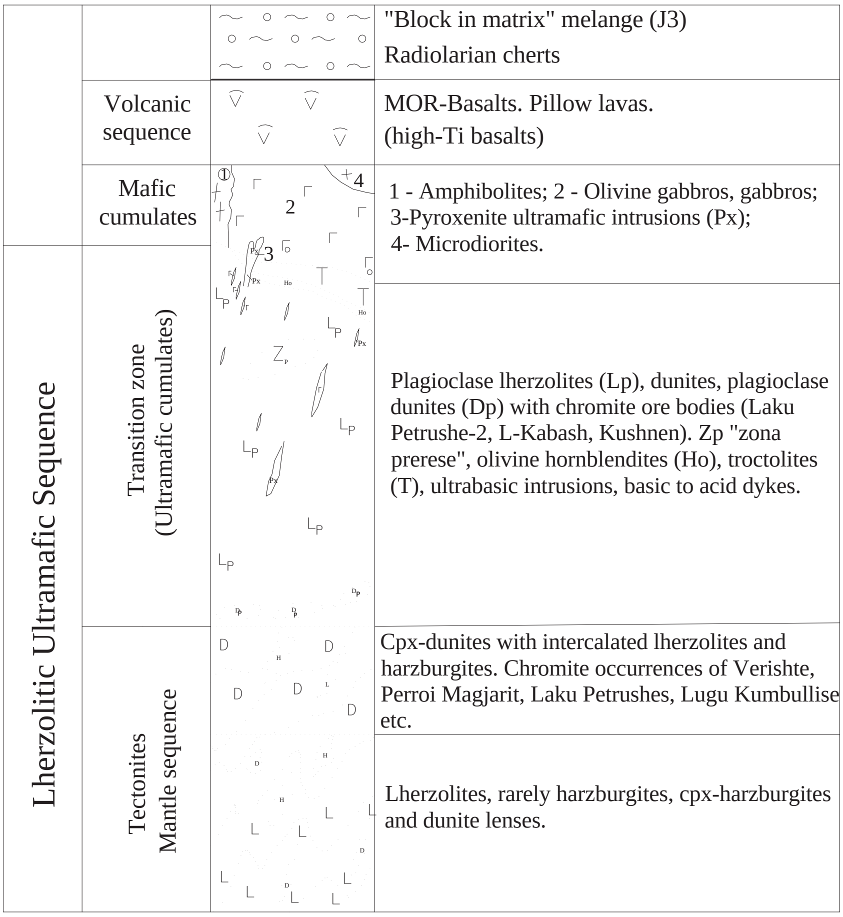

Figure 2. Schematic column showing the lithological constitution of the Puka ophiolite massif (modified from Vukzaj 2010).

Chromite mineralization is associated with the mantle rocks and ultramafic cumulate rocks of the Puka massif. More than twenty chromite ore bodies have been identified. Several such bodies occur in the mantle sequence (Fig. 1), including a group of occurrences in the area of Vrithi village (Perroi Magjarit, Boka Magjarit, Likonjat, Shkalle Gjader, Laku Pretushes no. 1, and the upper stream of the Gjadri River). These ore bodeis have moderate to high Cr#s [Cr/(Cr+Al)] and Mg#s [Mg/(Mg+Fe^{2+})] (0.65-0.80) and are usually surrounded by thin envelopes of dunite. They have disseminated, banded and massive textures, but nodular textures are rare (as in Boka Magjarit).

The ore bodies are relatively small lenses, with gradational to sharp boundaries with the host rocks.

In the cumulate ultramafic rocks, chromite ore bodies occur at depths of ca. 50-400 m, in close association with plagioclase-bearing ultramafic rocks (e.g., in Verishte, Lajthize, Fushë Madhe, Livadh Kabash, Lugu Kumbullisë, and Kuzhnen). These chromite ore bodies are commonly interesected by microgabbro, gabbro or pyroxenite dykes. They are small, lens-shaped bodies that

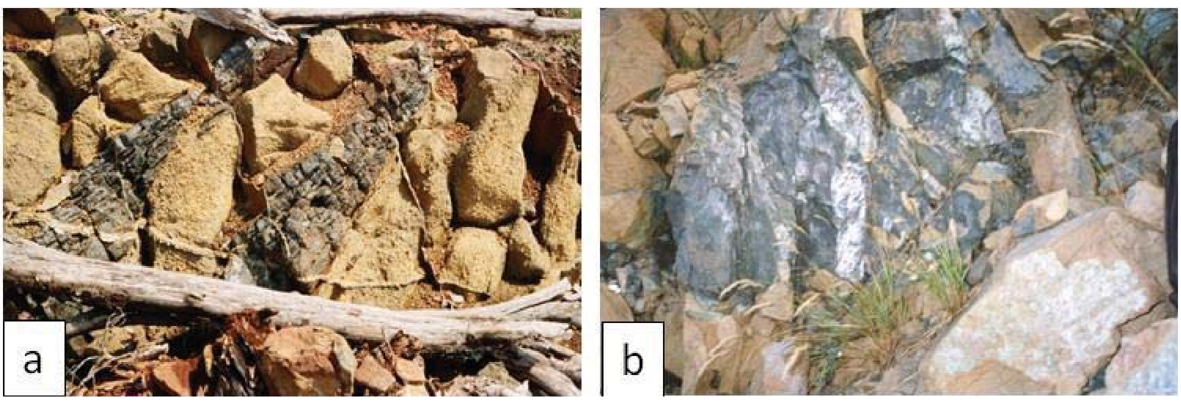

Figure 3. a) Chromite ore at Fushe Madhe. b) Chromite ore at Shkalle Gjader.

extend along strike for a few meters up to 100 m and along the dip for a few meters up to 70 m. Their thickness ranges from a few cm to 1-2 m. Most have banded to disseminated textures and the mineralization is heterogeneously distributed. Chrome contents range from 6 to 36-40 wt.% Cr_2O_3 (e.g. Fushe Madhe; Fig. 3), and varies depending on the host rocks.

The relationships between the chromite ore features and their mode of formation and the petrology of the host rocks are of great interest for understanding chromite mineralization and for elucidating petrologic features of the host rocks. The chromite ores hosted by magnesium-rich rocks (interbedded dunite-harzburgites in the mantle section and dunite lenses in the transition zone) have higher content of Cr, Mg and Ni than chromite ores associated with other parts of the ophiolite section.

Despite the limited presence of chromite mineralization in the mantle section (tectonites), the petrological features of the mantle rocks of the Puka massif show features similar to those of ophiolites in both the western and eastern ophiolite belts (Vukzaj 2010).

Magnetite mineralization in the Puka massif occurs between the gabbro-peridotite cumulate rocks (ultramafic to mafic transition zone) particularly at Pla, Luf and Boka e Qerretit. The magnetite ore bodies are lens-shaped and banded. The Fe_2O_3 content is 5-20 wt.%, rarely up to 30-40 wt.% of the rock mass. The magnetite mineralized belt is ca. 6 km long and 0.2-2 km wide, and contains a number of orebodies shaped like stretched lenses (Tershana 1996). The mineralized zones are closely associated with layers of cumulate ultramafic rock, separated from each other by intrusive bodies or olivine gabbro and pegmatite gabbro dykes with minimal contents of titanomagnetite.

Titanomagnetite mineralization also occurs in the hornblende gabbros and pyroxenite gabbros in the upper part of the cumulate section of the Puka massif, particularly in the Kashnjeti and Kaçinari areas. The mineralization is syngenetic with the gabbros. The occurrence of titanomagnetite in the cumulate section of the western belt of Mirdita ophiolites is in accordance with their petrological features.

High contents of PGE have been observed in the dunite of the cumulate sequence. However, the highest PGE concentration is in the pyroxenites of the Rrape area.

Zones of asbestos mineralization occur ca. 1.5 km NW of Puka in Koder Buqe and Koder Shullan, close to the contact of the ultramafic-gabbro contact in the Dedaj area. These areas have been strongly tectonized and the asbestos mineralization is focused in fault zones in moderately to intensively serpentinized harzburgite and lherzolite. The length of the asbestos fibres is 1-2 mm, rarely up to 3-4 mm.

A well-known hydrothermal copper deposit occurs in the Kçira gabbro massif. In other localities (e.g. Lajthiza, Dedaj) hydrothermal copper mineralization is found along faulted contacts between gabbros and basalts or ultramafic rocks. The ore bodies are lens-shaped. The main mineral associations are quartz-chalcopyrite and chlorite-chalcopyrite; massive chalcopyrite occurs as well.

Keywords: *Albania, Puka massif, ophiolite, mineralization, chromite*

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Petrology of Cr-rich podiform chromitites of Bulqiza, Eastern Ophiolitic Belt, Albania

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Abstract

The ultramafic massif of Bulqiza, which belongs to the eastern ophiolitic belt of Albania, is a major source of metallurgical chromitite ore. The massif consists of a thick (>4 km) sequence, composed from the base upward of tectonized harzburgite with minor dunite, a transitional zone of dunite, and a magmatic sequence of wehrlite, pyroxenite, troctolite and gabbro. Only sparse, refractory chromitites occur within the basal clinopyroxene-bearing harzburgites, whereas the upper and middle parts of the peridotite sequence contain abundant metallurgical deposits. The transition zone dunites contain a few thin layers of metallurgical chromitite and sparse bodies are also present in the cumulate section. The Bulqiza Ophiolite shows major changes in thickness, rock type, and chemical composition from west to east as a result of its complex evolution in a suprasubduction zone (SSZ) environment (Dilek et al. 2009). The peridotites show abundant evidence of mantle metasomatism at various scales, and mineral compositions suggest formation in a forearc. The composition of the melts passing through the peridotites changed gradually from arc tholeiite to boninite due to melt-rock reaction, leading to more Cr-rich chromitites in the upper part of the body. Most of the massive and disseminated chromitites have high Cr numbers (70-80), although there are systematic changes in olivine and magnesiochromite compositions from harzburgites, to dunite envelopes to massive chromitites, reflecting melt-rock reaction. Compositional zoning of orthopyroxene porphyroblasts in the harzburgite, incongruent melting of orthopyroxene and the presence of small, interstitial grains of spinel, olivine and pyroxene likewise attest to modification by migrating melts. All of the available evidence suggests that the Bulqiza ophiolite formed in a suprasubduction zone mantle wedge, in which the magma composition changed gradually with time.

Keywords: *Bulqiza ophiolite, Albania, high-Cr chromitite, melt-rock reaction, suprasubduction zone environment*

Diamonds and super-reducing conditions in ophiolitic chromitites

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Abstract

Separated and in situ diamonds in podiform chromitites of the Luobusa ophiolite, Tibet and the Ray-Iz ophiolite of the Polar Urals, Russia are significantly different in their morphology, inclusions, carbon isotopes and trace element compositions compared to metamorphic diamonds and most kimberlite diamonds. The in situ diamonds, which range from 200 to 500 µm across, occur within patches of amorphous carbon in chromite grains. They contain a variety of solid and fluid inclusions, including NiCoMn alloy, coesite, Mn-garnet, Mn-olivine, and MnO. The diamond-bearing chromitites also contain moissanite (SiC) and a range of native elements and alloys (Si, Fe, W, Ta, NiMnCo) indicating super-reducing conditions of formation, as well as minerals (coesite-stishovite, TiO_2-II and TiN) that require ultrahigh pressure conditions (UHP: ≥300 km depth). All of the analysed diamonds have highly depleted carbon isotopic values ($\delta^{13}C$ = -18.3 ‰ to -28.7 ‰) indicating derivation from a light carbon source in the mantle. The presence of diamonds in these ophiolitic rocks indicates a new environment of diamond formation in the oceanic mantle and may lead to a better understanding of the origin and emplacement of ophiolites.

Keywords: *Luobusa ophiolite, Ray-Iz ophiolite, diamonds, highly reduced minerals*

Origin of the Baer ophiolitic listwanite in the Yarlung Zangbo suture zone, Tibet

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Abstract

Listwanite is a suite of silica-carbonate alteration product, produced when CO_2-bearing hydrothermal fluids meet and react with serpentinized mafic and ultramafic rocks. The alteration products are of great importance for their economic significance. Gold, mercury, magnesite and base metal deposits are often associated with listwanite. In China the petrogenesis of listwanite and related mineralization, have not been studied in any detail. This paper reports the study of a listwanite body that crops out on the northeast edge of the Baer ophiolite, in the western part of the Yarlung Zangbo suture zone (YZSZ).

The Baer ophiolite, 500 km northwest of Saga County in Ngari Prefecture, is mainly composed of peridotite with lesser amounts of mafic rocks. Its composition and location suggest that is part of the Yarlung Zangbo suture zone. The Baer listwanite crops out for a few kilometers in a WNW direction along the northeast boundary of the ophiolite, where it has a width of ~20 meters. The relationship between the serpentinized peridotite and listwanite is gradational and the boundary is marked by a zone of carbonated serpentinite in which nearly all traces of the protolith are obliterated. Because the spinels in these rocks are more resistant to hydrothermal alteration than olivine and pyroxene, they can provide useful information on the protolith. Two stages of listwanite are present; stage 1 listwanite contains spinel relicts whereas stage 2 listwanite is essentially free of spinel. These two types have completely different fabrics and mineral compositions.

The Baer listwanite is composed mainly of SiO_2, MgO and CO_2. Eight samples (3 from stage 1 and 5 from stage 2) show significant variations in their major oxides. The dilution of SiO_2 and MgO in listwanite relative to peridotite is probably due to removal of these oxides by the hydrothermal fluids and dilution by fluid-derived CO_2. These variations imply that listwanization is not an isochemical process. The Baer peridotite and both types of listwanite show similar chondrite-normalized trace element patterns. All samples show positive Sr anomalies and the Sr contents increase from stage 1 to stage 2 samples. Neither stage of listwanite shows significant enrichment in LREE compared with the protolith, but the HREE show an initial loss in the peridotite and then increase in the listwanite.

The content of Au and Hg in both types of listwanite is not high enough to be commercial, which is consistent with other locations where mineralization is mostly concentrated in quartz veins rather than the listwanite itself. No large quartz veins were observed in the Baer listwanite and there does not appear to be any great potential for Au prospecting in this ophiolite.

Key words: *Baer ophiolite, Tibet, listwanite, mineralogy, geochemistry*

Analysis of hyperspectral remote sensing data of the Sarfartoq carbonatite complex, southern West Greenland

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Abstract

The Sarfartoq carbonatite complex occurs in southern West Greenland in a transition zone between Archaean gneiss complex to the south and the Proterozoic Nagssugtoqidian mobile belt to the north. The Sarfartoq carbonatite complex consists of a core zone composed of dolomite carbonatite and minor søvite (calcite carbonatite) surrounded by a fenite zone and a marginal zone of gneisses frequently altered due to hydrothermal activity. The purpose of this study was to evaluate spectral reflectance techniques and airborne hyperspectral remote sensing data recorded by the HyMap imaging system for compositional mapping in carbonatite complexes. Results of airborne gamma-ray spectrometry data acquired over the Sarfartoq carbonatite complex were also analysed in concert with the hyperspectral remote sensing data especially for the localization of mineral exploration targets. Spectral reflectance measurements show that several minerals and rock units of the carbonatite complex display well defined and characteristic absorption featuresin the visible to short-wave infrared wavelength region due to electronic transitions (involving iron in two and three valent state and rare-earth elements) and vibrational processes (involving the CO_3 anion, Fe, Mg-OH and Al-OH bonds). The analysis of the hyperspectral data was based on an unsupervised neural network trained by competitive learning, the Kohonen self-oganizing maps (SOM), matched filter processing and a hierarchical approach for the mapping of sparsely occurring søvite rocks. The resulting thematic lithologic map shows the distribution of dolomite carbonatite, calcite carbonatite, zones of fenite and carbonatite dykes, fenite and marginal alteration zone. Special attention was paid to the radioactive shear zones occurring at the margin of the carbonatite complex. In combination with airborne gamma-ray spectrometry results,the hyperspectral data analysis aimed to identify mineral exploration targets for rare earth elements, thorium and uranium mineralization.

To assess the accuracy of the mapping results field investigations in the study area were carried out. The results of hyperspectral data analysis due to the spatially contiguous nature of the remote sensing imagery could be used to better map the outcropping carbonatite lithology. The localization through hyperspectral remote sensing of the sparsely occurring søvite rocks is of petrologic and economic geology interest. This research shows that outcropping fenite lithology can be successfully mapped using remote sensing data.It is to be mentioned that in the exploration for rare earth elements (REE), thorium and uranium mineralization gamma-ray spectrometry data may provide direct exploration targets. The hyperspectral remote sensing could assist by distinguishing iron-stained zones and the presence of REE-rich carbonatite dykes. The study demonstrates the effectiveness of hyperspectral remote sensing for lithologic mapping and mineral exploration of carbonatite complexes.

Keywords: *hyperspectral remote sensing, infrared spectroscopy, carbonatites, lithologic mapping, mineral exploration*

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3D modeling tools jointly applied on Gerakario (Greece) and Kadiica (FYROM) porphyry copper mineralisations

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Abstract

The geotectonic setting of Serbo-Macedonian Zone (SMZ) facilitates the formation of porphyry copper mineralisations.

This zone hosts many known deposits having been discovered and located in the areas of Pontokerasia, Vathi, Skouries, Gerakario and Fissoka in Greece, and Buchim, Ilovitza and Osogovo in FYROM. The SMZ metallogenetic belt consists of strongly deformed metamorphic rocks of Palaeozoic age superimposed by Tertiary magmatic activity. The 3D modeling tools are frequently used to make cost- och time-efficient tools in mineral exploration, to visualize, correlate and interpret geological data. This paper aims at presenting a comparative evaluation of the porphyry copper mineralisations of Agios Pavlos (Gerakario area) and Kadiica (Bukovik-Kadiica area) based on 3D modeling tools of respective geological settings, deformation structures and geochemical distributions, in terms of better understanding related ore-genetic processes and exploration potential.

Keywords: *Porphyry copper deposits, 3D modelling,mineral exploration.*

Introduction

The 3D geo-modelinghas through years come to become a potential tool in mineral exploration. In this study ge-models are used on the porphyry copper mineralisations of AghiosPavlos, in northern Greece, and Kadiica in eastern FYROM, hosted by SMZ rocks, extendingfrom Serbia and western Bulgaria, in the north, to northern Greece in the south. Gneiss, mica schist amphibolite and marble are the main basement rock types. The age is uncertain, but zircon U/Pb dating in meta-rhyolites suggests Paleozoic times of around 560 ma (Meinhold et al. 2003).

Substantial porphyry copper mineralisations and deposits occur associated with acidic stocks of Tertiary age, making shallow intrusions into SMZ Paleozoic metamorphic formations. The mineralized and host-rocks belong to Oligocene-Miocene calc-alkaline complexes of dioritic, granodioritic and syenitic composition. It is likely that the widespread calc-alkaline igneous suites resulted from an anatectic partial smelting of the lowermost continental crust, in post collision activity processes.

The northern part of SMZ between Serbia and FYROM, is generally considered to comprise an Upper (low-grade) and a Lower (medium to highgrade) unit (Dimitrijević, 1959). The protoliths of both units are reported as volcano-sedimentary formations, which have later been intruded by igneous rocks during several magmatic pulses (Antic et al. 2012).

The southern part of SMZ between eastern FYROM and northern Greece consists of two major lithostratigraphic units of Paleozoic age, known as the Kerdylia and Vertiskos formations, separated by the NW-striking Stratoni-Varvara fault, a major structural feature that dominates the area (Kockel et al. 1977). The major part of igneous activity in the area is related to North Aegean Tertiary activity, taken place from the Oligocene to lower Miocene (Fytikas et al. 1980). Aegean volcanism evolved during the Cretaceous in Bulgaria and extended progressively southwards, through northern Greece, during the Oligocene to lower Miocene, to develop the currently active (from Pliocene until now) South Aegean volcanic arc. The subvolcanic porphyry stocks and dykes, for the Greek part, are mainly related to the Vertiskos formation and shows Oligocene to Miocene ages (Frei 1992).

Geology of AgiosPavlos–Gerakario area

In the area of Gerakario the geological setting is dominated by a complex series of porphyric stocks and dikes of quartz diorite-monzonite composition (Frei 1992), while the countryrocks are schist-gneisses(Tompouloglou1981). Potassicandphyllic alterations of syenite and granodiorite porphyries, respectively, are the main mineralogical features. The stock show lensoid forms with the long axis striking for 600 m NE-SW and 300 m NE-SE. Most parts of the volcanic rock are hydrothermally altered, predominantly tosericite and quartz mineral facies. Quartz enrichment occurs in the form of veinlets and silicified zones (Kelepertzis et al. 1986). Sulfidesform stockwork and dissemination mineralisations consisting of chalcopyrite and pyrite. An oxidation zone including malachite, azurite, goethite and limonite is occasionally present. Alteration is weakly developed, dominated by silicates, with biotite being the main alteration mineral. (Apostolou and Stefanidis 1987; Economou-Eliopoulos and Eliopoulos 1992). The mineralisation occurs as veinlets, of a few mm to some cm thick, as fillings of joints, as disseminations, especially when hosted by narrow shear zones in the wall-rocks. The main Cu-mineralisation is associated with potassic alteration zones withinsyenite porphyry, similarly to the porphyry copper style mineralization at Skouries (Frei 1992).

Local Geology of Kadiica – Bukovik/Kadiica region

Bukovik-Kadiica deposit is located in the eastern part of the FYROM in a hilly region close to the border with Bulgaria and 2 km northeast of the town ofPehcevo. The deposit can be described as one of a number of dacite plugs of Neogene origin that exist within the SMZ as part of the volcanic complex intruding into Palaeozoic sediments, andesites and gabbros. On a larger scale the Kadiica region is underlain by metamorphic rocks (metadiabases, schists, gabbro, diorite and younger grantoids) of Upper Proterozoic to Palaeozoic age (Tasev 2010; Tasev et al. 2012).

The Bukovik-Kadiica ore district has been located in the most eastern parts of the Besna Kobila - Osogovo - Tassos metallogenic zone (Aleksandrov, 1992; Janković et al., 1995) and has been characterized by complex polymetallic mineralisation. Within the same ore district there were determined ore body systems and intersected dykes of quartz-latites with an absolute age of 24–12 Ma (Serafimovski et al. 2001, 2010).

According to Singer et al. the ore of Kadiica deposit has an 1 x 0.6 Km axis dimension and covers an area of 0.5 km^2.

3D model of Kadiica mineralization

Using the lithological and the geochemical data from 11 drill holes a 3D grid was created that depicts the distribution of each assay (Ag, As, Au, Mo, Pb, Zn, Cu; Figs 1 and 2).

The software gives the opportunity to the user to create slices of the 3D grid and take a closer look to the spatial variation of an assay. From the grid showing the Cu distribution, an ore body with dimensions of 1000 x 600 m and 50 m thick, could be indicated

From the geochemical distributions it could be illustrated that high values of As are followed by high values of Au and Pb and low values of Zn.

Different to Au and Pb the Cu mineralization

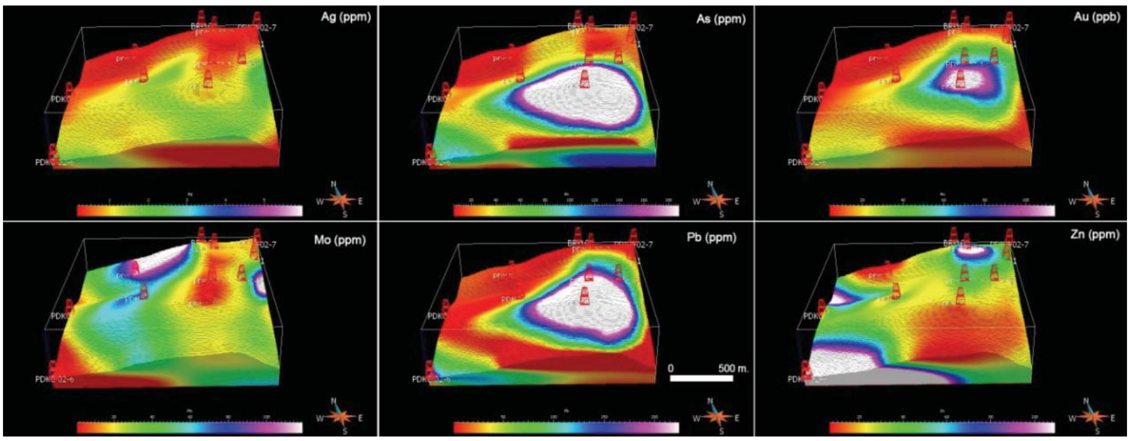

Figure 1. 3D geochemical distribution in Kadiica deposit for the following assays: Ag, As, Au, Mo, Pb, Zn.

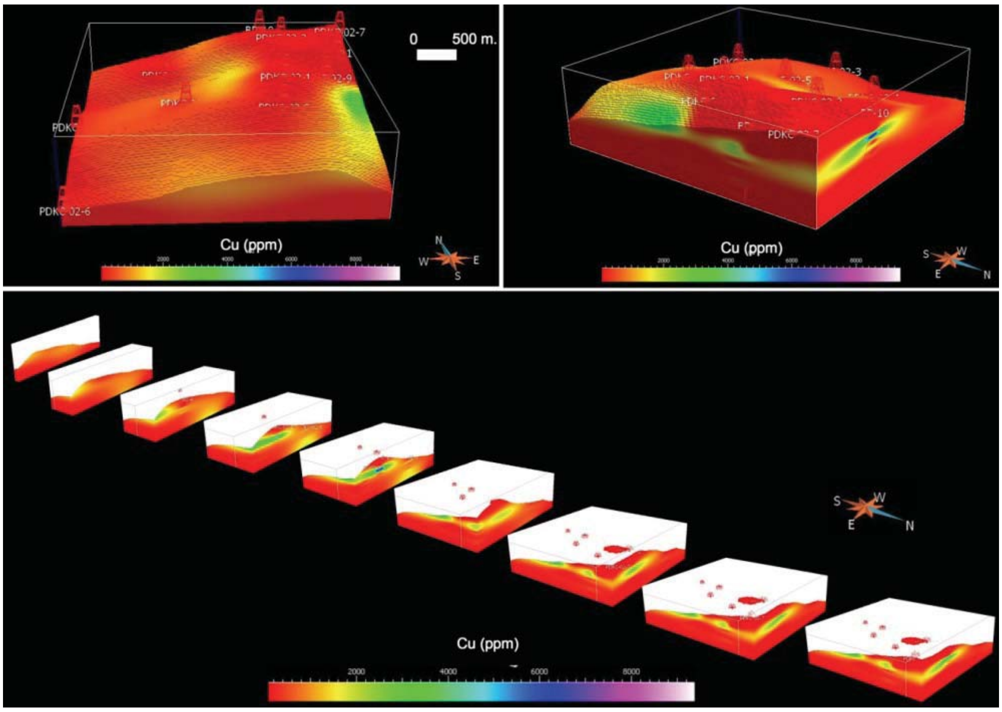

Figure 2. 3D geochemical distribution of Cu along withE-W geological sections across Kadiica deposit.

is located at deeper levels. Higher-grade Cu mineralization appears also in the western part of the main ore body (Fig. 2).

3D model of AghiosPavlos mineralization

From the 3D model of Aghios Pavlos mineralisation the following can be obtained:

i) The ore body responds to an area of 350 x 330 m, and has a thickness of 20-60m. (Fig. 3);

ii) the mineralization dips 30^{o} S;

iii) the mineralization seems to extend to south where over the explorationneeds to be focused, andiv) there are two ore bodies indicated, a western and an eastern one.

From the cross-sections it can be obtained that the level of main sulfide mineralization is lower than the oxidation zone (Fig. 4).

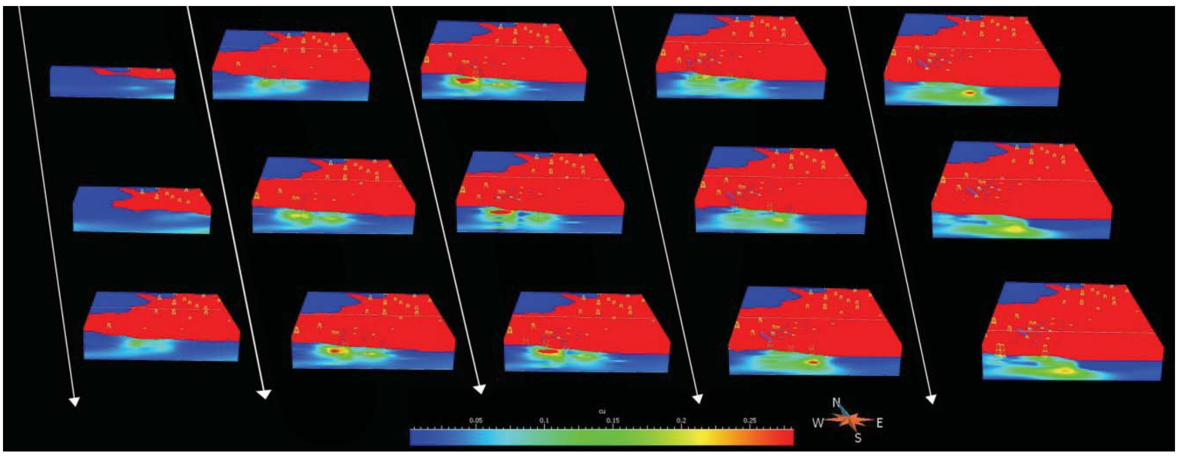

Figure 3. 3D geochemical distribution of Cu and along with W-E geological sections across AghiosPavlos mineralization.

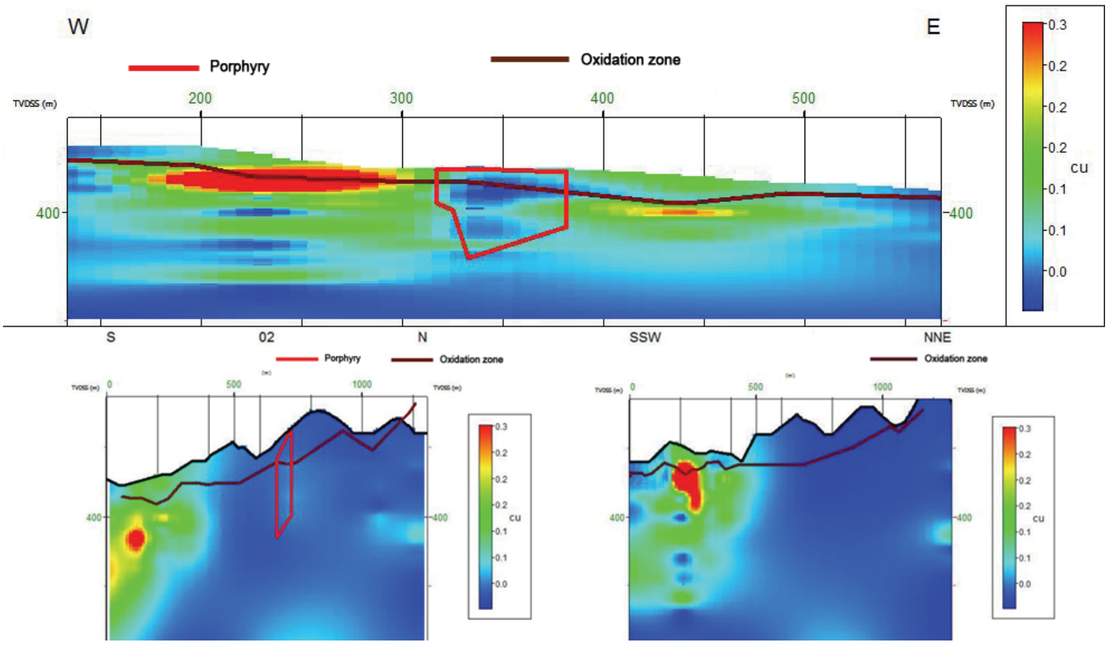

Figure 4. Cross-sections, striking W-E, S-N and SSW-NNE, cutting throughAghiosPavlos Cu mineralization..

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Implicit 3D geological modelling

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Abstract

Modelling a geological parameter by implicit method using the radial basic functions (RBF) means to represent its surface data with a single 3D function. This spatial function represents a signed "distance" from the object's surface. Points inside the object have a negative "distance" while points outside are positive. The object's surface is defined implicitly as the zero set of this function. This function is continuous and smooth as much as we wish and reasonably accepted for the practical use.

Implicit method based on RBF allow to up-to-date predictive 3D model that promotes the best locations for discovering additional economic mineralization based on all datasets. Complete 3D geological model that honours geometric relationships is established from on-site data collection and iterative modelling and can be completed direct from data base. It is very effective and useful especially for consulting agencies where an quick assessment required. Combined modelling and field investigation produces faster results than using conventional methods of modelling.

Applying implicit method of modelling straight to database make more crucial mentoring of geologists in the systematic collection of quality data and its interpretation and modular structural geological training course, that can be tailored to suit the participants at all skill levels and that relate to the deposit and geological environment types they are working in. The advanced techniques on 3D modelling based on the rapid 3D geological modelling software can quickly and effectively model features such as lithology, alteration, spectral data, structural data, geophysical information, grades and any other attributes on the points on the space taken in consideration.

Recommended a "outside-in" analysis results in more focused field work (and thus less field time), as the structural controls are broadly determined during the modelling stage by the application of fundamental structural geological concepts. A full 3D model is available before field work is conducted, often in about a week, so the resulting modelling and interpretation is used as a framework for field analysis. If more detail is obtained from the field, this information is fed back into the modelling, thus the analysis becomes an iterative process that integrates structural geology at all scales.

Primarily needed a careful assessment of the structural controls on mineralisation and how this manifests at the outcrop and mine-scale and the combined integrated structural geological 3D modelling and field work that produces high quality and beneficial results in real time and quickly, which allows for much faster implementation of strategies. Meshing of single domain assay data can be obtained very rapidly; while meshing of entire mine assay data can be conducted in a matter of hours as opposed to days of manual digitisation.

More than one geological interpretation can be used to generate different models as the editing process is not labour intensive; reducing the time line of geological modelling, creates new opportunities for testing multiple working hypotheses. The models are updatable and can be regenerated as new data of information becomes available.

Key words: *3D modelling, explicit, implicit, interpolation, radial basis function*

1. Introduction to implicit method of geo modelling

Most recent years in geological and mining circle has started to have a more acceptable approach (and enthusiastic) the implicit method of modelling of mineral resources and in general in geological modelling. The implicit method of modelling is based on radial basis function (RBF). This is pushed, forward, considerably, mostly from the use of advanced softwares and more stronger graphic cards computers.

But still classical method of modelling (so called explicit) for tradition and/or blaming, probably, the conservative attitude, it is still in use, in well established mining and exploration companies but also from junior explorers.

Should not mixed geological modelling (of lithology or resources) which requires a data base with real information of every point in space taken in consideration, with modelling of a idea which is based on the general knowledge and experience where there are not any experimental data. For example the schema of subduction, below, which, in regional scale, illustrate the mechanism of an offiolitic environment and mineralization related to it, it is not based on any world coordinative data and in fact is just a 2D modelling, static, mostly not in horizontal/vertical scale and not related to any real space in world coordinate, it is hypothetical, even it pretend to explain what can be the most appropriate geo model on region in consideration (in this case in northern Albania)

On same time even "the geological model" below (Fig. 2a) is based on the real data, it is static, based on traditional way of presenting the geology, it is a 2D and cannot be updated soon as the new results are added to database. For comparison we have displayed (Fig. 2b) same ore body generated by the RBF method.

RBF's are conceptually similar to draping a sheet membrane above the measured sample values while minimizing the total curvature of the surface. The chosen basis function will determines how the "membrane" will fit between the values. The diagram below illustrates how an RBF surface fits through a series of topographic values. As matter of fact values can be any attributes with 3D coordinates.

The RBF, as an exact interpolators methods, differs from the global and local polynomial interpolators, which are both inexact interpolators that do not require the surface to pass through the measured points. When comparing an RBF to IDW (which is also an exact interpolator), IDW will never predict values above the maximum measured value or below the minimum measured value as you can see in the cross section of sample data below.

The RBFs can predict values above the maximum and below the minimum measured values as in the cross section above which make almost same as kriging method used on from geostatisticiens. RBFs are formed over each data location, that change with distance. Optimal parameters are determined using cross validation in a similar manner as for

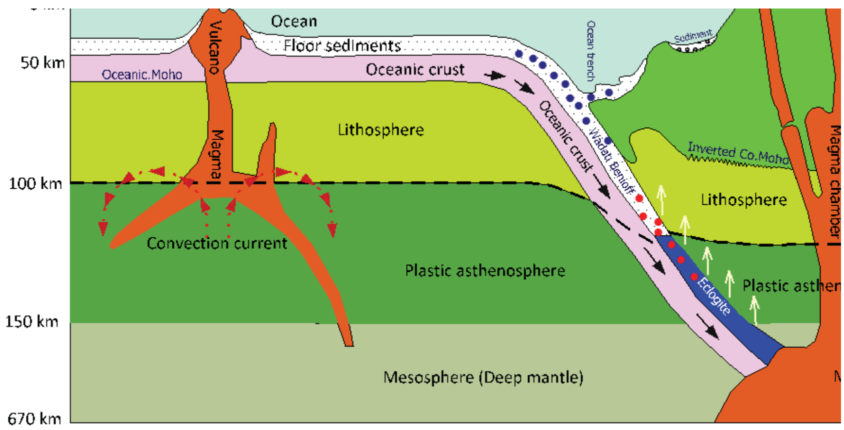


Figure 1. Sudduction schema of northern Albania (Kamberaj 2013, Platinum Resources internal report).

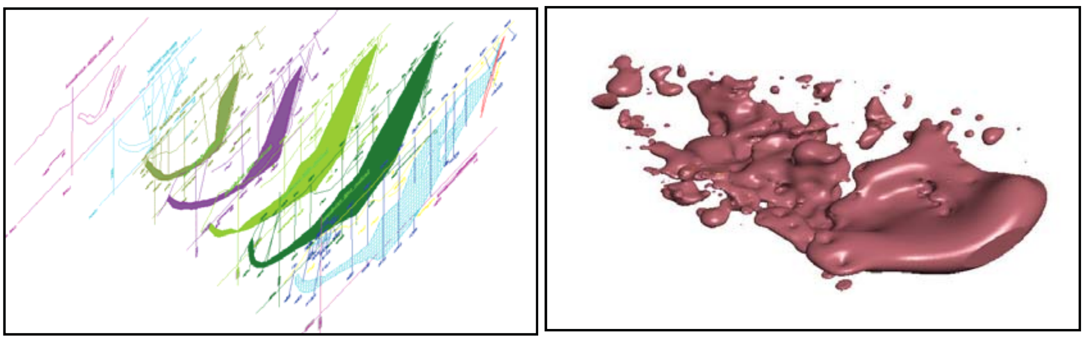


Figure 2.
a. Explicit ore body model of Zn-Pb, MDHBD deposit;
b. Implicit ore body model of Zn-Pb, MDHBD deposit.

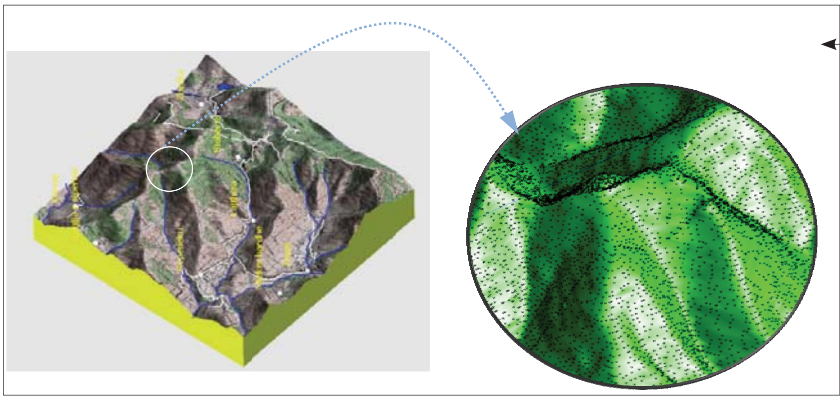
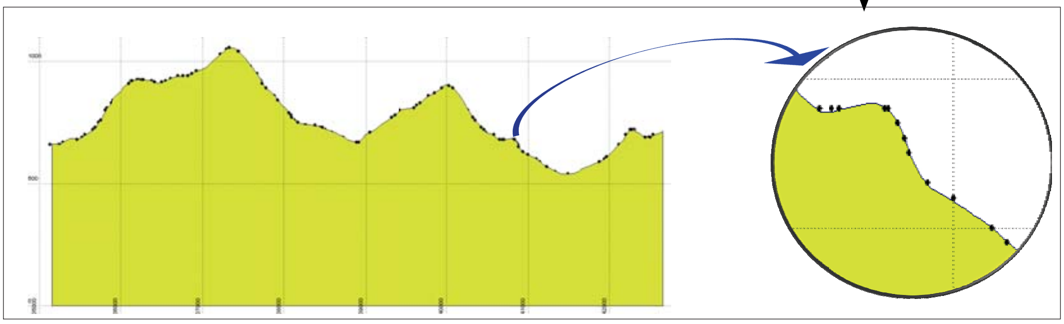
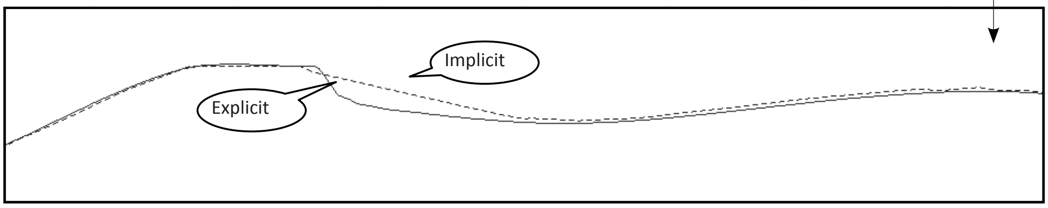


Figure 3. Implicit model of topography.

Figure 4. Section of Fig. 3 with experimental data and the RBF surface.

Figure 5. The difference between implicit and explicit topography surface.





IDW and local polynomial interpolation.

RBFs are used to produce smooth surfaces from a large number of data points. The functions produce good results for gently varying surfaces such as, ore grades, lithological boundaries, faults, elevation ore-waste boundary and any other attributes with space coordinates.

However, a caution should be taken when large data values occur within short distances and/or when the sample data is prone to measurement error or uncertainty.

RBF methods are a series of exact interpolation techniques; that is, the surface must pass through each measured sample value. The basic function φ in this context, is a real function of a positive real r where r is the distance (radius) from the origin. There are five different basis functions choices as:

a. For fitting smooth functions of two variables

1. Thin-plate spline, $\varphi(r) = r^2 \log(r)$

2. Multiquadric function, for various application, especially for fitting to topographical data

$\varphi(r) = \sqrt{r^2 + c^2}$

3. Gaussian, mainly for neural networks

$\varphi(r) = \exp(-cr^2)$

b. For fitting functions on three variables more practical would be choices of;

4. The biharmonic spline plus linear polynomial $\varphi(r) = r$

5. The triharmonic spline plus quadratic polynomial $\varphi(r) = r^3$

All these poly harmonic splines (including the thin plate spline) minimise certain energy semi-norms and are therefore the smoothest interpolators. Each basis function has a different shape and results in a different interpolation surface. RBF methods are a special case of splines.

Geostatistical application allows to use all of five different RBF's such as completely regularized splines, thin-plate splines, splines with tension, and inverse multiquadric. Sometimes, the difference between these is not great, geologist or mining specialist may have reason to choose one or the other and use cross-validation to select one. For all methods except inverse multiquadric, the higher the parameter value, the smoother the results.

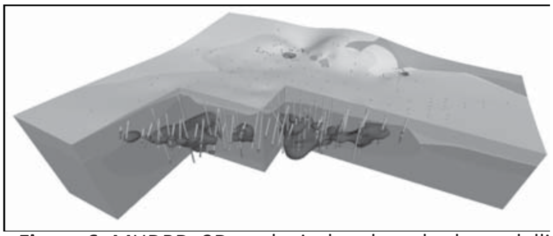


Figure 6. MHDBD, 3D geological and ore body modelling (Zn ore on red colour).

Figure 9. ZGJ, Implicit topography (NW).

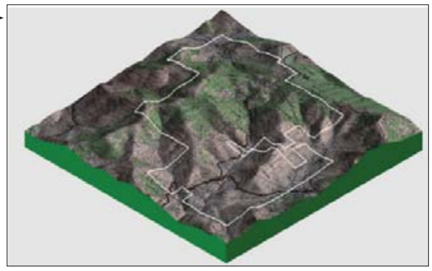
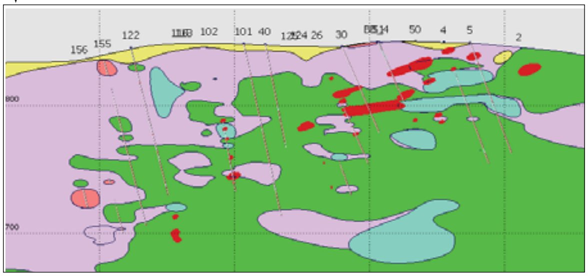


Figure 10. ZHRK, Section from a 3D geological model.



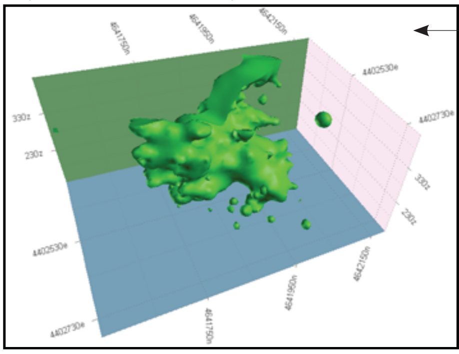


Figure 7. SKXH, ore body Fe_2O_3 above 18 wt.%.

Figure 8. UNG ore body Fe_2O_3 above 14 wt.%, (NW).

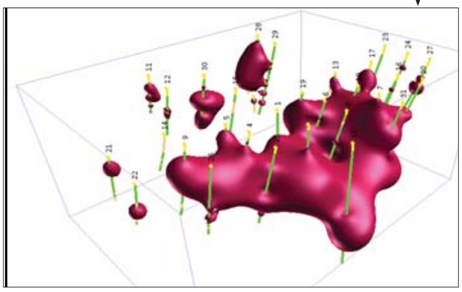
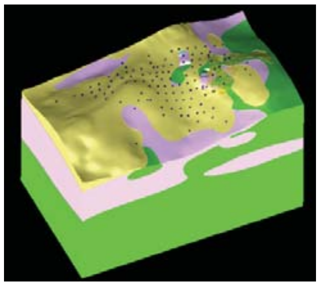


Figure 11. BB, 3D geological model.



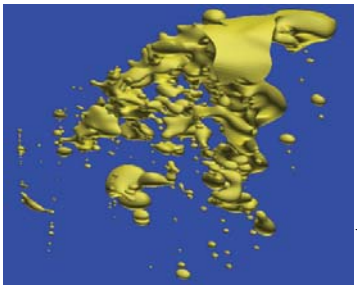


Figure 12. PT, 3D ore ody.

Each of the RBFs has a parameter that controls the “smoothness” of the surface.

Following are some examples from implicit resources and geological modelling.

Figure 13. Comparing the Implicit (g r e e n l i n e) a n d explicit block method of 3D resource modelling (S K X H deposit).

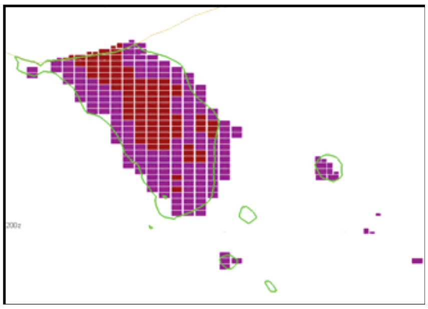


Figure 14. E-W Cross section with all grade surfaces of ore body (SKXH deposit).

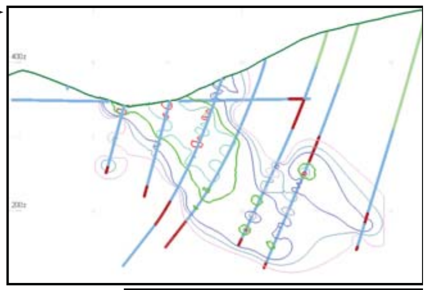


Figure 15. E-W section of implicit modelling for grades 14,15,16,18,19,20 Fe_2O_3% and superposed explicit ore body at 18% (hatched area).

