Stratigraphy and Age of the Timok Magmatic Complex (TMC)

Miodrag Banješević[1], Vladica Cvetković[2], Albrecht von Quadt[3], Irena Peytcheva[4]

[1]Geological Institute of Serbia, Rovinjska 12, 11000 Belgrade, Serbia, miodrag.ba@sbb.co.yu
[2]Belgrade University-Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, cvladica@rgf.bg.ac.yu
[3]Institute of Isotope Geochemistry and Mineral Resources, ETH-Zurich, CH-8092 Zurich, Switzerland, vonquadt@erdw.ethz.ch
[4]Central Laboratory of Mineralogy and Crystallography, BAS, 1113 Sofia, Bulgaria, peytcheva@erdw.ethz.ch

The data acquired in the frame of the SCOPES Project, along with already published data, enable a synthesis for the TMC stratigraphy and age. The synthesis reveals that the Timok Magmatic Complex (TMC) consists of the following and stratigraphical units: (i) Albian-Cenomanian sediments, (ii) Turonian-Senonian sediments and epiclastic rocks, (iii) Turonian-Campanian andesites, (iv) Senonian basaltic andesites and andesites, (v) plutonic rocks, (vi) latites, and (vii) Campanian-Maastrichtian sediments.

Andesitic volcanism occurred in the eastern parts of the TMC. It was predominantly characterized by effusive and shallow intrusive activity, which produced coherent and autoclastic andesitic facies. These volcanic rocks overlie the Turonian and Alb-Cenomanian sediments, while their cover consists of Senonian sediments and epiclastites. U/Pb zircon analyses showed that the shallow intrusions in the Krivelj area crystallized from 86.29±0.32 to 84.26±0.67 Ma, and that similar dykes in the Majdanpek area emplaced between 84.0±0.4 and 82.73±0.03 Ma. The Ar/Ar analysis of the lava flow facies in the Bor area gave an age of 89.0±0.6 Ma. Mineralization age was determined by Re-Os data which gave around 84 Ma for the Majdanpek, 86 Ma for the Bor and 88 Ma for the Krivelj area. Mineralized fluids which formed huge copper deposits in Majdanpek, Bor and Krivelj were likely genetically related to the Turonian volcanism.

During the Senonian the volcanic front migrated towards the central and western part of the TMC. The Senonian volcanic activity was predominantly represented by linear subaquatic effusions. The most abundant rocks are basaltic andesites and andesites, represented by lava flows (coherent or autobrecciated), hyaloclastic deposits, and rarely shallow intrusions. The basaltic andesites and andesites overlie Coniacian-Santonian sediments and underlie Campanian clastitic and Campanian-Maastrichtian reef sediments. The only available radiometric data for these volcanic rocks are an U/Pb zircon age of the subvolcanic dyke occurring in the Brestovac area. They revealed an age between 82.27±0.35 Ma.

Plutonic rocks are represented by diorites and monzodiorites. Along with latitic dykes, they occur in the western part of the TMC as intrusions within the Senonian volcanites. The U/Pb age zircon analysis of the Valja Strž intrusive rocks gave an age of 78.62±0.44 Ma. The age of mineralization in the western part of the TMC (Crni Vrh area) is dated by a Re-Os analysis which gave around 80 Ma.

The available stratigraphic and age data lead to the conclusion that the volcanic activity in the TMC continuously lasted for around 10 m.y. Non-explosive extrusive and shallow intrusive facies were predominant, followed by thick deposition of syn- and post-eruptive resedimented volcanoclastic rocks. The volcanic front in the TMC continuously migrated from east to west. The volcanic activity in the TMC was followed by volcanic processes in the Ridanj-Krepoljin Zone at around 70 Ma.

Did Timok Magmatic Complex (East Serbia, SE Europe) originate by subduction? A petrological and geochemical perspective

Vladica Cvetković[1], Miodrag Banješević[2], Albrecht von Quadt[3], Irena Peytcheva[3, 4]

[1]Belgrade University-Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, cvladica@mkpg.rgf.bg.ac.yu
[2]Geological Institute of Serbia, Rovinjska 12, 11000 Belgrade, Serbia, miodrag.ba@sbb.co.yu
[3]Institute of Isotope Geochemistry and Mineral Resources, ETH-Zurich, CH-8092 Zurich, Switzerland, vonquadt@erdw.ethz.ch
[4] Central Laboratory of Mineralogy and Crystallography, BAS, 1113 Sofia, Bulgaria, peytcheva@erdw.ethz.ch