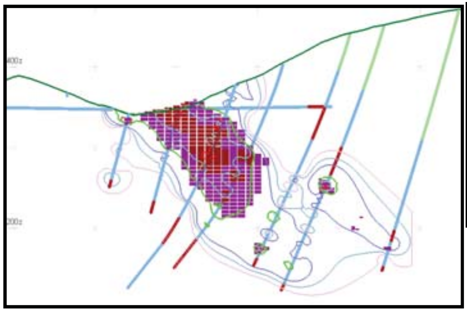


Figure 16. N-S section of implicit modelling for all grades 14,15,16,18,19,20 Fe_2O_3%.

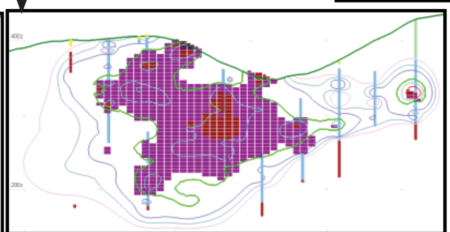


Figure 17. Horizontal section at 270 m of implicit modelling for grades 14,15,16,18,19,20 Fe_2O_3% (Pink coloured blocks displays explicit model of 18% only).

Synchronization between SQL Server Compact edition and MySQL - Applying geological data

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Abstract

Improved technology in small and medium enterprises in Albania depends on economic and social factors. If the costs of modeling a system for managing data and presenting them not only on the internet, will interfere with the independence of the system itself to the physical and virtual location and will result in a pure innovation for any small and medium business. Therefore, the purpose of this presentation is to help users in better data managing, especially geological data. In past research we have improved that the SQL Server CE is a good instrument for creating, manipulating and query geological data when there are no possibilities to connect on the WAN or internet. But there is a problem when the user or a geologist has to read or write the data in a WAN or Internet DBMS. We know that when the geologist is taking samples in the field (in sense of internet connection) there can be not possible to connect with this DBMS via WAN. In this sense we propose a combination use of both systems, MySQL and SQL Server CE, because as we know the MySQL is a network DBMS and the SQL Server CE is a local DBMS. This is made by an algorithm that is implemented in a background process and it communicate by default with the MySQL DBMS and SQL Server CE but when there are connection problems, the algorithm pass to store and manipulate data in the local SQL Server CE. During the normal work process, the algorithm try to restore a connection with the MySQL DBMS and when it is realized, the algorithm synchronizes the data that are stored in the SQL Server CE with the MySQL DBMS. In this way, the geologist will not notice the difference to work online or in local, and the most important innovation in this propose is the fact that the data will always be up to date and accurate.

To make the tests we used some 3D geological data like GPS data and we created a desktop windows base application. This application is made by C++ programming language with NET libraries. After the test we collected the results which show that the algorithm is correct because it is able to synchronize the two databases. While in terms of algorithmic complexity, the time to synchronize the two databases, MySQL and SQL Server CE, is bigger that the time to store or manipulate the data in one of them. Furthermore, the time to store or manipulate the data in both of the DBMS's is not much larger than the time to store or manipulate data in one of the databases, MySQL or SQL Server CE. With the results obtained, we believe that the Faculty of Geology and Mining and specially the Department of Geoinformatics may develop applications based on these technologies to improve the process of taking samples in the field.

Metadata in Albanian Geological Survey

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Abstract

After the 90s, the open market increased the demand of geological information from local and foreign investors, scientific community for investment purposes or academic one. Searching manually all this huge amount of information ended up with the impossibility of answering in real time to consumer requests. This was the main reason from which emerged the need to structure the information in a digital format, in such a way that could describe, explain, localize, retrieve and manage data as much as fast and simple possible. In addition, a large digital inventory is accumulated from preparation of different geological maps in depending on the program used to such shp file, dwg file or pdf file. All these digital data elaborated and created so far, need to be associated with Metadata. The accomplishment of files with Metadata was initially experienced for geological map of Albania at scale 1:25.000 derivate from ArcGIS as shape files. The standard used in creation of Metadata was the one used by One Geology project in combination with INSPIRE Directive. The challenge affront of AGS remain the fully compilation of all digital data with metadata.

Keywords: *metadata, standards, digital data, geological maps*

Introductions

AGS has an experience of more than 15 years in digital files creation with various thematic and scale. This way, we have a rich archive containing different file types such as shape file, *.dwg and *.pdf created from the elaboration of geological data, kept for more than 50 years in the Central Archive.

This geological information can be considered as a national asset of unique values, that's why their preservation in digital format accompanied with metadata – which are a way of reading digital data – is a must.

Based on the principle that data can be only gathered once, and for this reason must be preserved for the next generations, emerged the idea of associating digital data with metadata. Another reason that confirms this idea, relates to the INSPIRE Directive, which entered in force in 2007 and is expected to be implemented by all of EU Countries within the end of 2019. This directive requires to be created an infrastructure of spatial data for EU Countries. According to a survey, from all EU Countries that possess metadata, only 65% have followed the ISO standards (19115, 19119, 15836), ISO 19115 -32%; ISO 19115 and ISO15836 - Dublin Core (5%); ISO 19119 and ISO19115 (28%). *(Ref. INSPIRE Metadata Survey Results)*.

Metadata preparation for the geological map is an integral part and one of the objectives of the project "Converting to GIS of digital maps of scale 1:25,000 and 1:50,000", funded by AGS.

Metadata schema

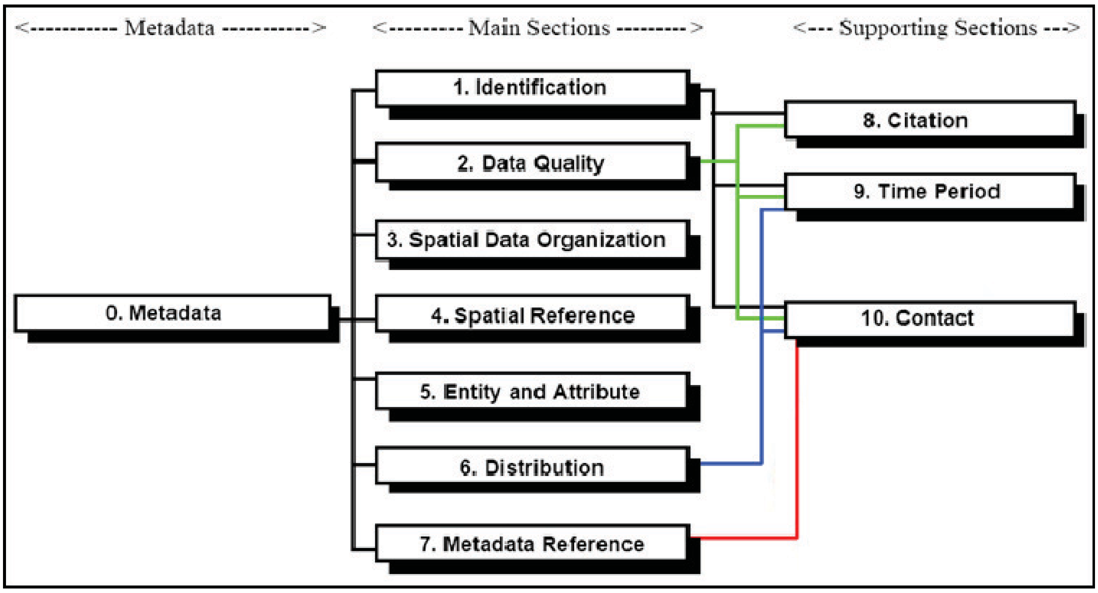
The metadata are divided into two groups i) the group of main data and ii) the section of auxiliary data. The main data section is composed by a group of 7 fields which are classified in a) Identification Data; b) Qualitative Data; c) Spatial Organized Data; d) Spatial References; e) Objects and Attributes; f) Geographic Distribution; g) Metadata References.

The auxiliary section contains data that give additional information for one of the groups of main data e.g. in the case of *Data Identification* as additional information are given also *Citation*, *Time Period*, *Contact Person* and so on. In a similar way, complementary data are given for the group of main data Geographic Distribution.

The EN-ISO19115 standard as well as MD-19119 international standards are chosen as a model of metadata for the geological map of 1:25,000.

The reason of this choice is that many of European Geological Surveys have adopted the above standards to describe their data. Considering the fact that Albania is member of EuroGeoSurvey, AGS should have the same platform. Once metadata are available, there is the possibility to operate on the exchange of geological information within EGS, standards unification, systems and protocols development in order to improve the discovery, download, presentation and distribution of main European spatial geographic data.

4. Data Quality: the information related to quality (thematic, geometric) and the utilisation of geological data in National level. Here should be included the information on the ***origin of these data sources*** (the source of geologic, topographic information etc.) for the final dataset.



Scheme 1: Metadata Scheme

The above mentioned models have been adapted and developed during the creation of Geological Map. The metadata profile utilised by One Geology project is entirely conform to INSPIRE profile, in respect of datasets reading but not limited to, additional useful information on evaluating and using data sources.

That's exactly why AGS metadata model is based on the models utilised by One Geology project. The scheme is the same as the one applied by the above mentioned project.

According to this scheme, data are grouped into for main sections:

1. Identification: the information includes the mandatory description of geological data sources as well as more information about the responsible institution (*Organisation Name*, *Responsible Persons*, *Links*, *Places*, *Roles*, information on utilised *Software*);

2. Maintenance: based on *EN-ISO19115 B.5.18 Code List* is recommended to include the *update frequency*. The *Procedure Description* and *Software* utilised for the update are optional;

3. Distribution: the information on *distribution format* and its *version* should be given by the subject who delivers the data, in our case by AGS;

ArcCatalog software has been utilised to create the metadata for the geological layer of scale 1:25,000 being attached to this layer.

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Landslide Susceptibility Maps of Vlora District

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Abstract

Landslide susceptibility can be defined as the relative degree of instability of the terrain. This map presents the probability of future landslide occurrences.

To build up a landslide susceptibility map we should consider the published methods or we can modify them to get a better-expected result. Most of them only implemented the heuristic method to the area prone to landslide and the problem of this method is in the subjectivity of defining parameters, the weighted and scoring values.

The objectives were building the inventory map of the landslides and the preparation of Landslide Susceptibility maps of Vlora district.

Initially were built up the lithological maps in scale 1:50,000 along with landslides, 87 landslides in total (inventory map).

There are many factors that should be considered to analyse landslide for the preparation of Landslide Susceptibility maps of Vlora district. We divided those factors into 3 groups of factors described follow

- Topography factors such as data of digital terrain model, slope direction and length.
- Engineering factors such as data of lithology, structure of geology.
- Land Use factors such as data of land use map.

The slope gradient is the most important factor to build up the landslide susceptibility mapping. This factor is generated from digital elevation Model on Albania, the classes of the slope gradient are extracted in grades classified into 9 classes: 0-5°, 5-10°, 10-15°, 15-20°, 20-25°, 25-30°, 30-35°, 35-40° and higher than 45°.

Lithology data were extracted from geological map. Lithology is one of the main factors influencing the type and the intensity of the morph-dynamic processes, including landslides. We involved lithology as a factor for susceptibility mapping, based on geological maps scale 1: 50,000, various formations in the study area have been grouped into 11 classes to prepare the lithology data layer. The 11 classes correspond to 1 strong sedimentary rocks, 2 stratified rocks, 3 sandy rocks, 4 average clay rocks, 5 soft clay rocks, 6 soft rocks the chaotic, 7 evaporate rocks, 8 soils with cohesion, 9 soils without cohesion, 10 soil layers with and without cohesion.

Land Use is one of the key factors responsible for the occurrence of landslides. The classes of land use are categorized into reservoir, forest, mixed garden, mixed forests, urban areas, pasturage, and agricultural lands.

For the preparation of Landslide Susceptibility maps of district Vlora is used Heuristic analysis and Bivariate.

Heuristic approach is based on the opinion of engineer-geologist experts. Landslide inventory map is accompanied with environmental factors to be main input for determining landslide hazard zonation, and then the experts define the weighting value for each factor. Heuristic approach takes into account a hierarchical heuristic model becoming a part of decision support system (DSS) which aims for spatial decisions.

Bivariate Analysis is based on using Raster Data. All the factors taken into consideration are converted to raster ones, than is made the analysis using Van Westen's formula for calculating the weight of each class "i" parameter "j".

In conclusion we can say:

- Gentle slopes are predicted to give low value for shallow landslides based on commonly lower shear stresses correlated with low gradient. At slopes from 10° to 30°, landslides may have high probability of occurrence. The remained slope angles more than 30° will give a relatively low probability of landslides occurrence because the existing of resistant lithologic units.
- Larger landslides have occurred in the cliffs of soft clay, soft chaotic rocks, stratified rocks and the rest in other lithological formations.
- According to Land-Use, larger landslides have occurred in coniferous forests, fir, agricultural lands, urban areas and the rest in other classifications.

A generic overview and demonstration of Micromine's 3D Geological Modelling software and its ability to model a variety of deposit types.

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Abstract

MICROMINE is an Australian headquartered Technology and Consulting company that has been developing a suite of solutions for the Exploration and Mining industry for over 25 years. With 23 offices around the world, MICROMINE is based in all the major mineral producing regions around the world and we are able to support our clients on their local time zone.

Our products cover the entire exploration and mining cycle, from field data collection and validation using Geobank Mobile, robust database management using Geobank, drill hole data display and manipulation through to 3d modelling, JORC compliant resource estimation, Pit Optimisation, mine design (underground and open pit) and mine scheduling using Micromine, and mine production management and control using Pitram.

We would like to present our Micromine, 3d geological modelling package to the audience and we would be keen to demonstrate the application of the software within the industry.

Micromine is a cost effective, easy-to-use yet powerful software package for mining engineers and geologists. Worldwide, more than 2000 mining and exploration companies use Micromine to develop and maintain their mining projects on a day-to-day basis.

The real strength of Micromine is its ability to convert raw data into information. Not all data is valuable and often it is out of date or irrelevant. Micromine combines an extensive range of data validation and processing tools, with the data modelling and visualisation tools needed to identify and present relevant information.

When that information is used to improve an organisation's existing knowledge and understanding of its mineral resources, such as helping someone to understand where to find the next major discovery, or providing the know-how to beat sliding metal prices, a real high yield return can be achieved.

The functionality of Micromine is arranged around a suite of modules, which enable you to tailor a package to meet your exact needs. An overview of the modules is included below:

Key Words: *3D modelling. Geobank, Micromine, mining, Pitram*

Core

Core is the 'engine' of Micromine. This powerful module allows you to import, validate, process, display and interpret a wide variety of surface, drillhole, and subsurface data.

Core incorporates Vizex (Visual Explorer), Micromine's integrated, intuitive and seamless 2D and 3D viewing and editing environment. Vizex allows you to simultaneously display, query, and interactively edit multiple data layers.

Core supports Google Earth and numerous CAD, GIS, GPS, image processing and mining application formats, most of which may be displayed in Vizex without conversion. Exporting to supported formats makes it easy to incorporate Micromine in a multiapplication workplace.

Core includes a powerful Plotting Module, featuring a Vizex-style interface. Its plotting capabilities enable the creation of complex plot layouts in minutes, using a selection of ready-made templates, which may be readily modified to create specific company templates. Core Plotting supports interactive pan and zoom within a 2D plot; and rotate, pan and zoom within a 3D plot. Plots are easily customised using templates and snippets, and layout editing is easy with familiar drag-and-drop.

Core includes straightforward macro tools that allow any Micromine process, such as creating multiple plot layouts, to be automated. The embedded Python programming language may be used for advanced automation or customisation.

Exploration

The exploration module provides advanced features for interpreting and reporting resource data. To improve the quality and presentation of data, the user is able to generate contour grids, DTM's, and wireframes, perform drillhole calculations and compositing, and carry out statistical analysis and polygonal modelling. Advanced string functions can be used to extract and display cross-sectional outlines and mine openings. Features include:

- Display Graphs and Stacked Sections
- Advanced Drillhole Display
- Geostatistics and Advanced Statistics Functionality
- Structural Geology display tools
- Strip Logs
- Drillhole Compositing and Calculations
- Digital Terrain Modelling and Contouring

Wireframing

Micromine's Wireframing module provides the tools for building, managing, and analysing the 3D solids and 3D surfaces used for advanced exploration, resource estimation, mining and geological modelling. Utilising powerful and intuitive tools, it visually constructs 3D shapes illustrating underground mine designs, or orebody interpretations, referencing data such as centre-line strings, profile shapes or polygonal strings.

Features include:

- Polygonal Wireframe Estimate
- Solid-to-Solid Interaction
- Wireframe building and editing
- Wireframing from Strings

Resource Estimation

The Resource Estimation module is designed specifically for detailed and advanced resource analysis and reporting.

Its block modelling tools are used for mine design and reserve estimation. Advanced exploration work, in-house resource estimation projects, resource estimation consulting, mining and orebody modelling all use the Resource Estimation module.

Micromine tools, such as form sets, simplify the process of setting up resource estimations and provide a documentation trail, an essential requirement for standards-compliant reporting.

Resource Estimation supports regular models and sub-blocked models, both of which may be aligned in any 3D orientation. Sub-blocking tools easily facilitate the conversion of sub-blocked models into regular models and vice versa, an essential feature for data sharing with other applications where sub-blocking is not supported. Resource Estimation sub-blocking tools also make it easy to combine different models for the same project, for example, an orebody model with a waste model. The module also includes unfolding and flattening tools to model complex folded deposits.

Stratigraphic Modelling

Micromine's Stratigraphic Modelling module is ideal for any stratified deposit such as nickel laterite, tin, phosphate, bauxite, iron ore and platinum. Its revolutionary modelling workflow produces a Seam Block Model (SBM), a highly efficient way to represent a geological layer along with all of its attributes. Stratigraphic tools include an intuitive and visual stratigraphic summary, making it easy to define and understand the relationships between layers prior to modelling. Sophisticated later interpolation options readily handle changes in thickness (such as unconformities, pinches or partings), producing the best possible 3D representation of the deposit, and well-established classical and geostatistical grade (or quality) interpolators provide the attribute information.

Implicit Modelling

Fast track your understanding of any structural or grade boundaries with Micromine's Implicit Modelling module, which uses radial basis functions (RBF's) to model grade shells, lithology boundaries, faults or surfaces. Using 3D points or drilllhole interval files as input, it generates 3D wireframe solids representing features like lithology units or zones of a specified grade range, or wireframe surfaces such as fault planes or surface topography. These wireframes are readily displayed in Micromine's Vizex (Visual Explorer) 3D visualisation environment and are a valuable tool for finalising geological or grade interpolations.

Mining

Used for underground and open pit designing. Grade Control functions allow the user to integrate different data types and interactively evaluate volumes, tonnages and grades within existing or new outlines. Features include:

- Open Pit Design
- Pit Optimisation Interface
- Blast Hole Design
- Underground Design
- Ring Design
- Grade Control

Surveying

Used to import and process survey data. You can acquire data using all the standard data collection methods, and can interface to virtually any data recorder. Features include:

- Calculations (e.g. Stadia, Angles and SAS)
- Co-ordinate Set-Out
- Cross-section and Top/Bottom Volumes
- Traverses
- Field Reductions

Pit Optimisation

The Pit Optimisation module uses the industry standard Lerchs-Grossman method to calculate a subset of blocks (from an existing Block Model) that gives a feasible pit with the greatest value.

- Supports MICROMINE formats, as well as formats from a wide range of other applications
- Works with the models of mineralisation with optional datum surface wireframe. It is not necessary to have full block models (combined ore, waste and air cells)
- Fully supports sub celled block models, there is no longer a requirement to regularise models before running
- Supports multiple elements and multiple processing methods, cut-off and cash flow methods

Scheduling

Micromine Scheduling provides a smart, integrated solution to assist short term planning of resources to tasks over a given period. It enables the optimum mineral extraction process necessary to meet corporate objectives.

Integrated within Micromine, the Scheduling module eliminates the requirement to import and export files with third party applications. Scheduling assists Mining Engineers and short-term planners to plan and schedule material extraction from underground and open pit environments. In keeping with Micromine's ease of use, the Scheduling workflow comprises five simple steps; prepare, configure, import and sequence, validate and report.

A Micromine specialist would like to present the above functionality graphically, through a user focussed demonstration of the software. This would be done using a real world data set to give an example of how Micromine can be applied for various deposit types.

Design and implementation of 3D geological database for mineral resources

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Abstract

When speaking about the mining sector, good data management is crucial for achieving the success of a project. For this reasons important that decision making is based on well managed data. In contrary, in the case that data are not properly managed, wrong decisions will be made leading to reduction in the efficiency of the company and the production.

Many mining activities (starting from exploration to exploitation and production) are progressing from traditional methods to contemporary and technologic methods by the means of utilization of the Geographic Information System. The time when the operations were based on paper maps and field slips have passed, beingreplaced nowadays by digital maps based on layer and high quality images.

In this way, GIS has replaced the old system of map analyses, the traditional means of their drawing and processing. In a general sense, the programs give the experts the possibility to manage, integrate, store, edit, analyze, share and display results with low cost in broad sectors including that of exploration new and old deposits.

This work is an attempt to present the method of executing the process of creating a geographic database in a three dimensional format. This process aims the use of contemporary programs in the field of geo-informatics and geological modeling, linking them with the knowledge in the mining field.

The development of the geological database is performed for Bulqize area, one the most richest areas in mineral resources. This area is continually under the processes of exploration and exploitation, making it one of the most envied deposit zones in the world regarding this mineral.

The three-dimensional geological database is based on digitized historical data. In order to develop it, several data sets have been used for example to extract drill data from geological maps, topographic maps, geological longitudinal or cross-sections and sampling information, the drilling form and the drilling location.

All collected data have been presented in the “Micromine” program, which made possible the processing of geospatial data and the further mining planification.

The real asset of this program stands in the ability to convert tabular data in useful information. Taking into account that not all the data are valid, “Micromine” offers the possibility of choice between a series of commands and provides a flexible and efficient environment for the evaluation, validation and processing of data in collaboration with their modeling and graphical presentation in order to identify the information. In this simple manner, information can be used to increase the knowledge of mineral exploration, understanding of the structures and their further development. It is worth mentioning that beside this, the role of the geologist during planning is considered vital to ensure that the gathered data are accurate.

Modeling 3D orebody using matlab

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Abstract

The aim of this presentation is to give information in a visual and statistical manner in order to better understand the study of oil-bearing reservoirs qualities and quantities. On the other side, using the same Matlab code, we can easily navigate in space into the oil-bearing reservoir to have an better image of how some essential parameters, permeability for example, change from different positions or to evaluate the heterogeneity of the porous medium. This method compares the effect of different surface normals on the visual appearance of lit isosurfaces. In one case, the triangles used to draw the isosurface define the normals. In the other case, the isonormals function uses the volume data to calculate the vertex normals based on the gradient of the data points. The latter approach generally produces a smoother-appearing isosurface. In geometry, a triangulation is a subdivision of a geometric object into simplices. In particular, in the plane it is a subdivision into triangles hence the name. Triangulation of a three-dimensional volume would involve subdividing it into tetrhedra ("pyramids" of various shapes and sizes) packed together. In most instances, the triangles of a triangulation are required to meet edge-to-edge and vertex-to-vertex. Different types of triangulation may be defined, depending both on what geometric object is to be subdivided and on how the subdivision is determined. A triangulation T of is a subdivision of into (n + 1)-dimensional simplices such that any two simplices in T intersect in a common face (a simplex of any lower dimension) or not at all, and any bounded set in intersects only finitely many simplices in T. That is, it is a locally finite simplicialcomplex that covers the entire space. A triangulation of surface consists of a net of triangles with points on a given surface covering the surface partly or totally. In the finite elemenet method, we have used triangulations as the mesh underlying a computation. In this case, the triangles must form a subdivision of the domain to be simulated, but instead of restricting the vertices to input points, it is allowed to add additional Steiner points as vertices. In order to be suitable as finite element meshes, a triangulation must have well-shaped triangles, according to criteria that depend on the details of the finite element simulation; for instance, some methods require that all triangles be right or acute, forming nonobtuse meshes. In more general topological spaces, triangulations of a space generally refer to simplicial complexes that are homeomorphic to the space. The concept of a triangulation may also be generalized somewhat to subdivisions into shapes related to triangles. In particular, a pseudotriangulation of a point set is a partition of the convex hull of the points into pseudotriangles, polygons that like triangles have exactly three convex vertices. As in point set triangulations, pseudotriangulations are required to have their vertices at the given input points.

Key Word: *3D ore body, Finite Element Method, convex hull, Triangulation, Matlab*

Modeling contaminated groundwater flow

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Abstract

The aim of this work is the modeling of contaminated groundwater flow in 2D by the diffusion convection model in its general form including the chemical reactions also. The used method is the finite difference method, instead of the most used, finite element method. The mathematical model consists of definition of the geometry of the surfaces that bound the domain, the equations that express the balances of the relevant extensive quantities (e.g., mass of fluids, mass of chemical species, energy), the flux equations that relate the fluxes of the extensive quantities to the relevant state variables of the constitutive equations problem that define the behavior of the particular phases and chemical species involved (e.g., dependence of density and viscosity on pressure, temperature, and solute concentration), sources and sinks, often referred to as forcing functions, of the relevant extensive quantities, initial conditions that describe the known state of the system at some initial time, boundary conditions that describe the interaction of the domain with its environment (i.e., outside the delineated domain) across their common boundaries. A model may be defined as a selected simplified version of a real system and phenomena that take place within it, which approximately simulates the system's excitation-response relationships that are of interest. For example, a groundwater system may be 'excited' by pumping, by the introduction of a contaminant, by artificial recharge or by changing a boundary condition. Its 'response' takes the form of spatial and temporal changes in water levels and in contaminant concentrations.

With the above definition, we emphasize that that allthis model can do, is to predict the future behavior of an investigated, say aquifer, system. However, this information may be used in different contexts and for different purposes. Modeling activities may be conducted to achieve any of the following objectives: (a) To predict the behavior of a system, say, an aquifer, in response to excitations that stem from the implementation of management decisions. (b) To obtain a better understanding of a system from the geological, hydrological and chemical points of view. (c) To provide information required in order to comply with regulations. (d) To provide information for the design of a monitoring network, by predicting the system's future behavior. (e) To provide information for the design of field experiments. In principle, for both (a) and (b), we need to write a flow and, sometimes

Most hydrological events, such as precipitation and streamflow, cannot be predicted, or at least, cannot be predicted beyond a certain time into the future, due not only to their complexity, but also to the inherent instability of the physical processes. When such uncertain hydrological data are used as part of the input to a deterministic model, the output will also be uncertain. Briefly, a stochastic process is a process for which we cannot predict the outcome of an experiment (a trial of the process), prior to performing it. This is contrary to a deterministic process, whose outcome can be controlled, hence, predicted. Ideally, for a stochastic analysis technique to be successful it needs to have the resultant methodology able to be computationally tractable, the stochastic analysis should indicate how to reduce uncertainty by collecting and using more measurements and observed data to be used in the calibration process.

Key words: *diffusion convection, modeling, contaminated transport*

Selecting sample size for modeling processes.

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Abstract

One of the most important questions that arise is how many samples do we need to gather information for modeling with minimum cost. For example, when we have to measure the concentrations in the border of a lake or a river, we have to optimize the number of measurements. The demonstration of programming illustrates sample size calculations for this problem. Most of the stochastic processes associated with modeling may be attributed to this problem. The decision to gather such information is a managerial one, based on a cost vs. benefit analysis. Ideally, for a stochastic analysis data technique to be successful, it needs to have the resultant methodology computationally tractable, the stochastic analysis should indicate how to reduce uncertainty by collecting and using more measurements and observed data to be used in the calibration process, should account for different types of errors, including errors in the data used for model development, errors in estimated parameters, and errors in the conceptual model, should be generally applicable, and not be limited to rarely occurring conditions and assumptions. For a stationary random process, a large number of observations made on a single system, at N arbitrary instants of time, have the same statistical properties as observing N arbitrarily chosen systems, from an ensemble of similar systems. Other it should provide prediction of uncertainty, and the measures of uncertainty should be understandable to nonspecialists, such as policy makers. We shall begin by defining the various statistical measures of a stochastic process and their use as tools in uncertainty analysis. Next, we shall discuss the Monte Carlo technique, which uses a deterministic model to analyze a large number of samples in the probabilistic space. To provide the multiple realizations of the modeled field required in the Monte Carlo simulation, the random field generation technique is presented. The kriging method is introduced for generating the complete information on the parameters of a modeled field, when the values of these parameters are known only at a number of sampled locations. This method provides the best estimate of missing data.

Key word: *data, statistic, random variable, modeling, Matlab, Monte Carlo*

Geoportal IMK - web-based application for easy access to selected spatial geological data of State Geological Institute of Dionýz Štúr, Slovakia. Use-cases of analysis and interpretation

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Abstract

State Geological Institute of Dionýz Štúr in its more than 70 years of history collected countless numbers of spatial geological data. After many years of digitalisation, database saving and other procedures, there are many of these data accessible through specialised map applications.

Geoportal IMK is our new web-based application for complex viewing, manipulation, querrying, printing, analysing and reporting of huge amount of internal geological data in the same place with other external open source data such as WMS, ArcGIS services and data in SHP format. User does not need any GIS system, only average or better internet connection is requested. Working with spatial data is fairly intuitive, application is user friendly and runs under most of internet browsers, like Google™ Chrome™, Microsoft® Explorer™, Opera™, Mozilla® Firefox® and others.

In the presentation we would like to show typical use-cases such as:

1. creation of complex report of locality (input: point, line or polygon acquired manually, as a result from spatial or attribute query, or as an import from accessible external sources; output: application generate - nearly in real time - about 50 pages information from geology, geoecology, engineer geology, hydrogeology, water, soil, climate, sun-energy, relief, geohazards altogether into the PDF formatted document), it is the main and the most important functionality of application,

2. spread of contamination (input: the same; output - raster model of colour - differentiated pixels, it could be vectorised and saved into local station or used as input to other analyses), useful for geoecology analysis

3, creation of vertical profile (input: line, polyline; output - PNG picture of elevated relief across profile line together with level of ground water and other selected attribute from database layers. Result also could be saved as XLS tab)

4. creation of micro watershed (input: point; output - vector layer which could be saved into local station or used as input to other analyses), also very usefull for geoecology analysis

5. creation of geostatistics (aggregate statistical tool and area representation tool - both for calculation of geostatistics over selected or imported polygons), useful for geology and other specialised analyses

6. other common GIS-like functionalities, such as zoom-ing, print-ing, querry-ing etc.

Karst hydrogeology of the "Lumbardhi i Prizrenit" River, Kosovo

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Abstract

Karst aquifers represent an important groundwater resource, thus understanding how they function is a major socio-economic challenge. In general, karst aquifers are characterized by a dual flow system consisting of low permeability fissured matrix blocks, which represent the main storage of a karst aquifer system and highly permeable karst conduits, which drain the aquifer system. A recent investigation estimates that around 12.5 % of the Earth's land surface is karst.
Karst regions contain aquifers that are capable of providing large supplies of water. Karst aquifers have complex and original characteristics which make them very different from other aquifers: high heterogeneity created and organized by groundwater flow; large voids, high flow velocities and high flow rate springs. Construction of a gravitational groundwater flow system can never be the best, especially not in karstic areas, where the conduits make up a very complex system. Groundwater flow in karst aquifers is notoriously difficult to characterize in the field at both regional and locals scales and is even more difficult to describe with numeric models. The characterization of karst aquifers at catchment scale is still a challenge and requires the development of large scale characterization techniques in order to deal with heterogeneity.
Prizren city is located in the south region of Kosovo, has experienced increase of population and economic growth that resulted with aggravating resource problems and increase of demand for water drawn from a karstic aquifer, restriction in the public supply, and reduced flow to surface water.
The main aim of this study is to investigate the Lumbardhi i Prizren River and the adjacent basins from the viewpoint of karst hydrogeology and also to contribute by extending the previous studies with knowledge and further information.
The extension of this type of source karst is not defined precisely, but based on the so far results it can be concluded that this part of the lies covers about 80 % of karst type. This canyon karst is about 34 km², beginning from Prizren to Brezovica with length of 18 km and with average width of 1.4 km². This study focuses on the use of hydrodynamic information to identify the hierarchical properties of the main flow paths, which we discuss based on the geological and structural characteristics of the karst reservoir. Changes in hydrodynamic parameters revealed marked disparity between the different parts of the aquifer. These discrepancies depended both on the scale of the hydrological analysis and on the connectivity between the different compartments of the karst aquifer.
With this study we have achieved to determine the hydrogeological factors of karst sources and selection of the most suitable option for water supply from these sources. Identification of these factors constitutes one of the main goals of this study in order to increase the water capacity for drinking, and for agriculture use.

Keywords: *karst, Lumbardhi i Prizrenit, hydrogeology, water supply*

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Zoning of karst in the upper part of the Struma River (Bulgaria) and its impact on groundwater regime

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Abstract

Bosnek karst region is located in the upper part of the Struma River. It is characterized by two different karst zones. The river waters play the main role into one of them. Some of the largest caves in the country are found in this karst zone. The movement of groundwater is carried out in isolated karst channels, which is important for the regime of karst springs in it. In the second zone, karst process occurs only by precipitation infiltration, it is a zone with a common water level.

Keywords: *karst, karstwater, regime, Struma river, Vitosha Mountain*

Introduction

Struma River is one of the largest rivers in Bulgaria. Upper river part passes through a typical karst area, which is characterized by strongly differing nature and degree of karstified. This research deals on karst groundwater section of this area, located in upper river catchment region before the river to exit Vitosha Mountain.

Prerequisites for karst formation and karst groundwater

Bosnek karst region is located in the southern part of Vitosha Mountain and Golo Bardo Mountain (Fig. 1). The springs of Struma River are located on the southern slopes of Vitosha Mountain at about 2180 m of altitude. Struma River gets its outflow from the groundwater accumulated in the weathering zone of Vitosha intrusive rocks, precipitation and snow melting. The landscape of the karst basin is mountainous with an altitude of about 800 m (near the dam of lake Studena) up to over 1400 m. The annual rainfall at studied region is higher than the average for the country (about 700 mm) – it is up to 1200 mm in the highest parts of the mountain. The river initially flows to the west, crosses the eastern part of the karst region, passes through several valleys, and then turns to the south. After crossing the border with Greece,

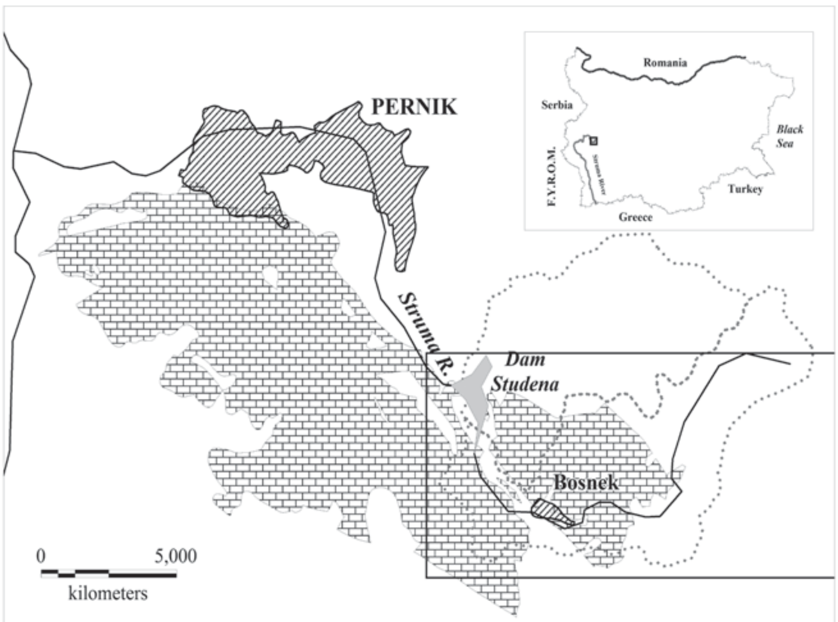

Figure 1. Location of Bosnek karst region and the study area.

it flows into the Aegean Sea.

Triassic carbonate rocks with a total area of distribution about 130 km^2 are karstified (Zagorchev et al. 1994). They consist of thick limestone and dolomite complex which integrity is disturbed by some faults with orientation 120-140°. Some horsts and grabens are formed by the faults. The studied area occupies the most eastern part of the karst region, including the river catchment areas down to the dam lake of Studena (102 km^2). The dam blocked Struma River, just after it leaves Bosnek karst region (Fig. 1). Karstified rocks there occupy an area of about 28 km^2. Some layers of siltstones and shales (with a thickness of over 50 m) play important role for karstification in this section (Fig. 2). They formed a local waterproof layer) separating the carbonate complex in two insulated floors extending parts which are intersected by Struma River.

importance. Up to 42 caves are found and studied in Bosnek karst region (http://hinko.org/bgcaves/viewcaves.php?ord=4&page=1&type=303) and 40 of them are located in the studied area. The role of Struma River is very significant for formation of the caves there, while the role of rainwater for karst forming is smaller. River waters continuously treat and seep deep into carbonate rocks and they are basic factor for speleogenesis in this region. Non karstified waterproof rocks are responsible for the formation of two separate floors karst systems located respectively above and below the local aquiclude of siltstones and shales. Each of the karst systems starts from the sink of river water into the rocks and ending with a spring which is called according to the name of the biggest cave of the system - respectively "Vreloto" (5,300 m) and "Duhlata" (18,200 m). The cave Vreloto is a typical spring cave and its water is formed by Struma River, immediately after its entry into the scope of the carbonate rocks. Spring "Vreloto" is

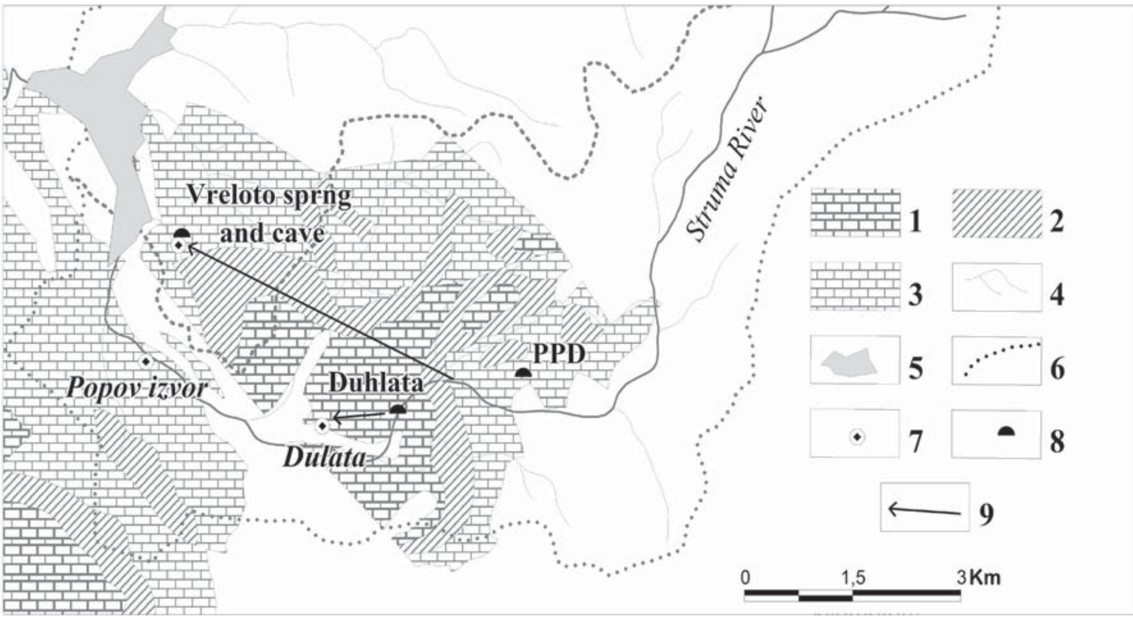

Figure 2. Map of karstified rocks and the main karst springs in the study area: 1. - Lower carbonate Triassic complex; 2. - Non karstified Triassic rocks, 3. - Higher carbonate Triassic complex; 4. - Rivers; 5. - Dam-lake; 6. - Watersheds; 7. - Karst springs; 8. - Main caves; 9. - Direction of karst groundwater flow.

Characteristics of karst and karst waters

Karst and karst water in Bosnek karst region were object of study by Metodiev (1983), Benderev et al. (1999), Mihaylova et al. (2006). The surface karst forms are relatively rare distributed in the studied region, regardless of very good carbonate rock outcrops. Mainly karst cracks and single dolines have been established. Nevertheless, the underground karst forms here are of great

located in a side valley of the main river. There are some caves among recharge zone - old and active ones formed by river waters. Sometimes during dry seasons, the river water completely disappears into the lower complex. The karst system "Duhlata" is situated higher than "Vreloto" complex. The cave "Duhlata" is a complicate system of galleries associated with the water of Struma River. Different river waters are collected in a single cave river which is drained by the spring called “Duhlata” near the village of Bosnek. The hydraulic connection between Struma River water and the mentioned karst springs has been demonstrated using tracing. During dry seasons of the year the river water seeps completely in a significant depth and no river flow into river bed among the area of carbonate rock distribution exists.

Another significant karst spring in the research area is “Popov izvor”. It is situated on the left bank of the river. The spring is mainly recharges by precipitation and it drains relatively less karstified zone of the system.

Comparison of quantitative and qualitative characteristics of karst springs.

In two of the mentioned main karst springs - “Vreloto” and “Popov izvor” during different periods of time were conducted regular regime monitoring of flow-rates and temperatures (Table 1). There are also a few sporadic measurements of flow-rate of the spring, located near the village of Bosnek.

Unequal frequencies of measuring water quantity leads to some difficulties for comparing the two spring regimes observed. Figure 3, shows the changes of flow-rates at the dates on which the measurements in both of the springs are performed in parallel. It was approximately found matching of maximum water quantities and the higher minimum values of spring “Vreloto” are due to continuous river recharge. Significantly higher discharge of the spring “Vreloto” is likely to be due to the higher degree of karstified, catchment area and river recharge.

Conducting daily monitoring of the two springs, although in different periods for each of them, allows comparison of the nature of changes in water quantities within 1 year (Fig. 4).

Comparing the nature of the spring hygrograms on Fig. 4 it is clear that changes of the flow-rate in spring “Vreloto” are relatively much more dynamic and fast, ensuring a relatively high minimum due to continuous river recharge. River recharge causes a wider range of spring water temperature (from 6.0 to 18.5 ^{o}C) and relatively smaller range of variation of TDS (Fig. 5). On the other hand, the absence of a river recharge and existence of a common water-saturated zone is a main reason that the periodic calcite saturation index in spring “Popov izvor” is greater than 1.

Discussion and conclusion

Analysis of geological, geomorphological and hydrogeological conditions gives a well-founded reason Bosnek karst region to be separated into two main areas according to their degree of karstification. The boundary between them

Table 1. Frequency of regime observations and characteristic values of water quantity.

Spring	Observation period	Frequency	Characteristic values of flow-rates for periods 1959-1975			
			Average	Minimum	Maximum	Standard deviation
Vreloto	1959-1961	monthly	303	87	1041	196
	1962-1975	daily				
Duhlata		episodically		1	720	
Popov izvor	1959-1992	monthly	89	5.8	709	109
	1993- to now	daily				

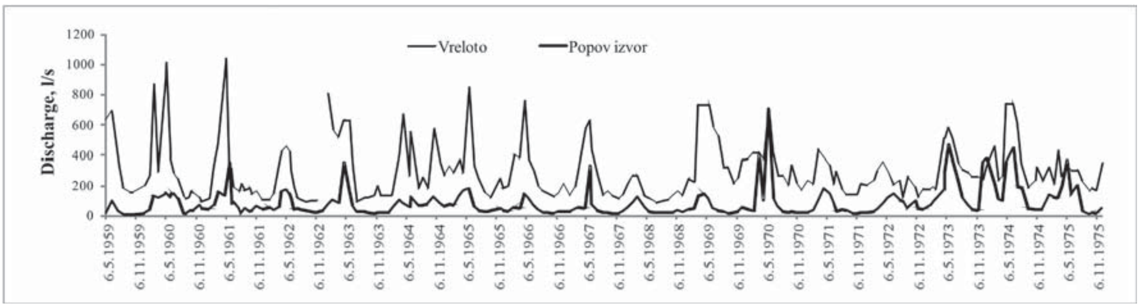

Figure 3. Hygrograms of water quantity of “Popov izvor” and “Vreloto”.

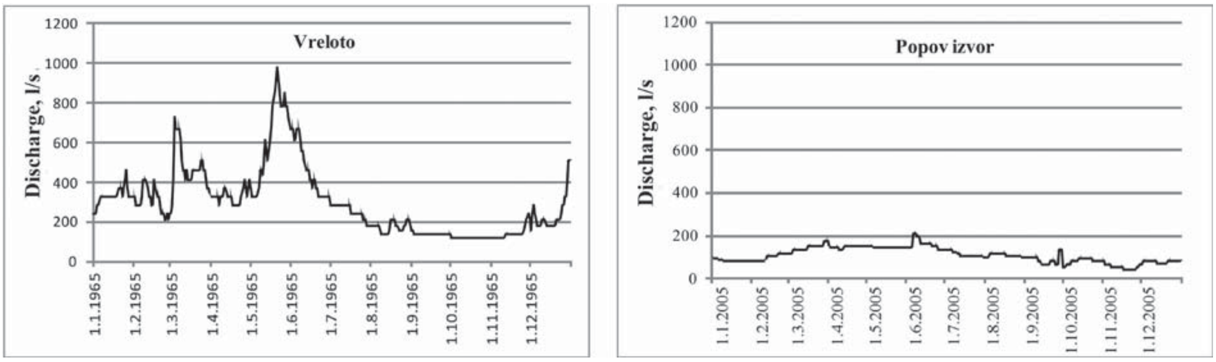

Figure 4. Hygrogram of water quantities within 1 year.

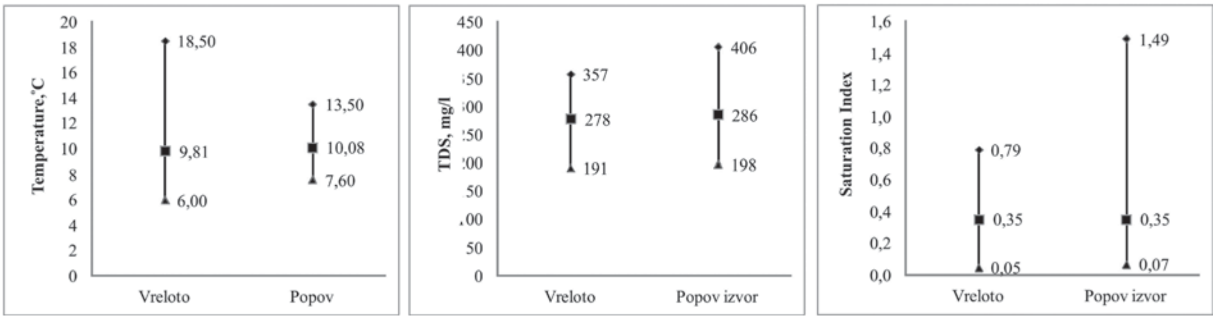

Figure 5. Temperature, TDS and calcite saturation index changes for observed springs.

is a streak surface occurrence of Low Triassic sandstones with northwest- southeast direction crossing through the dam-lake "Studena". The first zone, located north of this streak is related to the leadership of Struma River in the processes of karstification. Here are most of the biggest caves in the area. Groundwater is moving concentrated in wider and long channels. It is divided into two zones of layers of siltstones and shales, and formed two large karst systems - the caves of Duhlata and Vreloto. This zone occupies the main area of research region. Direct entry of river waters and their rapid passage through the karst massif identify high vulnerability of groundwater. In the second zone the degree of karstification is significantly lower and fracture-karst water is predominant. The main agent of karstfication is the precipitation. The small amount of negative karst forms and mountain landscape determine surface runoff. Unsaturated zone is less fissured strata. A saturation zone with a common groundwater level is assumed.

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Hydrochemical characteristics of groundwater in the Dukagjini basin, Kosovo

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Abstract

Groundwater in the Dukagjini basin is linked with two main aquifer types, karstic and alluvial. Their hydro-chemical composition is complex and varies in wider limits. These hydro-chemical features of groundwater are determined by a number of factors of geological and hydro-geological character, such as: a) wide area of their dispersion, b) lithological heterogeneity, c) different structural construction of separate sub-basins, d) relative position versus feeding area and local drainage, e) communication level with side basins, f) hydraulic connection with surface waters.

The complexity and wider variety of hydro-chemical composition of groundwaters of the Dukagjini basin is expressed in the diversity of their hydro-chemical types. The main hydro-chemical types are: HCO_3 - Ca, HCO_3 - Ca - Mg, HCO_3 - Mg - Ca, HCO_3 - SO_4 - Ca - Mg, HCO_3 - Na - Ca - Mg, HCO_3 - Cl - Ca - Mg - Na. Hydro-chemical types HCO_3 - Ca, HCO_3 - Ca - Mg, HCO_3 - Mg - Ca are mainly associated with carbonate rocks or alluvial deposits that are spread in their vicinity and feed, both from rainfall and from karst waters. Waters with higher content of sodium are mainly spread in molasses Neogen formations and those Quaternary in their vicinity.

Groundwater of karst type belong to the hydro-chemical bicarbonate type (HCO_3 HCO_3 - Ca - Mg - Ca, Mg - Ca - HCO_3) and have almost uniform chemical composition. This stable chemical composition is associated with nearly homogeneous formational composition of carbonate rock complexes in which these waters flow.

Contrary, the groundwater of alluvial deposits represent a chemical composition that varies in wider limits, apparently in hydro-chemical type of alluvial water varies from Ca - Mg - HCO_3 to Ca - Mg - Na - HCO_3 - SO_4. Karst groundwater have smaller dry residue (169.32 mg/l) than the waters of alluvial deposits (243.13 mg/l). Moreover, karst waters distinct from alluvial deposits because they present lower variation of the values of dry residues (σ = 26.10) and General Hardness (σ = 0.91) versus the respective values of alluvial deposits water (95.68 and 2.82). PH values ranges from 6.8 to 7.78 for karst water and from 6.3 to 7.1 for alluvial deposits waters. Character slightly acidic of groundwater of alluvial deposits apparently obliges to direct communication with slightly acidic precipitation and dissolve of CO_2 derived from human activity and decomposition of organic matter of the horizon of agricultural lands or insatiable zone. The formation of chemical composition of karst water is mainly connected with the process of digestion of carbonates while the formation of the chemical composition of groundwater in alluvial deposits is controlled not only by the processes of digestion but also by those of ion - exchange and mixture of groundwater.

Keyword: *basin, hydro-chemical, hydro-chemical composition, ion, karst, water, hydro-chemical type, underground*

Thermal water of carbonate rock aquifers of Albania

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Abstract

Owing to his geology Albania is not very reach on thermal water. In Albania are missing the recent magmatic and volcanic processes, usually responsible for the formation of high enthalpy thermal water at relatively small depths. However, important thermal waters are localized in deep lying carbonate karst rocks, which at about 10,000 km^2 or at about 33 % of the country's territory, are covered by thick flysh and molasses deposits.

The Albanides represent the assemblage of the geological structures consisting the territory of Albania, are part of southern branch of the Mediterranean Alpine Belt. The earth crust is characterized by a system of longitudinal fractures in NW-SE direction and transversal faults that touch even the mantle. The thickness of Albanian sedimentary basin is 8-9 km in Adriatic seashore.

According to special geothermal studies the maximal value of the Heat Flow Density up to 60 mW/m^2 is determined in eastern part of Albania. There are some heat flow anomalies, which are conditioned by intensive heat transmitting through deep faults. These fractures are responsible for the transmission of the geothermal energy from the deep lying sources to the ground surface. According to estimations with geothermometers, the aquifer temperatures recharging the hottest thermal springs vary from 220 to 270 ^oC. Based on the geothermal modeling, one can suppose that thermal waters rise from the depth about 8-12 km. Generally the temperature at a depth of 100m ranges 6.7 to 18.8 °C, in average 16.4 ^oC and at a depth of 500 m from 21 to 27.7 °C. The temperature ranges up to 105.8 °C at a depth of 6000 m.

Thermal water resources are related to deep, regional flow systems and thermal springs are often aligned along the faults. Thermal water of carbonate rock aquifers is located in four geothermal zones namely: a) Peshkopi; b) Kruja; c) Preadriatic and d) South Ionian.

Peshkopi geothermal zone represents the central part of Korab zone and relates to two tectonic windows where gypsum dome structures outcrop. Two important thermal springs are aligned along the deep tectonic contact of gypsum with surrounding Paleogene flysch formations. The thermal water is of sulfur gas SO_4-Ca type with high H_2S gas content and temperature 35 °C to 43.5 °C.

Kruja geothermal zone is most interesting in terms of thermal water in Albania. Thermal water is related to some deep anticline structures consisting of Mesozoic-Paleogene carbonate rocks. As testify some deep oil wells the aquifer of carbonate rocks are abundant in thermal water of Cl-Na type, temperature about 60 °C, and the H_2S gas content up to 1000 mg/l. Thermal water of deep karst rocks structures fids some big thermal springs like Uji Bardhe-Mamuras, Llixha and Hidraj near Elbasan, Holta, Langarica and Leskoviku. At an active fault crossing a longitudinal carbonate structure emerges the particular steam spring of Postenan. Thermal water of the central part of Kruja geothermal zone contain high sulfate concentrations originating from the dissolution of deep gypsum deposits constituting the substratum of the Albanides foreland fold and thrust belt. Identified resources of Kruja geothermal province in carbonate reservoirs are $5.9x10^8$-$5.1x10^9$ GJ.

Preadriatic geothermal zone is related to homonymous big artesian basin which deeps to the Adriatic Sea. The carbonate rocks aquifer is the deepest of the basin, and contains abundant thermal water. According to the results of a limited number of deep oil wells, the temperature of free flowing water emerging from depths about 2500 is 45-50 °C and the water type is Cl-Na and reaches on H_2S and NH_4 gases.

South Ionian geothermal zone is the widest geothermal province of Albania, but not the richest in term of thermal water. The carbonate rocks outcrop in some anticline chains and is covered by thick flysch deposits in syncline chains. There are not known thermal springs emerging in this province. Some deep free flowing wells confirm the presence of high temperature and highly mineralized groundwater. A deep well situated near the Dumre gypsum dome, at the depth about 1200 m fountains the groundwater with temperature 35 °C, mineralization about 325 g/l, and brome content of about 768 mg/l; the last parameters being the highest measured in the groundwater of Albania. Some deep wells drilled in South Albania, have fountain also high mineralized groundwater of Cl-Na type.

Cave development in an uplifting fold-and-thrust belt; case study of the Tatra Mts., Poland

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Abstract

The Tatra Mts. are characterized by a geological structure typical to fold-and-thrust alpine belt with post-glacial geomorphology. The uplift of the Tatra Mts. began in the Miocene and it is rotational in character. The rotation axis is horizontal and latitudinal orientated.

Relationship between cave development, tectonic setting and neotectonic processes has been investigated. Structural researches including geometrical structural analyses of measurements from 25 caves of the Czerwone Wierchy Massif have been performed. Based on the main tectonic conditions, impacting the development of cave passages, three groups of caves can be distinguished. (I) Caves which developed primarily on the steep bedding. Slickensides on the strata planes, the most probably resulted from a flexular slip, were observed in these caves. A few displacements in the passages cross section indicates rejuvenation of those movements due to asymmetrical uplift of the Tatra Mts. Movement on bedding planes predisposed them to speleogenesis. Faults other than inner-beds have a mostly local influence on the course of passages. Caves developed in those conditions are characterized by series of deep shafts, meanders and ramps which cross the paleo-phreatic conduits in lower parts of the caves. Specific conditions are in hinge zones of main folds where the large volume chambers or deep shafts developed, depending on geometry of the fold. This group includes the longest and deepest caves in the study area (e.g. Śnieżna Cave System, Śnieżna Studnia). (II) Caves which formed on the sub-vertical individual fault or on a conjugation of such faults. There is no dense related structure in the drag zone of those faults. Cave passages are rectilinear and high and the breakdowns as well as dissolutional features are common. Deep shafts irregular in the perpendicular cross section has been formed in the conjugation. Just three caves belongs to this group but they are quite deep and roomy (e.g. Wysoka – Za Siedmiu Progami Cave). (III) Caves developed on the dense net of the discontinuities related to major thrusts and faults. These caves are characterized by small volume of passages. The morphology of passages is pseudo-karstic or dissolutional modified by breakdowns. Caves are shallow and short and are located in the area where the bedding is gently inclined (e.g. Koprowa Studnia).

It can be concluded that the most predisposed to the development of the cave passages are folded bedding planes. They are long, steep and without bigger obstacles, further facilitated by loosening due flexular slip and rejuvenated displacement at younger tectonic deformation stages. In case of faults there are many factors facilitates or impedes concentrated water flow. The main thrusts are mostly gently inclined, which makes the water migrates along the other steeper surfaces. Just in one case of the lower part of the Mała w Mułowej Cave, drainage is guided by the trust. This is individual situation where limestone contacts with marly shale. In the minor fault zones dense net of discontinuities is hindering the concentrated flow for a long distance, preventing development of long or "human-size" passages. For example in Małołącka Cave well developed, roomy, vadose cascades are suddenly end in place where cave passage reaches gently dipping fault plane. From the other hand if the bedding planes are gently inclined, water penetrates the massif along steep and very steep discontinuity planes. That is the cause for no formation of large caverns.

In fold-and-thrust belts the favourable conditions to deep and long cave development are folded, well bedded rock complexes which are no strongly deformed by minor faults but where neotectonic movements extended some structures. The circumstance that neotectonic movements rejuvenate the same structures could lead to drainage along the same structural planes during a consecutive stages of cave system development. Brittle fault zone seems to be not optimal environment for the development of caves.

The immediate earthquake impact on caves: eyewitness data

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Abstract

In this paper are described events of the immediate earthquake effect on caves in different karst areas of the world. Their analysis is important for our better understanding of the influence of the paleoseismic events on the recent cave's morphology and deposits.

Key words: *karst, cave, earthquake, paleoseismology*

Introduction

During the last decades increased the significance of speleothems as recorders of paleoseismicity. At the same time, the available published data on the immediate impact of the earthquakes on caves witnessed by observers at the time of the seismic event or shortly after it are only few. Such data are collected in the works of Dublyansky (1995, 2000), Gilli (2005), Becker at al., (2006), Sebela (2008) and Kostov (2008). Undoubtedly, the data for the destructive consequence of the contemporary earthquakes on cave's sediments are of great importance for the future development of the paleoseismologic studies in karst terrains. According to my level of knowledge, the different individual cases of seismic impact on karstic caves will be displayed in chronological order.

Cases of immediate earthquake impact on caves

To my knowledge the first data about earthquake effect on cave is described in Mammoth Cave, USA. Large rock blocks fallen due to influence of the New Madrid earthquakes in 1811-1812 (Sebela 2008).

As a result of the catastrophic earthquakes in the region of Kresna – Krupnik, SW Bulgaria (April 4^{-th} 1904, M_s=7.2), was formed the collapse entrance of the Spropadnaloto Cave near the town of Razlog (Chankov 1958) (Fig. 1). This water cave is located at the foot of Pirin Mountain. The altitude of the entrance 930 m. a.s.l. and the total length of the galleries is 605 m.

The Edinpost newspaper of January 8^{-th} 1926 reported that at the period of Cerknica earthquakes in Slovenia of January 1-7 1926 (M=5.2), a stalagmite with diameter of 1 m in Postojna Cave collapsed (Sebela, 2008).

During the strong Crimean earthquake of September 11th 1927, the hydrogeological group of P. M. Vasilevsky worked in the cave Emine Bair Hosar on Chatirdag Plateau close to Simferopol. The researchers didn't felt the earthquake with magnitude of 7.0, caused panic between their colleagues on the surface near the cave entrance. Immediately after the first strong Crimean earthquake of July 26th 1927 with estimated magnitude of 6.0, the same team especially visited 15 Crimean caves but any significant deformations and collapses were not found (Vasilyevsky and Zheltov 1932, in: Dublyansky 2000).

During the very strong Germab earthquake of May 1st 1929 in Turkmenistan in the famous Baharden Cave close to the capital Ashgabat a group of visitors was at a depth of 60 m below the ground surface. The tourists have heard increasing noise. From the cave walls were felled stones and the surface of the underground lake has been excited (Dublyansky 1995, 2000).

Loud rumble and roar was the impact of the earthquake in 1952 in Flagstaff (Arizona, USA) with a magnitude of 5.2, felt in the Buddha Cave located in the Grand Canyon of the Colorado River (Gilli 2005) .

L.A. Shimanovskiy reported that the during the earthquakes of July 28-29^{-th} 1956 in the Perm region, Russia with magnitude of 4-5, from the ceiling of Andronovo Ice Cave near Perm felled giant gypsum block with weight of about 5 tons. Other minor breakdowns were also observed in the same cave (Shimanovskiy 1957 in: Dublyansky 2000).

According to information from the Georgian karstologist Maruashvili during Baldin earthquake

Figure 1. The entrance of Spropadnaloto Cave, SW Bulgaria, formed during the Kresna - Krupnik earthquakes of April 4 1904.

of 1957 was filled with rock detritus and no longer exist as a geographical object the karst pot hole Tsipuria (Georgia) (Dublyansky 2000).

Cavers from USA reported about hum "as an engine of Boeing 747" in Church Cave (Kings Canyon National Park, Sierra Nevada) during an earthquake of magnitude 5.5 in 1974 (Gilli 2005).

During the strong Vrancea earthquake of March 4-th 1977 in Romania, a group of Bulgarian cavers worked in Orlova Chuka Cave in North Bulgaria, close to Danube River. The speleologist Aleksey Zhalov reported: "…Suddenly heard a strange noise. The air seemed to vibrate. Like I was under a bridge that passes truck…the ground beneath us shook so that if we were standing on a raft along the sea. The walls of the gallery moved. The upper part of one moved to the direction of another and vice versa. The pressure and air temperature noticeably increased." (Zhalov 2005).

An earthquake of August 27th 1988 was felt at 550 m deep pot hole Vesennyaya (Bzib Ridge, West Caucasus, Georgia). An activation and motion of a breakdown situated at depth of 200 m was observed. The cavers working at that time in the cave have happily survived (Dublyansky 2000).

The Japanese speleologist Yano did not identify any damage and deformation in Nodjima Cave on the Avadji-Shima Island. The cave was visited shortly after the 1995 earthquake in Kobe (M_s=7.2) (Gilli 2005).

Žumer reported for strong wind flow, noise and splashing water in the underground river of Dimnice Cave (Slovenia) associated with the Ilirska Bistrica earthquakes of May 22-nd 1995. The epicenter was 25 km away from the cave (Sebela 2008).

Immediately after the earthquake of February 18-th 1996 in St-Paul-de-Fenoullet, French Pyrenees (M_s = 5.2), the team of Eric Gilli visited eight caves in the epicentral area. The only co-seismic effect associated with this event was the prevalence of broken thin stalactites (soda straws). In the Barrence du Paradet pot hole located ten kilometers from the epicenter were measured the orientation of the fallen stalactites on a flat floor. The preferred direction coincides with the epicenter of the event (Gilli et al. 1998).

The French karstologist Philippe Audra reported a similar effect (strong hum) in Muruk Cave in Papua New Guinea, during an earthquake of magnitude 5.1 (Audra 1999).

During the earthquake of February 2003 with M=3.5 a large number of speleothems were broken in Furong Dong Cave in China (Sebela 2008).

The daily "Bangkok Post" in his material "Preparing for the Worst" by 03. 03. 2005 reported for closed for visitors show-caves in Thailand after the seismic impact of the Sumatra-Andaman earthquake of December 26-th 2004 (M_s=9.0) that caused the tsunami wave in coastal parts of the country. Massive flowstones in the caves are cracked. The newspaper writes and the emergence of 29 new karst collapse sinkholes due to the earthquake (message from the US caver Robbert Higgins in the mailing-list Cavers Digest of March 4-th 2005).

On July 12, 2004 an earthquake with an epicenter Kobarid, Slovenia (Ms = 4.9), registered in the whole country and parts of Italy and Austria. The Postojna Cave guide Stanislav Glazar reported about an excitation of a lake surface and powerful sound. During the seismic event large group of French tourists led by Glazar was in the deepest from the surface place of the cave system - the gallery of so-called Russian Bridge (Glazar 2006).

At 10:49 on August 5, 2009 an earthquake of magnitude 5 struck NE Bulgaria. The epicenter was at the sea, 25 km east from Kaliakra Cape. In the village of Kamen Bryag has dozens of cracked buildings, fences and fallen chimneys. The quake, which lasted less than a minute, picked up a huge sea wave that swept rocks off the coast of Kavarna, Shabla, Balchik, surrounding villages and the archaeological reserve “Yailata.” Large rock blocks were fallen at the entrance of the medieval rocky church “St Konstantin and Elena” in “Yailata” reserve.

At the 80 m high Kaliakra Cape build of Neogene limestone is located the historical reserve “Kaliakra”. In a small natural cave is situated historical museum (Fig. 2). The museum curator Petranka Aleksieva says that during the earthquake very strong shaking in horizontal direction was felt in the cave. In the frames of the project between Bulgaria and Romania MARINEGEOHAZARD dealing with a building of Black Sea early-warning system, at March 2013 an extensometer TM-71 was installed in this cave.

Figure 2. The entrance of the historical museum on Kaliakra Cape, NE Bulgaria where the earthquake of August 5 2009 (M=5) was felt.

At March 20-th 2012 very strong earthquake of 7.4 magnitude struck Oaxaca, Mexico. The depth was 20 km. Shaking and significant uprising of the water level of cave lake was observed and videorecorded in Devils Hole Cave in Nevada, USA. The event started 10 minutes after the Oaxaca earthquake and last about 20 minutes. According to the Death Valley National Park news release: “... staff observed algae slough off the walls of the chamber, followed by water bubbles, swooshing sounds and swirling water. The water became turbid and the smell of sulfur filled the air. The water level ranged more than 5 ft. in total (~2.5 in either direction) throughout the event. The rising water level increased causing waves to rush along top of a shallow shelf and crash against the adjacent wall.” (Behrens 2012).

Discussion

The presented chronological list of cases of seismic impact on karst cavities do not claim to be complete. As is apparent from the described effects, there are different seismic effects on the caves. Assuredly their analysis is very important for our better understanding of the influence of the paleoseismic events on the recent cave’s morphology and deposits. A good suggestion for the future is a common project between the karst scientists dealing with seismicity in karst regions and cavers from all over the world for creation of data base and enlargement and detailisation of the available data.

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Comparative analysis of karst aquifers discharge on examples from the Carpathian Balkan Mountains and the Dinarides

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Abstract

Karst areas in Serbia are mostly developed in the Mesozoic sediments, and only partly developed in the Tertiary (Sarmatian) sediments. The main zone of distribution of karst aquifers in Serbia within the two major geo-structural units: Carpathian -Balkanides and Dinarides in which about 30 % are karstified rocks. In the area of Dinarides of western Serbia, karstified Triassic limestones and dolomites and limestones of Cenomanian and Turonian age are dominant, while in the Carpathian -Balkanides of eastern Serbia Jurassic-Lower Cretaceous carbonate complex prevails.

Karst aquifers in Serbia are very important resource when it comes to water supply. More than 80 % of the population in karst terrain uses water from karst aquifers. Virtually all of the major cities in eastern Serbia, western Serbia, and the Morava region use water from karst springs.

Quantification of elements and water budget in karst still remains a complex work because there are a lot of variables in the karst system. Having that fact in mind, standard research methods are not applicable, so it is necessary to modify the methods for each system separately. In the Carpathian-Balkan mountains there are over 70 karst springs that are important for regional water supply, of which 16 have registered a yield of over 100 l/s. In the Dinarides of western Serbia there are 14 regional aquifers.

The main characteristic of Dinaric karst is considerable coverage of aquifers formed in limestone with formations of Jurassic age - diabase - chert formations and ultramafic rock complex. It is evident that in the water budget of some aquifers, there are significant differences between the amount of runoff and open parts of catchment areas. This surplus is a consequence of underground circulation below mentioned formations. Another difference between Dinarides and Carpathian -Balcanides is relatively small distribution of non-carbonate rocks in the catchment areas in Dinarides. Also, in the peripheral parts of the karst massifs usually there is no clear indication of the presence of karst that underlain non-carbonate rocks, especially the younger (Tertiary and Quaternary) deposits.

Most of these aquifers were studied in detail, mainly for purposes of water supply. Some studies have dealt with the whole karst massifs, but rarely with entire regions of Dinaric karst and Carpathian-Balkanides.

This paper is an attempt to synthesize all available information about the draining of groundwater in karst hydrogeological systems in Carpathian-Balkanides and Dinarides, with emphasis on features that are of utmost importance for karst, all in order to highlight the potential differences in karst systems, caused by its geographical location and geological setting. In addition to consideration of the parameters of interest for the water budget of karst aquifers at a regional level, to some extent, analysis on narrower field of research were also made. Recession analysis, analysis of base flow and time series analysis were applied. Characteristics of time series were considered with autocorrelation, spectral and cross-correlation analysis.

Four distinctive karst springs were studied. Two of them were from Carpathian-Balkanides, one ascending (Mlava) and one gravitational (Grza). Other two were from Dinarides, one ascending (Vapa) and gravitational (Perućac).

Stable Isotopes in the Main Karst Aquifers in Dobrudzha Region (NE Bulgaria)

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Abstract

The investigated area named Dobrudzha Plateau is located in the northeast corner of Bulgaria, with a surface area of about 4000 km^2. Two groundwater bodies are dominant as groundwater reservoirs: deep, Upper Jurassic-Lower Cretaceous or Malm-Valanginian aquifer, and upper, Neogene or Sarmatian aquifer. Both are formed in carbonate rocks, limestone, dolomitic limestones and dolomites.The groundwater aquifers are the major source of drinking and industrial water supply, and irrigation. The Jurassic-Valanginian and Neogene-Sarmatian aquifers play significant roles as transboundary Groundwater bodies between Bulgaria and Romania. The aim of the present work is to study the distribution of some natural isotopes as: D (deuterium), ^{18}O (oxygen) and ^{13}C (carbon) mainly in the Malm-Valanginian aquifer. Some sources representing the Sarmatian aquifer and a limit number of surface water were sampled too. Five zones could be distinguished in the region studied: the surface and Sarmatian waters are in the first zone; to the second zone belong groundwater predominantly from the Sarmatian, but also mixed with groundwater from the Malm-Valanginian due to not perfect aquiclude; by analogy, mixed waters (predominantly from the Malm-Valanginian) are in the third zone; real Malm-Valanginian waters belong to the fourth zone; Malm-Valanginian waters 'injected' by thermal waters are in the fifth zone.

Key words: *karst aquifer, stable isotopes, SMOW, Dobrudzha, Bulgaria*

1. Introduction

Generally 20 points (mainly boreholes) were investigated (Fig. 1) from which 13 points belongs to Malm-Valanginian, 4 – Sarmatian and 2 respectively the Batova river and the Duranculak lake surface water. The only source located at about 3 km from the village of Batovo is assigned to the Paleogene. The points are located in two profiles with west east direction which include the recharge zone, the intermediate aquifer part and the drainage zone of the Malm-Valanginian aquifer. The water samples were taken during the high and low flow periods respectively.

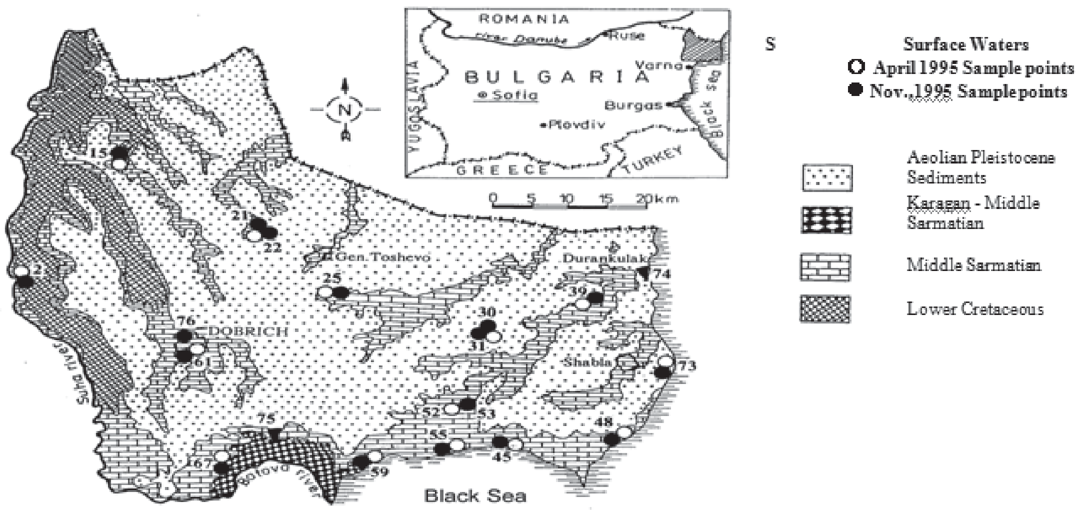

Figure 1. Principle scheme of the isotope profiles location.

2. Geology and hydrogeology of the region

The geology is relatively well known due to the boreholes drilled for different purposes. The boreholes generally reach significant depths (more than 400-500 m) but can penetrate into much greater depths (exceeding 4000 m). The area investigated is located on the Moesian Plate (Iovchev 1976), which has remained stable ever since the Hercinian folding. It has two main complex structures. One is superimposed over the other: a folded and fractured Paleozoic basement (Caledonian – Hercinian complex) is covered by a non-folded plate, which can nevertheless be somewhat fractured, with materials dating between the Perm-Triassic and the Quaternary. The Quaternary materials are built up of Aeolian Pleistocene sediments (loess). These materials cover most of the study area, except for the canyon floors. Their thickness varies between 5 and 40 m, increasing towards the north.

In the Southern Dobrudzha the Miocene is represented by various formations. The upper group comprises basically of two carbonate formations, and formation of banded marl and clay which can reach thickness of 45 to 80 m lies between them. The Sarmatian (upper) aquifer is one of the most extensive and highly exploited in the area. It is built up of limestones belonging to the Karvuna and Odartsi formations. Those two formations can be locally isolated by packages of low permeability (the Topola formation).

The deep aquifer consists of materials from the Malm-Valanginian. Forming a thick package of limestone, dolomite limestone and dolomite, this group is present throughout the region, but outcrops only outside the region. In comparison with the limestone of the upper aquifer, whose porosity can be of 5 different types (Pulido Bosch et al. 1997), the Malm-Valanginian owes its permeability to fracturing and karstification, as porosity is almost non-existent (Danchev et al. 1981). In general the average thickness of the Malm-Valanginian aquifer is about eight hundred meters while the Sarmatian does not exceed 250 m. Both aquifers tend to thicken toward the south and southeast.

The upper karst layer (Sarmatian aquifer) has a typical cross-border part (flow direction from Bulgaria to Romania) located approximately in the middle of the terrestrial border between both countries. The northwest part of Neogene-Sarmatian aquifer close to the Danube in Silistra area becomes thinner and thinner reaching to one meter width or less, gradually losing its importance. In general, the most powerful part of this layer is close to the Black Sea coast where the water usage is significant. This coastal part groundwater flow is discharging to the Black Sea.

The deep Malm-Valanginian aquifer plays the most substantial transboundary role in the region. This aquifer has a serious importance for the local economy particularly as a source of drinking water supply. Almost the whole part of Malm-Valanginian aquifer is transboundary forming a large transboundary groundwater body (Fig. 1).

There are series of intercalated materials from of the Hauterivian-Upper Cretaceous, Paleogene and Lower Miocene-Tortonian with highly varied hydrogeological behavior among the materials of the upper and the deep aquifers. Having in mind the confined character of the lower aquifer, the thickness of the materials, the predominance of clayey-marly materials, etc., this formation (for most of the region) is considered aquiclude-aquitarde.

3. Isotope content and ratios in the naturel water

Certain hydrochemical parameters were determined 'in situ' as follows: T, pH, Eh, dissolved H_2S, O_2, CO_2, conductivity and NH^4. The samples for D and ^{18}O were collected in 50 cm^3 glass containers avoiding possible evaporation during storing and transportation. In order to preserve the carbon isotope ratios of dissolved inorganic carbon in the samples a precipitation of bicarbonate and dissolved CO_2 according to the following procedure was performed: 1 ml 700 g/l NaOH was added to 1 l water and stirred. The pH being about 11, 16 ml 200 g/l $BaCl_2$ were added to the water and stirred again. The precipitate settled was then used in the laboratory for the carbon isotope measurements. All stable isotope determinations were performed in the Laboratory of stable isotopes and radiocarbon dating at the Institute of Nuclear Research of the Hungarian Academy of Sciences in Debrecen and some ^{18}O control measurement were made in Vienna at the Isotope Laboratory of the Geotechnical Institute - Arsenal.

The content of hydrogen and oxygen heavy isotopes in the natural water varies in wide limits: from -400‰to +50 for D and from -40 to +8 for ^{18}O (Feronskii et al. 1975). The low concentrations of these isotopes are typical for the atmospheric waters, as well as for the surface waters, while the high concentrations are normal for the sea and ocean waters. The isotope content is almost constant for the last water types, while the content of D and ^{18}O in the atmospheric and surface waters is determined mainly by the concrete climatic conditions and is quite variable. Generally the isotope content of the atmospheric waters is following the relation:

$D = 8 \times {}^{18}O + 10$; (the Craig line relation) (1)

A correlative link between the concentrations of ^{18}O and D in precipitation waters and the annual mean air temperature at the ground (t_a) is established by experimental way. Thus, the relation is valid for a wide range of temperature and it is expressed through the relations (2) and (3):

$^{18}O = 0.695 \times t_a$ 13.6 (2)

$D = 5.6 \times t_a$ 100 (3)

The relations expressed through (2) and (3) are correct only for the coastal regions. Moving away from the sea basin, the continental effect appears, hence, sometimes the calculated and experimental results are identical.

In some specific climatic zones (such as the eastern part of the Mediterranean basin) the relation (1) is expressed as $D = 8 \times {}^{18}O + 22$, while for the European part of the former USSR the relations (2) and (3) take differ as: $^{18}O = 0.4 \times t_a - 13$ and $D = 2.95 \times t_a - 100$, respectively (Chesko, 1990). In our opinion the latter relations can be better used for an approximate estimation of the isotope content of precipitation over the investigated area than the relations (2) and (3). Using the annual average air temperature of 10.27ºC in the Dobrich region, the isotope for the isotope characteristics of the precipitation waters were obtained as follows:

$^{18}O = 8.89$ and $D = 69.70$

The natural carbon has two stable isotopes ^{12}C and ^{13}C, which are involved in several migration cycles, together with the radioactive carbon isotope. One of the most important processes in the formation of the groundwater isotope content is the dissolving of the limestone due to the presence of the carbon dioxide. Other processes, as the carbon-acid leaching of silicate rocks, take place in the soils and in the aquifers, but the contribution of each one of them are not sufficiently clear.

The tritium was also investigated in a limited number of samples. Its content is within the range 0.2 0.4 TE. The conditions for the tritium cycle related to the ground waters are directly connected to the groundwater recharge conditions.

4. Results and discussion

4.1. The deuterium content in the ground waters is low (from -92.78 ‰ to 59.95 ‰), which proves their connection with the precipitation, i.e. the atmospheric origin of D;

4.2. Based on the Malm-Valanginia (Deep) and Sarmatian (Upper) aquifers locations sampled, no mixing of the ground waters with the contemporary sea waters can be proved. The isotope content of the contemporary sea waters is: -30 ‰ < D < -25 ‰ and -4 ‰ < ^{18}O <-3 ‰ (Reynolds et al. 1990), depending on the depth (from 0 to 900 m);

4.3. Five zones could be distinguished in the region studied (Fig. 2 and Table 1):

- the surface and Sarmatian waters are in the first zone;
- to the second zone belong groundwater predominantly from the Sarmatian, but also mixed with groundwater from the Malm-Valanginian due to not perfect aquiclude;
- by analogy, mixed waters (predominantly from the Malm-Valanginian) are in the third zone;
- real Malm-Valanginian waters belong to the fourth zone;
- Malm-Valanginian waters 'injected' by thermal waters are in the fifth zone.

4.4. It is quite probable that the ground waters of the fourth zone have been formed during the Pleistocene (The Ice Age), when the amplitude of the mean annual air temperature varied by 7 - 8ºC. Under these conditions, according to the relations (2) and (3), the following isotopes contents (in view of the geochronologic aspect) were obtained:

$-12.63 \leq {}^{18}O \leq -11.93$‰;

$-92.16 \leq D \leq -86.56$‰

4.5. The small amplitude of ^{18}O (3.79 ‰) in the investigated region and its negative values are explained by the low degree of the water metamorphosis as a solvent, due to the relatively low temperatures and the small isotope exchange potential of the water bearing rocks.

4.6. Taking into account the above conclusion and according to the type of water bearing rocks, one can deduce that in geochronical aspect, multiple cycles of the ground waters accumulated in the aquifers are accomplished and that the rocks are flushed very well.

4.7. Correlation links between the contents of [13]C and CO_2 in the Malm-Valanginian groundwaters were established (Fig. 3) and this proves the role of carbon dioxide in the formation of the groundwater isotope content.

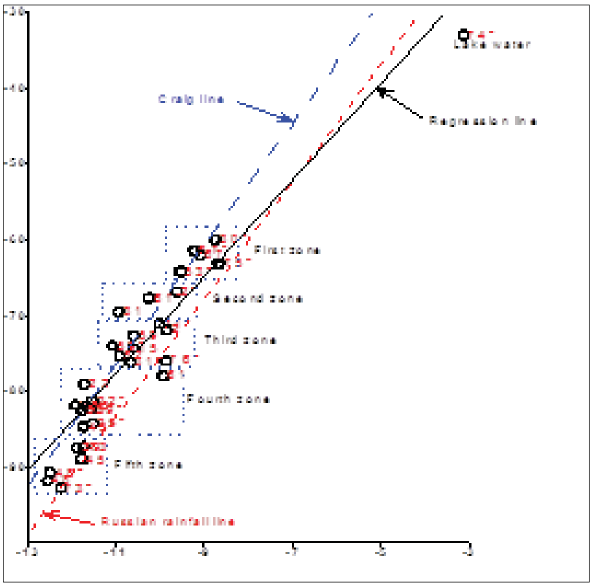

Figure 2. Distribution of the sampling points in [18]O ‰ versus D ‰ coordinate system.

Table 1. Distribution of the observed isotope ratios.

Zones	D(SMOW)	18O (SMOW)	13C (POB)
First zone	- 62.16‰ ± 1.63‰	- 9.05‰ ± 0.35‰	-10.15‰ ± 0.35‰
Second zone	- 68.02‰ ± 1.37‰	-10.27‰ ± 0.66‰	-7.36‰ ± 0.7‰
Third zone	-74.40‰ ± 2.23‰	-10.38‰ ± 0.48‰	-8.34‰ ± 1.06‰
Fourth zone	-83.79‰ ± 3.05‰	-11.70‰ ± 0.13‰	-8.02‰ ± 2.49‰
Fifth zone	-91.78‰ ± 1.04‰	-12.42‰ ± 0.16‰	-4.75‰ ± 2.57‰

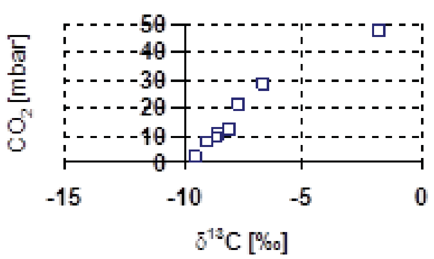

Figure 3. Relation between CO_2 and [13]C isotope concentrations.

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Estimation of karst groundwater resources in Slovakia

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Abstract

Although the major aquifer types in Slovakia (population of ~5.4 mil. inhabitants, area of 49,030 km^2) are quaternary alluvial and other quaternary sediments, neogene sedimentary and neogene volcanic aquifers, fissured crystalline Paleozoic / Mesozoic / Paleogene aquifers and karstic aquifers occupy only 5 % of the country area, they represent the most important groundwater source both form the quantitative and qualitative point of view. Groundwater resources and groundwater exploitation within the country are performed on the topographical background of 141 areal units, called "hydrogeological rayons". Hydrogeological rayons were delineated according to geological map in the 1:200,000 scale after its completion in 1970s, both in Czech Republic and Slovakia in former Czechoslovakia. 44 of these units, on the area of 8,747 km^2, contain karstic aquifers. In 2012, groundwater resources were estimated at the level of ~146.7 m^3·s^{-1} (~3 L·s^{-1} * km^{-2} in average) while exploitable groundwater amounts were counting 53.8 % of these (78.94 m^3·s^{-1}), but only 47,974.33 L·s^{-1} were already approved. The process of approval, estimation and classification of groundwater resources is controlled by the respective Commission on the Ministry of Environment. From karstic aquifers, approximately 19,700 L·s^{-1} of exploitable (both approved and not approved) groundwater amounts were registered, what represents 25 % of total exploitable groundwater amounts of the country. In 2012, the total groundwater usage in Slovakia was ~10.72 m^3·s^{-1} (13.6 % of the exploitable resources), while ~5.8 m^3·s^{-1} (54 % of the exploited amounts) were from karstic aquifers.

Karstic aquifers in Slovakia are all stratigraphically bound to Mesozoic, mainly its Middle Triassic and Upper Triassic part, where limestones and dolomites with karst-fissure type of permeability are found. The total area of outcropping carbonates is 2,324 km^2; dolomites take approximately 60 % of outcropping carbonates (limestones then 40 %). These form mostly mountainous type of karst aquifers (folded monoclines on the mountain ranges); only several morphologically visible karstic plateaus with canyon-like valleys of watercourses are found in Slovakia. Outcropping rocks are very different according to the character of permeability, character of groundwater circulation, type of groundwater regime, and also in the resulting yield of springs.

Groundwater chemical composition and quality originates mainly from the processes of the water-rock interactions. The Ca-HCO_3 and Ca-Mg-HCO_3 types of chemical content dominate in groundwater that is not affected by anthropogenic activities. The natural character of the groundwater circulation system conditions good qualitative properties of groundwater – most of the area provides best quality groundwater sources for regional waterworks. This groundwater fully meets criteria determined for their use for drinking purposes. In most cases, concentrations of trace elements are very low and mostly below the limits of quantification. Anthropogenic contamination was documented only rarely, usually close to settlements. It was mostly indicated by higher contents of nitrates, chlorides, sulphates, chemical oxygen demand and potassium. High iron and manganese may be found at the adjoining Tertiary artesian aquifers with reductive conditions. The chemical status of groundwater in karstic aquifers may be considered to be good, but future climate change may increase extreme hydrological events.

Electrical resistivity tomography as a tool for the dedection of near surface underground karstic waters

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Abstract

Electrical resistivity tomography (ERT) method has been used for the detection of karst water chambers in the "Ostreni i vogel" area, Dibra region in Albania. In this area a permanent spring water is present with an outcome approximately 400 litters per seconds, where many springs located in length of more than 50 m come to the surface creating an reservoir. The origin of those waters is karstic. 2D ERT profiles were performed in the area close to the contact between flysch and karstified limestone having as a scope the determination of the karst waters and their movement direction inside the limestone. For this reason, one profile with a length of 150 m were surveyed in the upstream direction about 400 m from existing stream, one with a length of 87 m in the present springs and another one with a length of 295 m along the stream direction in a distance around 30 m from the reservoir. In this study is clearly identified the karst inside the limestone and the direction of water movement which feed the existing springs. The water moves almost along the contact between flysch and limestone.

Keywords: *Electrical Resistivity Tomography, limestone, karstic waters, apparent resistivity, true resistivity*

Geological Settings and layout of geophysical surveys

The studied area belongs to the Mirdita zone (Gjallica subzone). A tectonically Silurian-Devonian (S-D) outcrop formation is exposed in a limited area (Fig. 1). They are situated in the boundary with Muhurr-Caja subzone and are represented by secirilitic schists, with black colour which contain graptolites.

The flysch of upper Titonian-Senomanian time (J_3^t-Cr_2^{cm}) belongs to the tectonic unit of Ostreni (tectonic zone of Krasta-Cukali). These deposits are tectonically situated over the flysch of Eocene of Okshtuni Unit (Krasta subzone and under the Triassic-Jurassic limestones of continental formation of Mirdita zone. The thrust contact between Triassic carbonates and flysch deposits is dipping at about 28°. In general the content of those formations is built by combination of different carbonatic and marls materials, sandstones and conglomerates with ophiolitic materials.

Layout of Geophysical surveys

The layout of geophysical surveys is shown in Figure 2a,b. The topography of the region is very rough and it was very difficult to realize geophysical surveys. However three ERT profiles were carried out. With magenta lines are presented the ERT profiles. Profile 1 is located in south-west of the spring (reservoir), and has a total length of 145 m. Profile 2 is located in the north-west direction of the spring and has e length of 295 m and is located approximately parallel to the stream. Profile 3, has e length of 87 m, and located exactly above the reservoir. With white line is presented the possible direction of karstic water movements. The thrust contact between flysch and limestone is also shown with interrupted line.

Methodology

Electrical Resistivity Tomography (ERT) is now a well-established tool for environmental

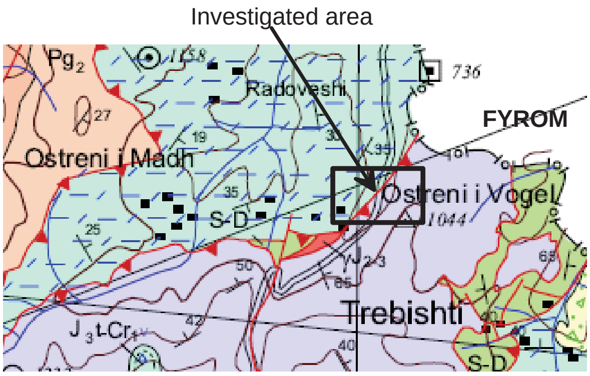
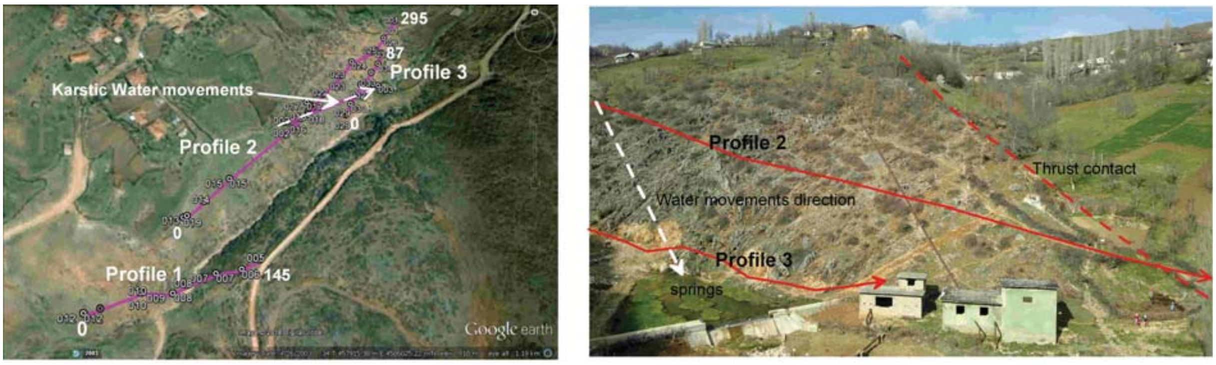


Figure 1. Geological map of the wider area of the region under geophysical investigation.



a) b)

Figure 2. Layout of ERT Profiles; a) on the Google Earth, b) schematic view.

and engineering site investigation, and is routinely applied to the detection of pollution (Daily et al. 1998; Goes and Meekes 2004), the characterization of geological (Meads et al. 2003) and engineering structures (Daily and Ramirez 2000), and for hydrogeologic studies (Binley et al. 2002). ERT provides a relatively low cost, non-invasive and rapid means of generating spatial models of physical properties of the subsurface. It is especially beneficial for contaminated land investigations where it is generally desirable to minimize ground disturbance. A category of environmental and engineering problems for which ERT has proved to be particularly useful is the near surface underground water investigation and particularly the study of the karst zones inside the limestone which serves as water collection and routes for water movements (Chambers et al. 2006) .

It has been applied successfully in several places in Albania as well, for investigating areas of complex geology, archaeological sites (Reci et al. 2009), to delineate the geometry of complex landslides (Muceku and Reci 2006, 2008; Reci et al. 2013). Technically the ERT is obtained by using different multielectrode arrays, such as the Dipole-Dipole, Wenner, Schlumberger, Wenner-Schlumberger, Gradient etc., the choice of which depends on the subsoil, the depth of investigation, the sensitivity to vertical and horizontal changes in the subsurface resistivity, the horizontal data coverage and the signal strength (Loke 1996, 1999). In this work, we conducted multi-electrode 2D resistivity imaging. To do a joint interpretation of resistivity data, experiments with different multi-electrode arrays, namely, Wenner Alpha array (WENNER α) Wenner Beta array (Dipole-Dipole), and Wenner Gamma array were used. The final resistivity data are taken from Wenner array since there are high contrast of resistivity values in the vertical direction and it ensures a smoothing on the values during the inversion procedure of apparent resistivities.

Results and discussion

In Figure 3, is shown the spatial distribution of logarithmic resistivity values of the surveyed area for each profile. From the resistivity values of ERT profiles we distinguish two zones related to true resistivity distribution. The low resistivity values (blue colour), normally are connected with karst filled with water and in some places the surface layers (profile 1, up) composed form clays and soils. The high resistivity values (yellow-red colour) are related with limestone.

As seen from Figure 3, in the profile 3 (down), which is above the reservoir, we see the low resistivity values in the middle of the profile related with the water reservoir and the springs. In the profile 2, the karst with water is well determined and is located almost in a zone of about 100 m in length and the level is almost the same with that of the reservoir. So, the direction of water movements from profile 2 to the reservoir is given connecting those two anomalies (Fig. 2b). Profile 1, which is located upstream, does not represent interesting features. It shows the upper part with low resistivity values composed by Quaternary soil and deeper we see the compact limestone with very high resistivity values. With white line is presented the possible direction of water movement, which connect the low resistivity values on profile 2 with the reservoir (spring) in profile 3. This direction is almost the same with the contact of the geological thrust which is present in the region. So, we can say that the huge karstified limestone formation, serve as a collector of the waters and the contact

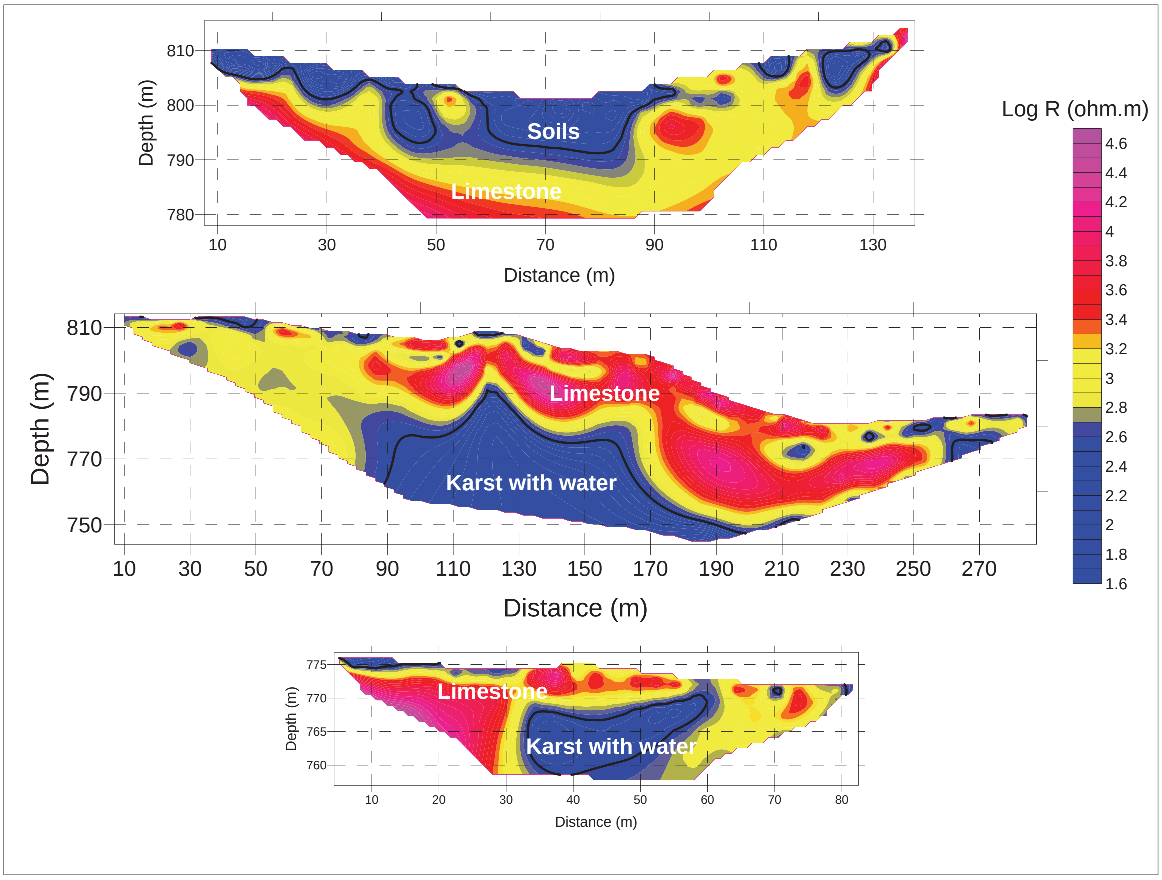


Figure 3. The distribution of logarithmic values of true resistivities of the ERT profiles (1 up, 2, middle and 3 down, respectively).

with flysch serves as screen for them. For that reason the waters comes out as several springs. The flysch formation has a slope of around 30 degrees and for that reason the water basin is deep in the reservoir.