The origin of the Timok Magmatic Complex (TMC) has been variously interpreted. Most authors suggest that the TMC originated by Late Cretaceous eastward subduction of the remnants of the Mesozoic Tethys under the southeastern European margin. This model was mainly based on the fact that most TMC rocks are calc-alkaline andesites and related rocks, which posses a 'subduction geochemical signature'. The latter is commonly described as the presence of LREE- and LILE-enriched patterns, as well as a variable Eu-anomaly and Nb-Ta-Ti negative spikes on chondrite- and primitive mantle-normalized diagrams, respectively. This signature was commonly interpreted as having resulted from subduction processes, although it is known that the rocks from settings unrelated to contemporaneous subduction can have similar geochemical affinities. Accordingly, the fact that any mixture of mantle and crustal material would produce a similar geochemical signature was used by most opponents of the subduction hypothesis.

In spite of their generally enriched trace element patterns, the TMC rocks display relatively unradiogenic initial strontium isotope composition ($^{87}Sr/^{86}Sr_{initial}$ range 0.7039-07049). A very similar range of Sr isotopes is reported for the analogous Late Cretaceous rocks in Romania and Bulgaria. Hence, the central question addressed here is: what processes were responsible for the combination of high LILE contents and LILE/HFSE ratios with relatively low initial strontium isotopes, observed in the TMC volcanic rocks.

A possible role of low-pressure differentiation processes was examined by geochemical modeling. The assimilation-fractional crystallization and pure fractional crystallization processes were modeled for Turonian-Campanian andesites and Senonian andesites and basaltic andesites, respectively. The results indicate a minor role of crustal material added by assimilation. Because such small amounts of crustal rocks could have not produced high LILE/HFSE ratios this geochemical signature must have come from the mantle component, i.e. it is the result of source mixing processes. This, in turn, raises the question: if this mixing event had happened long time before magmatism took place, or they occurred roughly concomitantly. The first model would imply that the mantle lithosphere was already hydrated and LILE-enriched when the TMC magmatism took place, whereas the second one favors a subduction model, i.e. introduction of metasomatic agents shortly before or during magmatism. In this context, we compared the geochemistry of the TMC rocks with neighboring magmatic rocks of relatively well-known source characteristics, such as the East Serbian Palaeogene mafic alkaline rocks (low LILE/HFSE and $^{87}Sr/^{86}Sr_{initial}$ – asthenosphere-like mantle) and Serbian Tertiary potassic/ultrapotassic rocks (high LILE/HFSE and $^{87}Sr/^{86}Sr_{initial}$ – metasomatized lithospheric mantle). The TMC rocks show similar Sr isotopic ratios as do the Palaeogene alkaline volcanics, but in terms of the trace element composition they are indistinguishable from the latter. The source modeling based on Sr/Nd and La/Yb ratios indicate that such geochemical pattern could have been produced by source mixing processes involving depleted mantle (asthenosphere?) material and subduction fluids. The presented geochemical evidence and the existing age pattern shown by the studied rocks, in combination with the characteristics of the mantle lithosphere underneath East Serbia, inferred from study of mantle xenoliths, support the subduction model for the origin and evolution of the TMC.

Metallic mineral deposits of the Bor metallogenic zone s.s. (Republic of Serbia)

Rade Jelenkovic
Faculty of Mining and Geology, Belgrade University, Serbia *radej@rgf.bg.ac.yu*

The Alpine metallogenic unit in the southern sector of the Carpatho-Balkan arc is represented by two metallogenic zones: the Oravita-Krepoljin zone in the west, and the Bor-Srednegorie zone in the central part. They were formed at the front of the Jurassic-Cretaceous oceanic slab, subducted from the Vardar zone beneath the Eurasian plate. The mineralization is associated mainly with late Upper Cretaceous calc-alkaline igneous activity.

The Bor-Srednjegorie zone extends from Lilieci-Linbcova and Bozovici in the north (Romania), over Bor (Serbia) to Burgas (Bulgaria), extending through the Black sea and Tracia into Turkey. It is over 600 km long and from 0.5 km in the north to 80 km wide in its eastern sector.

In Serbia, the Bor-Srednegorie metallogenic zone (Bor metallogenic zone s.s.) is associated with a rift-graben environment, where volcano-intrusive complexes were developed, with a predominance of polygenic volcanic rocks of central type development.

Copper and gold are the dominant metals in the Bor metallogenic zone. Current estimated measured and indicated mineral resources (reserves of theA, B and C_1 category according to the Serbian classification) are 1090 Mt @ 0.38% Cu, 0.14 g/t Au (4145 Mt Cu, 153 t Au). They are accompanied by Fe (sulphide, oxide) and Pb-Zn, Mo, sporadically PGE, and exceptionally Mn. The most prominent types of metallic mineral deposits of the Bor ore zone are:

- Porphyry copper/molybdenum deposits /PCM/ (subtypes: PCM hosted by multistage composite plutonic granitoid complex /type: Valja Strž/, PCM related to high-level dyke swarms above plutonic body /type: Veliki Krivelj, subtype: Cerovo-Cementacija/; PCM associated with high sulphidation massive sulphides (subvolcanic type) /type: Bor- Borska reka/ and PCM related to an initial rift fault structure /type: Majdanpek/);
- Hydrothermal cupriferous pyrite deposits of massive sulphide and stockwork-impregnation type of mineralization (type: Choka Dulkan, Tilva Mika etc.)
- Hydrothermal massive base-metal sulphide deposits (type: Tenka);
- Hydrothermal massive Cu-Pb-Zn-Au sulphide deposits (type: Choka Marin);
- Hydrothermal vein deposits (Cu, Pb-Zn and Au) (type: Kraku Bugaresku);
- Skarn deposits (Fe-oxides, Pb-Zn, Cu) (type: Valja Saka, Potaj Cuka) and
- Epithermal gold deposits both of high and low sulphidation type (Kuruga, Zlace etc.).

Major ore elements of the Bor ore zone are Cu, Au, Mo, Fe (Py) ± Pb-Zn. Trace elements are Se, PGE, Ag, Cd (recoverable) and W, Sn, Bi, Sb, As, (Ba) (unrecoverable). The principal associations of elements are classified as follows:

- Cu, Au, Mo ± Ag, PGE (porphyry copper);
- Cu, Pb/Zn, Fe (Py), Au/Ag ± Se, Bi, Sb (massive sulphide);
- Cu, Au, Fe (Py), As ± W, Sn, Se, Sb (cupriferous massive sulphide/replacement);
- Fe-S (masive pyrite);
- Cu, Fe (Py) ± Mo, Bi, W (skarn).

Ore deposits are found within 16 ore fields, and are grouped into 5 ore districts. They belong to different morphostructural types of ore mineralization and display a diversity in ore paragenesis, associations of minerals and elements.

Occurrence of the colusite group minerals at the Bor ore district, Serbia

Ljubomir Cvetkovic & Aleksandar Pacevski
Faculty of Mining and Geology, University of Belgrade, Serbia
cvele@mkpg.rgf.bg.ac.yu, pacevski@mkpg.rgf.bg.ac.yu

The compounds $M_{34\pm x}S_{32}$, where M is Cu, V, As, Sb, Sn, Ge, Fe, with adition of Mo and W; $x \leq 3$, occur rarely in nature and in insignificant amounts. Minerals of this composition were described as arsenosulvanites, colusites, germanites and nekrasovites. They present basically the copper-vanadium sulfosalts of the mentioned elements and were formed in porphyry-copper, porphyry-copper-molybdenum, copper vein, volcanogenic massive sulfides, gold vein and marble deposits, in ore-bodies of quartz, quartz-barite or carbonate composition of hydrothermal genesis. Their associations include sulfides (pyrite, chalcopyrite, bornite, galena), sulfosalts (enargite, luzonite, stibioluzonite, sulvanite, mawsonite, tetrahedrite-tennantite) and tellurides (hessite). In such types of ore-deposits, the minerals of the colusite group were formed at a high oxidation potential, apparently due to the presence of As^{5+}, Sb^{5+}, Sn^{4+}, Ge^{4+}, Te^{4+}, Cu^{2+} in their composition. A great diversity is present among the members of this group as the cosequence of a very complex crystallochemistry of their minerals, for what the strongly expressed a different types of isomorphism at the third position in the colusite formula $Cu_{24+x}V_2(As, Sb, Sn, Ge)_6S_{32}$, $(0 \leq x \leq 2)$ are responsible.