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Some solutions and experiences in tapping coastal karstic aquifers in the Adriatic basin

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Abstract

The Dinaric system (Dinarides) is a long, NW-SE oriented orogenic belt, parallel to the Adriatic Sea. The External tectonic unit of the Dinaric system comprises coastal zones and islands of Slovenia, Croatia, Montenegro and Albania where karst aquifers are often almost the sole water resource and an essential factor for national economies and the development of industry and tourism. Although on the Italian side of the Adriatic basin karst has a limited extension along the coastal strip, many famous historical towns were built on the eastern Adriatic shoreline in close proximity to major karstic springs. And although the discharge regime of springs is variable and the presence of brackish water often disturbs the regular water supply, in the absence of other alternatives the population has concentrated around springs. For instance, three major historical towns and ports on the Dalmatian coast (today Croatia), Dubrovnik, Split and Rijeka, occupied the discharge points of the strongest local springs, Ombla, Jadro and Zvir, respectively.

Hydrogeological evolution of littoral karst was decisively affected by the rise of the Adriatic Sea level by about 100m during the last interglacial state. There are, therefore, many springs which previously discharged above sea level that are now submerged. The dynamic of coastal aquifer discharge and problem of interfacing salty-fresh waters have been studied for many years. The classical Gyben-Herzberg law, similar to the case of Darcy law, is problematic and may lead to uncertainty when applied to karst. It is thus important to distinguish aquifers opened towards the sea, those having some incomplete barrier (presence of wide range salinity of brackish waters), and finally those discharging over complete barriers. The last are more "safe" from sea water intrusion and provide the most convenient ambience for tapping and engineering regulation. The most common barrier in the Adriatic basin is the Eocene flysch. From its extension and position, very much depends fresh water supply.

Tapping coastal aquifers and distinguishing fresh from sea waters is usually a very difficult task. The Phoenicians constructed special structures such as iron funnels and leather pipes to force fresh waters to flow upwards to the surface. Fresh water was also tapped by tubes, amphorae or specially constructed bells and driven down spring outlets to catch the flow. Today we know that the most appropriate solution is to tap fresh groundwater flow as far as possible from the discharge zone and direct contact with the sea. In many cases the placement of horizontal galleries directly into the conduit enabling gravity flow has become a better option than pumping from drilled wells or shafts. But whatever intake is applied, systematic monitoring of discharges or pumping rate vs. water salinity should ensure sustainable aquifer development and prevent effects of water quality deterioration. Many modern methods are also nowadays available for searching coastal aquifers, deep and submerged discharge zones and choosing optimal aquifer tapping and regulating solutions. Among them are remote sensing, geophysical methods (electrical resistivity, induced polarization, gravimetry, VLF, etc.), speleo-diving, remotely operating vehicle (ROV), camera logging, infra-red thermovision recording, simultaneous hydrochemistry, and tracing tests.

During the last half century many successful projects have been implemented in the Adriatic basin and have solved the problem of increased water demands and pressures on coastal aquifers. There are also many sublacustrine springs registered along the lake shores, as in the case of the Skadar/Shköder Lake, the largest in the Balkans. Only on the Montenegrian shoreline has the average groundwater flux from the submerged springs been estimated at more than 10 m^3/s. From, one of the largest reservoirs of fresh waters in all of Europe, one recent project successfully conducted ensures the water supply of all Montenegrian tourist cities and ports. Experience gained from this project and a sophisticated solution to distinguishing lake and groundwaters can accordingly be applied at many other submerged springs along the lakes and the Adriatic coast.

Assessment of the seismic impact from quarry blasts on Glava Panega Karst Spring (Bulgaria)

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Abstract

The study presents the results of the assessment of the impact of grouped blasts from quarry situated at 1,250 km from the karst spring "Glava Panega" in North-West Bulgaria. The executed survey is in the frames of the program of the owners of the quarry for it safety exploitation and preserving the waters of the karst spring. The natural noise of the emerging water is compared to the records from the grouped blasts realized on 04.10.2013. The results are compared to the national and international criteria for the safety limits of accelerations and velocities of the ground in relation to the seismic frequencies. Reference to the maximum expected ground accelerations from earthquakes on the concerned site is also presented. The average vertical velocity of the ground from the quarry blasts, recorded inside the cave above the spring is 0.00078 cm/s, and the horizontal one – 0.0071 cm/s. The average vertical acceleration from the quarry blasts is calculated to be 0.38 cm/s^2, and the horizontal one – 1.87 cm/s^2. These results indicate that no one record overpasses the accepted critical level of ground velocities (5 cm/s) from artificial blasts and the maximum expected accelerations from earthquakes for the area - 0.10 g (98.1 cm/s^2).

Introduction

The karst system of Glava Panega Spring is situated at the nearest vicinity of a quarry for limestones and marls – at about 400 m westwards from the border of the concession. The spring is of Vauclusian type, composed by two lakes connected by underground channel. The surface of the upper lake is at altitude 185 m and its depth is 11.5 m. In its eastern part, at the depth of about 3 m under the water surface begins a dipping down channel, changing in slowly ascending gallery. It was explored by divers to a distance of 230 m and to the depth of 51 m from the surface. The system includes also two caves – the so called Upper and Lower caves. The map of the karst system around the spring (vertical and horizontal planes) is represented on Fig.1. The caves are sub-horizontal and interconnected, forming two principal levels. The total length of the galleries is 660 m, and the vertical level difference is about 40 m.

An interruption of the water springing was recorded many years before the existence of the quarry. Data were communicated from the French Consul G. Lejean in 1873 (referenced by Popov, 1962). The reason of this interruption could be a temporary internal barraging of the water by rock collapse, or it could be an effect of strong local seismic events that was not reported at this time. The area is of low seismic hazard. The expected maximum intensity (MSK-64 scale) is VII degrees, the seismic coefficient is Ks=0.10 g. Consequently, the impact from the quarry blast obligatory has to be with ground accelerations lower than 98.1 cm/sec^2.

Here bellows the results from the executed blasting the 4th of October 2013 will be discussed.

Technical conditions

The blast field was composed from 32 boreholes of 115 mm diameter and drilled to the average depth of 8.3 m (the depth is varying from 3.8 to 11.6 m), filled with chemical explosive, in total 3400 kg. The exploding was executed following a special scheme "Nonel" with delay of 25 ms between the single blasts in the boreholes.

For recording the waves from the grouped blast a 24-channels seismic equipment RAS-24 (SEISTRONIX, USA) was used. The records were digital, with digitalization time step of 1 ms, the amplification for all channels was the same – 24 dB. Only six pairs of recorders were used (in total 12 channels – 6 for vertical and 6 for horizontal recorders). The scheme of the recorders position is given on Fig. 1, C. Two pairs of recorders were inside the cave, directly above the spring channel, one pair was at the entrance of the cave, and the last three pairs were positioned outside the cave, in parallel line to the lake coast.

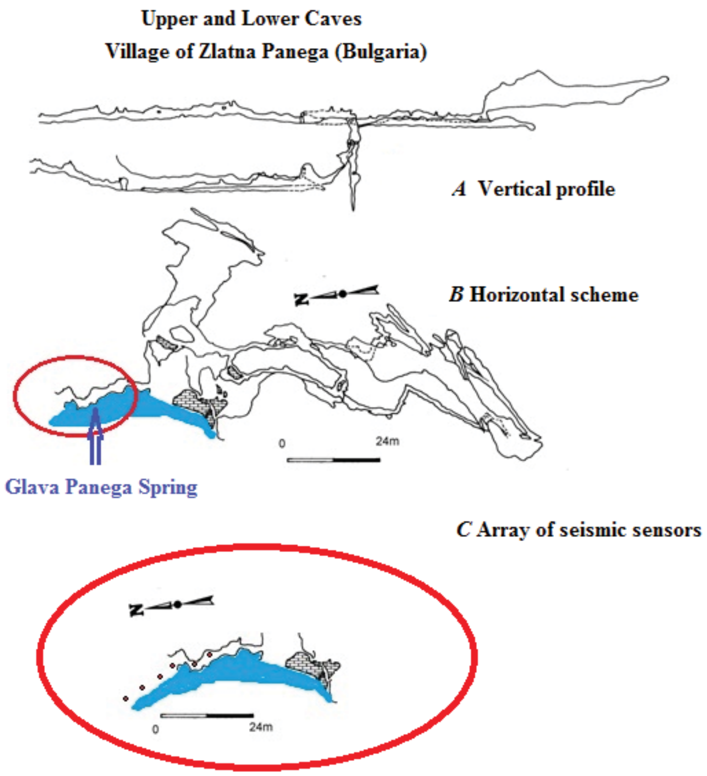

Figure 1. Scheme of the karst system of Glava Panega Spring (A and B - from the archives of Bulgarian Federation of Speleology) and disposition (C) of the recording seismic sensors.

The characteristics of the recording sensors are typical for the widely used seismic recorders of conventional type (Aaron 2000). The vertical recorders were produced by GeoSpace Co, Pat. no. 3119978 and their sensibility for frequencies between 10 and 100 Hz is 30 V/[m/s] or 0.3 V/[cm/s] at the own frequency of 60 Hz. The horizontal recorders were of type Sensor SM-6 with own frequency 14 Hz and their sensibility for frequencies between 10 and 100 Hz is also 30 V/[m/s]. The pairs (one vertical and one horizontal recorder) are placed at a distance of 5 m between them. The time length of the registration is 8 s and permits the receiving of the all package of interfered waves.

Methodology

The sequence of the data processing was (Shanov and Isaev 2013):

1) The records of length of 8 s from all receivers were analyzed. Two groups of records were separated to be compared with the requirements of the international standards – one from the vertical recorders and the second from the horizontal recorders. Because the registrations were with the same amplification of 24 dB, for each of them, with the digital step of 1 ms, the transformation in mV of the recorded amplitude u_r was done following the equation from the definition of the unit dB:

$$u = u_r / 10^{1.2} \text{ [mV]} \qquad (1)$$

The resulting amplitudes were divided by 300 000 μV/[cm/s]. At this manner the real registered velocities of the ground displacement in cm/s was obtained.

2) The frequency specter for the peak ground velocities for each of the groups was determined using the program Win_Point 2 of the software WinSism 7.

3) The ground acceleration a for every receiver and for the total length of the record was calculated:

$$a_i=[(u_i-u_j)/t_{j-i}].10^{-3} \text{ [cm/s}^2\text{]} \quad (2)$$

The time interval of digitalization between i and j records t_{j-i} was 1 ms.

Natural background

A record of the natural seismic background was done before the blasting (Fig. 2). The devices inside the cave, both horizontal and vertical, have recorded lower amplitudes of the seismic noise than those outside the cave. The weather was windy and this could explain the amplitudes differences. It is not possible to find any indication about pulsing discharge of the karst spring. The maximum peak of vertical ground velocity recorded inside the cave is 0.000033 cm/s, and the horizontal one – 0.000095 cm/s. These values could be appropriated to the seismic noise from the springing water. Nevertheless, they are at the limit of the sensors sensibility.

the graphs with the safety thresholds, according the international standards, and it is shown that the chosen method of blasting assures nondestructive impact on the spring area. The recorded values are much lower than the critical level of 5 cm/s.

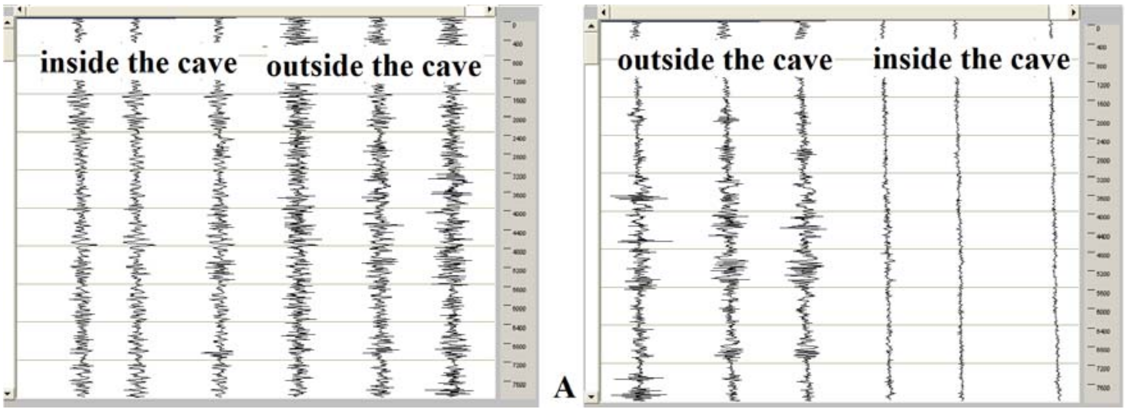

Figure 2. Records of the natural seismic background inside and outside the cave over Glava Panega Spring. A – horizontal sensors; B – vertical sensors.

Results

The original records from the grouped blasts on 04.10.2013 are represented on Fig. 3. The clear difference of the amplitudes recorded by the horizontal receivers (1-6) and the vertical receivers (19-24) is well seen.

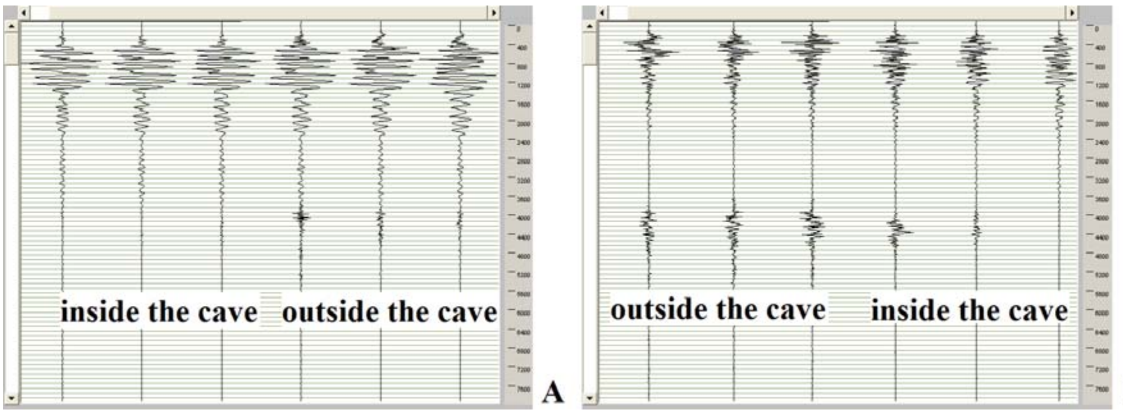

Figure 3. Records of the seism from grouped blasts on 04.10.2013 by the horizontal (A) and the vertical (B) sensors

The spectral analyzes have shown that seismic receivers from both two groups – vertical and horizontal registered dominant interfered waves of high amplitudes in the interval from 3 to 13 Hz. The peaks are at 5 and 10 Hz.

The values of the horizontal velocity of movement of the superficial layer at the spring Glava Panega recorded during the blasting from 04.10.2013 are from 0.0063 to 0.0078 cm/s, the average value being 0.0071 cm/s. These values are compared to

The average acceleration is evaluated at 1.87 cm/s^2 based on the recorded values from 1.25 to 2.81 cm/s^2. In this case the peculiarity is that the recorded values of the horizontal accelerations inside the cave above the spring are two times lower than the recorded outside the cave. This is one confirmation that at a depth from the surface the accelerations are lower.

The shear surface waves contain the most important part of the radiated elastic energy. But no one of the records riches the normative value of 98 cm/s^2 (the seismic coefficient for the area is 0.10 *g*). Taking into account the fact that above the spring Glava Panega (in the cave) the recorded horizontal component of the acceleration is 2 times lower than the acceleration on the free air surface, it becomes clear that a dangerous impact on the spring discharge from the grouped blasts in the quarry is impossible.

The effect from the blasting of 04.10.2013 shows very low vertical velocities at the nearest vicinity of Spring Glava Panega – from 0.00061 to 0.00091 cm/s, and the average value is 0.00078 cm/s. All presented values are far below from the normative thresholds for damages.

Very low values of the maximal accelerations from the seismic records with vertical sensibility are also registered on the site at the Spring Glava Panega during the blasting from 04.10.2013 – from 0.14 cm/s^2 inside the cave over the spring, to 0.69 cm/s^2 outside the cave. The average velocity is 0.38 cm/s^2. No one of the registrations passes the normative threshold of 98 cm/s^2.

Conclusion

The results from the analysis of the recorded seismic waves from the grouped blast in the quarry near the karst spring Glava Panega show that the methodology used for recording and calculation of the peak ground velocities and accelerations effective and can be applied for assessment of the impact from industrial blasts on karst areas.

All obtained results show that outside the prescribed by the Regulation for Safety Execution of Blasting Activities radius of 500 m around the blasted field (the real calculated safety distances for the shock wave according the passports of the blasting are 350 and 300 m), applying the chosen method of blasting, no dangerous impacts exit for the natural karst structures at the vicinity of Glava Panega Spring.

Taking into account that the spring is discharging fresh water from the depth greater than 50 m where the horizontal component of the acceleration is at least 2 to 3 times lower than on the free surface (Okamoto, 1973) it becomes clear that the blasts from the quarry are not able to impact the water discharge if the prescribed method of blasting with delay of 25 ms between the charged boreholes in the quarry will be strictly applied.

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The effect of "iron oxides" existent in the sedimentary rocks on the deterioration of cultural heritage

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Abstract

Some monuments belonging to Egyptian cultural heritage are exposed to various deterioration factors especially those represented by iron oxides that in sedimentary rocks form the cementing material. In many cases, this cement represents a severe danger because of its important solubility in water. In consequence, the buildings and tombs built or carved in these stones are exposed to the damage because of the dissolution of iron oxides, phenomena called "stone bleeding" when the stone become brittle due to loss of cementing material.

We will present two cases, the first one being represented by some tombs located in Bahariya Oasis in Egypt, which were carved in sandstones where the grains are held together by cement composed of iron oxides. Two samples collected from the mural paintings of these tombs affected by the dissolution of the iron oxides were examined with the scanning electron microscope and with X-ray diffraction. After analyzing these samples, we found that their main components consist of quartz and iron oxides represented by wuestite , feroxyhite and goethite with a percentage above 20 % from the total components of the samples. The important percentage of the iron oxides proves that they are not traces in the samples, but important components. The presence these iron oxides in the sandstones representing the support of the mural paintings leads to a high friability and finally to their complete destruction.

The second case is represented by the Sarabium archaeological site located in Atfiyah – Giza, Egypt. This site is built in limestones containing a high percentage of iron oxides and which are very loose because of the loss of the cementing material due to the high content of water represented by a ground source crossing this site. Also the high air humidity plays a significant role in their destruction of some monuments located on this archeological site. This source of ground water is represented by an agricultural drainage system and contains sulfates, phosphates and other salts. These waters rich in salts rise through the limestone by capillarity, the salts crystallized in the depth or on the surface of the rocks exerting a high pressure within the grains. This process also affected in a significant manner the monuments from Sarabium beside the problem related to the iron oxides loss.

After analyzing a sample from Sarabium archeological site with the scanning electron microscope and X- ray diffraction, we found that the major components are represented by calcium carbonate with a percentage of 54.5 % followed by other components as dolomite representing 7.19 % and zinc oxide representing 11.28 %. In this sample, the iron oxides are represented by 15.3 % feroxyhite and 11.66 % wuestite, their total percentage in the studied limestone sample being of 26.96 %. We also analyzed some physical properties of this sample and we found a porosity of 10 %, density of 2.3 gm/cm^3 and the compressive strength of 5.033 KN/cm^2.

The results show that the iron oxides in limestone represent the cement and their presence causing the limestone friability. These oxides which easily dissolve in humid climatic conditions, the presence of the ground water accelerating this process, the high salt content of the ground water source (the agricultural drainage system) and the unfavorable air temperature lead to the disintegration of the stone in a form of a powder. At the end, the result is the loss and destruction of this precious archeological site.

The presence of iron oxides in sedimentary rocks caused severe deterioration phenomena to the archaeological buildings built by these rocks and finally to the loss of the cultural heritage.

In this research, we will discuss this phenomenon with an application on some tombs and archaeological sites which are severely affected by this problem.

Stone properties and damage induced by salt crystallization in some Jordanian stones

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Abstract

Limestone and basalt samples were selected from four archaeological sites in north and northeast Jordan. The selected stones were investigated with physico-mechanical methods and ultrasonic technique and the changes in their properties after artificial weathering by salt crystallisation test were studied in order to obtain information about their weathering behavior and durability. It was found that the susceptibility of the studied stone samples to salt damage is determined by their petrophysical rather than mechanical properties. In terms of loss of stone material, the damage induced by the crystallisation of salt in the stones seems to be dependent on their proportion of micropores and free porosity. Durability estimators for the evaluation of the weathering resistance of stone were consequently developed.

Keywords: *durability, salt crystallisation, Jordanian stones*

Introduction

The assessment of the intensity of stone deterioration is an essential aim for preservation and conservation purposes (Siegesmund et al. 2002). For the quantification of deterioration, a fundamental understanding of stone weathering mechanisms and their influence on stone structure is necessary. Weathering processes affect the physical and mechanical properties of stone and induce various changes in its structure (Nicholson 2001; Benavente et al. 2004). Changes in stone due to weathering might include modification of porosity and pore structure, development of cracks and loss of stone cohesion (Tuğrul 2004). The study of these changes in stone properties helps to provide information about the weathering of the stone and its durability.

However, stone deterioration processes are controlled by multiple factors; intrinsic factors inherent to the stone and its natural heterogeneity and extrinsic factors related to the surrounding environment (Siegesmund et al. 2002). The interactions between the various properties of stone and the weathering processes affecting them do create a complex system. In such a complex system there is no single controlling parameter, but rather a multiplicity of factors is actually involved (Nicholson 2001).

A simple and good approach to understand the weathering of stone and to assess its durability is, therefore, to consider a certain type of weathering processes and try to determine the most important parameters controlling this weathering (Bourgès 2006). Such an approach has been widely used for testing building stone in the field of civil engineering and architecture (Nicholson 2001; Benavente et al. 2004; Angeli et al. 2007; Yu and Oguchi 2009, 2010).

In this work, the changes in stone properties upon artificial weathering by salt crystallization test are studied in order to provide the necessary information for understanding and assessing the deterioration of the selected stones and their durability.

Materials and Methods

To study the effects of artificial weathering on the properties of stone, five samples of limestone and basalt were selected. These stone samples were artificially weathered by salt crystallisation test which was carried out by total immersion in a solution of sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$) according to the standard test DIN EN 12370. 25 salt weathering cycles were performed on the limestone and basalt samples. At the end of the test, the samples were submerged in distilled water that was changed daily before eventually rinsed thoroughly in water to remove all the salt from their pores. The samples were finally dried in oven and the loss of stone material after the test is calculated from the change in the mass of specimen as a percentage of initial mass.

Different laboratory tests were carried out to characterize these stone samples and to study their properties before and after salt weathering test. The porosity and pore structure properties were measured by water absorption method (according to the RILEM standards) and Mercury intrusion porosimetry (MIP). MIP measurements were carried out using the porosimeter combination PASCAL 140/240 (from Porotec) with a pressure in the range from 10 Pa to 200 MPa, whereby pore radii in the range of about 58 µm–3.7 nm can be measured.

The biaxial flexural strength (β_{BFS}) and static modulus of elasticity (E_{stat}) of the studied stones were measured on 5 mm thick drill core slices following the method of Wittmann and Prim (1983). Measurements were performed using a universal *Zwick Z010* apparatus with a preload of 5 N at a rate of 0.5 mm/min.

The velocity of longitudinal ultrasonic waves (V_p) was measured with portable ultrasonic device UKS 12 from Geotron-Elektronik. The system is composed of an ultrasonic generator USG 20 and 50 MHz Philips scopemeter. The dynamic modulus of elasticity (E_{dyn}) was determined on prismatic specimens by the extensional wave measurement procedure (Erfurt and Krompholz, 1996), which involves measurements of the travel time of longitudinal wave and the resonance frequency of the base extensional wave. Measurements were carried out using the portable ultrasonic system UKS 12 with USG 30 ultrasonic generator and 100 MHz Fluke 99B scopemeter.

The fracture density (F_D) of the stones was also measured. It is a measure of the total surface area of fractures per unit volume of stone (Nicholson, 2001). It affects the mechanical strength of the stone and its other properties, particularly the elastic properties. The fracture density can be estimated using the following stereological equation (Karcz and Dickman 1979).

$$F_D=2P_L \quad (1)$$

F_D = fracture denity (fracture surface area per unit volume) [mm²/mm³];

P_L = number of point intersections of fractures per unit length of grid line [mm^{-1}].

Results and Discussion

The visual examination of the stone samples at the end of salt crystallisation test showed that the limestone samples exhibited two different weathering behaviors; some samples were subject to fracturing without significant loss of stone material whereas the others showed mainly granular disintegration and preferential weathering in form of pitting, and suffered relatively greater loss of stone material. The basalt samples exhibited no considerable macroscopic signs of damage.

The limestone samples exhibited a slight continuous increase in total accessible porosity with increasing number of weathering cycles. The accessible porosity after 25 weathering cycles increased for some samples by around 10 %. This indicates a continuous breaking up of grain contacts due to weathering, leading thereby to the development and enlargement of cracks and pores (Fitzner 1988). On the other hand, the basalt samples showed a decrease in porosity, particularly at the beginning of the test. This might be attributed to pore-clogging by trapped salt crystals (Nicholson 2001; Yu and Oguchi 2010).

In general, salt appeared to crystallise in pores of varied sizes and modified them in different ways. Pore enlargement and crack developments can be seen in all weathered samples, albeit to varying extent. In the basalt samples, salt remained trapped in pores even after extensive rinsing with water. The remaining salt was either deposited in pore entries resulting in peak shifts towards smaller pores or inside pore cavities reducing thereby the total pore volume, particularly the volume of capillary pores.

The sound limestone samples showed varying degrees of cracking with the highest fracture density being 0.018 mm²/mm³. The fracture density of the limestone samples increased continuously with increasing number of weathering cycles. The basalt samples, however, showed no visible macrocracks within 25 cycles of salt weathering.

All the samples showed a decrease of biaxial flexural strength after weathering. This is clearly evident for the limestone samples. A corresponding decrease in the static modulus of elasticity of all weathered samples is also evident. The elastic and mechanical properties of a stone are highly influenced by microcracks and fracture density (Walsh 1982). Therefore, the reduction in biaxial flexural strength and elasticity modulus was higher for the stone samples which were subject to greater fracturing and microcracking as indicated by fracture density and MIP measurements. The dynamic modulus of elasticity of the stones was also reduced after weathering. However, the reduction in the static modulus of elasticity was much greater.

The total loss of stone material (or dry weight loss DWL) is the parameter most frequently used to evaluate salt damage to building stone in durability tests (e.g. Benavente et al. 2004; Yu and Oguchi 2009, 2010). The dry weight loss was calculated for cubic and prismatic specimens after extensive desalination with water and drying to constant mass by comparing the initial and final mass. In terms of total dry weight loss, the studied stones showed generally quite good resistance to 25 cycles of salt weathering. This might be attributed to their relatively low porosity, pore space characteristics, and good mechanical resistance.

The velocity of longitudinal ultrasonic waves (V_p) was measured on cubic specimens of each sample along three orthogonal directions before and after weathering. Measurements were carried out both in dry and water saturation conditions. The limestones, and to a lower extent the basalt samples, showed slight anisotropy (up to 5 %). The anisotropy of the limestone samples which were subject to cracking increased after weathering, which might indicate preferred fracturing and crack propagation along certain directions. The other samples showed generally a decrease in anisotropy after weathering.

For all stone samples, the velocity of longitudinal ultrasonic waves in water saturated specimens is higher than that in dry specimens. The increase of velocity in water saturated specimens before weathering was below 2 % for almost all the stone samples. After weathering, all the samples showed a reduction in ultrasonic velocity due to development and widening of cracks and fissures. The stones with the highest degree of cracking suffered the highest reduction in ultrasonic velocity. These samples showed also a considerable increase of velocity in water-saturated specimens compared to dry ones. This confirms the mitigation of the influence of cracks on ultrasonic velocity in water saturated stones. The basalt samples exhibited a lower reduction in ultrasonic velocity after weathering. No visible fracturing could be noticed in these samples and the damage in stone structure was limited; only small proportions of cracks that might affect ultrasonic velocity were developed after weathering as shown by MIP results. The increase in ultrasonic velocity in water-saturated condition for the basalt samples was lower after weathering, probably because of the reported reduction in porosity.

The susceptibility of the studied stone samples to salt damage was estimated based on their properties in the sound condition. The aim was to develop durability estimators from the physico-mechanical properties of the sound stone that can be used to predict and assess stone resistance to damage without the need for performing the time-consuming and costly accelerated weathering tests. This can be useful for durability tests that are intended to test the resistance of building stone to damage for a particular use under certain environmental conditions. It has also important applications in the field of conservation for replacing damaged stones and selecting suitable restoration materials.

For this purpose, the physico-mechanical properties of the stone samples before weathering are characterised and the induced damage after salt weathering test is to be evaluated using suitable parameters. Many studies have been dedicated to develop durability estimators from the different properties of stone and its pore structure characteristics (e.g. Benavente et al. 2004; Yu and Oguchi 2009, 2010). In most of these studies, total dry weight loss (DWL) of stone is the only parameter used to indicate damage. A few authors have been considering the use of other additional parameters to provide a more reliable assessment of damage. For example, Nicholson (2001) used the change in fracture density besides DWL to evaluate damage. Angeli et al. (2007) proposed two parameters to quantify the alteration and weathering of stone.

In this study, the total dry weight loss (DWL) and the change in fracture density (ΔF_D) after weathering are used to indicate the damage induced in the tested stones in 25 cycles of salt weathering. These damage indicators are correlated with the petrophysical and mechanical properties of stone before weathering in order to understand the influence of the various properties on stone susceptibility to deterioration and to develop suitable durability estimators.

In terms of total dry weight loss (DWL), stones with high values of water absorption (or free porosity), saturation coefficient, and microporosity, as well as low values of ultrasonic velocity showed generally higher degrees of damage. In its turn, fracture density influences mainly the mechanical and elastic properties of stone; higher fracture density implies lower strength, moduli of elasticity (particularly static modulus) and ultrasonic velocity. The increase in fracture density is also responsible for the increased difference between ultrasonic velocity in dry and water saturation conditions. Based on the correlations with stone properties, durability estimators for damage as indicated by DWL and change in fracture density are proposed. The dry weight loss in the tested stones (DWL) correlates very well with the product of microporosity (in this study $P_{m0.1}$ ($r < 0.1$ μm)) and water absorption that is with ($W_{abs} * P_{micro}$); the Pearson correlation coefficient $r = 0.98$.

Conclusions

The aim of this study was to investigate archeological stone samples from jordan with physico-mechanical methods and ultrasonic technique in order to study their deterioration upon accelerated weathering and to assess their durability. The selected stone samples were characterised by physico-mechanical methods and their microstructure was studied.

The study of the changes in the properties of the stone samples upon artificial weathering by salt crystallisation test helps to understand their weathering behavior and to evaluate their resistance to deterioration. The studied limestone samples exhibited weathering in form of granular disintegration and pitting or cracking. The damage induced in the stones after salt crystallisation test was evaluated by two indicators; total dry weight loss of stone material (DWL) and change in fracture density (ΔF_D). On the one hand, the petrophysical properties of the stones seemed to be very important for determining their susceptibility to salt damage. The proportion of micropores and the water absorption capacity (or free porosity) of the stones were the most important parameters that determined the induced damage in terms of DWL. On the other hand, the mechanical and elastic properties were not directly correlated with stone damage indicated by loss of stone material. These properties were instead more related to the fracturing behavior of the stones. Based on these results, durability estimators were developed to assess the susceptibility of stone to weathering. The size of the samples used to develop these estimators was, however, small. Further research with a larger number of samples and various stone varieties would be required for confirming the results.

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Masonry cracks in historic buildings related to material incompatibility

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Abstract

The built cultural heritage in Albania is protected by law and many regulations. Although there is place for the improvement of the legal framework and its implementation is a problem. Authenticity as an important principle in the preservation of cultural heritage is equally damaged, as from the abandonment of historic buildings, as well as from wrong interventions. The lack of funds from public authorities, as well as economic problems of the owners make a number of historic buildings to degrade. Their anti-seismic systems being mostly of wood degrade faster than other materials, thus bringing first the loss of resistance to seismic action and then destroying the building. Some conservation and restoration projects tend to preserve the original architecture of the building, and to improve, according to them the initial state of construction. So timber ties and wood floors are not restored but replaced with reinforced concrete elements. This is a completely wrong intervention not only because of the principle of authenticity but also because concrete is an incompatible material with the materials used in historic buildings. Problems that arise from this kind of intervention show up with cracks in the places where a wrong intervention was done.

Masonry cracks in historic buildings are the primary concern in the architects and engineer community. Cracks are observed in several cases after interventions with incompatible materials, in particular when replacing wood element (such as the anti-seismic system) with concrete one. The types of cracks are discussed by practical examples in the perspective of the causes, risks and repair methods.

Thus the specialists of the restoration need to have advanced knowledge in contemporary methods to analyse and study the structure, the materials and the anti-seismic systems of the historical buildings.

At the end of the analysis it is important to conclude if the structural system or anti-seismic system is still effective today or needs improvements. In all cases the new materials shall be compatible with the existing ones.

Rock porosity and durability: the contribution of the image analysis

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Abstract

Rock weathering is strictly connected with the increasing of the porosity. There are different techniques to measure the porosity: the increase of voids accessible to water is therefore correlate with the increase of the decay.

At the moment two methods have been widely used to evaluate the water absorption of a stone. The first method, described in EN 13755 Determination of water absorption in atmospheric pressure, measures how much water can get into the prismatic specimen from its 6 faces during the period of immersion in water until a constant while the second, named water absorption by means of a contact sponge, measures how much water can be absorbed by a flat surface in a defined time.

Generally rock porosity increases with the increasing of artificial ageing but not always there is correspondence with the decrease of mechanical strength. The explanation is in the kind of the evolution of the porosity: so a reliable method to evaluate the kind of porosity is needed.

In this work image analysis has been used used to investigate six kind of rock in the natural state and after natural weathering. This kind of technique, together with other more frequent test methods, add important information on the decay evolution of the stone.

The mensiochronology for historical buildings: the case study of walls of Capua, Italy

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Abstract

The mensiochronological analysis is a valid tool for the conservation of cultural heritage, in fact, the metrology of building components is a historical-critical effective practice to support the preservation of the architectural heritage of culture, understood as a set of material evidence of civilizations. The metrology used for investigation is the result of twenty years of studies about historic buildings techniques, in particular the case studies have permitted to increase our knowledge about limestone and tuff masonry, wooden floors and roofs, fixtures and floorings. The methods integrate the historical-critical and documentary analysis, allowing the technician to determine the age of the structures based on their technological characteristics and not on the stylistic ones. These are useful for the analysis of buildings whit historical connotations that are not characterized by solemn formal elements; indeed these were subjected to incessant changes in the social and territorial context from the medieval to contemporary age. These transformations are recognizable through mensiochronological parameters. For each constructive areal and for each category of object, in fact, it has been possible to define the related chronotypes. In particular, this paper examines the walls of Capua, Italy.

Capua born on account of renouncing of the ancient osco-samnite and roman S. Maria Capua Vetere. The new town, that date back to the IX century A.C., rise near the roman Casilinum and enjoy a good geographical situation with a better defence against the enemies incursions. Around on three sides, it is protected by the Volturno river, while, at south, it is guarded by the fortified defence system.

In the Medieval Age, the town-walls includes rectilinear courtains, quadrangular towers and various urban gates that are preserved, at south, by the castle of Stones, at north by the castel of Towers. The built-up area is extended around to the main streets, that are: the present day Corso Appio; the Corso Gran Priorato di Malta and, lastly, via Roma.

In the course of the XVI-XVII century, at south-west, rise the castle of Carlo V, the munition lines advances toward the south, it is enlarged and renovated with powerful bastions, high oblique courtains and deep moats around of his perimeter. During the Austriac Age, in the first quart of the XVIII century, the reignigns build forepart bastions for the purpose of turn away the enemy and to procure a bigger long-range guns. The Borbone realize maintenance and restoration works of the courtains and bastions, that carry on until the XIX century. In the Contemporary Age, the defences are in a bad condition at cause of carelessness and lush vegetation, although, his material evidences are, just the same, actually observable.

Through mensiochronology it has been possible to define the many phases of construction of the walls of Capua and above to acquire new information compared to local historiography.

Paleozoic limestone from the Prague Basin (Barrandian area, Czech Republic) as a raw material for production of alternative hydraulic binders (natural hydraulic lime and/or natural cement): their characteristics and properties of material formed during the firing

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Abstract

Ordinary Portland cement (OPC) is the most widespread type of hydraulic binder nowadays.

However, demand for alternative hydraulic binders such as natural hydraulic lime (NHL) and/or natural cement (NC) increased during past decades. This increased interest is influenced by the search for suitable materials applicable in the restoration of artworks, as well as by the environmental friendliness due to their lower emissions of CO_2 and lower demand on energy than OPC.

The southwest surroundings of Prague (Czech Republic) is well known for the production and use of different types of inorganic binders from the Middle Ages. Lime burning was based on various types of pure and impure limestones (Upper Proterozoic-Lower Palaeozoic age of the Prague Basin), which are suitable for processing and production of NHL. The local lime became famous thanks to Italian builders as "pasta di Praga" in Baroque. Later, NHL burning was supressed by OPC.

This study focuses on the experimental laboratory burning of several limestone facies belonging to the Upper Silurian beds (Přídolí ls.) and/or Lower Devonian beds (Radotín ls., Kosoř ls., Řeporyje ls., Dvorce-Prokop ls. and Zlíchov ls.). This project aims to investigate the influence of variability of the phase and chemical composition of raw material on the phase composition of burned material.

Mineralogical and petrographical characteristics were studied by optical microscopy, cathodo luminiscence, and electron microscopy of thin sections. Phase composition of non-carbonate phases was examined by means of X-ray diffraction (XRD) of insoluble residues obtained by treatment with both the hydrochloric acid and/or acetic acid. Wet silicate analysis provided data on the content of major elements from which standard cement and lime indices and modules were calculated.

Majority of Dvorce-Prokop limestone show content of insoluble residues above 20 wt.%. Non-carbonate phase encompasses both silica (quartz and/or amorphous SiO_2 phases) and clay minerals (dominant illite and subordinate kaolinite). Na-plagioclase, K-feldspar, chlorite, and rutile are accessory phases. Selected types Dvorce-Prokop limestone contain higher amount of dolomite which suggests partial dolomitization of this limestone facie. Kosoř ls. are rather poor in non-carbonate phases (insoluble residues around 10 wt.%). These characteristics are related to hydraulic potential of studied samples: Dvorce-Prokop limestones exhibit higher hydraulicity compared with Kosoř limestones.

Laboratory firing experiments of these limestone were performed by a calcination at the temperature ranging from 850 to 1200 °C (after 50 °C step). XRD of burned products shows that limestones with high content of silica (some of the Dvorce-Prokop ls.) produced binder with high amount of newly formed dicalcium silicate. Gehlenite and other calcium aluminates and aluminosilicates are typical for burning of limestones with higher content of clay minerals (illite and kaolinite) which are common in Kosoř ls., Řeporyje ls., and Dvorce-Prokop ls. Brownmillerite was formed in limestones exhibiting higher proportion of Fe-oxihydroxides (specifically in Řeporyje ls). Increasing content of free lime and portlandite correlates with lower content of non-carbonate material (some varieties of the Dvorce-Prokop ls. from Bráník Rocks and Kosoř ls.). These results show clear dependence of primary limestone composition on properties of burned raw material. It is evident that high content of clay minerals, quartz and/or silica, as well as peak temperature of burning, have significant influence on the formation of mineral phases typical for hydraulic lime such as larnite, gehlenite, and/or brownmillerite.

Decay and conservation trial of Late Jurassic sandstone with dinosaur tracks in a museum environment (Museum of Lourinhã, Portugal)

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Abstract

Late Jurassic dinosaur footprints were found on a coastline cliff in Lourinhã, Porto das Barcas, Lagido do Forno (coordinate 39°14.178'N, 9°20.397'W, Portugal) in June 2001. The locality is characterized by steep cliffs with high slopes that are composed of gray and red sandstones/siltstones. The location belongs to the successions of Lusitanian Basin representing the Porto Novo Member of the Lourinhã Formation.

Three natural infills of tridactyl tracks, possibly ascribed to ornithopod, a bipedal herbivore were found, representing a left foot movement, a right and a left one, respectively. Footprints are 300-400mm wide and have a height of 330-360mm. The footprints are characterized by round fingers, which are elongated due to some degradation/erosion. The footprints were collected from the field in 2001 and subsequently cleaned, consolidated and glued in the laboratory of the Museum of Lourinhã before being exhibited in a museum display. Stone matrix was removed and a consolidation product was applied, probably a polyvinyl acetate. The footprint with broken central digit was glued with an epoxy resin, Araldite. Both applied products were confirmed by analysis of μ- FTIR and both presented colour change and detachment surface problems. The footprints have been exposed in the palaeontology hall of the Museum of Lourinhã, Portugal from 2004 without climate controlling. These trace fossils form an important part of the palaeontological collection of Late Jurassic vertebrate fossils from Lourinhã Formation. Presently, it is considered a unique heritage in danger of disappearing due to high decay level of disaggregation of its geological structure. The footprints display several pathologies, such as "Blistering", "Powdering", "Exfoliation"' as well as "Dirt", "Fracture"', "Inscriptions", "Consolidants" and "Adhesives" and are now in very poor conditions. Laboratorial analysed were made to evaluate the presence of salts.

Moreover a microclimatic study was conducted inside the museum to evaluate the influence of thermo-hygrometric parameters on the decay processes. The future interventions will depend on the results of consolidation trials that are currently under progress by using stone samples taken from the same layer and location from Porto das Barcas applying different commercial consolidation products.

Aggregates -trends And Perspectives. The Romanian Contributions For A European Vision

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Abstract

Aggregates represent an engine of the economy and a factor of influence of living standard. Natural aggregates consist of manufactured crushed stone and sand/gravel created by crushing bedrock or others occurring unconsolidated rocks. Almost 65% of the aggregates consumed in Europe annually are used for building construction purposes. In present, about 90 % of the overall aggregates production in Europe comes from non-metallic resources, from quarries and pits. Others remaining 10% of the European aggregates production comes from marine deposits, recycling of industrial waste, such as slag and ashes, and recycling of construction and demolition waste (UEPG report 2011). Many of the countries within European Union have elaborated mineral plan in aggregate industry. In the future rules a major role is the implementation of mineral planning in each SEE countries. In Romania is only a document to refer at construction materials: National Strategy.

Keywords: *Aggregates, raw material, quarry, aggregates policy, sustainable management*

General data

Aggregates resources are very important for infrastructure works (e.g. around 30,000 tons of aggregates are needed for the overall construction of 1 km of a national road where they are present in the road base, in the bituminous or concrete mixes. Quantities corresponding to 20 % of the European consumption of aggregates refer to construction of the surface of roads, runways, railways and waterways. Despite society dependence on natural aggregate, urban expansion often works to the detriment of the production of those essential raw materials. Worldwide demand is estimated to rise by 4.7 % each year. In advanced European economies, the annual aggregates demand reach to 12 tons per capita. The sector had suffered under the economic crisis from 2009 and a further decline in production was reported (www.sarmaproject.eu). Nevertheless, it is anticipated that the aggregates demand will reach soon the level from 2008 of 3.5 billion tones and will reach 4 billion tones in the medium term, driven mainly by economic growth in Central and South-East Europe. Aggregates demand increased the last years in Europe and especially in South-East Europe being in strong correlation with GDP/capita (Fig. 1).

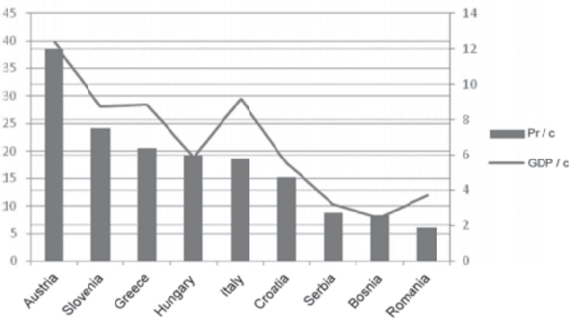

Figure 1. Aggregates production in 2011 in South-East Europe – Tonnes/capita (right vertical scale) & GDP (€000)/capita (left vertical scale) (calculated on estimated data, UEPG2012).

In Romania, a country with a complex geological structure, over 500 deposits of natural aggregates were exploited in 2000's and in the present the crushed stone need is biggerthanother aggregates (sand & gravel). The distribution of the exploitation and/or stone processing units or concrete and prefabs factories is equilibrate across the national territory withno long distance to the aggregate exploiting sites. In 2012, in Romania, there werea lot of types of mineral substances quarried for crushed stones and producing aggregates: amphibolites, andesites, basalt, limestones, dacite, diabases, diorites, dolomites, granites,

Table 1. Situation of aggregates resources, currently and potential available (source www.namr.ro).

Types of licenses	Crushed stone	Sand and gravel
Active licenses (currently resources)	101	224
Waiting licenses (potential available)	162	245
TOTAL	263	469

granodiorites, sandstones, micashists /gneiss, porphyries, serpentinites, green shist, tuffsbesides sands and gravels (Table 1).

The production of recycled aggregate well developing in Western Europe is present in Romania by processing of marble exploitation waste. There is a great number of inefficient cutting blocks or fissured material accumulated as waste inthe greatest deposit of marble from Romania in Ruschița quarries that produces such of waste (Maruntiu et al. 2013). There is a waste recycling plant and production of aggregates used in various field in this area. Only when it is proved that the recovery/recycling process is sustainable, in comparison with primary aggregates, the contribution of recycled aggregates can be considered net positive (Blengini et al. 2013).

Production and practice in aggregates industry

For the production of aggregate in Europe, including Romania, some conditions are necessary to be met: *a.* sand, gravel or solid rock must exist in sufficient quantity to make mining worthwhile and must be accessible to transportation systems and to the markets; *b.* the exploitation field must be of appropriate size to locate a pit or quarry and also the processing equipment; *c*. the deposit must physically be able to be mined without causing unacceptable impacts to the environment; *d*. the operation can take place without affecting the environment or the lifestyle of people.

Crushed stone and sand and gravel commonly are obtained from dry pits or quarries, but in some places may be mined from water-filled excavations using dredges. The crushed rock production activity involve infrastructure works on-site and off-site (www.sarmaproject.eu), development of quarry structure, extraction of rocks, after blasting, crushing and sieving, storage and transportation. Sand and gravel deposits are exploited with excavators after removal. In most mining places automated aggregates sorting and sizing equipments exist.

Most of extractions from Romania, and in generally in South East Europe, take place in pits utilizing conventional earth-moving equipment. Crushed-stone mining generally requires drilling and blasting of solid bedrock which breaks the rock into rubble of a size suitable for crushing. The report of UEPG 2012 based on productions declared by of Member States mentioned for Romania an aggregate production of about 100 mil tones, slightly lower than 10-11 years ago.

The environment and aggregates resource efficiency

There are potential environmental impacts associated with aggregate extraction including the conversion of land use, landscape changes and habitatsloss, noise, and dust, blasting effects, erosion and sedimentation. Most of the environmental impacts associated with aggregates mining are relatively bad (Larger 2002). Any quarry extraction of aggregate resource lead in Romania, also, directly or indirectly, to environment modifications often negative ones (Fig. 2). Gradually, these modifications became so important that the introduction of supervising and management system got necessary to diminish/ eliminate the effect of the negative actions of quarrying (Marica and Bindea 2011).

Quarried sites reclamation has very high potential to improve our quality of life, create wealth, increase biodiversity and restore the environment. For the future, the increase of aggregate need must to refer to streamline of sustainable chain and, also, an eco-friendly quarrying and planning aggregate demand. The recovery of exploited areas is a mandatory requirement in the European perspective derived from the respect for natural values and protected places.

To limit the negative impact of aggregate mining, the environmental management of the companies must ensure limited intervention on the soil, arranging extraction platform and slope stability, with respect to the quarry bands and maintaining the equipmentin good operation conditions (Marica and Bindea 2011).

Sustainable management of aggregates at the local and national scale

Sustainable aggregates resource management (SARM) represents an efficient management of actions with low environmental and social impact of the exploitation and associated waste over the entire life cycle of the quarry (Solar et al. 2004; www.sarmaproject.eu).The management aspects of a quarryand sustainable management of aggregate exploitation require knowledge of each exploitation, from execution of the project to the end of quarry.

Figure 2. Andesites quarry with environment modifications (Harghita County, Romania).

All these requirements are provided by the Romanian legislation and involve feasibility of extraction, impact on the environment, reclamation plan and social impact. A flexible management adaptable to the local realities may rich the profitability target under reasonable ecological conditions (Marica and Bindea 2011). The majority of aggregate producers from Romania introduced a really efficient management system of quality. Also, the environment management system aims at supporting carrying out of all the industrial processes within an organization in accordance with the ISO 14001 European norm Standard, in view of supplying elements of a new efficient management system, structured and integrated in the global management activities of the company in question. In present, the mean directions for such companies from aggregate industry are to certify the quality of products by Romanian and European standards, to achieve the products only by conformity with standards and norms, and to introduce in their current activity the Environmental System of Management.

The main objectives of the sustainable aggregates management should be security supply and resources efficiency and, at the same time, it is necessary the increase knowledge and awareness of potential impact in local communities. This means that the local community can exercise considerable influence over decision-making authorities in various ways.

Aggregate planning and the future in aggregate industry

A minerals policy may be defined as a policy to secure the supply of the economy with mineral resources by the entirety of action that a state can take to influence the supply of mineral resources on its territory and beyond (Tiess 2011). Many of the EU countries have elaborated national mineral policies that recognize mineral and mining in general and the aggregate industry as a key sectors contributing to jobs, wealth and a high quality of life for its citizens.

Romania hasan official document referring to thestrategy of the mineral resources - National Strategy for Mining Industry. It also refers to construction materials including aggregates.

An aggregate policy can be defined as a policy to secure the sustainable supply of the economy with aggregates (www.snapsee.eu). Such a policy, actingin countries like Great Britain and Austria, includes the entirety of the actions at the local, regional or national level that influence the supply of aggregates on proper territory.

The national aggregates policy framework should include a mineral statement, objectives, strategies and action plan. An innovative approach of the sustainable aggregate planning ,including Sustainable Supply Mix (SSM), is that it aims to ensure the supply with aggregates resources on one hand as well as to improve efficiency and solve the problems of land use on the other hand.

Remarks

In present, crushed stone and river aggregates production volume is the first placeamongthe mineral resources from over the world and from Europe. The principal objectives of sustainable aggregate resource management (SARM) are security supply, resources efficiency and environmental protection during and afteroperations. The quarry sites recovery is the concrete response that restores environmental quality and impedes the loss of biodiversity in the affected areas.

Planning of primary and secondary aggregates in all countries must be carried out in an integrated way because the demand for aggregates used in the construction industry depends on technical quality of products and the end-uses.In order to achieve transparency, stability and security for all concerned stakeholders, a necessary part of the each country mineral policy framework has to be transferred in the planning of aggregate demand.

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Characterization and Decay State of the Building Materials of Roman Ceramic Kiln in the Archaeological Site of Dion, Greece

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Abstract

The building materials and the decay state of a roman ceramic kiln in the Archaeological Site of Dion were studied. The walls of the heating chamber are constructed from bricks and two kinds of mortars as binder material. Bricks consist of quartz and calcareous materials, mortars are fine with high porosity, consisting mainly of silicates and calcite with different compositions of mortar and aggregate. For the characterization of the building materials and the decay state microscopic and spectroscopic methods were applied, giving information about the chemical and mineralogical composition of the building materials, the physicochemical characteristics, the firing temperatures. The study of the preservation status of the building materials of the furnace confirmed that this is an elaborate monument, with significant differences in the behavior of the components and the corrosion process. These differences, combined with the environmental conditions and especially the fluctuations of temperature and humidity, pose a particularly difficult case of conservation.

Key words: *ceramic kiln, building materials, mineralogical composition, deterioration*

Introduction

Dion archaeological site is one of the most important religious centers of ancient Greeks in central Macedonia. In later years became an important Roman town. The kiln is located in the northern part of the Forum of Dion (Fig. 1), dated in the 5th century AD.

This ceramic upward vertical furnace combustion (updraft) (Fig. 2) is a very common type of furnace in the Mediterranean area. The excavated portion of the furnace consists of four pairs of walls, of a length of 1m and a width of 0.50 cm each one, constituting the lower part of the structure, the heating chamber. The chamber dimensions are 4.50 m x 2.50 m. The side walls of the chamber were formed of a reddish hue soil, stones and pieces of bricks and tiles, covered with a coating layer of solidified clay, due to the effect of high temperatures developed and the continuous combustions in the area. The walls of the heating chamber are constructed with bricks and binder (Hasaki 2001; Pantermalis 2006; Pingiatoglou 2010).

Figure 1. Dion, Roman forum and the kiln.

Figure 2. Roman ceramic kiln.

Materials and Methods

The characterization of the building materials and the decay state of the kiln was performed by Optical and Stereoscopic Microscopy, Sieve Analysis, calculation of Mortar-Aggregates ratio, Porosity and Specific Weight measurement, X-Ray Diffraction, Scanning Electron Microscope (SEM), Atomic Absorption Spectroscopy (AAS), X-Ray Fluorescence Spectroscopy (XRF). 5 samples of bricks and 2 samples of mortars were studied.

Results and Discussion

The use of these instrumental techniques led to the identification of minerals and in identifying also of new mineralogical phases, resulting in the materials during firing and during the exposure to various environmental conditions. By comparing and cross-checking the results of these methods, information were extracted on the mineralogical and chemical composition of building materials, the physicochemical characteristics and firing temperatures. The results of the various methods and techniques are identical, while each technique provided additional information on the integrated study of the material (Massari 1993; Filokyprou 2008).

CHARACTERIZATION BRICK

A micro-grain porous brick, composed mainly of quartz, plagioclase, potassium feldspar, calcite, epidote, mica and metallic minerals. Extensive biological deposits and inclusions of shells were identified. The firing minerals recognized were albite, hematite, anorthite (Fig. 3).

MORTAR

Two different fine mortars were used.

Mortar 1 Analysis of the samples showed that is mortar reinforced with lime, has a porous structure, with traces of straw and biological alterations. Many internal cracks, salts, powdered ceramic granules and inclusions of shells are appeared. It presents a high percentage of silicon and calcium oxide and relatively high proportion of aluminum and iron oxides. It consists mainly of calcite and quartz. The ratio mortar/aggregate is equal to 1/2 and is characterized good. Great disparity in gradation is observed and it is generally very fine material. High porosity, 35 %, is observed also, characteristic of old mortars, consistently developing small resistance (Fig. 4).

Mortar 2. It is characterized as fine mortar, mixed with straw and fine siliceous aggregates, quite concentrated. Inclusions of calcium and many internal cracks are observed. Basic component is calcite and a small percentage of mica in the form of leaflets is present, but from the results of XRD a presence of aragonite is also observed, probably due to inclusions of shells. The firing materials recognized were mullite, spinel, and wollastonite. The existence of mullite leads to the conclusion that in the area of the chamber, where the sample was taken, temperature was developed over 1100 C. The ratio of the fine grains is very high and this is an indication that the mortar can easily be disintegrate. The ratio Mortar / Aggregate it is not good because of the large contribution of aggregates (89.32 %). High porosity is observed, 42 % (Fig. 5).

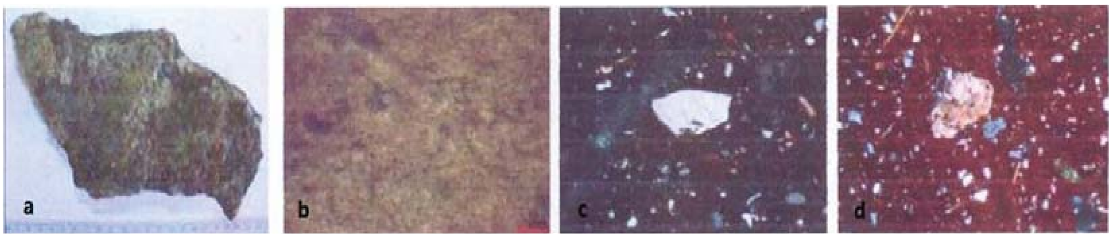

Figure 3. Plinth a) Macroscopic image, intense biological corrosion, b) Microscopic image, blackheads and microorganism colonies, c) polarizing microscope, ceramic with a large and many small angular quartz grains and elongated crystals of white mica. d) Calcite in pellet form, angular grains of quartz and elongated crystals of white mica.

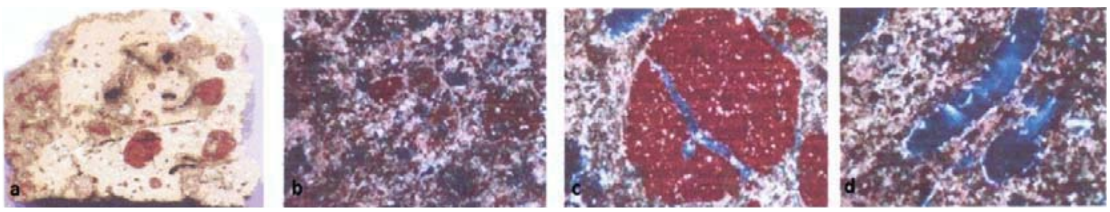

Figure 4. Mortar 1 a. Macroscopic image, spherical grains of powdered ceramic, b. polarizing microscope, calcite and quartz granules, c. spherical granules of powdered ceramic with crack, d. pores.

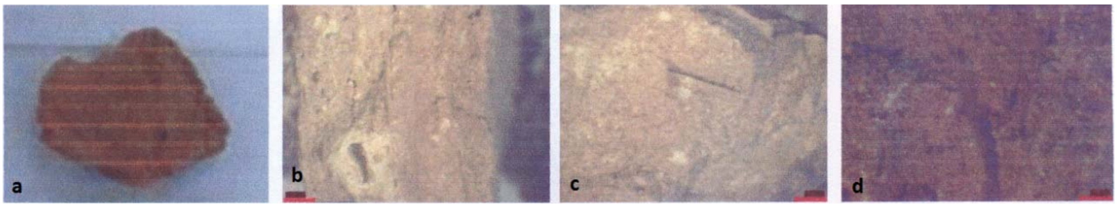

Figure 5. Mortar 2 a. Macroscopic image, b-d. Microscopic images, calcium inclusions and straw fingerprints.

DECAY STATE

The effect of environmental conditions is evident in the preservation status of the building materials. In the area of ancient Dion, because of its geographical position, the presence of rivers and springs that flow between the archaeological remains, the humidity is high and in combination with fluctuations in temperature, causes condensation on the surface of building materials. The amount of rainfall is high and strong, heavy rains are common in the region, increasing the levels of ground water (Torraca 1981; Amoroso 1983) (Fig. 6).

Figure 6 a. Kiln image, 2013, b. biological corrosion, c. delaminations and collapses.

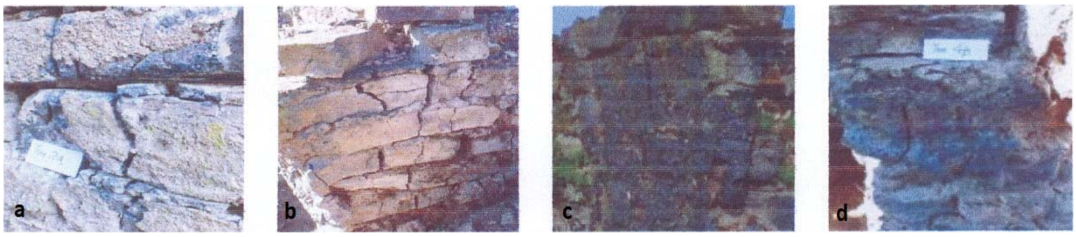

Figure 7. a-d. Walls furnace, slates hue brown hue, cracks, impact effect of very high temperatures, melting and solidification of materials.

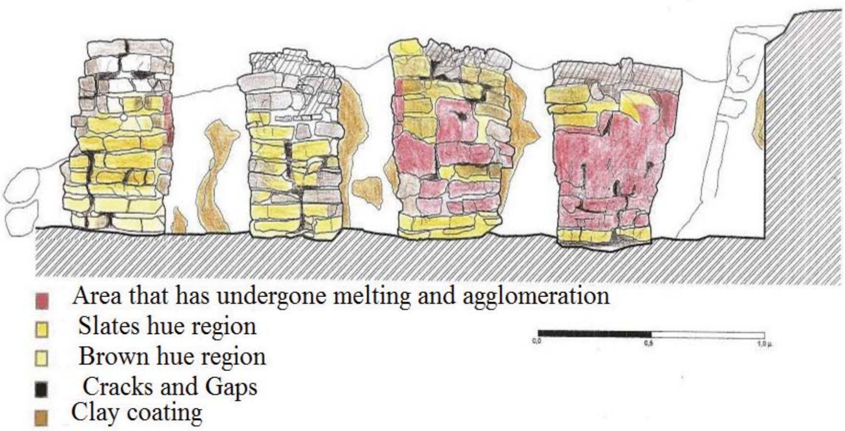

Figure 8 Mapping walls, Decay state of building materials of the kiln.

The upper surfaces of the brickworks and theirs narrow sides exhibit the most acute problems of deterioration of the binder material, detachments bricks of and collapses, resulting in impairment of their volume. Inside the chamber plants and microorganisms grow. In all surfaces of the walls lesions due to temperature effect are observed. Most bricks have undergone color changes, changes in the shape and texture of the material, cracks, fractures and delaminations. In many areas of the surface brown layer thickness of a few microns to millimeters, with very strong adhesion to the underlying brick is observed. These are clay debris which covered the surface of the blocks (Figs. 7 and 8).

Conclusions

The bricks used were bricks micro-granules consisting mainly of quartz and calcareous materials. Mortars are fine-grained, highly porous, consisting mainly of calcite and silicates with different compositions of mortar and aggregates.

Firing minerals recognized are mullite, spinel, and wollastonite. The existence of mullite, high temperatures phase, leads to the conclusion that in the corresponding area of the chamber, the temperature was developed over 1100 ^{o}C.

The study of the preservation status of the buildings materials of the furnace confirms that this is an elaborate construction, with significant differences in the behaviour of components and consequently the corrosion process. These differences of materials, in combination with the environmental conditions and mainly sharp fluctuations in temperature and humidity prevailing in the area, create a particularly difficult case of protection and conservation.

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Research data regarding the use Of native lithic materials In the restoration of art works and monuments

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Abstract

Within the present European geopolitical context there is an increased interest in Romania concerning the specialists in stone monuments restoration. According to the generally approved international guidelines, an important issue is related to the use of lithic materials coming from the same source as the original ones. The new materials must have certain features regarding the resistance, surface aspect (color, pattern, texture, roughness etc), and to allow the correlation between the old stone's ancient patina due to superficial (supergene) alteration and the presence of biofilms, with the newly extracted stone – particularly for the facade. The paper deals with aspects concerning the conservation degree and ancient patina of Romanian lithic materials monuments, of different periods affected by natural and anthropogenic causes, with consequences on the historical development of the region. There are discussed main phenomena related to their present conservation state, the lithic materials from monuments restored/preserved, respectively, the recently discovered ones, on which no interventions have been performed. The analysis of these lithic materials was achieved, through a correlation between the destruction and alteration process, specific to the Romanian region and their casuistic and consequences of the specific degradation and deterioration phenomena. Also, for their analysis the nature and characteristics of the lithic materials have been considered, along with the procedures of manufacturing, restoration/ preservation, identifying some anomalies and inadequate interventions, already notorious.

Keywords: *indigenous lithic materials, conservation state, making patina, old monument, preservation and restoration*

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Archaemetric analysis on several clay moulds from ancient Durrës

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Abstract

Several moulds used for the production of relief cups have ben discovered lately in the city of Durrës, once the famous Dyrrhachium. We have chosen to analyse six amongst them. They belong to two different production groups. Five are used for the modelling of the so-called "megarian cups" and one for the modelling of the so-called "Corinthian relief coups". In the city of Durrës have ben discovered in the last decades several cups of the first productions, some even having the names of the potters or the probable owners of the workshops. While for the second production groups, it is the first time that we have such discovery. For that reason we thought that would be interesting to analyse such finds. But, to have a comparison base, we proceeded on the analyse of the examples from the clays of the Durrës hills called Currila.

The analyses used were the Inductively Coupled Plasma – Mass Spectrometry (ICP – MS) using an acid digestion process. All samples were digested and analysed in duplicate. Samples were ground using a mortar and pestle into a fine powder, placed into a 15 ml polypropylene test tube, and covered to prevent contamination. All plastics used were acid washed. The preparation of the liquid samples have ben digested and diluted in several phases with acid compositions. A control vessel containing only acid solution was also analysed for each set of digestions for background correction. In addition, a soil sample that had been well-characterized by ICP-MS was included with analysis as a secondary standard. NIST standard 1643e was analysed prior to sample analysis to ensure accuracy. Calibration curves were created at 10, 50, 100, 200, and 500 ppb with Inorganic Ventures standard 71A. The internal standard was 5 ppb Inorganic Ventures standard 71D.

Chemical compositional data were log transformed and subjected to various statistics. A Ward's method cluster analysis was used to analyse data from eight elements: Al, V, Cr, Mn, Ni, Sr, Ba, and Ce. Cluster analysis defined two compositional groups. One included moulds 1-4 and 6 and the other mould 5 and the clays. These groups are also easily discerned using principal components analysis. The first two principal components together account for over 90 % of the variation in the data. There are very strong differences between the two groups in terms of the amounts of various trace elements present.

Given the results of ICP-MS analysis of the moulds and clays it is likely that mould 5 was produced in Durrës from local clays that are the same as or similar to those of Currial hills. The other five moulds may also have been made in Durrës, but do not match the clays we analysed.

Enhancement oftraditional lime-based plasters using Phase Change Materials (PCMs)

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Abstract

The improvement of the energy efficiency of buildings is currently one of the highest priorities of the energy policy of the European Union. Member States must take measures to encourage existing building owners to renovate their properties by upgrading the thermal performance of building shells. Traditional building insulation materials are normally used in thick or multiple layers in order to achieve higher thermal resistance. This results in complex building details and possibly heavier load-bearing structures. Advanced, sustainable and better performing insulation building materials are therefore needed. Such materials are part of a more general solution to industrial and societal challenges, since they offer better thermal performance in their use and improved sustainability throughout their lifecycle, using less resources and having lower energy requirements at production stage.

Phase change materials (PCMs) are examples of advanced thermal performance materials that may be used as additives in the production of composite building materials. PCMs are in fact used in many different applications, due to their ability to absorb and release thermal energy, in the form of latent heat, during the melting or solidifying processes respectively. The principle of latent heat storage can be applied to any porous building material, but current research primarily concerns gypsum wallboards, cementitious composites and insulation materials.

A PCM-enhanced plaster is a heat storage medium combining an appropriate PCM with a cementitious or non-cementitious matrix to produce a low cost thermal storage material with structural and thermostatic properties. Although important research efforts have been conducted in the recent past to boost the penetration of PCM-enhanced plasters in the building material market, their applicability remains restricted to specific application fields.

This research work focuses on the design and production of novel cementless PCM-enhanced plasters with improved properties. It is part of a recently funded by M-era.Net (through the Cyprus Research Promotion Foundation) project (KOINA/M-ERA.NET/1012/01) aiming at the development of thermally efficient and durable materials which will be particularly appropriate for application in southern European climatic conditions and which will meet EU strategic policy targets of reduction in primary energy use in the building sector. The composite materials under study could be suitable for use not only in new structures, but also for renovation and retrofitting purposes of existing buildings. The lime-based nature of their matrix will further extend their application and enable their use in listed and monumental buildings, due to their compatibility with traditional substrate materials.

In this study, two reference mixtures were designed and produced in the laboratory; one with a hydrated (aerial) lime binder and one with a natural hydraulic lime (NHL 3.5) binder. The aggregate fraction for both mixtures was made up of 100 % calcarenite sand (0-2 mm). The binder/aggregate ratio was 1:3, while the workability was kept constant in the range of 170 ± 5 mm. The aforementioned parameters and raw materials were chosen based on previous research. Optimised mixtures based on the design of the two reference mixtures, with the addition (5 % w/w) of commercial PCMs as filler,were also designed and produced. All specimens were submitted to a series of physico-mechanical and thermal tests at different time intervals (28, 56 and 90 days) in order to evaluate their behaviour.

The test results are promising and show the potential of the use of PCMs in enhancing the thermal and physical performance of traditional lime-based hydrated and hydraulic lime composites. The thermal conductivity of the PCM-enhanced plasters was significantly reduced, compared to the reference mixtures. Their porosity values, on the other hand,were found to not change significantly with time, while their capillary absorption kept reducing even 90 days after the day of production. The latter was generally lower compared to the reference mixtures. The compressive/flexural strengths and dynamic elastic modulus of the PCM-enhanced hydraulic lime plasters increased with time, as expected; however, they were significantly lower than the equivalent strengths and modulus of the hydraulic reference mixture.

Dimension stones in Budapest, changes in stone use in the past two millennia

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Abstract

The present paper provides an overview of the use of natural stones in the development of a city in Central Europe. The example is Budapest, the capital of Hungary. The development of the city was partly controlled by the availability of natural stones. The oldest known stone structures in this city are attributed to the Roman period and date backs to 1st century AC. The most common lithotypes that were used are sedimentary rocks, and especially limestones. Besides the most common travertine records of the use of calcareous marl are also known in Roman stone structures. Andesitic tuffs and volcanic rocks with high heat storing capacity were used in "Roman therme". Medieval stone structures are less common. Turkish/Islamic period has also another imprint in terms of stone use. In the Turkish spas besides the local stones, decorative stones from longer distances were alos brought to the city, such as red limestone from West Hungary. The city has been significantly developed at the end of 19th century and beginning of 20th century with newly erected stone buildings. The great need for stone resulted in the opening of new quarries and the start of the subsurface stone exploitation in the forms of galleries. The exploitable stone resource was a porous limestone of Miocene age. The limestone itself has a good workability; however it has a lower resistivity against environmental condition. The 100-150 years old buildings now show severe signs of decay. The main factors causing the deterioration of the porous limestone are freeze-thaw damage and air pollution. The latest architectural elements of the city display great variety of stones with less amount of local and increasing surfaces of imported stones.

Cretaceous siliceous rocks as building material in local architecture in Myślenice (the central part of Polish Outer Carpathians)

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Abstract

The architecture style of the Myślenice town is characterized by the presence of objects; build with Carpathian bedded siliceous rocks – mainly spiculites, gaizes and cherts, derived mostly from local outcrops and quarries. They belong to the Cretaceous Mikuszowice Cherts Member of the Lgota Formation from the lithostratigraphic point of view. This material has a special decorative value. Siliceous rocks give the urban scene unique style and for this reason. Myślenice is one of the most original towns among Carpathian settlements.

Key words: *Outer Carpathians, local architecture, building and decorating material, gaize, cherts*

Introduction

Small urban centers in the Polish Outer Carpathians are characterized by the extensive use of local raw materials in the construction industry. The different types of sandstones, which are common lithotype in the Flysch Carpathians represent the most common raw rocks are. This material is easily accessible in many natural outcrops. Until today, these rocks are explored in local and large quarries.

Myślenice is a small town located in the Outer Carpathians, about 30 km south of Kraków (Fig. A). First mentions of Myślenice come from 1253 - 1258. At that time, it was an area with system of fortifications, with a castle and stronghold, to protect Kraków from the south, which was the Polish capital. Myślenice received its Magdeburg rights town charter in 1342, and it started to develop as a local center of trade and crafts. Carpathian hard rocks are the primary material used here for buildings.

Lithology and genesis of siliceous building rocks

The Outer Carpathians are built mainly from sedimentary rock, deposited during Jurassic through Miocene in the Western branch of the Tethys Ocean. These sediments represent turbidities deposited in the deep Carpathian Basins in that times, and consist predominantly of siltstone and sandstone series known here as a flysch series. Hard, siliceous rocks are characteristic for the Cretaceous flysch among different lithotypes. These are mainly spiculitic sandstones, spiculites, spongiolites and so called “gaizes” formed in the Silesian Basin of the Carpathians, which are now part of the Silesian Nappe. In lithostratigraphy these deposits form the Lgota Formation.

The Lgota Formation (Aptian–Cenomanian) has been subdivided on three informal lithostratigraphic units. The lower division consists of thick-bedded sandstones and gravelstones with thin intercalations of black and grey shales. The middle division consists mostly of thin- and medium-bedded, siliceous, dark sandstones with distinct parallel and cross lamination. The sandstones are interbeded by black, grey, green and spotty, non-calcareous shales. The characteristic feature of the upper division, named the Mikuszowice Chert Member, are bluish cherts occurring within middle and upper parts of medium- and thick-bedded, fine-grained deposits. The rocks of the Mikuszowice Chert member represent the main body of the spicule-bearing deposits within the Silesian Nappe. They are composed of centimeter-thick turbidites, which are fine-grained siliciclastics as greywackes, mudstones and siltstones, with biogenic admixture, and also calcarenites to calcisiltites, usually silicified. In some places, siliciclastics pass into carbonate sediments with variable detrital admixture. Turbidites represent predominantly T_{de} intervals of the Bouma sequence. A high content of siliceous sponge spicules constitutes the most distinguishing feature of these deposits, visible only in thin sections. High silica content and well developed sedimentary structures formed characteristic bicolored blue-brown stippling, visible on the rock cross-section, well recognizable in local architecture (Bąk et al. 2001).

Exploitation of siliceous rocks in the Myślenice area - historical mining and quarrying

Siliceous rocks derived from Carpathians deposits accompanied mankind since immemorial times. It was locally exploited and used to the various utility purposes.

The oldest data on the use of these rocks come from the late Paleolithic and concern Świdry Culture (9000 years B.C.) (Valde-Nowak 1995; Waśkowska-Oliwa et al. 2008). Artefacts made of Mikuszowice cherts were documented among archeological findings in the Outer Carpathians. Archeologists have found the location of Mesolithic camp site dated to ca. 6000 year B.C. in the area of Myślenice. A number of archeological artefacts made of cherts from local outcrops, several scrapers and sharp parts of wooden weapon s made of flakes and microlith among the others were found (Waśkowska-Oliwa et al. 2008) within this site.

Since the Middle Ages to the Baroque Myślenice were one of the major centers of glass industry (Buczkowski et al. 1974). Small glassworks were located close to quarries where the siliceous rock material to glass production, as spiculites, gaizes and cherts was mined at that time. The close vicinity of Myślenice town was for centuries the exploitation area for siliceous rocks of the Mikuszowice cherts. One of such natural outcrops of this rock and operated near-by glasswork were probably located in the vicinity of a large quarry existing and still operating in the Barniasiówka Range (Bąk et al. 2013).

Gaizes, spiculites, cherts and siliceous sandstones of Mikuszowice Chert Member were also the key material for road construction as angular crushed stone. Lgota Formation was used also for construction of retaining walls, shafts and artificial levees on Carpathian rivers (Bromowicz et al. 1978).

Siliceous rocks in architecture of the Myślenice town

The most common use of the Mikuszowice Cherts stones was connected with decorating and ornamental purposes. Details and finishes of buildings made of cherts and gaizes suited distinctive style of local architecture. In the Myślenice center, houses in terraced, semi-detached as well as town styles are decorated with local siliceous rocks. Such elements of houses exterior as eaves, cornices, gutters, chimneys stack, window frames and sills, flashings, damp proof courses and door steps are usually made from local, siliceous stones (Figs. B-F). Many of house gates arranged as semicircular arches are made from material of Lgota Formation, especially most decorative elements as spandrels, keystones and extrados. Cretaceous rocks of the Silesian Nappe are very common elements of the urban streets as pavements, paving, edgings, facings, fences, flower tubs and lamp-posts. These elements are present in different parts of the Myślenice town center and surrounded districts, as elements integrated into the buildings created in the second half of the XX century.

Rock material for architectural purposes was a subject of detailed selection. Because of oblique joints which are very characteristic, these rock brake up on almost equal blocks, easy to use without further processing. Particularly available are silicified thin- and medium-bedded strata commonly present in the Mikuszowice Chert Member.

Two methods of stones arrangement were used depending on the intended decorative effect. Blocks of siliceous rocks were laid perpendicular or parallel to the bedding (Figs. C and D). The blocks were laid perpendicular to their cross- sections to show their distinctive layering. For these purposes were used rocks with large amount of autogenic silica which possess a characteristic gray-bluish shades, including dark streaks and various types of laminations with clastic intercalations. This method was used in vertical architectural elements for utilizing the decorative potential of local material. Horizontal architectural elements (as pads and pavements) were created by the collateral setting of blocks in a vertical arrangement (according to the principle of minimum usage of materials). This method allowed to present decorative elements of geological structures located on beds surfaces. There are varicolored limonitic seams, Liesengang rings, turbiditic erosional structures, biogenic and mechanical hieroglyphs.

The architectural elements of siliceous rocks combined with singular blocks provide an interesting and quite original and unique texture. Architectural compositions of the Cretaceous siliceous rocks give an expression to Myślenice town and unique style. This is the only Carpathian settlement with so many objects made of spiculites, gaizes and cherts.

Discussion

Exploitation of rocks belonging to the Lgota Formation (including the Mikuszowice Chert Member) was carried out in the Outer Carpathians for hundreds of years (e.g. Gradziński 1960; Rajchel 2003). This rocks are known as a construction material for monuments of pre-Roman and Roman times, as famous as the Wawel Castle in Kraków (Bromowicz and Magiera 2003a,b) and Baroque monuments in Kalwaria Zebrzydowska (Bromowicz et al. 1976). However, this is not a very popular building material. It is rarely used compared with other Carpathian rocks (Rajchel 2004). The massive sandstones from the

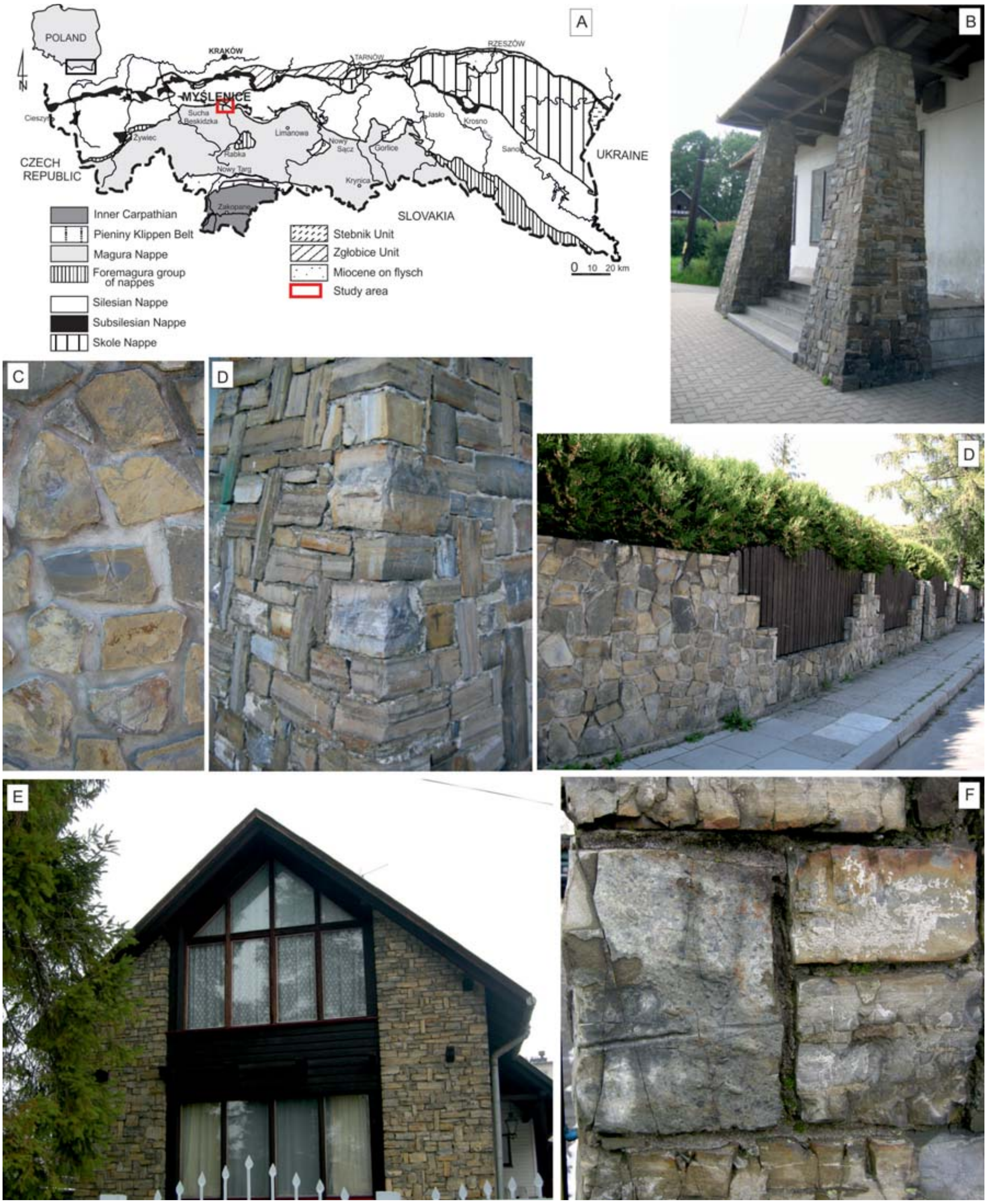

Figure A. Myślenice area on the background of Polish Carpathians tectonic sketch-map (map after Żytko et al. 1999 – modified).
Figures. B-F – gaize in Myślenice architecture – examples.

lower part of the Lgota Formation constitute main mined lithological type. The blocky character of these sandstones enables their usage as dimension stones. The rocks from the middle and upper part of the formation (including Mikuszowice Chert Member) are siliceous and the deposits are fractured by joint therefore they were commonly mined for production of the good quality crushed road stone (Bromowicz et al. 1967). They were only marginally utilized as dimension or rubble stone outside the Myślenice area. Myślenice is the only town in the Polish Outer Carpathians, where gaizes and cherts were used for building on a such large scale. This raw material was available in this region due to the continuous exploitation in several quarries (Peszat et al. 1976). Because of that in the 2nd half of the XX century, natural stone was relatively inexpensive. Currently siliceous rocks are not used in the building in the Myślenice town. This activity has been finished in the 80's and 90's of the last century.

Conclusions

The Myślenice town was the place of commonly used local siliceous rocks in the second half of the XX century. These rocks represent Cretaceous, Outer Carpathians turbidites deposited in the Silesian Basin of the Tethyan realm and were known as Mikuszowice cherts. These are spiculites, gaizes, cherts and strongly silicified sandstones which served as a decorative and building stones. Myślenice town is the only place in the Polish Carpathians where Cretaceous siliceous rocks were used in urban architecture in such scale.

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Seismic and thermal properties of the upper mantle in the SE-Carpathian-Pannonian Region (CPR)

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Abstract

A 3D seismic and thermal model of the upper mantle in the SE-Carpathian-Pannonian Region (CPR) is presented in order to assess a coherent geodynamic interpretation. The seismic model is expressed in terms of shear waves velocity (V_S) and thickness of a layered mantle down to a depth of 350 kilometres. The velocity model is obtained by means of an advanced non-linear inversion technique of group and phase velocity dispersion curves (Hedgehog method).

The Hedgehog method allows the definition of a set of seismic cellular models of lateral resolution up to 0.5°x0.5°, without resorting to any a priori model, in which the V_S and the thickness of the layers are independent variables.

Given the well-known non-uniqueness of the inverse problem, the representative solution of each cell is determined through the application of an optimization algorithm, namely Local Smoothness Optimization (LSO). LSO selects, between all the models result of the inversion, the one that minimizes the V_S lateral gradient. The representative cellular model is also validated with the use of independent geological, geophysical and petrological data, e.g. the distribution of seismicity, obtained from international bulletins.

Using an advanced seismic velocity–temperature conversion technique, we infer the temperature and melt distribution in the upper mantle (down to 300 km) starting from the velocity models. The presence of melt suggested by the seismic reconstruction as well as by geochemical evidence in the area requires an extension of the standard conversion procedure to allow for a correction of seismic velocities for the effect of hydrous melt occurrence.

Being the seismic velocity–temperature relationship strongly nonlinear and influenced by several perturbing factors a variable mantle composition is adopted in the study domain in accordance to petrological evidence and corrections for the effect of anelasticity and water presence in the mantle rocks are considered.

The results show a strongly heterogeneous mantle beneath the Intra-Carpathian plate, with an extremely undulated lithosphere-asthenosphere boundary (LAB) showing major "boudinage-like" features. This is the case of Apuseni Mts., which present a thickened lithosphere (about 150 km) with respect to the neighbouring Pannonian and Transylvanian Basins. The Intra-Carpathian plate lithosphere is characterized by relatively lower velocity with respect to the East European and Moesian plates, suggesting widespread metasomatism and/or small scale melt generation regions supplied from the shallow asthenosphere.

A detached slab remnant is clearly imaged in the NE-Transylvanian Basin, about 150 km to the West of the collision front, that may suggest relic subduction, as confirmed by the absence of relevant mantle seismicity and by strong thermalization of the slab. Above the slab remnant, lithospheric partial melting induced by the upwelling asthenosphere feeds the Călimani-Gurghiu-North Harghita volcanic chain.

The presence of a high velocity almost vertical slab suggests sinking process beneath Vrancea region, where intra-slab intermediate depth seismicity is associated with slightly lower velocity layers. We speculate that dehydration of a serpentinized slab and/or lateral thermal erosion suggested by the thermal modelling could be a common cause in the onset of seismic activity and magma generation for South Harghita chain.

Thermal model generally shows a higher temperature gradient beneath the European and Moesian plates with respect to the Intra-Carpathian plate, with temperature as high as 1400-1500 °K just below the LAB corroborating the hypothesis of a super-adiabatic upper mantle in which large scale convection is inhibited.

Geochemical constraints on the origin and evolution of the Xanthi Plutonic Complex (Rhodope Massif, N. Greece)

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Abstract

The post-collisional Oligocene Xanthi Plutonic Complex (XPC), comprising granodioritic, monzonitic and gabbroic rocks, intrudes the metamorphic basement of the Rhodope Massif in N. Greece. Major and trace elements, REE, and Sr, Nd and Pb isotope geochemistry reveals at least two groups of magma, an "acid" one represented by granodiorite, bearing microgranular mafic enclaves (MME) of quartz diorite composition, and a "basic" one represented by gabbro and monzonite. The geochemical data show both enriched-mantle and crustal origin. The evolutionary process of both groups is governed by magma mixing rather than crustal assimilation. Moreover, some of the mafic rocks can be considered as mantle derived rocks, a view strongly supported by the Sr, Nd and Pb isotopic ratios.

Keywords: *Rhodope Massif, Oligocene magmatism, mantle/crust interaction, Xanthi Plutonic Complex*

Introduction

The Xanthi Plutonic Complex (XPC) belongs to a series of Oligocene extension-related, high-K calc-alkaline plutonic intrusions cropping out in the Rhodope Massif (N. Greece). It is located on the ENE-trending Kavala–Komotini fault zone (Fig. 1) and cuts at its north-western side the Nestos Shear Zone (NSZ). The exposed area (about 40 km^2) is an elongated body of nearly E-W direction (Fig. 1). It is in magmatic contact with gneisses, mica-schists, amphibolites, calc-silicate rocks, marbles and Eocene-Oligocene sedimentary rocks, forming an extensive contact metamorphic aureole with skarn mineralization. Geophysical data suggest that the XPC is a laccolith-shaped body, extending several kilometres southwards. Based on mineral separates and whole-rock K/Ar, Ar/Ar, and Rb/Sr radiometric data, the age of the complex ranges from 30 to 25 Ma (e.g. Kyriakopoulos 1987; Christofides et al. 2012).

The "acid" group, occupying the central

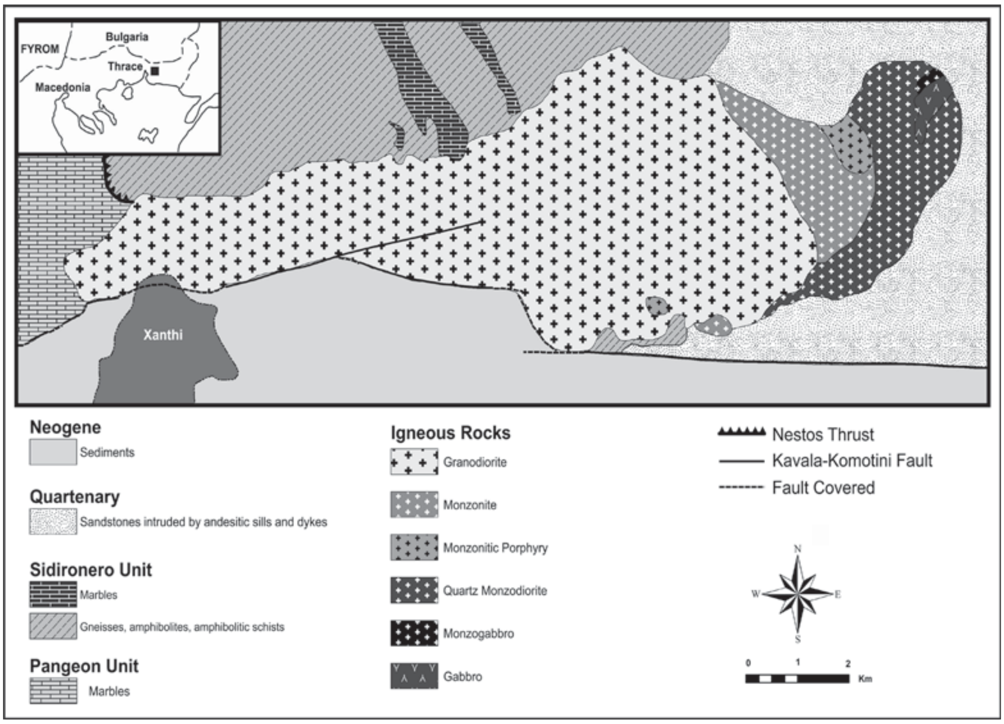

Figure 1. Simplified map of the Xanthi Plutonic Complex, modified from Christofides (1977).

and western part of the complex, comprises granodiorite grading into monzogranite, bearing microgranular mafic enclaves (MME) of quartz diorite composition. The "basic" group occurs in the eastern part of the complex and is composed mainly of monzonite/quartz monzonite, quartz monzodiorite, and subordinate monzogabbro and olivine gabbro (cumulitic and microgabbro). A small marginal exposure of monzonite porphyry occurs at the north-eastern part of the XPC. The main mafic minerals in the "acid" group and MME are biotite and hornblende, whereas in the "basic" group are pyroxenes (ortho- and clinopyroxenes), biotite, ± hornblende and olivine.

Materials and Methods

Major element and some trace element analyses were performed with the XRF method (X-ray Fluorescence). Trace element and REE were analyzed by Inductively Coupled Plasma-mass spectrometer (ICP-MS). Isotopic Sr and Nd analysis were performed with the TIMS procedure. Isotopic Pb analysis was carried out using conventional digestion and ion-exchange procedures.

Results and Discussion

Silica content of the XPC ranges between 44-61 wt.% for the "basic" group, 53-57 wt.% for the MME and 62-69 wt.% for the "acid" group. A characteristic feature of the XPC rocks is their high potassium content (up to 6 wt.% for the "basic" group) which classifies them as high-K calc-alkaline to shoshonitic (Fig. 2). In figure 2 a different evolutionary process for the "basic" and the "acid" group is implied with MME holding an intermediate position. This distinction is also obvious in most element variation diagrams (e.g. Rb, P, Ba, Nb, Zr; not shown). Some of the elements e.g. Ba, Nb and Zr behave as incompatible in the first group and then become compatible dropping in the granodioritic group. Magma mixing has been reported as the main process for the evolution of the XPC (Christofides et al. 2011).

Trace element patterns (Fig. 3) show LILE enrichment with Nb, Ta, P and Ti negative anomalies presented in all samples. Some gabbroic rocks though display small LILE depletion. Rb as well as Th and U show a wide range in the "basic" group probably because this group is composed of a wide range of rock-types. REE patterns (Fig. 4) are tightly bundled and relatively flat which is

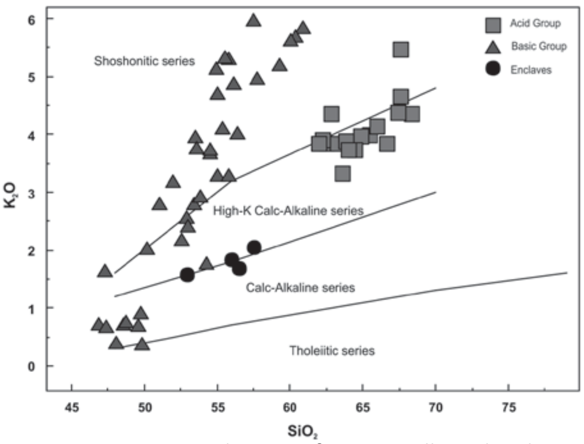

Figure 2. SiO_2 vs K_2O diagram after Peccerillo and Taylor 1976.

consistent with early fractionation of olivine and pyroxene from a mafic parent magma at least for the "basic" group. They show LREE enrichment both in the "basic" group [(La/Yb)CN = 3.5-18.6] and the "acid" group [(La/Yb)CN = 6.3-13.4] as well as in the MME [(La/Yb)CN = 5.8-16.9]. ΣREE increases from gabbro to monzonite and then drops to the granodiorite. All rocks have negative Eu anomaly except the microgabbro and some cumulitic gabbros which are not presented here. Some monzonites display higher enrichment in LILE and LREE in respect to the granodiorites. Potassium along with most trace element patterns shows that monzonites are more evolved than granodiorites. LILE and LREE enrichment in destructive geotectonic enviroments is the result of either slab derived melts that enrich the mantle wedge and/or continental crustal component.