The ores from the Bor copper deposit contain a small amount of the colusite group minerals, with members belonging to the subgroups of arsenosulvanite, srictly colusite and germanite, which display a significant variety in chemical characteristics, consecutively resulting in the appearance of an unusual members and in some cases, in a new species eventually. Due to the mode of their occurrence in the ore in predominantly single very small grains, mainly the chemical (EPMA) and quantitative optical investigations were performed on arsenosulvanite, Sn-rich and Sn-poor colusite, mawsonite, germanite-(W), bornite-(Ge) and sulvanite.

Mineralogy of the Coka Marin polymetallic deposit, Bor ore district, Serbia

Aleksandar Pacevski[1], Ljubomir Cvetkovic[1] & Perisa Zivkovic[2]

[1]Faculty of Mining and Geology, University of Belgrade, Serbia
pacevski@mkpg.rgf.bg.ac.yu, cvele@mkpg.rgf.bg.ac.yu
[2]Nikola Tesla 11, 19250 Madjanpek, Serbia

The Coka Marin polymetallic (Cu-Au-Ag-Zn-Pb) deposit is situated in eastern Serbia, about 25 km north from the town of Bor. This deposit, consisting of three bodies of massive sulfide, is situated in a large volcanic system, mainly built up by different types of andesitic events, formed in several phases. The orebodies are composed of colloform to fine-grained pyrite in which veinlets and nests of luzonite, enargite, chalcopyrite, bornite, sphalerite, galena, barite (predominant gangue mineral) and other less common minerals are present. Three stages of mineral deposition are unequivocally established: an early disseminated pyrite stage, an intermediate Fe-Cu-As-S stage, which resulted in the formation of Cu-pyrite ore, rich in Au and Ag, and a late polymetallic stage, which resulted in the formation of Zn, Pb, Cu, Au, and Ag ore.

Pyrite is the major mineral in the deposit and shows different chemical and textural features. Based on a reflected light study and electron micro-probe analyses with energy-dispersive spectrometry (EMPA-EDS), a chemically zoned pyrite was found in several samples. Thus, our studies revealed the presence of Cu-pyrite (up to 8 wt% Cu) and As-pyrite (up to 4.5 wt% As). Besides chemical zoning, pyrite also shows different zoning patterns caused by mineral inclusions, corrosions and overgrowth zones. There is a great variety of pyrite texture, including colloform aggregates, replacements, idiomorphic crystals, framboïdal pyrite and irregular aggregates. Marcasite is generally present in pyrite aggregates.

Luzonite and enargite are the predominant Cu-minerals in the deposit. Other common Cu-minerals in the deposit are: chalcopyrite, bornite, covellite, tetrahedrite-tennantite and chalcocite. Sphalerite and galena are generally the main minerals of the Zn and Pb stage. Sphalerite is more abundant than galena and occurs as the yellow-brown Fe-poor and black Fe-rich varieties.

Precious metals, Au and Ag are commonly concentrated in the deposit. Reflected light microscopy revealed the presence of grains of native gold, up to a few µm in size, in the samples of the first stage of ore formation (pyritization), grains of native gold up to 50 µm in size in Cu-pyrite ore of the second stage, containing about 10 wt% Ag (by EMPA-EDS), and rare grains of native gold up to 100 µm in size in the polymetallic ore of the third stage.

Less common minerals, which occur in subsidiaryt amounts in the orebodies are: idaite, digenite, arsenopyrite, seligmannite, stannite(?), freibergite(?), colusite (?) and several undetermined minerals noticed during the current study.

Geological setting, lithogeochemistry, and hydrothermal alteration in the Crni Vrh licence area, Late Cretaceous Timok belt, Eastern Serbia

Fethi Benkhelfa & Robert Moritz
Earth Sciences Institut, University of Geneva, Switzerland
benkhel1@etu.unige.ch, robert.moritz@terre.unige.ch

The Crni Vrh licence area belongs to Dundee Plemeniti Metali and are located in the Western Timok tectonic zone, Eastern Serbia, about 27 km south of Madjanpek, 18 km northwest of Bor and 140 km southeast of Belgrade. The licence area includes from north to south the Coka Kuruga, Lipa and Coka Kjupatra high-sulfidation type gold-copper prospects. Coka Kuruga and Coka Kjupatra are characterized by extensive silica caps and altered andesites (silicification, advanced argillic alteration, pyritization). The Lipa prospect is an open pit mined between 1958 and 1967, with estimated total ore reserves of about 1Ma tons with 1.1% Cu; 3-6 g/t Au and about 20 g/t Ag. The Lipa prospect is currently the target of extensive exploration drilling, and is the subject of the present contribution. Specific aims are to constrain the geometry and evolution of the hydrothermal alteration, identify breccia events, and clarify the genesis of this prospect.