Initial isotopic Sr and Nd compositions of the XPC (Fig. 5) show enriched mantle origin for most rocks. Isotopes of both the "acid" and the "basic" groups are similar implying minor crustal contamination. Moreover, some monzonites show higher Sr and lower Nd isotopic values than the "acid" group samples showing more evolved samples similar to their trace element patterns. Some more mafic samples exhibit a trend towards the DMM (Depleted MORB Mantle) area, probably due to mantle heterogeneity under the Rhodope Massif as has been reported in previous studies (e.g. Perugini et al. 2004). Lead isotopic ratios show enriched mantle origin for all rock groups as well (Fig. 6). A mixing among a depleted mantle and an EM-II component seems to satisfactorily

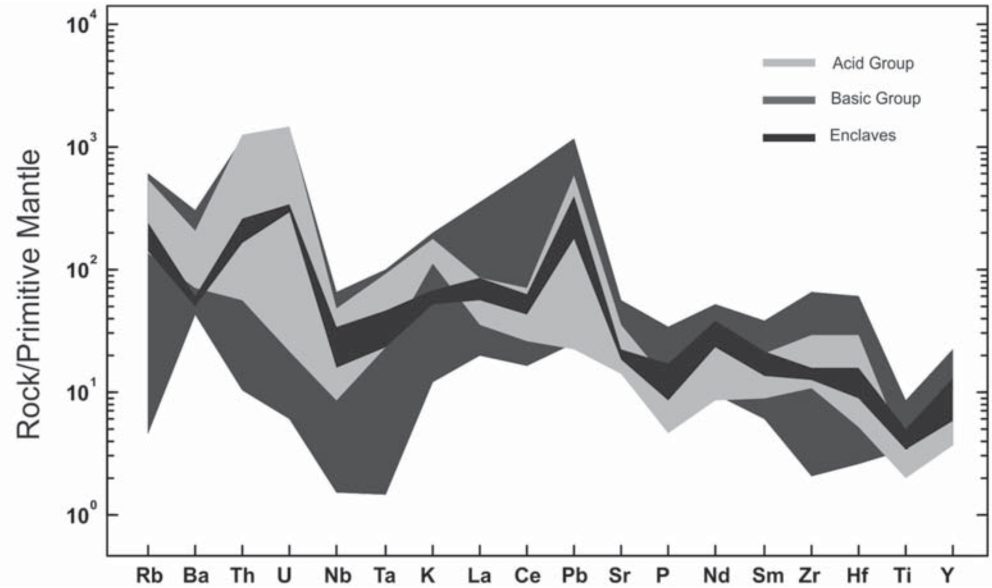

Figure 3. Primitive Mantle-normalized incompatible trace element diagram. Normalisation values from Sun and McDonough (1989).

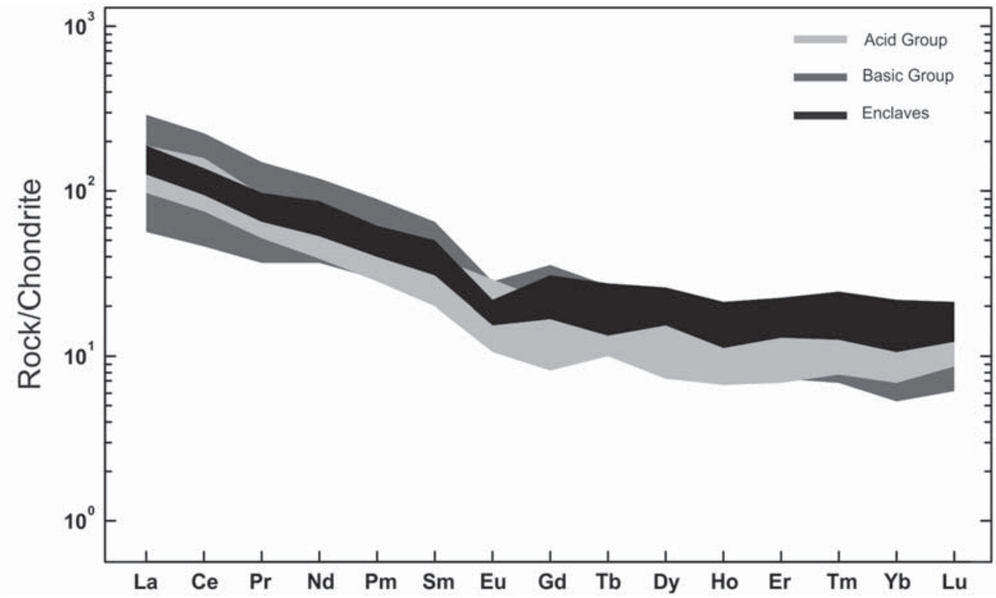

Figure 4. Chondrite-normalized REE diagram. Normalisation values from Boynton (1984).

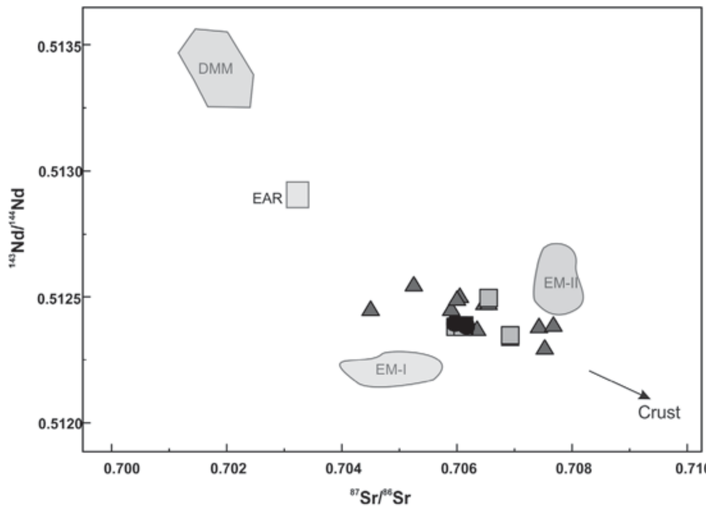

Figure 5. $^{87}Sr/^{86}Sr$ vs $^{143}Nd/^{144}Nd$, data for reference mantle reservoirs from Wilson (1989) and references therein. Symbols as in figure 2.

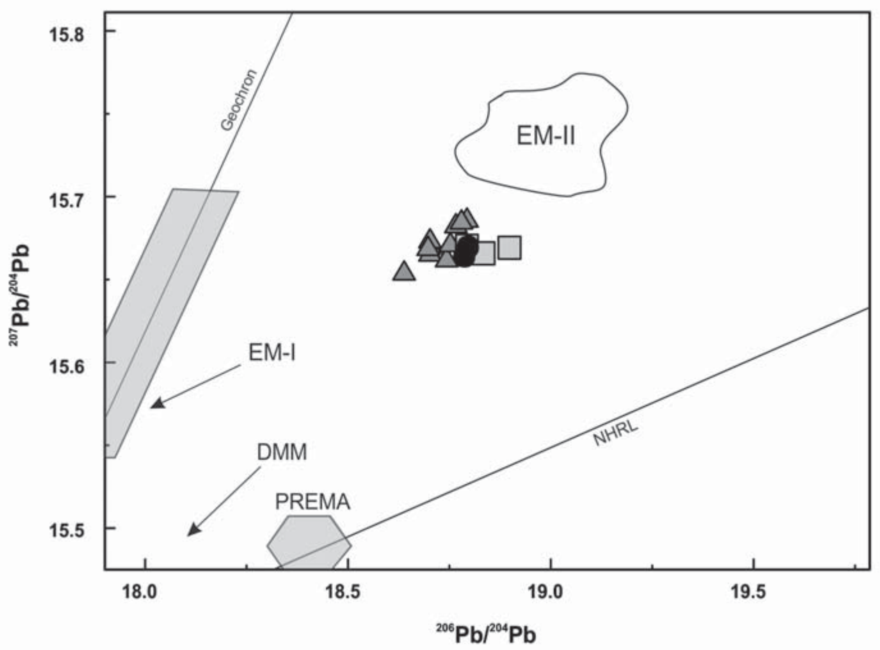

Figure 6. $^{206}Pb/^{204}Pb$ vs $^{207}Pb/^{204}Pb$, data for reference mantle reservoirs from Wilson (1989) and references therein. Symbols as in figure 2.

explain the Xanthi isotopic compositions of the most mafic members. A crustal component of continental origin resulted in the increase of the isotopic ratios in more felsic members of both groups.

Conclusions

Mixing seems to play a major role in the evolution of XPC rocks although a specific mixing model is not defined yet due to the complex geochemistry and is still in progress. The LILE depletion and the low LREE enrichment of the gabbroic rocks from the basic group, in conjunction with the Sr, Nd and Pb isotopic compositions favor for mantle derived melts. The geochemical data imply an enriched mantle-derived component mixed with continental crustal melts for the origin and evolution of the XPC rocks.

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Had Late Oligocene-Early Miocene magmatism in the Dinarides different phases? The case study of the Rudnik Mts. volcanic complex

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Abstract

During the Late Oligocene-Early Miocene wide spread magmatism occurred along the Dinaride orogen that left behind after the Neotethys closure. It roughly occurred between 40 Ma and 20 Ma and produced mostly acid/intermediate and subordinate basic rocks. The magmatism is interpreted by the post-collisional gravitational instability of the Dinarideorogen and is distinguished from younger magmatic episodes that were presumably caused by the Pannonian and Aegean extensions, in the north and south, respectively. The newest studies suggest that in some provinces at least two different phases of this magmatism can be distinguished. This study focuses on the data acquired in the Rudnik Mts. complex, where the presence of two phases appears to be most obvious. The Rudnik Mts. volcanic complex is associated to Pb-Zn deposit that belongs to the Serbo-Macedonian metallogenetic belt. The Rudnik Mts. volcanic rocks emplaced within slightly deformed Upper Cretaceous flysch strata containing numerous limestone exotic blocks. New U/Pb zircon ages and K/Ar age determinations on mineral data and volcanological studies revealed the presence of two magmatic phases that occurred ≥30 Ma and ≥20 Ma, respectively. The first phase is represented by extrusions and subvolcanic intrusions of dacite/andesite rocks, whereas the second phase is of rhyodacitic/quartzlatitic character, and it resulted after a complex explosive-extrusive activity including plinian/sub-plinian explosive events followed by effusions and shallow intrusions. The volcanic rocks of these two phases are geochemically similar, both having a calc-alkaline affinity and LILE- and LREE-enriched patterns on primitive mantle- and chondrite-normalized spider diagrams. In spite of this distinctive similarity, younger quartzlatite/rhyodacite rocks are richer in K_2O, Rb and Ba and poorer in Sr than the Oligocene dacite/andesite volcanics. A special petrographic type of the Lower Miocene volcanic rocks is leucominette which also form transitions to quartzlatite/rhyodacite. This is an evidence that mixing between an ultrapotassic lamprophyre/lamproite magma and an acid calc-alkaline magma has played important role in petrogenesis of quartzlatite/rhyodacite rocks. The model for the Mt. Rudnik volcanic complex is based on two stages involving: 1) effusive/extrusive dacite/andesite volcanism in Oligocene, and 2) mixing between ultrapotassic and dacite melts and formation of hybrid melts in the Early Miocene. This two-stage model explains widespread products of Plinian eruptions as well as the formation of powerful hydrothermal systems and precipitation of Pb-Zn/Ag deposit in the Early Miocene.

Comparison between $^{176}Hf/^{177}Hf$ of zircon and whole rock samples from Mesta Volcanic Complex, West Rhodopes: Evidence for crustal contamination

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Abstract

Mesta Volcanic Complex (MVC) from the Central Rhodope Magmatic Zone (CRMZ) is located on tectonically thickened crust. Unlike the East Rhodope Magmatic Zone (ERMZ), CRMZ only comprises a limited variety of mainly felsic rocks with strong crustal characteristics. The comparison between $^{176}Hf/^{177}Hf$ of zircon and whole rock provides new insight into magma generating processes in Mesta Volcanic Complex and can help to distinguish anatectic melting from wall-rock assimilation.

Keywords: *Mesta Volcanic Complex, $^{176}Hf/^{177}Hf$ isotopic composition*

Introduction

Late Eocene-Early Oligocene (35-26 Ma) extensionally triggered magmatism is widely spread in the Rhodope massif. It forms a segment of a vast 500 km long and 130-180 km wide magmatic belt known as Macedonian-Rhodope-North Aegean Magmatic Belt (Harkovska et al. 1989). Within the Rhodope massif there are two magmatic zones (East Rhodope and Central Rhodope) differing considerably in geochemical and isotopic composition of the rocks presented. Moreover, the geochemical and isotopic characteristic of East and Central Rhodope magmatic rocks reveal strong dependence on the crustal thickness (Marchev et al. 1994). Crust beneath East Rhodopes is relatively thin reaching up to 35 km thickness (Shanov and Kostadinov 1992) and the magmatic rocks are characterized by a wide variety of compositions ranging from mafic to felsic. The mafic rocks show progressive decrease of crustal input from early to late magmatic stages (Marchev et al. 2004). Based on Sr-Nd-Hf-Pb isotope data Kirchenbaur et al. (2012) ruled out the significant role for shallow-level crustal assimilation during the petrogenesis of the East Rhodope magmas. The CRMZ (including West Rhodopes) is located on tectonically thickened crust (42-50 km) exhibiting a poor variety of mainly rhyolitic to dacitic compositions and very seldom basaltic-andesitic dykes (Harkovska et al. 1998). MVC is the westernmost locality of the Late Eocene-Early Oligocene volcanism within the Rhodope massif. It is comprised by felsic rocks with crustal signature and the utter lack of mafic-intermediate compositions, which raises the question of their genesis. In this study, we compare $^{176}Hf/^{177}Hf$ isotopic composition of whole rock samples and their zircons in order to understand whether Mesta volcanism is related to anatectic melting of basement rocks or strong crustal contamination of a mantle-derived precursor.

Geological setting

Mesta Volcanic Complex crops out in an elongated SSE-NNW-oriented graben structure, that locates between the West Rhodope block to the east and Pirin horst to the west (Fig. 1). The graben basement is built up of several metamorphic units intruded by Eocene-Oligocene granitic plutons (Georgiev et al. 2010 and references therein). The lowermost Pangaion-Pirin Unit consists of two lithological types: marbles and orthogneisses. The orthogneiss protolith is dated at 291-270 Ma. Lithology of the intermediate Sidironero-Mesta Unit is quite heterogeneous including orthogneisses, schists, amphibolites, ultramafics, paragneisses and eclogites. The age of the orthogneiss protolith is determined at 164-134 Ma. The uppermost Vertiskos-Ograzhden Unit is made up mostly of orthogneisses yielding protolith ages within 462-426 Ma and granites aged at 241-222 Ma. The Mesta basin is filled with Upper Eocene-Oligocene sedimentary and volcanic rocks (Harkovska et al. 1998). Within the volcanic complex two polygonal calderas (Kremen and Banichan) and two linear

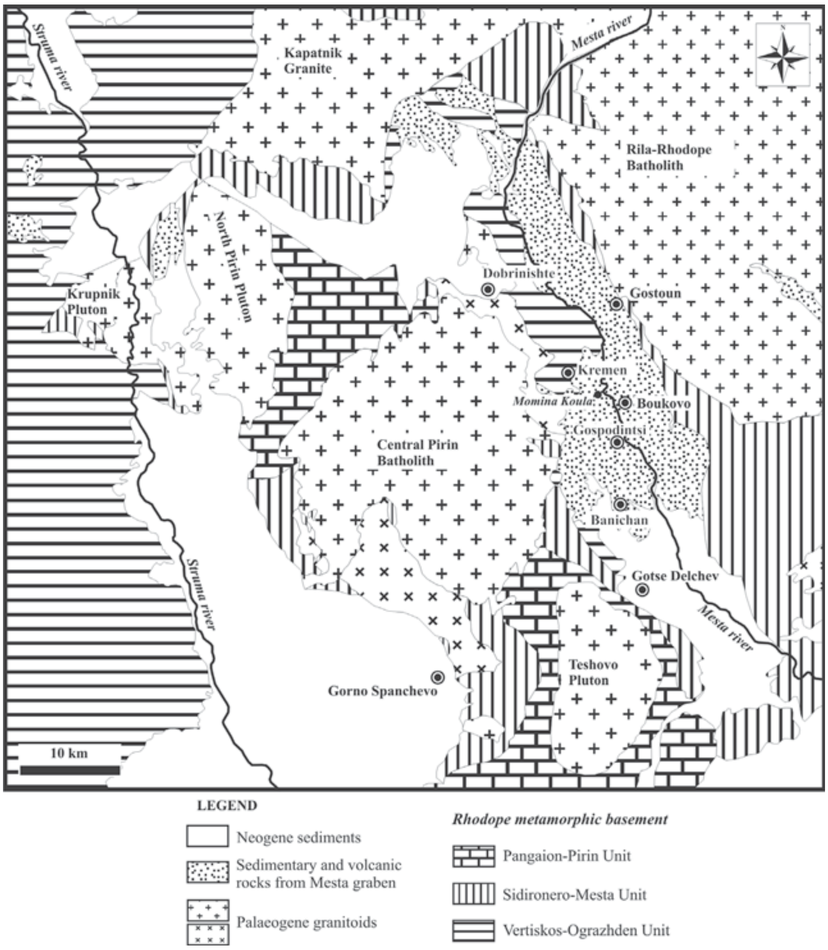

Figure 1. Geological map of West Rhodopes and Pirin Mts. after Georgiev et al. (2010).

volcano-tectonic zones (Dobrinishte and Gostoun) are described (Harkovska 1981). The subvolcanic and volcanic rocks form stocks, domes, dome-flows, cryptodomes, dykes and pyroclastic flows comprised by two main rock types: older rhyolites and younger trachyrhyodacites (Filipov and Marchev 2011; Filipov et al. 2012).

Materials and Methods

Four representative rock samples have been selected for this experiment: 1) a rhyolitic body near the Gostoun bridge, 2) a trachyrhyodacite 3 km north of Gospodintsi village, 3) a trachyrhyodacitic dyke near Boukovo village, and 4) a trachyrhyodacite from Momina Koula area. Three whole rock samples (one rhyolitic and two trachyrhyodacitic) were analyzed for their Hf isotope composition at Steinmann-Institut, Bonn using a Thermo-Finnigan Neptune MC-ICP-MS. U-Pb zircon dating of four samples was performed at the Geological Institute of BAS using New Wave UP193FX LA coupled to ELAN DRC-e quadrupole ICP-MS. $^{176}Hf/^{177}Hf$ isotopic composition in zircon is determined on Lambda Physik ArF excimer laser coupled to Nu-500 MC-ICP-MS at ETH-Zürich. Cathode-luminescence (CL) images of the zircon samples were obtained at Belgrade University using JEOL JSM-6610 LV SEM-EDS.

Results and Discussion

U-Pb zircon dating yielded emplacement ages for the rhyolite and trachyrhyodacites between 34.4-33 Ma. The CL images of zircons revealed abundant inherited cores and xenocrysts comprising over 60 % of all extracted crystals. The xenocryst ages vary broadly from 1520 Ma to 42 Ma, with half of them (424-149 Ma) matching the protolith age of the basement rocks from Mesta graben. It appears that nearly 50 % of the matching xenocrysts correspond to the orthogneiss protolith from Pangaion-Pirin Unit and the rest of them correlate with Sidironero-Mesta and Vertiskos-Ograzhden basement rocks.

$\varepsilon Hf_{(33Ma)}$ compositions in magmatic zircons from the Gostoun bridge rhyolite exhibit considerable variations from 0 to -6.3 (Fig. 2a). Hafnium isotope analyses of inherited cores yielded values of -5.4 and -6.3, which is similar to the whole rock $\varepsilon Hf_{(33Ma)}$ value of -6.5. Magmatic zircons from Gospodintsi trachyrhyodacite exhibit much more radiogenic εHf$_{(33Ma)}$ from +2.7 to -1.9 compared with the inherited zircons that are characterized by εHf$_{(33Ma)}$ variations from -6.5 to -8.9 (Fig. 2b). The whole rock εHf$_{(33Ma)}$ (-4.4) falls between the contrasting values of the magmatic and inherited zircons. It seems that Boukovo trachyrhyodacitic dyke has been contaminated by heterogeneous sources implied by the xenocrystic εHf$_{(33Ma)}$ from +2.7 to -7.3 (Fig. 2c). The only magmatic zircon analyzed gave positive εHf$_{(33Ma)}$ of +0.3, but the whole rock εHf$_{(33Ma)}$ (-7.3) is similar to the less radiogenic xenocryst values. Zircon populations from Momina Koula trachyrhyodacite showed εHf$_{(33Ma)}$ between 0 and -6.8 for the magmatic and of -9.5 for the inherited crystals (Fig. 2d).

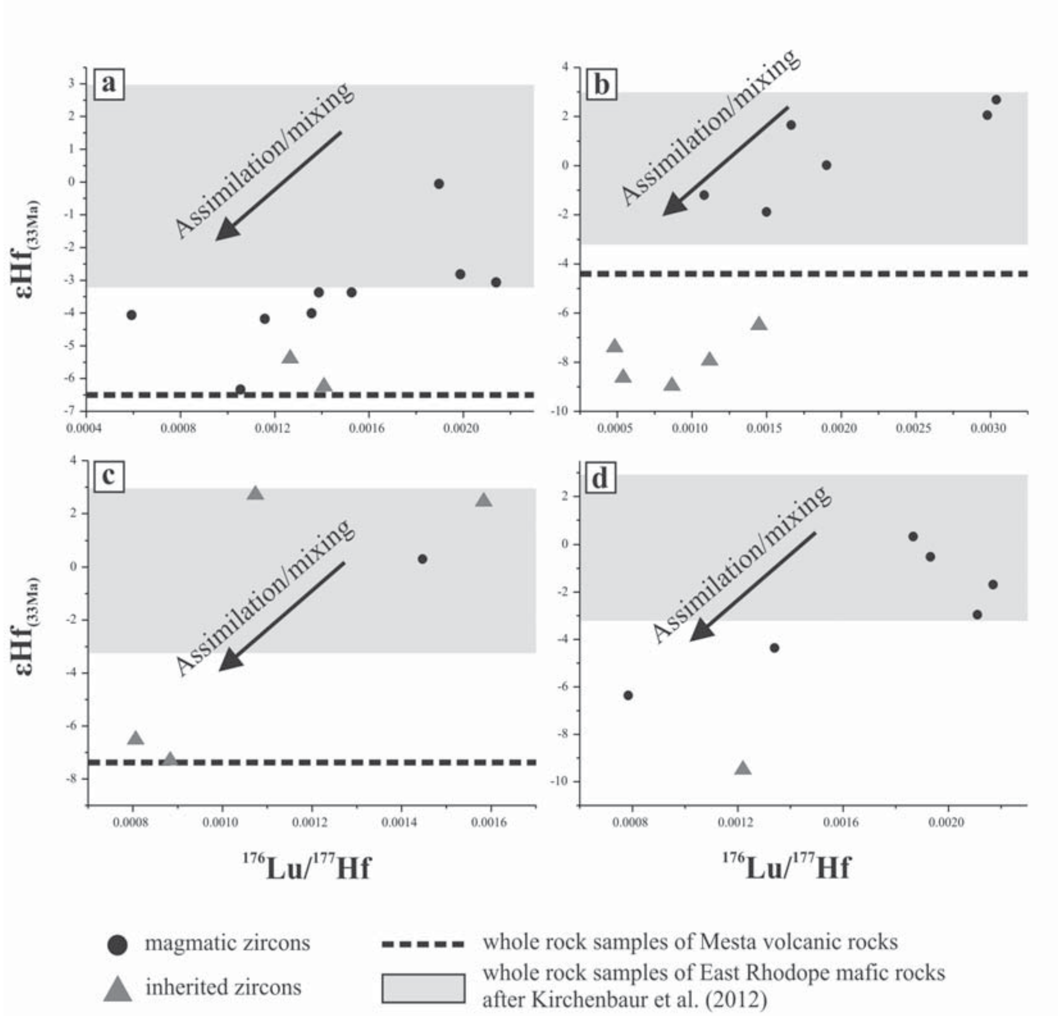

Figure 2.
εHf vs. $^{176}Lu/^{177}Hf$ variation of zircon and whole rock samples for: (a) rhyolite from the Gostoun bridge, (b) trachyrhyodacite from Gospodintsi village, (c) trachyrhyodacitic dyke near Boukovo village, (d) trachyrhyodacite from Momina Koula area.

The isotope signature of magmatic zircon populations reflects the melt composition at the time of crystallization, but the melt evolves to different compositions upon magmatic differentiation. The whole rock $^{176}Hf/^{177}Hf$ represents the combined effect of mixing sources with different isotopic compositions. The observed highly variable εHf of magmatic zircons (Fig. 2a,b,d) could be caused by magma mixing, but it does not seem that whole rock isotope compositions have been affected by the $^{176}Hf/^{177}Hf$ variations of magmatic zircons. In general, whole rock compositions are influenced by less radiogenic sources resembling the xenocrysts εHf values. Figure 2a,b,d displays that magmatic zircons are characterized by more radiogenic $^{176}Hf/^{177}Hf$ in contrast to xenocrysts and that the trachyrhyodacitic magmatic zircons are more radiogenic than those in the rhyolites. Surprisingly, magmatic zircon εHf variations more or less fit with the field of the East Rhodope mafic rocks. In the case of Gospodintsi trachyrhyodacite (Fig. 2b), it appears the rock is a product of two isotopically contrasting sources (magmatic and inherited), as reflected in the whole rock isotopic composition. This can be considered as a clear evidence for wall-rock assimilation since bulk isotopic composition has preserved the hybrid features of both magmatic and inherited components.

Conclusions

Our study demonstrates that Mesta rhyolites and trachyrhyodacites are produced through mixing of magmatic and metamorphic components. The magmatic component is characterized by more radiogenic $^{176}Hf/^{177}Hf$ ratios relative to the inherited (metamorphic) component. Taking into account the age and isotopic composition of the zircon xenocrysts, the most adequate explanation of the discussed patterns involves assimilation of heterogeneous crustal rocks. Although MVC magmatic zircon εHf variations resemble the Hf isotope signature of the East Rhodope mafic rocks, their bulk rock Hf isotopes are much less radiogenic. Therefore, we can conclude that while shallow-level crustal assimilation has no significant role in East Rhodopes, this petrogenetic process appears to be leading in MVC. Magma mixing also seems to have played role, resulting in increasing of $^{176}Hf/^{177}Hf$ ratios in the trachyrhyodacite magmatic zircons compared to those from rhyolite, but it has not influenced significantly the bulk isotopic composition of the rocks. Anatectic melting is not a viable scenario since the isotopic signatures of magmatic zircon and whole rock samples are different.

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Petrology and zircon U-Pb geochronology of trachytes from Kozhuf paleovolcano, FYROM – adakite-like signatures by amphibole fractionation

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Abstract

Kozhuf paleovolcano is a part form the Late Miocene to Pleistocene rifting magmatic activity in the Vardar zone. The U-Pb zircon LA-ICPMS dating yielded an age of 5.988 ±0.026 Ma (zircon ID-TIMS). The rocks studied are trachytes which represents one of the most widespread varieties in the area. The phenocrysts are presented by plagioclase, rare sanidine, amphibole, clinopiroxene and phlogopite. The rocks exhibit geochemical adakite-like features with weak Eu (0.79-0.93) anomaly, high La_N/Yb_N ratio ranging from 28 to 39, high Sr (1200-1800 ppm) and low Y (12-13.5 ppm) content and listric-like profile of REE chondrite normalized pattern. This is probabaly due to amphibole fractionation of water saturated magmas in crustal levels (8.3-6.1 km) with almost suppressed weak plagioclase fractionation.

Key words: *adakite-like rocks, U-Pb zircon dating, geochemistry, Kozhuf paleovolcano, SE FYR Macedonia*

Introduction

Late Miocene to Pleistocene rifting magmatism presented by predominantly basic to intermediate, rarely acid potassic to ultrapotasic volcanic rocks crop out in the Vardar zone in FYROM and southern Serbia (Yanev et. al. 2008 and reference there in). The Kozhuf paleovolcano is located at the border area of FYROM and Greece (Voras volcanic area) and represents the biggest manifestation of that magmatic activity. According to Boev and Jelenkovic (2012) it is built of: “alkali basalts (small bodies), quartzlatites (delenites), andesite-latites (trachyandesites), transitional latite-quartzlatite and quartzlatite-latite (delenitelatite), as well as latite, trachyte, trachyrhyolites and rhyolites” along with pyroclastics and volcaniclastic sediments. The rocks studied are the trachytes (corresponding to the “quartzlatite” – the most widespread volcanic rocks in Kozuf, of Boev and Jelenkovic 2012) that crop out in the vicinity of Momina Chuka, Zharena and Duditsa summits.

The aim is to constrain the time of magma generation using high temperature U/Pb zircon dating and study the petrology and geochemistry of the rocks.

Analytical methods

Major and trace elements of bulk samples are determined on fused pellets using a Philips PW2400 XRF spectrometer (at ETH-Zurich) and LA-ICP-MS (at GI-BAS, Sofia). In-situ U-Th-Pb age dating of the zircons and mineral geochemistry is made applying the LA-ICP-MS method (GI-BAS) and ID-TIMS (at ETH-Zurich). The major element mineral chemistry is achieved by energy-dispersive X-Max Large Area Analytical Silicon Drifted spectrometer (Oxford) coupled with a scanning electron microscope JSM-259 6610 LV at the University of Belgrade. The whole-rock $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios are obtained after a chromatographic cleaning procedure by ID-TIMS (TritonPlus), and the $^{176}Hf/^{177}Hf$ ratios of the heterogeneous zircons are achieved by spatial controlled in-situ LA-MC-ICP-MS (at ETH-Zurich).

Geochemistry

The trachytes analyzed show relatively constant SiO_2 contents ranging from 63.5 to 65.3 wt.%. The rocks are high-K calc-alkaline with total alkalis in the range of 8.15–8.50 wt.%, with slightly prevailing of Na_2O over K_2O and normative quartz of 11-14 %. On a primitive-mantle normalized diagram, the rocks show peaks in LILE (U, Th, Pb) and troughs in Nb, Ta, Ti and P (Fig. 1). They show high contents of LILE and very steep LREE chondrite-normalized patterns and almost flat HREE normalized patterns with well pronounced listric-shaped profile. The rocks exhibit geochemical adakite-like features with weak Eu (0.79-0.93) anomaly, high La_N/Yb_N ratio ranging from 28 to 39, high Sr (1200-1800 ppm) and low Y (12-13.5 ppm) content.

The measured $^{87}Sr/^{86}Sr_{(i)}$ ratio is 0.709048-0.709145 and εNd -6.77/-6.96 are similar to that analyzed in Kozhuf area and Miocene to Pleistocene magmatis rocks in the Vardar Zone reported by Yanev et al. (2008) and were referred to previous metasomatic event. The $εHf_i$ of the autocrystic zircons and zircon rims show variations in the range of -2.7 to +0.9.

observed. The chondrite REE normalized pattern shows abundance of LREE in respect to HREE and slight negative Eu anomaly.

Clinopiroxene – diopside ($Mg\#_{69-71}$) is rare and forms crystals up to 1.5 mm in size. Its chondrite REE normalized pattern is similar to that of the amphibole but with lower contents of the REE.

Phlogopite ($Mg\#_{69-71}$) forms euhedral, rarely embedded in the amphibole crystals. Opacitized rims, consisting of Fe-Ti oxides are observed. High Ba content (4600-5800 ppm) is analyzed.

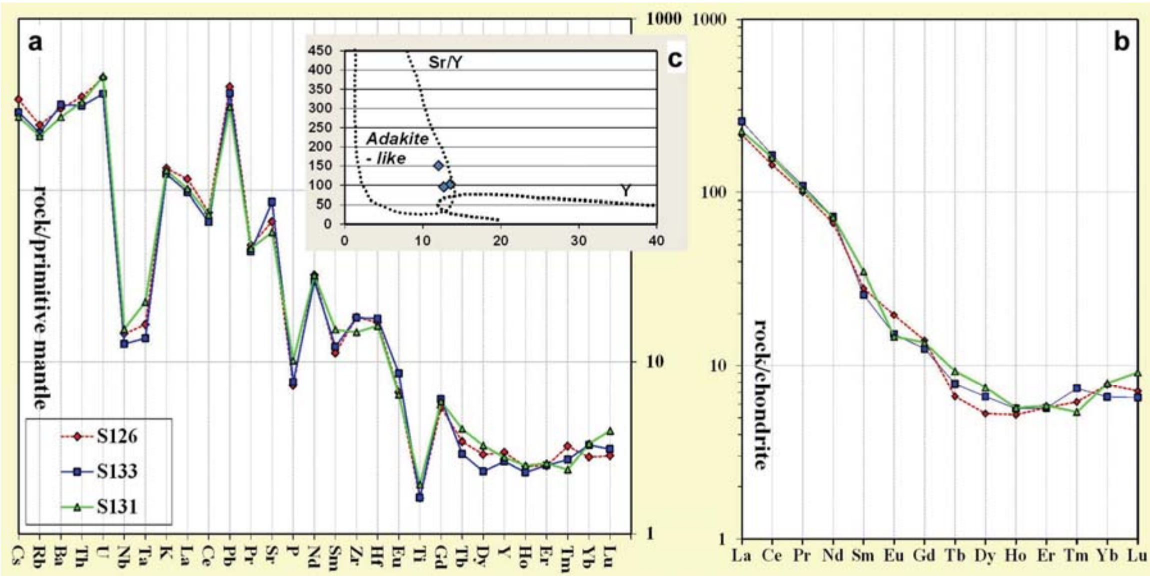

Figure 1. Geochemistry of the trachytes from Kozhuf paleovolcano: a) primitive mantle normalized spidergram; b) chondrite normalized REE pattern; c) Y vs Sr/Y diagram for distinguishing adakite-like characteristics.

Petrology and mineral chemistry

The phenocrysts consist of feldspars (plagioclase, rarely sanidine), amphibole, clinopiroxene, phlogopite set in a glassy groundmass and microlites of the same minerals. Sometimes glomeroporphyric structure of the all of the minerals is observed. Accessories are presented by apatite, zircon and magnetite.

Plagioclase represents the dominant mineral phase. It shows well expressed oscillatory normal zonation ranging from labrador (An_{50}) in the cores to andesine (An_{32}) in the peripheryes. Well pronounced positive Eu anomaly (Fig. 2) is observed and contents of Sr (2300-3200 ppm) and Ba (up to 1400 ppm, with higher amounts in the cores) are analyzed.

Amphibole (magnesiohastingsite to edinite, $Mg\#_{52-55}$) is one of the most abundant mineral and reaches size up to 1 cm. Thin opacitized rim is

Zircons are predominantly long, rarely short prismatic with well-expressed magmatic oscillatory zonation. It is highly abundant of HREE in respect to LREE and well pronounced possitive Ce anomaly is observed.

P-T conditions of crystallization

The P-T conditions of the amphiboles using the geothermobarometer of Ridolfi et al. (2010) shows continental depth of 6.1-8.3 km and temperature in the range of 850-890 ^oC. The clinopiroxene is not in equilibrium with the liquid composition (bulk rock). The zircon saturation temperature of the rocks is around 750 ^oC and Ti-in-zircon thermometer shows 710-735 ^oC.

Geochronology

The published K-Ar ages (Boev and Jelenovic 2012 and reference there in) for the magmatic rocks of the Kozhuf area are in the range of 6.5-1.8 Ma.

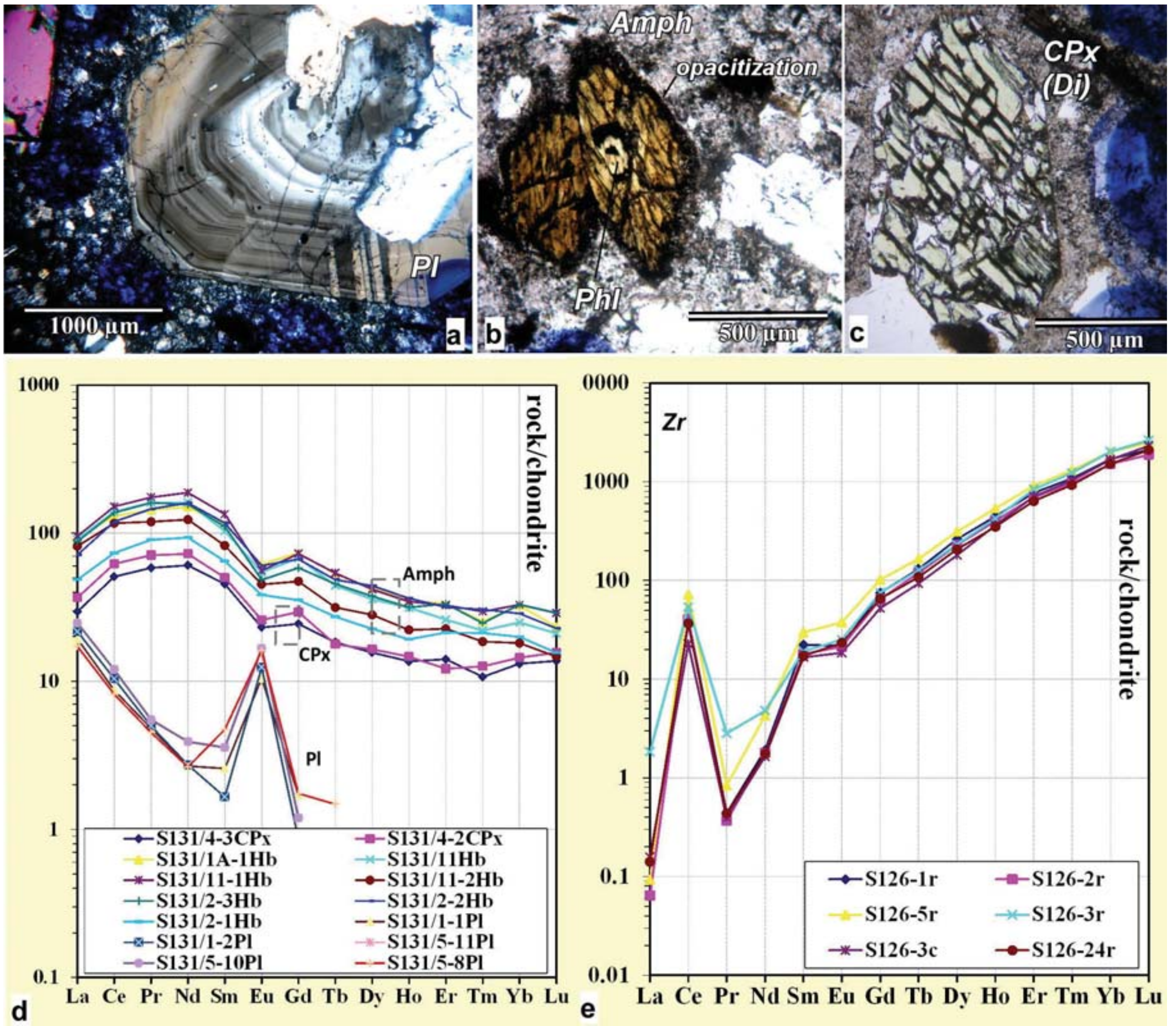

Figure 2. Petrology and mineral geochemistry: a) plagioclase with normal oscillatory zonation; b) phlogopite embedded in amphibole with opacitized rim; c) diopside; d) chondrite normalized REE pattern of some of the rock-forming minerals; e) chondrite normalized REE pattern of zircon.

Our sample for zircon U/Pb geochronology study is from Momina chuka dome. 40 spot analyses of distinct zircon zones of 30 grains are made. The zircon population is presented only by own magmatic grown zircons (no inherited crystals or cores are observed) with LA-ICPMS Concordia age of 5.909 ±0.034 Ma (with Th disequilibrium correction), which is pretty consistent with the ID-TIMS age of 5.988 ±0.026 Ma obtained (Fig. 3).

Discussion and conclusion

The trachytes in the the vicinity of Momina Chuka, Zharena and Duditsa summits, Kozhuf paleovolcano, are dated at 5.988±0.026 Ma (zircon ID-TIMS). They are part of the Late Miocene to Pleistocene rifting magmatic activity in the Vardar zone (Yanev et al., 2008 and reference there in). The rocks exhibit geochemical adakite-like features with weak Eu (0.79-0.93) anomaly, high La_N/Yb_N ratio (28 to 40), high Sr (1200-1800 ppm) and low Y (12-13.5 ppm) content. One of the most probable mechanisms for generation of strongly fractionated REE patterns and high Sr/Y ratios in water saturated magmas is fractional crystallization of minerals that preferentially partition Y and HREE in the absence of significant plagioclase fractionation. Hornblendes and clinopyroxenes partition the HREE over LREE (with preferation partitioning of MREE) and their fractionation is referred to formation of the so-called listric-shaped REE pattern and adakite-like signatures (Richards and Kerrich 2007, and reference there in). The amphibole in the rocks studied shows crustal depths of 6.1-8.3 km and temperature of 850-890 ^{o}C, so it is formed in upper crustal levels. The lower $Mg\#_{69-71}$ of the diopside and phlogopite is probably related to their crystallization in deeper level. The absence of inherited zircon grains and cores can be interpreted as a sign for small degree of assimilation. The higher $^{87}Sr/^{86}Sr_{(i)}$ (0.709048-0.709145) and εNd -6.77/-6.96 is probably due

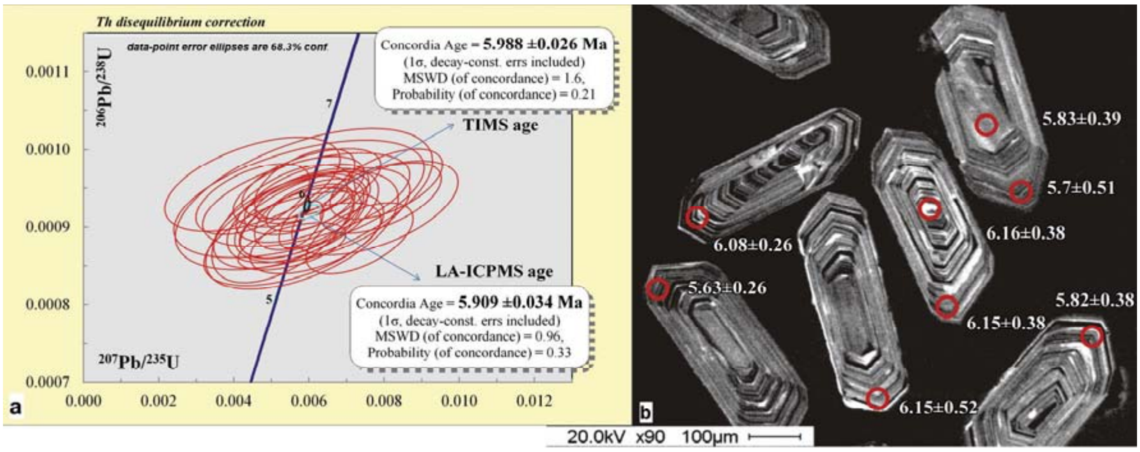

Figure 3. Geochronology: a) zircon CL images and $^{206}Pb/^{238}U$ age; b) LA-ICPMS zircon Concordia age.

to melting of a substrate affected by previous metasomatic event.

Usually magmatic rocks with adakite-like features are refered to be fertile and connected with mineral deposits. In the Kozhuf area, the Sb-As-Tl-Au Allshar deposit and Au Duditsa mineralization are well known and are connected with this magmatic activity (Boev and Jelenovic 2012).

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Mineral diversity, melt inclusions and gabbroic xenoliths of the Upper series of Zvezdel volcano (Eastern Rhodopes): Evidence for mush chamber recharge and magma differentiation

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Abstract

This study demonstrates the importance of the process of mafic recharge in the genesis of the Zvezdel volcano and the mechanism of mixing on the basis of detailed study of mineral chemistry, melt inclusions and troctolite xenoliths. We show that variations in mineral chemistry are the result of repeated injection of basaltic magmas in an evolving andesite to dacite mush magma chamber, whereas troctolite xenoliths and melt inclusions provide information about lower to mid and upper crustal evolution of Zvezdel lavas.

Keywords: *magma mixing, mush chamber, recharge, Eastern Rhodopes*

Introduction

Magma mixing has been widely recognized from field observations, mineral composition studies and whole rock and isotopic data. Evidence for the magma mixing in the Zvezdel volcano was reported by Nedialkov (1986) and later by Raicheva and Marchev (2006). Here we examine the texture, major and trace element composition of minerals and phenocryst-hosted melt inclusions of the Upper series of Zvezdel volcano with the aim to resolve whether we have a simple mixing of two melts or recharge into a mush chamber. We also discuss the genesis of the plutonic cognate troctolite xenoliths as cumulates complementary to the more evolved Zvezdel mafic magmas.

Geological setting

Zvezdel volcano is located in the Eastern Rhodope volcanic area which represents a part of the Macedonian-Rhodope-North Aegean volcanic zone (Harkovska et al. 1989). It is considered a stratovolcano (Nedialkov and Pe-Piper 1998; Yanev et al. 1998) with parasitic and satellite volcanic vents and domes. The volcanic structure is composed of lava flows intercalated with epiclastic and rare pyroclastic rocks, and cut by domes and dykes. The central part of the volcano is intruded by a co-magmatic differentiated intrusive body of monzogabbro, monzonite, quartz-monzonite and granite-aplite rocks (Nedialkov 1986). $^{40}Ar/^{39}Ar$ data constrain the time span of volcanism between 32.16 ±0.30 and 31.13 ±0.06 Ma (Singer and Marchev 2000; Moskovski et al. 2004; Georgiev and Marchev 2005).

Analytical methods

Major and trace elements of the bulk rocks were determined by XRF at Washington State University (USA) and University of Lausanne (Switzerland). REE and some trace elements were measured by ICP-MS at Washington State University or by LA-ICP-MS at the Geological institute of BAS (Sofia, Bulgaria). Major elements of minerals and melt inclusions were analysed by electron microprobe at University of Florence (Italy) and University of Belgrade (Serbia). LA-ICP-MS analyses of the trace elements in the minerals were carried out at ETH Zurich and Geological Institute of BAS.

Geochemistry

The Zvezdel volcanic rocks are predominantly high-K calc-alkaline with subordinate calc-alkaline and shoshonitic varieties ranging in composition from basalts to andesites and dacites. Two evolutionary series (Upper and Lower) have been determined on the basis of their stratigraphic position, and the mineral and chemical compositions of the lavas. The volcanic rocks of the Upper series are classified as basalts, basaltic andesites to shoshonites and andesites. Trace element spiderdiagrams show typical patterns of orogenic rocks with negative anomalies of Nb, Ta and Ti and Pb peak. Chondrite normalized diagrams are LREE enriched with negative Eu/Eu*, which deepens from basaltic to evolved rocks.

Petrography and mineral chemistry

The Upper series of Zvezdel volcano includes at least 8 discrete lava flows. The rocks are highly porphyritic with phenocrysts, and microphenocrysts of plagioclase (pl), clinopyroxene (cpx), orthopyroxene (opx) ± olivine (ol) ± Ti-magnetite (Ti-mt). The major phases (pl, cpx and opx) show distinct mineral textures, compositions and zoning patterns indicative of complex magmatic histories (Fig. 1).

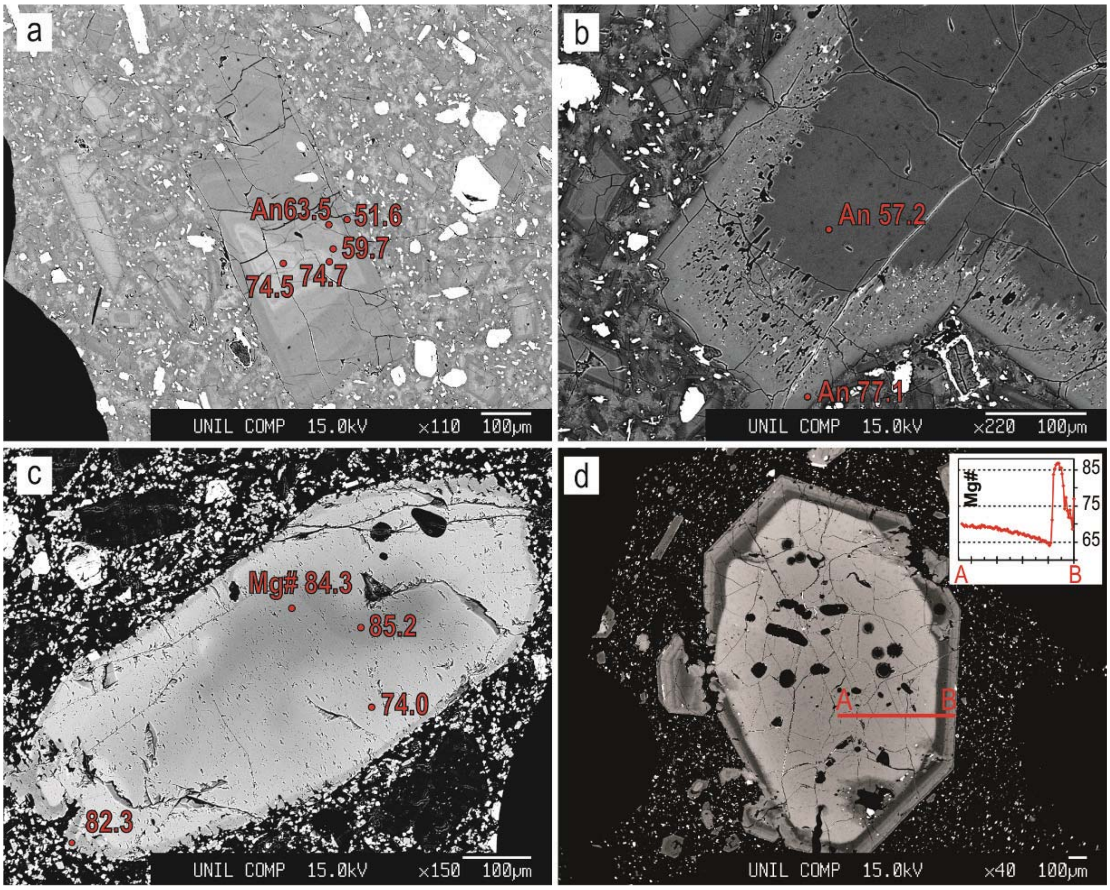

Figure 1. BSE images of a) normally zoned pl type 1; b) sieved, reversely zoned pl type 2; c) cpx type 1; d) reversely zoned cpx type 2. Inset shows Mg# variation from core to rim (line A-B). Note scale in c and d.

Pl is the predominant phenocryst phase. On the basis of textures and compositional zoning, it is divided into 2 main types. Type pl 1 has generally homogeneous clear high-Ca cores (An_{89-73}). It usually shows normal (Fig.1a) or slightly reverse zoning but some crystals have complex zoning. Type pl 2 is reverse zoned (Fig. 1b) with high-Na cores (An_{46-59}) and high-Ca sieved zones (An_{86-64}).

Test of pl – melt equilibria using partitioning of Ca and Na between plagioclase cores and bulk rock shows that type pl 1 is in equilibrium with basalt to basaltic andesites, while pl 2 is not in equilibrium with any volcanics of the Upper series. The latter is in equilibrium with the majority of melt inclusions.

Cpx phenocrysts are roughly classified into two major types: high-Mg (cpx 1) and low-Mg (cpx 2). Type cpx 1 phenocrysts are usually smaller than cpx 2. They are normally zoned or slightly reversely zoned (Fig. 1c). Mg-# values of the cores are in the range 85.2 - 82.5 ($Wo_{44.0-45.1}$ $En_{45.7-47.5}$). Subtype 2a cores have Mg# 77-68 ($Wo_{37.9-43.6}$ $En_{39.4-46.1}$). Their zoning could vary both in the same sample and in the different lava flows and could be normal, reverse and complex. The composition of the rims often reaches cpx 1 cores. The most Fe-rich cpx cores (cpx 2b) are resorbed with Mg# 66.4-63.3 ($Wo_{35.7-39.7}$ $En_{38.9-41.4}$). Their zoning could vary both in the same sample and in different lava flows and could be normal, reverse (Mg# up to 85; Fig. 1d) and complex.

Trace element study of the cpx shows that cpx 1 has lower concentrations of incompatible and rare earth elements and higher contents of Cr and Sr, which are compatible in cpx and pl, respectively. All cpx display a concave-down REE pattern, with the MREE slightly enriched over both LREE and HREE. The Eu/Eu* of cpx 1 is 0.60-1.09 and much deeper in cpx 2 (0.24-0.59). The low Mg outer rims of the cpx 1 are enriched in trace elements, while Mg rich outer rims of cpx 2 have lower contents of trace elements, suggestive of derivation from more evolved and more basic magmas, respectively.

Similarly to cpx, opx is divided into two subtypes. Subtype opx 2a has cores with Mg# 77-66 ($Wo_{2.4-4.0}$ $En_{63.1-73.2}$). They could be normally zoned, but usually are mantled with cpx with Mg# up to 85 (Fig. 2a). Subtype opx 2b has the most Fe-rich cores (Mg# 60-64, $Wo_{3.5-4.3}$ $En_{57.8-60.7}$). Usually, they are mantled with cpx (Mg# 73-68). The chondrite normalised diagrams of opx show heavy rare earth enrichments and negative Eu anomaly.

Pyroxene–melt equilibria, using Fe-Mg exchange between core composition and whole rock analyses, indicate that cpx 1 is in equilibrium with basalt to basaltic andesite melts. Its more primitive nature is reflected in the higher contents of Cr and Sr and lower concentrations in incompatible trace elements. Subtype cpx 2a and opx 2a are in equilibrium with basaltic andesites to andesites. The most Fe rich pyroxenes (cpx 2b and opx 2b) are not in equilibrium with the host rocks, but they could be in equilibrium with the melt inclusions (see below).

Fresh ol is present only in the basalts and shoshonites. Phenocrysts and microphenocrysts are normally zoned with Fo_{80-73} cores and Fo_{73-63} rims

In the topmost basaltic flow, plutonic troctolitic xenoliths up to 2-3 cm in size were found. They are composed of slightly zoned olivine (Fo_{79-78}) and plagioclase (An_{93-90}) and display adcumulate, partly poikilitic textures (Fig. 2b). Their mineral composition is typical for the type II arc cumulates of Beard (1986).

Melt inclusions

Glasses from the melt inclusions (MI) in the pl 2 and cpx 2 in the host basalt and shoshonite show sum of major elements from 93 to 98 wt.%, mostly in the range 94-96 wt.%, which suggests that the magma was relatively H_2O-rich (~5 wt.%). The MI show a wide range of SiO_2 (62.2-72.7 wt.%), but MI with SiO_2 65.5-68.0 wt.% predominate. Compositionally, they are more evolved than groundmass and groundmass glass of their host rocks. Generally the MI continue the trend of the bulk rock analyses and groundmass glass, but they have higher contents of FeOt, TiO_2 and K_2O and lower contents of MgO, CaO and Na_2O.

Discussion and conclusions

The data presented above demonstrate that the lavas of the Upper series of the Zvezdel volcano are products of mush chamber recharge. During the late stage (Upper series) evolution of the

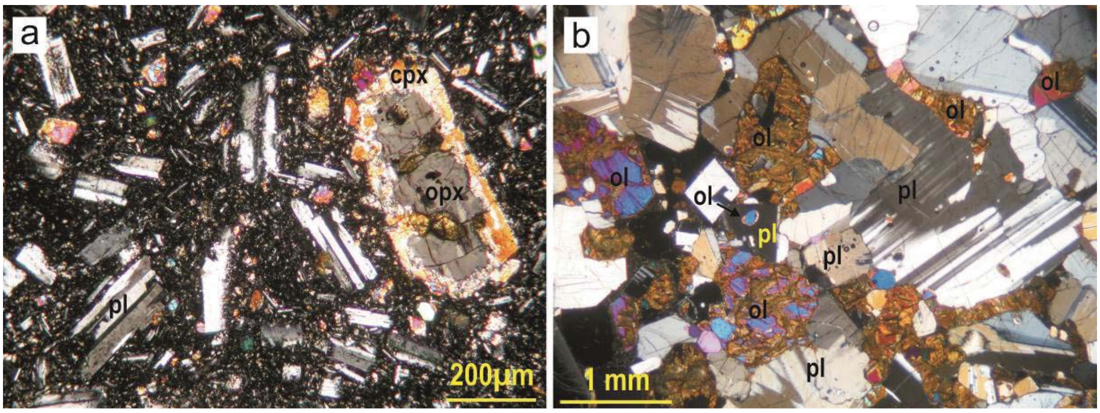

Figure 2. Photomicrographs of basaltic host (a) and troctolitic cumulate (b), cross-polarized light.

Apart of individual phenocrysts, Na-rich pl, high-Fe cpx and Ti-mt form crystal cluster. It is also important to note that the Mg# of the mantles of the reversely zoned pyroxenes increases from the oldest toward the youngest lava flows and that cpx 2, opx 2 and pl 2 predominate over type 1 phenocrysts.

Zvezdel volcano, lower temperature (~1000 °C) andesitic magma was stored at 10-13 km and evolved to produce zoned mush. We suppose that varying compositions of pl 2, cpx 2 and opx 2 and their MI reflect a prolonged fractionation in andesite/dacite magma chamber. This magma chamber was repeatedly recharged by more mafic, higher temperature (~1150 °C) magma. Injected magma caused separation and corrosion of the crystals from the mush, whereas glomeroporphyric clusters, most probably, were disrupted from the more crystalline zone (the rigid zone of Marsh, 1996).

The origin of troctolites involves a complex crystallization history which includes preliminary lower crustal differentiation of hydrous, mantle-derived basalt, and fractionation of ol + Cr spinel ± pyroxene. Ascent of these basaltic melts into the shallow crust would lead to both H_2O saturation and precipitation of high Ca pl and relatively low Mg (Fo_{78-79}) ol, which formed the troctolite cumulates either in the existing or in a separate magma chamber. Injection of the last basaltic flow disrupted and entrained these rigid rocks.

Our study reveals that part of the crystals in the Upper series of Zvezdel volcano are not truly phenocrysts, but antecrysts crystallized from ancestral magmas.

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On the transition of the Eastern Aps to the Pannonian basin: Constraints from the modelled origin of the Pohorje tectonic block

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Abstract

The Miocene evolution of transitional area of the Eastern Alps to the Pannonian basin has so far been explained as a consequence of lateral eastward escape of the Austroalpine units and left rotation of the Adriatic plate. The origin and Miocene evolution of the Pohorje tectonic block (PTB) in northern Slovenia shed somewhat different light to these processes. It seems to be connected to three key factors: opening of the Pannonian basin, magmatism and left rotation.

Greater changes in the region occurred in early Miocene with opening of the Pannonian extensional basin, origin of asthenospheric bulge below the basin and opening of extensional listric Labot fault (LF). Pohorje granodioritic magma was emplaced close to the LF at around 18.7 Ma. This is the time when PTB was still an integral part of the common Koralpe, Pohorje and Kobansko block, here named the Steiermark tectonic block. Therefore, the magmatic activity of the PTB could not develop within the Periadriatic strike-slip zone, because PTB has never been a part of it. Though considered as a laccolith previously, Pohorje magmatic body represents a single batholith shaped intrusion with several apophyses, and grades from deeper granodiorite to shallower porphyritic granodiorite. No evidence of occurrence of pure dacite has been found. Magma did not intrude the mid-Miocene rocks at the apical part, what constraints the lowest age of the batholith emplacement.

Rifting of the Pannonian basin was accompanied by transgression of Central Parathetys into extensional depression along the LF in the late lower to early middle Miocene. Left rotation of the detached part of the Austroalpine followed along strike-slip reactivated LF. Southwesternmost parts of the Austroalpine metamorphic basement east of the LF were gradually extruded and synchronously left rotated. This process started already in late lower Miocene. The Steiermark block was extensionally disintegrated along the LF and finally, uniform Pohorje-Kobansko block was detached from it in middle Miocene. In the course of extrusion and rapid cooling, the Pohorje-Kobansko block split to PTB and Kobansko block in middle Miocene. Oblique strike-slip Lovrenc fault developed between the two and Ribnica-Selnica tectonic half-graben north of the fault. The PTB was transpressively uplifted between the Labot and Lovrenc faults and independently extruded toward the east-southeast.

In the west, PTB was synclinally bent along the SW-NE trending axis. In the bent zone, weakly viscous granodiorite magma was remobilized at about 17-16.5 Ma, forming some undeformed subvolcanic dacite dykes. Pole reversal in the time of cooling under about 560 deg. C gave character to mafic dykes, deeper parts of granodiorite and some remobilized dykes.

In continuation of extrusion, PTB was thrust onto the mid-Miocene sediments of the Pannonian basin, and ultrabasic body was unroofed at its root on the eastern margin. At around 14.5 Ma, extrusion ceased. Upper part of the PTB was detached along subhorizontal shear plane, and unroofed toward the east into the basin. Paleomagnetic sign of right rotation was imprinted into the footwall of wider shear zone. This represents the most rapid tectonic unroofing of strongly uplifted PTB. Erosional relics of mylonitized and cataclastic rocks from the shear zone were represented as intrusions of dacite into the granodiorite, and some of them as mafic dykes, up to now.

The only possible agent triggering left rotation of the area east of the LF, and extrusion and tectonic unroofing of the PTB can be found in right rotation of AP at this stage. Signs of this rotation are numerous within the Periadriatic fault zone west of the LF, though explained previously as a consequence of domino effect within the zone. According to the present model, they represent evidence of right rotation of the AP. This could equally explain rotation of the Periadriatic fault line west of the Labot fault toward the south. The model could support also the origin of the Miocene Giudicarie line in Italy on the AP western margin. If correct, this would mean that the eastward extrusion of the Eastern Alps was prevented or ceased at least in the course of left rotation of the region along the LF.

Spatial data modeling and analysis for dynamic coastline changes and assessment

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Abstract

Coastal changes are attracting more focus since they are important environmental indicators that directly affect coastal economic development and land management. Coastline and coastal areas are not only the supports for local economic activities, but also, a source of food and energy, apart from offering diverse opportunities for recreation and tourism. Coastline mapping and coastline change detection are critical for coastal resource management, coastal environmental protection and sustainable coastal development and planning. Changes in the shape of coastline may fundamentally affect the environment of the coastal zone. These may be caused by natural processes and human activities.

In this paper, we tend to give a model of the dynamic changes of Albanian Adriatic coastline, using spatial temporal data, by taking advantage of Geographic Information System (GIS) and Remote Sensing (RS). Our main objective is not only detection of actual coastline spatial position, but dynamic assessment of future position. Coastline mapping focuses on some specific issues such as mapping methods used to acquire coastline data, models and database design used to represent coastlines in the geographic database, and coastline -change analysis methods.

Coastline-change analysis requires understanding of the coastal processes that cause the change as well as the coastal mapping methods. The net rates of variations in the position of the coastline are calculated according to transects disposed perpendicularly to the baseline and spaced equally along the coast. Analysis of the relative impact of the natural factors and human activities is a fundamental process for coastline changes monitoring and future assessment.

We have used contemporary methods of detection of Albanian Adriatic coastline changes. In this study, we have used the data obtained from several sources. We have combined topographic maps (1:10,0000, 1870; 1:75,000, 1918; 1:25,000, 1960, 1986 and 1:10,000, 1995), digital aerial photographs of 2007 year, satellite images of Landsat TM and Ikonos, and field observed GIS data. Generation of spatial data is carried out through vectorization process and image processing. All vector files of the coastline, generated from different source, are converted to the same system of projection: Universal Transverse Mercator (UTM), WGS 84, zone 34 N.

In 1990 year, 56 % of Albanian Adriatic littoral was in accumulative process, 44 % was in abrasion process, meanwhile in 2007 year 43 % of Albanian Adriatic littoral was in accumulative process, and 57 % was in abrasion process. In Albanian Adriatic littoral, about 55 % of beaches are in abrasion process (13 % of these are in emphatic abrasion) and 45 % was in accumulative process (30 % from these are in emphatic accumulative process). Thus, coastal erosion presents a serious problem throughout Albanian Adriatic coastal areas.

Coastal erosion is one of the most important environmental issues that challenge the capabilities of scientific institutions, governmental agencies and local authorities. Whether it is due to natural factors or human activities, coastal erosion causes significant economical losses and environmental damages.

Keywords: *Coastal erosion, coastline change and assessment, database design, spatial data modeling, image processing*

Peak Flow Transposition of Ishmi and Erzeni River Basins

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Abstract

Development of calculation methods for determining the hydrological parameters is essential in ungauged watersheds. Nowadays studies of watersheds and developments of sophisticated three-dimensional mathematical models have led to the solution of a large number of problems in the field of hydrology. The data needed for these models are numerous and in most cases modellers are limited in use to the full potential of these models. Time taken for data collection and processing, demand for skilled personnel and the high cost involved are other factors that limit their usage. Almost all these sophisticated models do not prove valuable for applications in ungauged watersheds.

To determine peak flow in ungauged watersheds is used area-ratio method which has as basis the connection between peak flows and power of area ratio in watersheds with the same geomorphological features. The purpose of this study is to determine the transposition exponent ‘n’ to Ishmi and Erzeni basins, based on a series of data with maximum flows and on the assumption that maximum flows are largely dependent on surface watersheds.

Keywords: *Peak flow, n-transposition exponent, area-ratio, ungauged watersheds*

Introduction

The majority of constructions works require engineers to deal with ungauged basins. This has led to the use of a numerous methods to determine hydrological parameters.

Estimation of peak flow with different return period is the main challenge in design of hydraulic structures. Determining precisely the peak flow is of great importance as it affects the safety and cost of each structure. Definition of a small flow versus what can really happen to most structures poses a danger, not only to the destruction of the structure, exit out of service, but also for the safety of people and property located in the area of flood. Otherwise definition of a flow greater than what can actually happen, can result in an over designed and costly structure, which can affect negatively the overall cost of project. For these reasons is necessary to determine flows that approach the real values in different locations to make an appropriate design of structures. Transposition of flow through area-ratio method is used more efficiently and effectively for design purposes.

Data

In this study are taken in considerations annual peak flows from stations given in table no. 1,

Table 1. Data of Selected River Basin.

River Basin	Gauging Station	Watershed Area (km²)	Peak Flow (1/100 years)	Length of record
Erzeni	Ibe	248.00	285.5	1975-1992
	Ndroq	663.00	1149.8	1953-1992
	Sallmonaj	755.00	1279.2	1955-1990
	Perroi i Zallit Ibe	79.80	127.5	1969-1992
Ishmi	Lana Tirane	20.00	88.0	1957-1992
	Lumi i Tiranes Shupal	70.76	177.0	1970-1992
	Ishmi Sukth Vendas	651.00	1992.6	1951-1992
	Zeza Fushe Kruje	71.34	528.2	1957-1992
	Gjola, Ura e Gjoles	468.00	1307.8	1951-1992
	Terkuza, Zall Herr	112.90	439.9	1975-1992

for years 1951-1992 from (IGEWE) Institute of Geo-Sciences, Energy, Water and Environment, Tirana. Years in which there has been missing data or questionable data are not taken into consideration.

To determine the peak flow with a return period 100 years is used Log Pearson Type III distribution. The data for the respective basins surfaces are defined by Arc - GIS (Fig. 1) and were compared with those of Hydrological Bulletins.

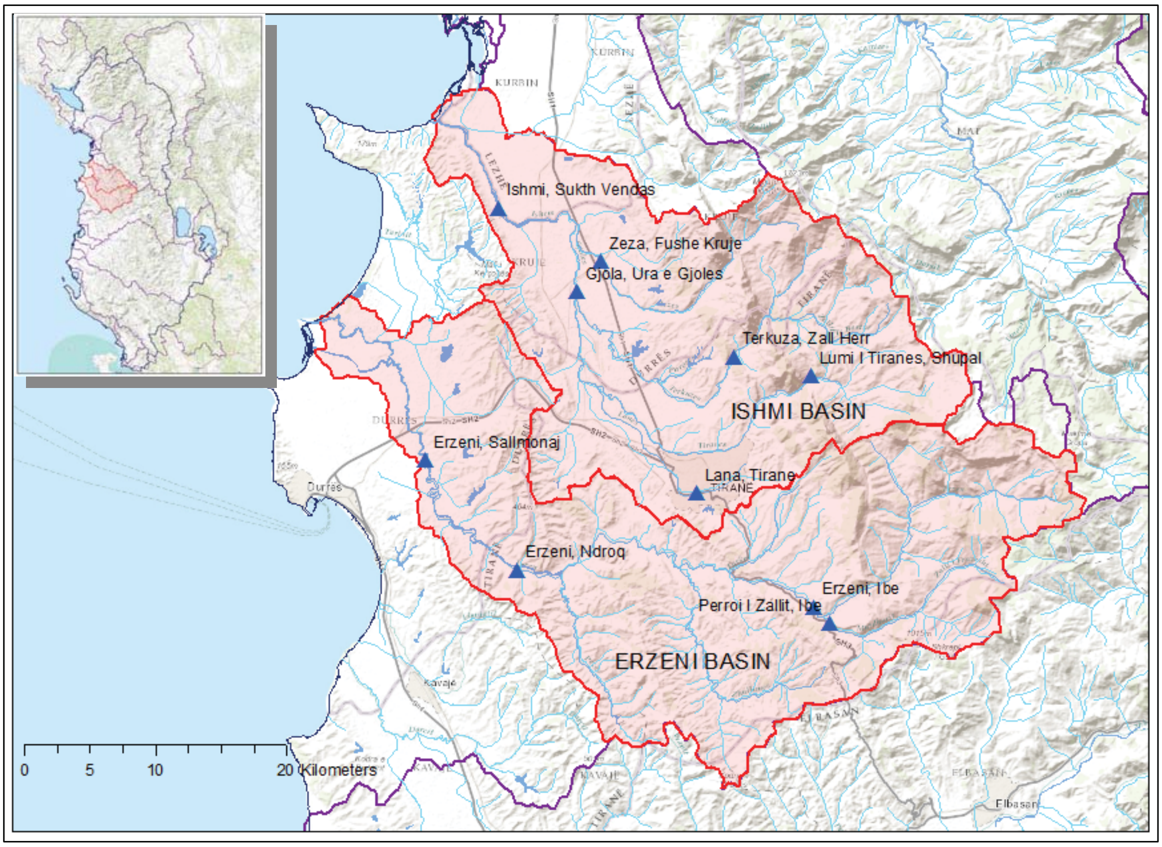

Figure 1. Erzeni and Ishmi River Basins.

Analysis

If the drainage area ratio of the two locations falls between 1.5 and 0.5, there is no significant tributary inflow occurring between either site, and both watersheds are physically and climatically similar, then peak flows can be estimated by using the area-ratio equation:

$$Q_d = Q_g \left(\frac{A_d}{A_g} \right)^n \qquad (1)$$

Q_d - Peak flow at the design location (m³/s)

Q_g - Peak flow at the gauge location (m³/s)

A_d - Watershed area at the design location (km²)

A_g - Watershed area at the gauge location (km²)

n - Transposition exponent

The transposition exponent n is determined by regressing the logarithms of T-year flow (T = 100) against the logarithms of drainage area for each region. The exponent ‘n’ for each region is the average of the coefficients for the logarithm of drainage area for all T-year flows.

Results

Flood Transposition within the Same River Basins

For watersheds within the same river basin from analysis resulted these transposition exponent; n=0.96 for Erzeni basin and n=0.698 for Ishmi basin respectively. For watersheds within the same river basin the error in peak flow transposition is computed using the Mean Ratio of Absolute Error. The error for Erzeni basin is 15.2 % and for Ishmi Basin 33 %.

Flood Transposition between the River Basins

Flood transposition using watersheds from both basins shows a wide scattered nature in the behaviour of peak flow values. The value of the transposition exponent resulted n=0.673. The error in estimation of peak flow was checked when a value 0.673 is used for 'n' it was identified that the average error is 43.8 %.

Conclusion

- Considering that the maximum flow rate is proportional to the n-th power of the surfaces ratio, the transposition of peak flow with return period 1 in 100 years gives a good estimation of the maximum flow for watersheds within the same basin if the drainage area ratio of the two locations falls between 1.5 and 0.5.
- From analysis resulted that the transposition exponent are: n=0.96 for Erzeni basin and n=0.698 for Ishmi basin, while for two basins taken together n=0.673.
- Calculation of error in determining the maximum flow using the power exponent n=0.96 for Erzeni basin, n=0.698 for Ishmi basin and n=0.673for both basins resulted: 15.2 %, 33% and 43.8 % respectively. More reliable peak flow estimates could be obtained when watersheds from the same river basin are used for transposition.

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Mapping of the liquefaction prone areas in the Adriatic coastal zone in Albania

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Abstract

The liquefaction is a phenomenon that causes the loss of shear strength and stiffness of soil during a seismic shaking as a result of increased pore water pressure accompanied by the reduction of effective stress. The soil no longer behaves like a solid, rather it acts as a viscous fluid. As the bearing capacity of soil to sustain foundation loads is related to strength, liquefaction poses a serious hazard to structures and must be assessed in areas where liquefaction prone deposits exist.

The types of soil that are more prone to liquefaction are loose saturated silts and sands below the groundwater table at a depth of less than 20 meters, generally dating from the Holocene Age.

Some very important urban centers as Durres, Vlora etc., are located on these kinds of deposits. In the last years, new urban centers are developed into previously uninhabited areas such as the coast from Shkëmbi i Kavajës to Karpen, Lalzi Bay etc.

The geological-engineering studies for the construction of new buildings are based on the Albanian Technical Code KTP-5-78, which does not explicitly require the evaluation of this phenomenon as part of the study. The Seismic Design Code KTP-N2-89 is limited only to the classification of the site soil conditions into three categories, I, II, and III, which should be determined based on the seismic microzoning studies and the respective engineering geological studies. The category of soil is used only to evaluate the seismic excitation of a construction according to the expected seismic intensity (MSK-64) and liquefaction criterion is not a code requirement during the seismic design.

Previous quantitative liquefaction analysis, carried out from the authors in different sites located in the coastal area of Albania, and for different levels of hazard (i.e. 10 % in 10 years (72- years Return Period), 10 % in 50 years (475-years RP) and 2 % in 50 years (2475-years RP), has shown that the likelihood of liquefaction is very likely for the first level of safety and almost certain for the second and third levels.

Actually, the Albanian practice of foundation’s design doesn’t consider the liquefaction phenomenon. In these conditions, the construction of shallow foundations in liquefaction prone areas, without applying any soil improvement techniques, may lead to vulnerable structures in case of a seismic shaking.

This study aims at identifying and mapping all the areas susceptible to liquefaction in the coastal areas of Albania. The methodology used is the mapping of the areas composed by quaternary loose sands and silts with water table level near the surface. The map is elaborated in G.I.S. environment and different susceptibility levels to liquefaction are given.

Interpretation of the permeability in Fangu Hydropower dam site based on "Lugeon" permeability test

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Abstract

Evaluation of the permeability of rocks and soils is one of the most important steps in a dam design. The extents of grouting and cut-off depths required in a dam foundation are directly related to the hydraulic conductivity (permeability) of the rock masses involved. Water leakage may have a significant impact on the environment, the construction, and the long-term operation of the project hence it is important to have a good understanding of the groundwater regime and geological features of a site at planning and design stage, so that the water leakage can be properly controlled.

Fangu rock-fill dam will be constructed with a crest length of about 400 m, a maximum height above the river bed level of 87 m, and total storage capacity of about 135 million m^3.

Fangu Hydropower dam will be constructed at the Valley of Fani River that is located in the West North of the Rreshen city in Albania. This zone has a rapid relief with big differences of quotas. The dam is mainly founded on Quaternary's deposits composed by colluvium and alluvial materials, represented by gravel silt clay, beds of sands and silt clay layers with a thickness of about 4.00-6.5 m; Sedimentary and volcanic rocks represented by basalts, mainly strong to very strong, green grey color, fractured and ultrabasic rocks represented by moderately strong green, grey and black color serpentines, very fractured.

According tectonics aspects, in the area where is the place to be constructed the new hydropower there are met some tectonic zones of several meters thick. These zones are found in the contacts between different rocks or inside the same rock.

Fani river valley, the area where the hydropower will be constructed is surrounded from small streams which are very active, especially river Fan which is more active and erodes the base of the rock masses. The level of the underground water is nearly the same in winter and in summer in this zone and it is very close to the surface of the ground (-1.00 m) in major part of the zone of the river bed and very deep in the slop part of the valley. They are neutral water, non- aggressive towards iron and concrete. The level of the underground water depends from the level of the water on the river bed.

The design of earth dams is very much based upon the permeability of rocks and soils. In this regard, special attention is paid to the performance of permeability tests considered as very important and critical for the design of this hydropower dam. The type of test performed is Lugeon test, widely used to estimate average hydraulic conductivity of rock masses. The performance of this test took place in the dam site in nine boreholes at different depths of the rock mass and then was estimated the permeability in Lugeon units (uL) and the coefficient of permeability k (m/s^2).

According test results, the condition of the rock where the dam will be constructed is god, the upper part of rock deposits is destroyed and have high permeability. The rock qualities improve with increasing depth and the rock low permeability.

Considering the geological- engineered conditions where will be build the hydropower is decided that the dam will be a rock-fill type and the foundations will be placed in rock formation depth with low permeability.

Some results on the performance of vertical changes of river beds in Albania based on the monitoring process.

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Abstract

River flow is one of the main factors that influences dynamic relief modeling and its forms. A continuous information of the progress of this process has a role in planning of expectations for eventual oriented measures in problematic cases. The monitoring process of the riverbed morphology provides us with this information for the phenomena that occur in bed, their evolution in time and space, as well as the impact of the human factor in these processes (Rosgen 1996). Under the motto "Monitoring, control and prediction", the making of observations and measurements in the field assumes a continuity and consistency in coverage at any time the state of the riverbed, channel flow and problems of which they are compounded.

The information required is periodic primary measurements taken by field surveying methods through the fixed monitoring profiles installed in the riverbed cross his flow (cross sections). Based on the annually comparative measurements, from 2004 onwards, we could win graphics that reflect recent fluctuations of the riverbed in the places where we have fixed monitoring profiles (Dhimitri 2011). Results presented, often of disturbing proportions in terms of evolution of vertical erosion, will serve to reflect nationallity the way we treat our rivers, and what should we do to improve this situation caused.

Keywords: *Albania, erosion, monitoring process, dynamism of riverbed, morphology*

Introduction

Significant problems are created especially in the last 10 years in the valleys of some of our rivers, mainly intheir lower and middle stream (Lleshi 2002). The most important consequences have been thelevel decrease of the riverbed due to the vertical erosion, damage and soil erosion, pollution of surface and groundwater, demolition of civil or industrial engineering constructions, damage and loss of biodiversity, water flooding, damage of the forests and the whole ecological system, landslide in the river banks, etc. Natural geological processes are generated and accelerated due to the human interventions (Group of Authors 2002). In these conditions, monitoring of the dynamics of morphological changes that occur in river channels, as a completely new experience in Albania, started at 2004 in Erzeni and Ishmi rivers. In 2006, began to extend throughout the river network of our country (Dhimitri 2011). Currently, we have 47 monitoring profiles under surveying distributed on the rivers of Albania (fig 1). It is still a modest number compared with the

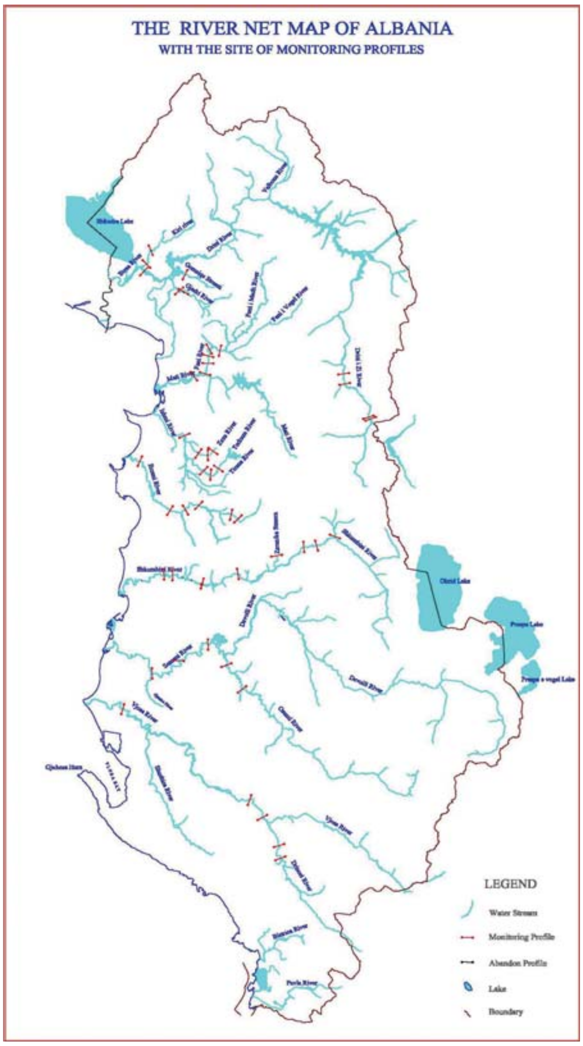

Figure 1. The River net map of Albania with the site of monitoring profiles.

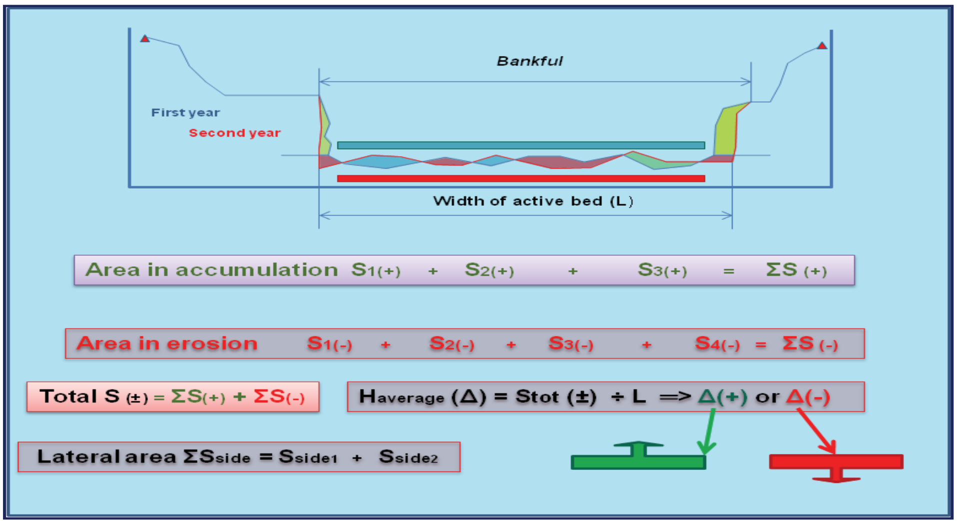

Figure 2. Calculation mode in a monitoring profile

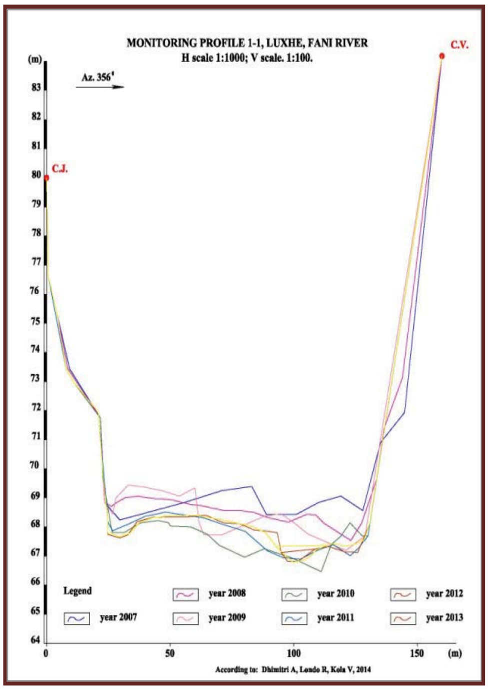

Figure 3. The change of profile lines during years.

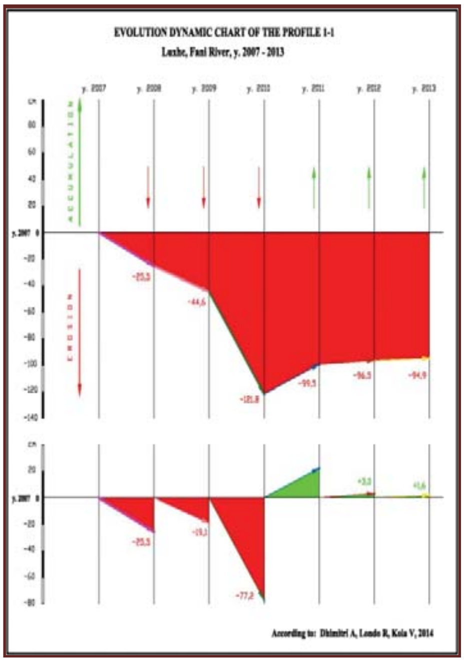

Figure 4. Performance of erosion in monitoring profile, Luxhe.

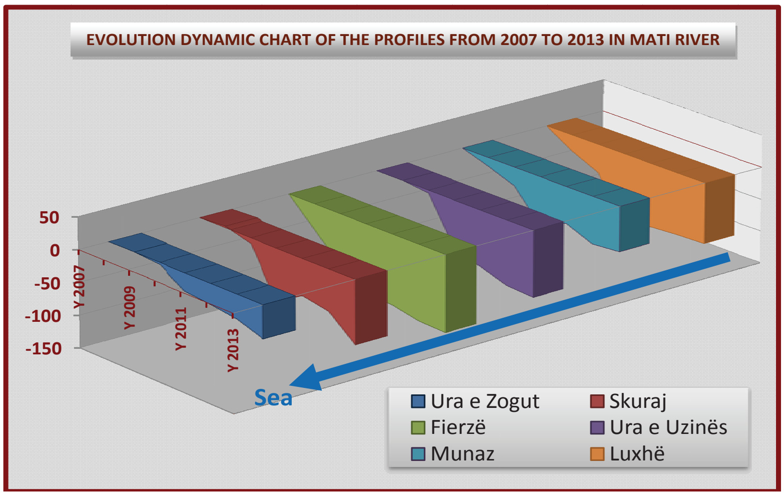

Figure 5. Performance of erosion in monitoring profiles in Mati-Fani river.

multiple problems encountered, but that will grow in the future.

Determining role of the erosion display come from the extraction of river aggregates in an extreme and totally uncontrolled way. Removal of large amounts of sand and gravel from the bed has made possible the activation and acceleration of cutting back erosion (Kondolf 1994). Consequently,the energy on the increaseduring peak water flowsmake possible the extent of erosion in the horizontal direction towards the river banks. This is also reflected in the results shown in graphical representations obtained from the monitoring process.

Methods

Asnoted above, the main component of the monitoring network is the line of monitoring profiles between two fixed centers or other immovable objects. To determine the erosive or cumulative type of the profile and his performance, we calculate all the lines that correspond with each annual measurements.

The change of the profile configuration, from successive measurement to the initial one, determines the sedimentation areas (green color) or erosion areas (red color) in riverbed. The difference of accumulation surfaces (+) and those in erosion (-) gives the trend of the profile. Division of this value by the length of the active bed (the part of the bed where water flow is active) determines the value of Δh, consequently the increase or decrease of the riverbed on his average in its entirety in this

Table 1. The value of vertical changes in the river bed of Albania.

No	River	Profile site	Time in years	Changes	Dynamics		
					E	N	A
1	Drini i Zi	Plepat-Gjoricë	2008–2012	+ 14.6 cm			+
2		Okshatinë	2008–2012	+ 56.3 cm			+
3		Ura e Muhurit	2008–2012	+ 13.2 cm			+
4		Ura e Zall Sinjës	2008–2012	+ 16.8 cm			+
5	Drin-Gjadër	Lumi i Gomsiqes	2007–2013	+ 20.4 cm			+
6		Kullaxhi	2007–2013	– 7.7 cm		+	
7		Mali i Rrëzuem	2009–2013	– 43.3 cm		+	
8		Bardhaj	2009–2013	– 2.6 cm		+	
9		Zalli i Kirit	2009–2013	– 23.2 cm	+		
10		Beltojë	2007–2013	– 41.5 cm	+		
11	Mat-Fani	Luxhë	2007–2013	– 94.9 cm	+		
12		Munaz	2007–2013	– 70.5 cm	+		
13		Ura e Uzinës	2008–2013	– 103.4 cm	+		
14		Fierzë	2007–2013	– 119.0 cm	+		
15		Skuraj	2007–2013	– 98.9 cm	+		
16		Ura e Zogut	2008–2013	– 51.2 cm		+	
17	Ishmi	Zall Herr	2004–2013	– 507.0 cm		+	
18		Çerkezë-Zgafnor	2007–2013	– 4.67 cm		+	
19		Çerkezë-Morinë	2004–2013	– 92.4 cm		+	
20		Kurcaj	2004–2013	– 12.9 cm	+		
21		Verjan	2004–2013	– 200.5 cm	+		
22		Zezë	2004–2013	– 150.5 cm	+		
23		Bilaj	2004–2013	– 0.5 cm		+	
24	Erzeni	Bërzhitë	2005–2011	– 55.0 cm	+		
25		Dobresh	2004–2012	– 150.0 cm	+		
26		Fortuzaj	2009–2013	+ 8.0 cm		+	
27		Pezë-Helmës	2005–2013	– 12.0 cm		+	
28		Ndroq	2009–2013	+ 27.1 cm			+
29		Jubë	2009–2013	+ 25.2 cm			+
30	Shkumbini	Kalush	2006–2013	– 47.4 cm	+		
31		Thanasaj	2006–2013	– 7.2 cm		+	
32		Broshkë	2007–2013	+ 31.2 cm			+
33		Ura e Peqinit	2009–2013	– 27.9cm	+		
34		Labinot	2007–2013	– 8.3 cm		+	
35		Mirakë	2007–2013	– 19.1cm		+	
36		Perroi i Rrapunit	2007–2013	+ 35.9 cm			+
37		Pr i Zaranikës	2007–2013	+ 23.2 cm			+
38	Semani	Ura e Re Berat	2008–2013	– 13.9 cm	+		
39		Ura Vajgurore	2008–2013	– 84.6 cm	+		
40		Ura e Kuçit	2009–2013	– 8.3 cm		+	
41		Imësht	2009–2013	– 78.9 cm	+		
42		Ura e Mbrostarit	2007–2013	– 21.2 cm		+	
43	Vjosa	Andon Poçi	2008–2012	– 41.6 cm	+		
44		Ura e Subashit	2008–2012	– 1.7 cm		+	
45		Tepelenë	2008–2012	– 14.6 cm	+		
46		Memaliaj	2008–2010	– 30.4 cm	+		
47		Ura e Mifolit	2008–2013	– 21.8 cm		+	

(E=erosion; N=neutral; A=accumulation)

profile (Fig. 2) (Dhimitri 2011).

We have to present a synthesis of the entire process carried out by identifying dynamic changes and all modifications that the bedding morphology has undergone in the course of time. There are installed 47 monitoring profiles in all rivers of Albania (Fig. 1). In figure 3 it is shown the lines for each annual measurement in Luxha profile on Fani River, while in figure 4 it is shown the average of the changes inthe profile over the years (successive and partial) (Dhimitri 2011). Figure 5 shows an overview of the progress of all profiles in Mati-Fani River.

Results and Discussion

In table 1 it is shown the results in monitoring profiles in the rivers of Albania. It is noted that in most of the profiles, the process of erosion prevails (Fani, Ishmi, Erzeni, Semani and Vjosa River). We have accumulation of their material in 10 of them, while 9 are considered stable profiles for several years because the amount of sedimentation or erosion does not exceed ± 10cm. Judging from observations made on the the field, it is noticed a direct relationship between the aggregate extraction and decrease of the riverbed in the place where profile is fixed. Of course, the other geological or neotectonic factors are not ignored, but generally, the decrease of riverbeds in Albania is attributed to this extraction.

The number of profiles is modest to give a full judgment for everything is happening in the riverbed, and the measurement techniques used with Total Station instrument requires greater involvement in people and time.

Increase the number of profiles and the exploitation of possibilities for an automation process is our goal. It will make possible a more detailed information and real-time performance on the dynamic changes in the riverbed.

Conclusions

- It is made the parametric evaluation of the progress of erosion and accumulation in 47 profiles installed throughout the river network of Albania.
- There are strong erosion processes observed in riverbeds, which result closely associated with extraction of sand and gravel without criteria and in an extreme mode.
- The rivers where the extractionis limited, represent a stable bed as a subject of natural geological processes of sedimentation or erosion.
- The applied methods for monitoring process of the riverbed are considered the best in actual conditions in accordance with technical equipments available to the Albanian Geological Service.
- The monitoring system that we have installed, although with a modest number of observation stations, has worked with the best.
- The addition of the monitoring profiles and modernization of the process remains the main challenge in the future
- The monitoring results will serve to define the areas that can be used for an oriented extraction, those that must be exploited necessarily, and those that must be conserved. They also serve to orient the measures to be taken in riverbed for eliminating or limiting the damage caused, and to predict theevolution in the future.

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Landslide Susceptibility of Kavaja

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Abstract

In this paper, a GIS-based methodology has been used to produce a landslide susceptibility map of Kavaja located in central-western part of Albania. The landslide inventory was compiled at 1:25,000 scale through: field recognizance to investigate landslide occurrences, collection of historic information of landslides from the Central Archive of the Albanian Geological Survey and interpretation of landslide occurrences from aerial photographs coupled with field verification. For this study the Bivariate approach was used to obtain the susceptibility map. In order to explain these landslides, six landslide casual factor maps were selected and prepared in GIS: geology, slope, aspect, land-use, distance from stream, and seismicity. The landslide susceptibility map is the combination of all Wij of each factor. The final landslide susceptibility map of the study area indicates that the low, moderate, high classes respectively cover 129.7 km^2 (84 %), 14.3 km^2 (9 %), 10.5 km^2 (7 %) of the study area. The high landslide susceptibility zones are predominantly characterized by: the geological features N_1^2(h)c, slope angles between 10° and 25° and West facing exposition slope and Northeast facing slope, the land-use features are urban areas and shrubs, distance from stream 0-25 m, and earthquake zone with magnitude M > 3.5 and I > VII.

Keywords: *Landslide causative factors, Landslide Susceptibility, GIS*

Introduction

In natural systems, landslides are recognized as one of the most significant "natural hazards" in many areas throughout the world (Crozier and Glade 2005). Landslide is a general term used to describe the mass movement of soil and rock downslope under gravitational influence. Landslides annually destroy or damage industrial or residential developments, forest and agricultural land. They result in death, missing people, injury and homelessness. They affect settlements, roads and other infrastructures, constituting a major problem worldwide. Man and nature combine in increasing landslide risk. Climate change has locally increased the intensity of rainfall, raising the frequency of fast moving, shallow landslides. Population growthand the expansion of settlements and lifelines through potentially hazardous areas are increasing the impact of landslides. GIS software has been widely used around the world in landslide hazard management because of its capability to predict in advance potential landslide-prone areas by applying different models and approaches.

The two main methods that are generally applied to landslide susceptibility assessment are qualitative methods, which are direct hazard mapping techniques, and quantitative methods, which are indirect mapping techniques. Both qualitative and quantitative approaches are based on the principle that future landslides are more likely to occur under the same conditions of the past. The methodologies proposed from literature (Van Westen 2004), can be grouped into five categories: direct geomorphological mapping, analysis of landslide inventories, heuristic approach, statistical approach and process based conceptual models.

The Bivariate approach was used for this study. Here, ranking values of each parameter sub-class are based on cross tabulation data which define the spatial correlation between the landslide inventory map and causative factors maps.

Geographical position and Geological setting

Geographically, the study area is about 155 km^2 and is located in central-western part of Albania. Based on morphological features, the study area can be divided into two geographical regions: a) Lowlands' areas are represented by the Adriatic flat plain; b) rolling hills which represent an anticline structure in the centre of study area. The elevation ranges from 0 to 220 m above sea level. The rivers and streams have short lengths and flow through gently sloping as well as flat country side. The Shkumbini and Darci are two major rivers that drain this area.

This area, which belongs to pre-Adriatic depression of Albania geological terrains, consists entirely of Pliocene age molasses formations which transgressively overly formations of the Ionian and

Kruja zones. The main geological formations that outcrop in the study area are Quaternary deposits The upper portion of the lithologicalprofile is made of claystone of Hetmesi formation (N_2H), sandstone-conglomerates of the Rrogozhina formation (N_2R) and Messinianmolasses deposits.

Landslides of the study area and the Bivariate approach

The landslide inventory was compiled at the scale 1:25,000 using fieldwork to investigate landslide occurrences. This was combined with historic landslide information from the Albanian Geological Survey's central archive and the interpretation of landslide occurrences from aerial photographs. 89 landslides were identified in the study area. Each landslide was evaluated in the field using a standard data sheet.

Based on the analysis of the landslide inventory and field work, three major types of slope movement can be identified. Rotational slides occur principally in Q (moraine deposits) and $N_2^1h(c)$ formation. Translational slides occur in the $N_2^r r\ (a)$ geological formation located in the Kryevidhi hills. Earth flows only occur within the $N_2^1h(c)$ formation. The average area of a landslides approximately 1.25 km^2 and depths vary from 1.2 m to 15 m.

In this study, landslide susceptibility analysis was performed using a statistical bivariate method, namely the statistical index (Wi) method. This method is based on a statistical correlation of a landslide map with the different parameter maps. Weighting values of each parameter sub-class are fundamentally based on cross tabulation data defining the spatial correlation between the landslide inventory map and causative factors maps. To perform this, each thematic map was overlaid and crossed separately with the landslides map using ArcGIS 10.1. Weighting values were generated for each parameter map based on the natural logarithm of the landslide density in the class divided by the landslide density ofthe entire map. This method is based on the Van Westen equation (1):

$$(1) \qquad W_{ij} = \ln\left(\frac{A_{ij}}{A_{ls}} * \frac{B}{B_{ij}}\right)$$

Where: Wij - The weight given to a certain class i of parameter j, Aij - area of landslides in a certain class i of parameter j, A_{ls} - total area of landslides in the entire map, B – Total area of the entire map Bij - Area of a certain class i of parameter

Landslide Causative Factors

The causative factors of the landslides were chosen after a careful bibliographical review and associated field investigations. These factors are: geology, slope angle, aspect, land use, seismicity, and distances from drainages. Rainfall data are not used in the analyses because our study area is very small and rainfall accumulation and intensity is more or less homogeneous. The distribution of landslide occurrences, based on statistical index weights (Wij) per causative factor class, is shown in Table 1.

Geology is considered as a fundamental causative factor in this research because it strongly influences slope stability. In this study, a digital geology map of the area was compiled from six geological sheet sat the scale of 1:25,000. From the Table 1 it can be seen that the $N_2^1h(c)$ (Wij =1.23) and $N_2^2r\ (a)$ formation (Wij=0.67) are more susceptible to landslides than the other geological formations. Slope factoris one of the principal factors affecting landslide occurrence. The slope map of the study area is derived from the DEM (digital elevation model) using Arc_GIS10. The DEM is created from isohypse maps which are extracted from topographic maps at a scale of 1:10,000. The slope classes map is generated by separating the slope angles into six different classes i.e. 1) 0°-10°, 2) 10°-20°, 3) 20°-25°), 4) 25°-30°, 5) 30°-40° and 6) >45°. Analysis shows that slope classes 2 and 3 are more prone to landslides than slopes with moderate or steep slope angles (Table 1).

The slope orientation relative to the movement of the sun is another factor that can influence slope failure. The difference in the amount of solar radiation received may result in differences in soil temperature, moisture and soil thickness. The aspect map of the study area is derived from the DEM created from contour lines which are extracted from topographic map at the scale of 1: 10,000. From the results listed in Table 1, it can be seen that West facing (Wij=0.63) and Northeast facing (Wij =0.54) slopes are more susceptible to landslides than slopes with other orientations.

Land-use is the factor related to the effects caused by human activities on landslide occurrence. Excavation of steep slopes for house building, agricultural terraces and deforestation is considered one of the main preparatory factors for landslide occurrence. The land use map is provided by ATTC (Centre for Agricultural Technology Transfer). From Table 1 it can be noted that urban area (Wij=1.52) and shrub (Wij =0.81) land-use areas are more predisposed to landslides compared to other land-use areasbecause human activities and modification of the landscape play an important rolein triggering landslides.

Table 1. The distribution of landslides occurrence for land-use and weight Wij values.

Landslide Causative factors	Parameter subclasses	Area %	Landslide Area %	Statistical Index (W_i)
Geology				
1	$N^2_2rr(b+c)$	11	0	-3.65
2	$AlQh_2$	1	0	-1.24
3	lQh_2	2	0	0
4	$AlQh_1$	41	0	0
5	**$N^2_2rr(a)$**	**10**	**19**	**0.67**
6	$N^2_2h(dk)$	1	0	0
7	$N^1_2h(c)$	12	2	-2.04
8	**d_c_p_Qh**	**23**	**79**	**1.23**
Slope angle				
1	0°-10°	76	39	-0.6818
2	**10°-20°**	**21**	**57**	**0.9879**
3	**20°-25°**	**2**	**4**	**0.9097**
4	25°-30°	1	0	-0.2027
5	30°-40°	0	0	-1.3469
6	>40°	0	0	0
Aspect				
1	Flat	18	0	-4.16
2	**Northeast**	**9**	**15**	**0.54**
3	East	9	9	-0.17
4	Southeast	11	10	-0.10
5	South	11	6	-0.66
6	Southwest	10	14	0.34
7	**West**	**9**	**17**	**0.63**
8	Northwest	15	18	0.22
9	North	9	12	0.28
Land-Use				
1	Agriculture area	60	17	-1.27
2	Not forested	21	42	0.69
3	**Urban Area**	**6**	**28**	**1.52**
4	**Shrub**	**6**	**14**	**0.81**
5	River	1	0	0
6	Forest	6	0	-2.94
7	Agriculture area	60	17	-1.27
Distance				
1	**0 -25 m**	**15**	**30**	**0.71**
2	25 – 50 m	14	21	0.44
3	50 –100m	23	22	-0.06
4	>100 m	48	27	-0.60

The distance from water courses is an importantparameter that controls the stability of a slope. Rivers and streams are extracted from topographic maps at a scale1:25,000. Streams may adversely affect stability by eroding the slopes or by saturating theground i.e. increasing the water content.Four different buffer areas werecreated in the study area to determine the degree to which the streams affected the slopes. Analysis shows thatstream distance classes 0-25 m (Wij=0.71) and 25-50 m (Wij =0.44) are more prone to landslides compared to other stream distance classes.

Seismicity is a major factor in the triggering of landslides. Landslides occur during earthquakes as a result of two separate but interconnected processes: seismic shaking and pour water pressure generation. The study area is divided into 2 zones. The northern part as a much higher recurrence level for major earthquakes. The earthquake records for this zone show magnitudes of 3>M>5 and intensities of I >VI. The southern zone is characterized by micro earthquakes of very low intensity and magnitude of M<2.

Landslide Susceptibility Map

All Wij layers for all the causative factors created in Arc_GIS10 (Appendix) are summed by Eq. (2) in raster calculator in Arc_GIS 10.1 to obtain landslides susceptibility index map. The preparation of a landslides susceptibility map involves, manipulating, analyzing and presenting these data in GIS

(2) $$LSI = \sum_{j-i}^{n} W_{ij}$$

Where: LSI: Landslide susceptibility index, Wij- weight of class i in parameter j, n-number of parameters. The Wij maps of each different causative factor are obtained in Arc_GIS 10.1.

The LSI values in the landslide susceptibility map Fig. 1 of the study area obtained using Eq. (2) in raster calculator. The landslide susceptibility index values range from -2.2 to 0.89. For simplification the map interpretation the LSI values are divided into three different susceptibility classes, which are: Low landslide susceptibility LSI <0.25, moderate susceptibility 0.25>LSI>0.5, high susceptibility LSI>0.5. From the comparison of the landslide inventory map and susceptibility map, the area in the landslide inventory map showing where landslides occurred matched the data on the landslide susceptibility map. The area of each susceptibility classes and landslides occurrence in this susceptibility classes are showed in Fig.1

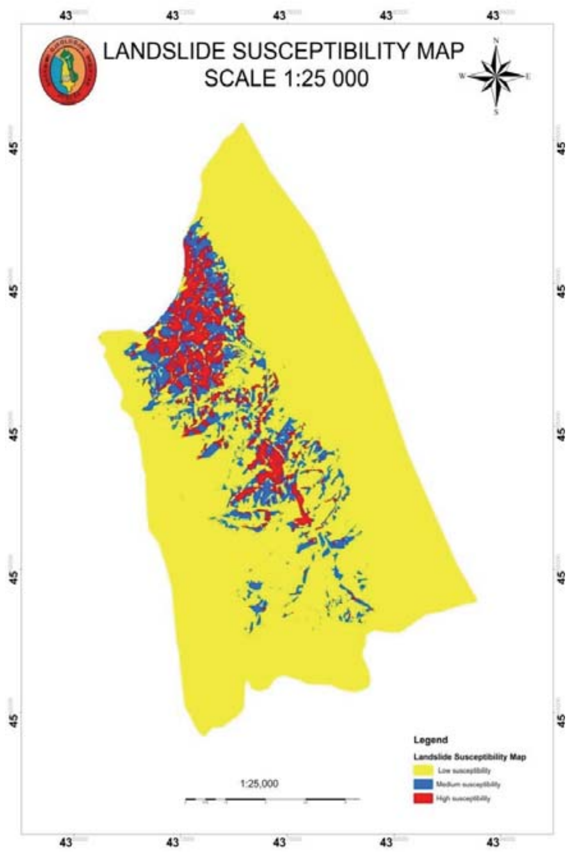

Figure1. Landslides occurrence in susceptibility classes

Conclusions

Landslides susceptibility mapping are very necessary due to the strong impact of these processes on people and their goods. The landslide susceptibility map is a useful tool in urban planning, specifically for the definition of the land use zones and for the design of future construction projects. The final landslide susceptibility map of the study area indicates that the low, moderate, high classes respectively covering 129.7 km^2 (84 %), 14.3 km^2 (9 %), 10.5 km^2 (7 %) of the study area. The detected landslide areas in the low, moderate, high and very high landslide susceptibility classes are respectively 0.11 km^2 (9 %), 0.43 km^2 (34 %), 0.71 km^2 (57 %). The high landslide susceptibility zones are predominant characterized by the geological formation $N_2^1h(c)$, slope angles between 10°-25° and west facing exposition slope and northeast facing slope, distance from stream 0-25 m, earthquake zone with magnitude M>3.5 and I>VII. This preliminary map should serve as a positive model to be applied in other region with similar geological conditions as Kavaja.

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Geoenvironmental Peculiarities of the Territory of Georgia

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Abstract

Uncontrolled relationship between the humanity and nature is a bigger threat to the existence not only for nature but also for human. The modern development of the industry, together with the positive factors gave rise to a negative tendency that is expressed in the global pollution of our Planet. The territory of Georgia is not exception. Based on the results of our study in 2000-2012 years, the general state of contemporary geo-environmental protection of Georgia strongly affected as geochemical, hydro chemical, biochemical and radiological pollution and man-made waste. Special concern is caused by mining industry. The environmental pollution index near the mining enterprises reaches catastrophic values. These is the Madneuli (South-East Georgia) copper-gold mine, Chiatura (Central Georgia, Imereti district) manganese deposit and now not operational Uravi (North Georgia, the Southern Slope of the Greater Caucasus Ridge) arsenic deposit and processing plant. At these facilities has been a steady deterioration of the geoecological conditions.

As a nuclear pollution of anthropogenic origin (recorded after the Chernobyl accident), in Georgia there are natural radiation anomalies of U, Ra, Th, K etc. These anomalies in the majority of cases are associated with granites (mainly Paleozoic time) and Middle Jurassic coal rakes and are often located near settlements. 2012 years research showed that the level of contamination of anthropogenic origin has decreased. According to the results of hydro geological and hydro chemical investigations of the rivers water in Georgia, we indicated three types of their environmental systems: well-protected; poorly protected; not protected. Bacterial contamination of the river's waters was observed in the western part of Georgia (on the Black Sea coast), where the industrial waste water flows into the sea and pollutes the coastal zone.

As a result of these studies is create 1:500 000 scale geoecological map of the territory of Georgia. Our studies have shown the necessity for continuous geoecological monitoring of the territory of Georgia.

Monitoring of geological hazards of environment in Slovakia

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Abstract

Environmental monitoring is systematic, in time and space defined observation of specific characteristics of environmental compounds at selected sites (in general, forming the monitoring network) or influences acting on them, which with some degree of interpretation ability represent a monitored territory, with option of extrapolation to a larger territorial unit. Partial Monitoring System of Geological Hazards (PMS GH) in Slovakia is an inherent element of the national environmental monitoring network, which comprises 10 relatively autonomous systems. However, some of these systems are mutually interlinked and for the assessment of geological hazards vital are data from the systems Climate, Meteorology, Water, Wastes, and Radioactivity.

The PMGS GH is mainly focused on those geological hazards occurring in the conditions of the Slovak part of the Western Carpathians, i.e. adverse natural or anthropogenic geological processes that threaten the natural environment, and ultimately humans. The main intentions are:

- regular monitoring of changes and dependencies of observed characteristics, forecasting the scenarios of the processes activity, verifying the authenticity of forecasts in practice, determination of critical alert levels and their verification;
- generalization of these findings to the territory of the same geological structure and terms of landscapes and checking the validity of such generalizations.

Recently, the PMGS GH consists of 8 subsystems:

01 Landslides and other slope deformations;

02 Tectonic and seismic activity of the territory;

03 Anthropogenic sediments of the nature of environmental loads;

04 Impact of mining upon environment;

05 Monitoring of radon bulk activity in the geological environment;

06 Stability of rock massifs underlying historical objects;

07 Monitoring of alluvial sediments;

08 Volume unstable soils.

Almost 20 years of the monitoring networks operation has already provided immense series of well-justified data, which allow us to identify the outliers in the values of observed characteristics. In several cases these excesses led to informing the respective bodies of state administration, self-governments and other relevant institutions about impeding danger of, for instance, landslides, onrushes of water from abandoned mining works, aggravation of potable groundwater quality, etc. Moreover, in some landslides sites, the early warning systems have been developed (Veľká Čausa, Okoličné).

In 2010, the Eastern Slovakia was heavily impacted by hundreds of slope instabilities due to excessive long-term precipitation. The monitoring system yielded vital data for properly oriented engineering geological surveys and consequent corrective measures. In the case of mass movements these data are of immense importance, because in addition to almost yearly recurring floods, slope movements in Slovakia are perceived as the most impeding geological hazards – about 5.25 % of the territory is disturbed by them.

Due to tectonic dissection of the Western Carpathians and their contact with Pannonian Basin Slovakia is regularly hit by seismic quakes of macroseismic levels. These events are monitored by the National Network of Seismic Stations (12) with additional local stations.

The monitoring data and their interpretation are yearly submitted to the Section of Geology and Natural Sources of the Ministry of Environment in the form of annual reports, which are regularly opposed and after their approval published on the project website http://dionysos.gssr.sk/cmsgf/. The website is linked with the State Geological Institute of Dionýz Štúr website www.geology.sk and the Slovak Environmental Agency www.sazp.sk.

The necessity of an anti-seismic law in Albania based on NDSHA method of risk calculation

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Abstract

The high seismic activity of Albanian territory is well known. A system to monitor this activity began to be constituted since 1968 with the first seismographic station in Tirana. After that, from 1976 until 1995, 14 stations, called Albanian Seismological System Network (ASN) (Muço et al. 2001), were installed to monitor the entire Albanian territory. This network collects data about seismic activity also in collaboration with networks of neighborhood countries (Ormeni 2008/b; Ormeni and Milushi 2012; Ormeni and Dushi 2012).

Key words: *NDSHA, seismicty characteristics, geologial setting, miratory waves, chaotic informal urbanization*

General seismicty characteristics of Albania.

The seismicity of Albania is characterized by an intense microearthquake activity, by small and medium sized earthquakes, and seldom by large ones (Muço 1995; Ormëni and Marku 2009), wich are possibly linked with the low velocity layers of Albanian crust (Ormeni 2008). For different parts of the territory, beginning from ancient times, seismic events of large size are reported, which have caused large damage.

Large events are rare but with serious consequences. The continental collision and low velocity layers not only directly influence the activation of longitudinal faults on the edges of the orogen and on the segments of transversal faults cutting through this contact, but has a tectonic implication even on the inner part of the country.

The most damaging earthquakes and in the same time, the ones with highest magnitude for the country during last century, are: (1) the Shkodra earthquake of June 1, 1905 with MS=6.6 (Sulstarova and Koçiaj 1980), (2) the earthquake of Ohri Lake, February 8, 1911, with MS between 6.4 and 6.7, (3) the Tepelena earthquake, November 26, 1920, with MS between 6.0 and 6.4, (4) the Durres earthquake, December 17, 1926, with MS between 5.8 and 6.2, (5) Dibra earthquake of November 30, 1967, with MS from 5.5 to 6.6 and (6) the Montenegro earthquake, April 15, 1979, with MS between 6.6 to 7.2 (Muço 1992; 1995) (Fig. 1).

The typology of the earthquakes in Albania comprises all four primary and well-known types of earthquakes: earthquakes with main-shock followed by aftershocks, earthquakes with foreshocks, main-shock and aftershocks, swarms and compound earthquakes.

The earthquake foci are concentrated mostly along active faults. The most important seimogenic zones of the country are: (1) the Ionian-Adriatic longitudinal seismogenic zone, which marks the boundary between the Adriatic microplate and the Albanian orogen, (2) the Mat-Moker-Bilisht longitudinal seismogenic zone, (3) the Drini-Ohri-Korça seismogenic zone, (4) the Shkoder-Peja transversal seismogenic zone, (5) the Lushnja-Elbasan-Diber transversal seismogenic zone and (6) the Vlora-Tepelena transversal seismogenic zone (Aliaj and Muço 2000) (Fig. 1).

In Albania the seismic hazard evaluation is carried out on a probabilistic way, based on the intensities of strong historical earthquakes, the earthquakes of this century as well as on seismotectonic synthesis.

Briefly on geological setting of Albania

The geological environment of Albania, although it's small geographic surface, is very interesting. Divided into 13 tectonic zones, 12 of which are grouped into two greater divisions Inner and Outer Albanides, and the thirteenth division is exempted from those groups, but is divided in Adriatic and Albano-Thessalian Depressions, the geology of Albania includes a wide range of rocky types (Fig. 1). Those types present a whole lithologic column, beginning from the Erath Mantle to they still unconsolidated, recent depositions. From the point of view of geological age, these formations start from the Ordovician-Silurian (Korabi tectonic Zone) up to Holocene (depressions).

The tectonic activity in Albania is visible, in both features, vertical and horizontal. Two traversal faults, permeate Albania in west-east direction (numbers 4 and 5 in Fig. 1), having contact with quasi all of tectonic zones, which are oriented northwest-southeast direction. The first one Scutari-Pec, in north Albania serves as dividing boundary between Albanian Alps tectonic zone and tectonic zones of Inner Albanides, situated south of this fault. The second, sometimes called Vlorë-Elbasan-Skopje, divides in half the geographic territory of Republic of Albania, following the river valley of Shkumbin, and the same time dived in northern e southern part the Inner Albanides, and is a quasi geographic border between Outer Albanides and Adriatic Depression.

In general, the tectonic zones of Albania have over thrust relationship, process which has superimposed them on each other east toward west.

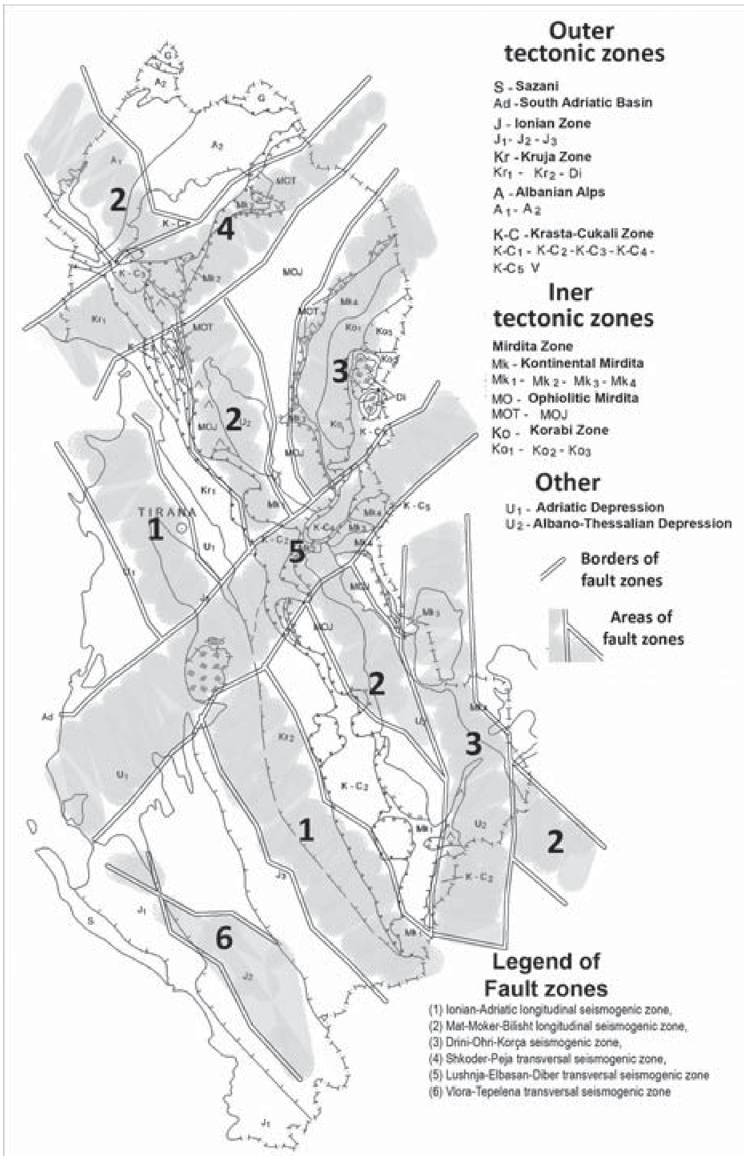

Figure 1. Schematic map of Albania, which combine tectonic zones of Albania with their fault zones (after Sokol Marku based on Muço et al. 2001, SHGJSH 2010&2012).

The problematic posed by cities expansion

A demographic balance stabilized for centuries, was interrupted in Albania after the political changes of the year 1990. This was characterized by two directions of internal migratory movement:

Figure 2. Examples of new construction in free spaces between old existent buildings. Tirana (photo. by S. Marku).

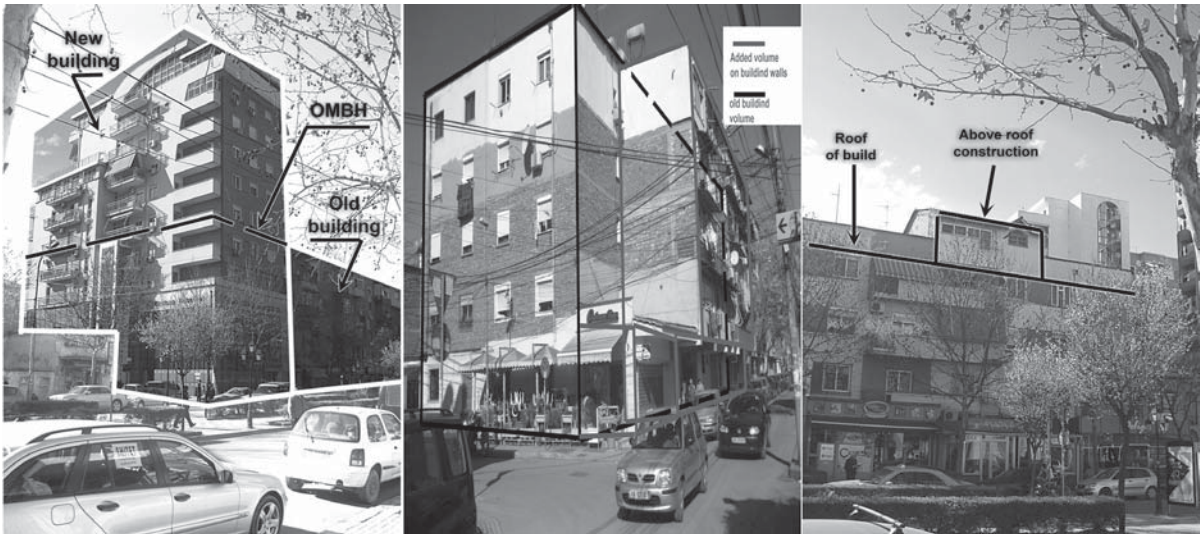

Figure 3. Examples of constructions in Tirana, close to an older and lowerst build (left)(OMBH-Old maximum building high of Tirana, 4-6 flors about 11-13 meters), addition on the walls of old bulid (center) and above old roofs (right) (photos by S.Marku).

(a) from peripheral areas to big cities of Western lowland, and (b) from rural areas to cities. Now, as a consequence of this movement, the population of Tirana is increased from 9 % of the total population of Albania, to about 26 % of this total.

This migratory movement was accompanied with elevate request of building construction. The solution was a chaotic informal urbanization. This urbanization process included not only free areas from builds, but and in areas between existent building (Fig. 2), intervention for adaption in building basements, intervention on external build walls for building enlargement (Fig. 3, center), elevation of old houses above existing roofs (Fig. 3 right).

Few words, the expansion of Albanian cities in general, and of Tirana in particular, is characterized by a real chaos, which so far is not based on any study on vulnerability in case of earthquakes.

Studies performed to date, based on the seismic zoning rate periods before the outbreak of migratory movements, and consider building characteristics, considering them as independent units from each other. If we take into account that Tirana and other cities, host of migratory waves, not respect the norms in construction engineering, leads to the conclusion that, norms, according to which, the seismic risk estimated today do not provide assurance that the effects of fluctuations possible, and if moderate, will have consequences harmless or insignificant.

For this, there is an urgent need to develop a series of measures, summarized in a specific legislation on anti-seismic measures in Albania. This plan on account of the recent global experiences must rely on calculations based on NDSHA method, which takes into account all factors that can lead to concrete negative consequences during the seismic event (Panza et al. 2001, 2012, 2013; Peresan et al. 2013).

Albania still lacks the necessary legal basis to determine antiseismic measures.

Recent catastrophic events occurred not only in Japan but also in our neighbor Italy, require that this legal basis is drafted, taking into consideration lessons learned from global experiences.

Today a large number of researchers around the World (http://www.issoquake.org) are strongly supporting the definition of anti seismic measures based on NDSHA method (New Deterministic Seismic Hazard Analysis). NDSHA should be taken into consideration in Albania too, where the daily increase of the building activity, is concentrated around Western Lowlands, an area created by post Pliocene tectonic movements, still very active.

New constructions, distributed over the Earth surface with even greater density than before, increase the risk of possible disasters, and make invalid the rules established so far for seismic zoning.

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Engineering geology mapping on urban area prone to landslides, Vlora, Albania

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Abstract

In the present paper are shortly described the results of engineering-geological mapping in which a special attention has been shown to mass movements with respect to urban development and planning of Vlora town. The studied area is located in the southwestern part of Albania along the Adriatic coastline. It is one of the most beautiful areas in Albania, as it includes many attractive beaches. In last decades large movement of population has occurred in this area, as result of socio- economic changes in Albania. In order to precede the intensive urban development in this area it was necessary to perform engineering-geological studies, which will help to support the institutions and planners for a more rational use of geologic environment as well as to provide solutions that are economically feasible. These studies will also provide support to design institutions and experts for a more accurate design of engineering structures in urban areas and in particular those located on hilly slopes so as to avoid as much as possible any geological hazards like landslides, erosions, etc. as well the need to know what steps of engineering measures has to be taken. This work presents the results of engineering-geological mapping carried out for the Vlora's urban area on scale 1:10,000. The aim of this study was to provide detailed information on lithology, geomorphology, geodynamic phenomena, soils and rocks physical and mechanical properties and, finally, conclusions and recommendations.

Keywords: *hill's slope, mass movements, earth flow.*

Methodology

The purpose of engineering geological mapping for the urban area of Vlora town is to provide information about the characteristics of terrain for the sake of planning, land use and geo-hazard evaluation. In recent years information about ground conditions of urban environment has received increasing importance, confirmed by the problems resulting from unfavorable geotechnical conditions (landslides, erosion, collapsible soils, etc.). Vlora town has been in the last years occupied very rapidly and uncontrollably by many engineering objects like residential buildings, roads, etc. It should be noted that besides lying on flat urban areas a lot of such engineering structures (2-3 storey residential buildings and roads) are built over hilly areas, which have affected the stability of slopes. As a result, most of these slopes have begun to slide down. In these conditions, in order to precede the urban development and provide due protection to residential buildings and roads, it was necessary to conduct the required engineering geological works in this area. This is why during period 2009-2012 a detailed engineering geological mapping was carried out on scale 1:10,000 (Muceku et al. 2013). The work in connection to this study has been made in three phases: (i) data collection and desk study; (ii) field and laboratory works; and (iii) interpretation and correlation of the data obtained from field and laboratory tests, and the compiling of engineering geological map together with preparation of engineering geological study. During the first phase were studied geotechnical papers, reports and historical maps showing rating of landscape and previous hazard areas. While during the second phase the work is made in the field according to engineering geology mapping on scale of 1:10,000. The earth surface was observed from this work in relation to geotechnical characteristics of soils and rocks, rock depth, rock's weathering crust, geological structure and discontinuities, resulting active erosion, hydrogeological features (underground water-table and types, aggressiveness features against irons concrete), fluvial and coastal changes, tectonics activity and slope mass movements. In this phase were performed several exploration works such as boreholing (10.0-15.0 m to 20.0 m deep), the pick-up of undisturbed, disturbed soil and rock specimens, which are analyzed in laboratory to determine the mechanical and physical properties, including the following: grain size distribution, bulk density, Atterberg's limits, moisture content, specific density, oedometer test, shearing box (φ-internal friction angle, c- cohesion) and uniaxial compressive test for rocks etc. In the third phase were enlightened the outcomes of the first and second phases through interpretation and correlation of data obtained from desk studies, and results of field and laboratories work, from which it was made possible to prepare the engineering geology map in scale 1:10,000 and geotechnical texts that have depicted the observation synthesis, field measurements and laboratory results based on the goals of the investigation.

Results

It should be noted that the data supply are in compliance with the respective investigation phase for engineering-geological mapping in scale 1:10,000 with special attention to mass movements for urban development and planning purposes of Vlora town. In this respect, within the framework of set up tasks and objectives for the assessment of engineering geology features of the study area are applied the followed criteria: (i) geology, (ii) geomorphologic features, (iii) mass movement and (iv) soil and rock physical mechanical properties, which are being described below.

Geological setting

The studied area is geologically built of Quaternary, Molasses and Premolasses deposits (Xhoma et al. 2009).

Quaternary deposits: These deposits are widespread in the whole of study area. They are found on flat areas (marine deposits), which represent the lowlands of Vlora's territory and are also part of the Adriatic coast. These soils cover mostly the hill slopes. The engineering-geological and geotechnical investigations carried out in the flat morphological unit (from top to bottom) have shown that it is represented by beach deposits (fine to coarse sands and sand-silt mixtures), 4.0-6.0 m thick, swampy and lagoon deposits (organic silts and silty clays, inorganic silts and very fine sands) with a thickness of 15.0 m up to 25.0 m that are spread out on the east of beach sands, as well as marine and lagoon deposits (inorganic silts and very fine sands, sand-silt mixtures) with a thickness of about 20.0-70.0 m, which are extended in the lower part of lithological profile below of the above deposits. Mostly of the hills slopes are covered by diluvial soils with thickness 1.5-7.0 m. They consist of inorganic silts and clays and very fine sands. The soils of hill slopes consist of inorganic clays and very fine sands.

Molasses and Premolasses deposits: The hills that form this zone are built by molasses of Lower Pliocene (N_2^1h), Upper Messinian (N_1^3m), Tortonian (N_1^3t), and premolasses deposits of Aquitanian (N^1_1a) Burdigalian (N^1_1b). The molasses deposits are generally composed of claystone and siltstone rocks intercalated with sandstone layers, beside of molasses of Lower Pliocene (N_2^1h), which consist of claystone and siltstone rocks.

Morphology characteristics

From the geo-morphological point of view this zone represents a flat-hilly terrain with various features such as flat areas, slope mass characteristics, drains, concave and convex slopes, extent and type of vegetation, etc. The flat area extends on western part of Vlora town whereas in the east are located a series of hills which extend in chain shape from north to south. The study area is intensively affected by differential tectonics movements, which have occurred during the neo-tectonic stage of geological development. The whole landscape of the flat unit lies between quotas of 0.5 m (beach sands) up to 10.0-13.0 m above sea level. While the other morphological unit is represented by Kanina-Radhima hills with heights ranging from 88.0 m (Kuzbaba), 117.6 m (K. Topit) up to 382.7 m (Kanina castle), 628.0 m (M. Ledhes) and 736.0 m (M. Sturos) above sea level. In general, the slope angle of hills ranges from 12°-35° in K. Topit -Kuzbabai hills and 20° up to 35°-40° in Kanina-Radhima hills.

Mass movement

The hills zone in the study area is much affected by active landslides. The mass movement occurrences in this zone and their spreading has pointed out that their activity is closely related to the geomorphology, lithological formations, geological structure, geotechnical properties of bedrocks and soils, neo-tectonics active faults, seismicity, relationship between slope's angle direction and dip inclination angle of molasses and premolasses strata, precipitation events and manmade works (Fig. 1). As mentioned above, most of the hilly areas are generally represented by slopes, with angle varying between 15°-35°, that are built by rocks with low geotechnical parameters (very weak and weak rocks) and soils as well as high precipitations at range of 1.200-1.400 mm/year (Themelko et al. 1996) which have contributed to mass movement phenomena (Muceku et al. 2014). From field works has resulted that the mass movements are of earth flow type (Cruden et al. 1996). As shown in Fig. 1, they have occurred on the hill slopes with angle that

Table 1. Physical and mechanical properties of geotechnical units of hills slopes soil.

Geotechnic unit no.	Wn %	γ kN/m3	γo kN/m3	ϕ (o)	c kPa	τc kPa x104	Soils & Rocks Type USCS
no. 1	28.9-30.8	18.0-18.5	26.7-27.0	15-18	12-19	-	CL-ML
no. 2	23.5-25.7	19.0-19.6	26.8-27.0	18-22	20-35	-	CL-ML
no. 3	8.2-13.8	21.6-22.9	25.1-25.5	28-30	65-98	-	CL-ML
no. 4	3.90-6.50	23.1-24.0	25.4-25.9	-	-	0.19-0.22	claystones
no. 5	4.6-7.2	25.4-25.7	25.6-26.1	-	-	0.53-0.65	siltstone-sandstones

W_n-water content, γ-Bulk density, $γ_o$-Specific density, ϕ-internal friction angle, c- cohesion, $τ_c$-unaxial compress strength).

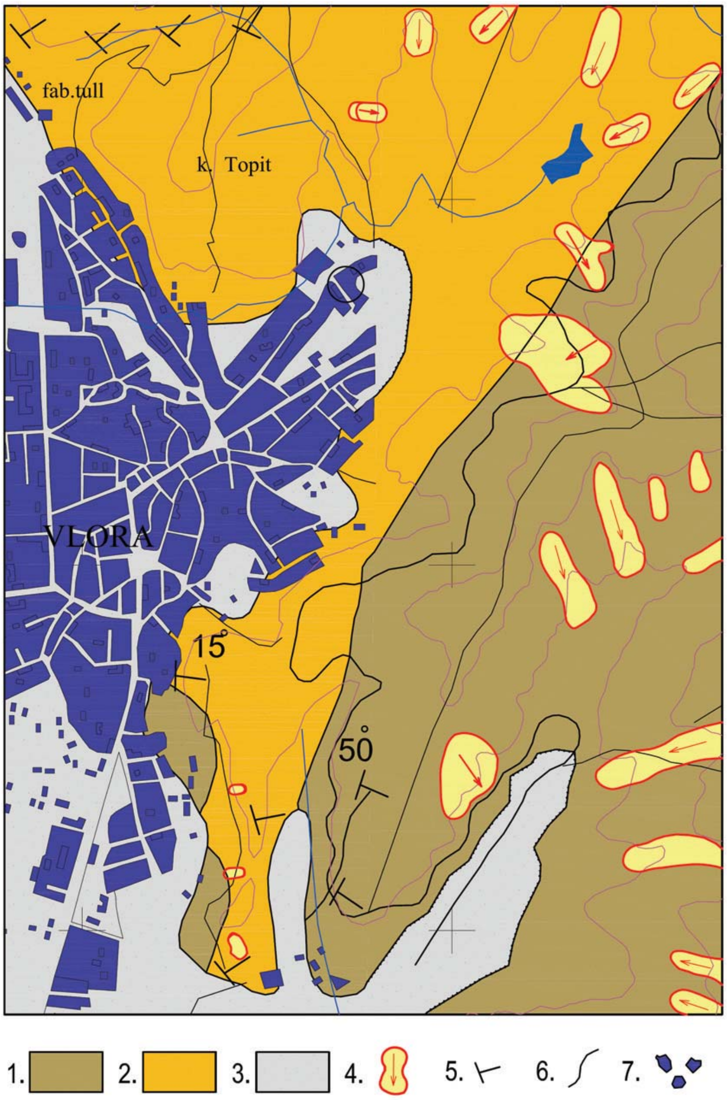

Figure 1. Engineering geological map of Vlora urban area on scale 1:10,000.
1. Engineering geology zone of weak rocks, 2. engineering geology zone of very weak rocks, 3. engineering geology zone of soils. 4. earth flow, 5. bedding with amount of dip, 6. normal boundary, 7. Vlora town.

exceeds 15^o. The landslides are 20.0-70.0 m long, 15-50 m up to 120 m wide and 2.5-3.5 m up to 6.5-7.5 m thick. The earth slide material consists of inorganic silts and clays with sands and gravels. The ruptured surface extended in the direction of movement whereas the state of activity of mass movements is active during heavy rain periods.

Physical mechanical properties

As a result of the analyses made on mass movements in urban area of Vlora town, in this paragraph are shortly treated only the physical mechanical properties of soils and rocks in the hilly zone. Numerous soil and rock specimens have been taken from field works and tested in the laboratory for their physical and mechanical properties. Based on these tests several geotechnical units are determined (Fig. 1, Table 1). The geotechnical unit no.1 represents the hill's slopes soils, which are composed of inorganic clays and silts with low to medium plasticity "CL and ML" type (Samtani et al. 2006), beige color, in medium-stiff consistency. They are 1.5-7.0 m thick. The geotechnical unit no. 2 build the landslides bodies. They consist of inorganic clays and silts "CL and ML" type (Samtani et al. 2006), medium consistency with thickness 1.8-3.0 m up to 4.5-5.5 m. Below this unit we have the geotechnical unit no. 3, weathering crust of weak rocks, 1.5-3.5 m thick. Also, in studied are distinguished the geotechnical unit no. 4 and 5, represented by claystones and siltstones-very weak rock (Romana 1996) and claystones and siltstones intercalated by sandstones layers-weak rocks (Romana 1996). The mean geotechnical properties of soils and rocks are given in Table 1.

Engineering geological map

The engineering geological map on scale 1:10 000 (Fig. 1) was prepared based on lithological, morphologic, mass movement and soil and rock physical mechanical properties criteria. The mapped area was divided in several zones corresponding to different lithological composition. According to geomorphologic criterion, the studied area is separated in two morphologic units, which are the hilly and flat morphologic units. The soils and rock physical mechanical properties made possible to distinguish rocks (very weak and weak rocks) and soils (cohesion and cohesionless), which are presented on the map. A careful consideration was dedicated mass movements evaluation, which are distributed in eastern part of mapped area over hills slopes with angle 15^o-35^o (Fig. 1).

Conclusions and recommendations

From engineering geological mapping on scale 1:10,000 was concluded that hills area of Vlora town is much affected from mass movements-earth flow, which constitute a real risk for of the citizens.

For protection of the engineering objects (buildings, roads etc.), which are threatened from mass movements occurrence is it necessary to take the engineering measures.

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Structural origin of landslides in the Vistula River source area (Silesian Beskid, Outer Carpathian, Poland)

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Abstract

The Vistula source area is situated on the western slopes of the Barania Góra Range in the Silesian Beskid Mountains (Polish Carpathians). In 2010-2012 as a result of cartographic work author recognized more than 170 landslides. Mapping has been carried out within the Landslide Counteracting System (SOPO). Research area is built by flysh rocks of the Silesian Unit of the Outer Flysch Carpathians. Northern part of research area is dominated by Upper Cretaceous medium to thick-bedded sandstones of the so-called Upper Godula Beds, interbedded by shales and thin-bedded sandstones with the Malinów Conglomerate, local litostratigraphical horizone, in they upper part. They are covered by thick-bedded coarse grained sandstone of the Lower Istebna Beds, which outcrop in the southern part of research area. All these rocks are monoclinally lying to the SW or S at an angle 10-30º. Most of recognized landslides are the complex with various types displacement and some of these colluviums contains longest caves in the Polish part of the Outer Carpathians (e.g. Wiślańska Cave and Miecharska Cave). Formation of these landslides predominantly depended on tectonic structures and regional seismic activity. Study area is one of the most active areas in Poland. Research were based on the analysis of lineaments of the Digital Elevation Model (DEM), aerial radar photography, topographic maps and the measurements structures (faults, joints) and bedding planes in outcrops. They showed relationships between formation of the main and minor landslide scarps, tension cracks and existing faults and joints in rocks. Most displacements of rock masses occurred consequently or obliquely to the beds dip (to SW or S) along SE-NW and ENE-WSW oriented discontinuities. The differences in the development of precipitates rocks were also significant for a few landslides. Highly anisotropic Upper Godula Beds were weighted down by the overlying more homogeneous Lower Istebna Beds (southern part of research area) or by the Malinów Conglomerate (northern part). In the upper part of these landslides colluviums are large size blocks. The biggest landslide complexes induced by tectonic condition of the region have been identified in the Gościejów Valley, Malinka Valley and especially especially in more detail studied in the Biała Wisełka Valley. The Biała Wisełka Landslide Complex (an area of 350 hectares) is a ones of the biggest in the Polish part of the Outer Carpathians. These landslides development along ENE – WSW direction normal faults, which are parallel to the regional scale folds axis. Their main and minor scarps reach the height of 30 meters. The minor scarps probably are result of faulting, slumping and sliding blocks of the hanging wall of the fault. At the foot of highest scarps were created deep tension cracks. Toe reach the height of 10 meters. The Biała Wisełka Landslides Complex has been segmented along SE – NW trending oblique-slip faults. The scale of recognized mass movements that produced the very varied morphology of colluviums shows the catastrophic processes of the landslide developments in historical time. Furthermore, as a result of research at the map was applied many, not recognized earlier, faults. This fact proves that detailed recognition of the issues connected with geohazards may lead to very important conclusions in terms of regional geology.

Protection against rockfalls at the historical site of Berat

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Abstract

Berat is an old city in Albania with more than 2500 years history. This city is known for the particular architecture of some quarters composed by houses situated in the face of the hill, on top of which there is a castle. The houses, with many windows are situated one above the other. Therefore Berat is called also as the city of "one above the other windows".

Houses of the old part of the city, situated along the slope of the hill, are under threat of natural hazards associated with the possibility of rockfalls. In the lower part, is the main road at the entrance to the city from Tirana. The road is often full of cars and also serves as a place to walk for many people. In the half-height of the hill is situated an old church also exposed to the rockfalls. In fact (referring only to last 3-4 decades), have been identified many dangerous blocks. Some of them have fallen, putting at risk the lives of many people. The last one, the fall of a rock block of about one cubic meter in the cartier of Mangalem in July of 2009, going through a house and finishing in the street on a parked car, pointed again the danger for the lives of the residents and their property. After that, the situation was considered as an emergency and a detailed study was considered necessary in order to avoid similar situations and to ensure a long-term stability.

This paper aims to identify the degree of danger posed by the rockfalls and to propose possible measures to reduce and eliminate the risk. To guarantee the protection against the rockfalls, is proposed to cover the entire slope with hexagonal wire mesh and to apply an individual bolting support to potentially instable blocks.

The entire potentially instable area is divided in five zones: zone A, B, AB, C and D. The zones A, B, AB, and C, with a total area of about 41 thousand square meters, are characterized by the fall of rock blocks. In each zone, the wire mesh will be unrolled from the upper to the lower part, and temporarily will be attached in the trees in the upper part of the slope. After that, the wire mesh will be fixed in the upper part by rock bolts and it will be conducted the removal of unstable blocks in the area under the wire mesh. Finally, the wire mesh will be fixed by rock bolts following the entire mesh surface.

The zone D, with an area of about one thousand square meters is characterized by flysch rocks and potential instabilities in form of sliding. This area, in its lower part is separated by the national road by a wall having a height of 1.5 meters. To guarantee the stability and to protect the national road, it is proposed to ensure the slope stabilization by the application of flexible mesh membranes fixed by anchors according the entire surface. As supplementary protection measure is considered the raise of the wall for another one meter.

For all the cases, calculations are performed in order to ensure the right support capacity of the entire structure and the long term stability. In addition, comparison is made with the schema proposed by Geobrugg AG considering the use of rockfall protection barriers.

Development of LILW repository in Slovenia

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Abstract

Slovenia has a relatively small nuclear program with limited amounts of radioactive waste and spent fuel production. But in accordance with the international and national standards it is developing all necessary facilities for disposal of this waste. In the last few years the work is focused on development of low and intermediate radioactive waste (LILW) repository for which in 2010 the site was adopted with a governmental decree on the National Spatial Plan for LILW repository at Vrbina site in Krško municipality. Possible natural hazards for such repository on the adopted site could be:

- Seismic hazards with an event during the construction or emplacement period of repository

- Geo-mechanical hazard on underground structure stability within the construction time

- Ecological (geochemical) hazard caused by inadequate sorption properties of the hosting soil and on radionuclide pollution.

During the last decade different investigations and planning activities have been performed in order to construct the repository. Extensive geological, hydrogeological, geotechnical and geo-chemical field investigations have been carried out in three phases supporting the preparation of safety analyses for repository and its design.

The most important activity at the starting phase was siting and site characterization for the repository. In the first step, characterization of two most promising sites took place, but after the siting was completed, the characterization of the selected site at Vrbina, Krško continued in two successive phases among which the last one is still running.

Characterization is devoted to the determination of geological structure on the site, the hydrogeological model (groundwater level in two different aquifers, groundwater water flow direction, piezometric water levels, etc.), geomechanical model (differentiation of "homogenous" zones with similar mechanical characteristics, determination of physical, deformation and strength parameters for each of the units) with prediction of behaviour under different loading conditions (construction, earthquake, etc.), and geochemical model, together with sorption and other chemical parameters important for the safety analysis. At the same time, the zero state capture on radionuclides, heavy metals and other human contamination has been taken.

In former steps, the wider area has been investigated, while the lust, running step is devoted to the characterization of the hosting soil in immediate vicinity of the silo repository.

The findings so far show that the silo underground repository is feasible but not easy to construct and much care should be taken for sufficient support at all phases of construction, to minimise disturbing of the hosting rock.

In parallel, with the aim to decide on the optimal technical design of repository from nuclear and radiation point of view the Special Safety Analyses has been performed for three repository types at Vrbina location, close to the NPP Krško:

• for a surface vault – type repository, constructed on artificial embankment (variant E),

• for a near-surface silos – type repository (variant B), and

• for an underground repository (variant D).

The safety assessment of the three repository types consisted of dose assessment for workers within repository through its operating and closing phase: for the normal evolution of events and for abnormal events, as well as for the post closure repository phase: for the design scenarios and for some alternative scenarios.

The assessment has been performed in accordance with the IAEA recommendations and Slovenian National Regulatory Acts. With the first step, potential events have been identified and in accordance with the repository type characteristics and scenarios have been developed. These scenarios have further been analysed from the nuclear safety point of view: each of scenarios identified as important, either due to the high

occurrence to be expected or due to the expected strong consequences, has been modelled and calculated. The resulting effective equivalent doses to a member of the critical group have been compared to the international dose constraints. This way, 6 scenarios for normal events within the period of repository operating and closing phase have been treated and 12 scenarios for the abnormal events. For the post closure repository period, we have identified two design scenarios for each of the three repository types and a number of alternative scenarios: 7 for the surface repository, 3 for the silo and 4 for the underground type of repository.

The doses to a member of the critical group have been calculated for each of the mentioned scenarios. Results proved that very low doses for all design scenarios through the operating and closing repository period were to be expected. The doses from abnormal events were some higher. The highest dose to the worker has shown for container fall-and-crash scenario within the surface and silos repository and for the fire scenario within silo and underground repository type. In both cases, the doses were well below the dose constraint prescribed by Slovenian regulation. Dose calculations for the post closure period gave very low doses to the members of the critical group for all three repository types. For the surface repository, the calculated dose was one order of magnitude below the dose constraint, while for the other two types, these values were 5 orders of magnitude lower. The calculations for alternative scenarios gave some higher doses, especially for the case of all - barrier - demolition scenario (after 300 and 10,000 years). This scenario is highly unlikely to occur; it was taken as the limit scenario. In this case, the calculated dose was one order of magnitude higher than dose constraint for normal operation, but was well below the ICRP recommendations.