The mineralization at Lipa is hosted by Senonian volcanic rocks of the second volcanic stage of the Timok magmatic complex. The mineralization at Lipa is hosted by the upper part of the volcanic sequence composed of hornblende andesitic clast-supported breccia. Based on XRF analyses of least altered whole rock samples, the host rocks are andesite/basalt according to the Winchester and Floyd (1977) classification diagram. Thus the volcanic rocks in the Western Timok belt around the Lipa area appear to be more basaltic in composition compared to other counterparts from the Banat-Timok-Srednogorie belt.

The main ore body at Lipa is controlled by a steeply dipping NNW- oriented fault. In the open pit the mineralization, mainly enargite with luzonite, is in veins, matrix cementing host rock clasts of hydrothermal breccia, and dissemination in hydrothermally altered rocks. At depth, as revealed by drill cores, the mineralization consists of a brecciated massive sulphide, veins and disseminations.

The hydrothermal alteration at the Lipa prospect was studied by transmitted light microscopy, XRD and Raman spectroscopy. Propylitic alteration with zeolite veins is predominant on surface followed by argillic alteration (mainly with kaolinite and quartz) in the open pit vicinity. Intense silicification and advanced argillic alteration occur within the open pit. The latter is characterized by quartz-diaspore-dickite and pyrophyllite-quartz assemblages. Drill cores next to the open pit show propylitic alteration with a sericite-chlorite-calcite-quartz assemblage down to a depth of 120m. Next, a transitional propylitic-advanced argillic alteration consists of pyrophyllite-sericite-calcite±quartz. Advanced argillic alteration occurs below 125m and the predominant assemblage is pyrophyllite-diaspore-quartz. Alunite is only present below 294m in assemblages together with quartz, dickite, pyrophyllite and diaspore in various proportions. Abundant anhydrite and gypsum veins are present in the advanced argillic alteration zone, and anhydrite is part of the assemblage within this alteration zone. Anhydrite also cements fragments of the brecciated massive sulphide.

High gold and silver concentrations are especially associated with the propylitic zone (depth of 74-121m), and a zone between a depth of 145 and 208m on both sides of the brecciated massive sulphide characterized by the advanced argillic alteration assemblage pyrophyllite-diaspore-quartz. Gold contents are low within the advanced argillic alteration assemblages containing alunite in the lowermost parts crosscut by the drill holes. Lead and zinc are also enriched within the zone of the brecciated massive sulphide ore body.

Structural and tectonic features of the western part of Carpatho-Balkanides: evidence from palaeostress analyses of Ravanica area

Branislav Trivić[1], Dušan Jelic[2]

[1] Belgrade University, Faculty of Mining and Geology, 7 Djusina St., Belgrade; btrivic@rgf.bc.ac.yu
[2] Geological Institute of Serbia, 12 Rovinjska St., Belgrade; jelidusan@sbb.co.yu

This paper presents the results of detail structural and tectonic analysis of the Ravanica area (cross-section Monastery Ravanica – Vavilo). Investigated area is the most western part of Getic Nappe (Ridanj – Krepoljin zone). It predominantly consists of Ravanica limestones.

Field data were taken under detail palaeostress analysis combined with statistical analysis of brittle structures, mostly in mesoscopic field size. Clearly detected fault planes with numerous striations and shear stress orientations analysis were observed and studied by statistical analysis of stress tensor and its method of normalization - Simple Shear Tensor Average.

Three dominant deformation stages were detected in the investigated area.

D1 – The oldest deformation stage indicates a regime of ENE – WSW oriented stress field, with local deviation of ESE – WNW and E - W directions. This field stress distribution, detected in horizontal plane in the western rim of the Getic Unit, resulted in thrusting of Supragetic over Getic Unit at the end of Early Cretaceous and the beginning of Late Cretaceous (Austrian stage, 100 Ma). Overthrust has east direction in general. It is related to the period of Nappe Stacking (Willingshofer, 2000).

D2 – Second deformation stage is dominantly exposed in the investigated area. It is documented in Ravanica limestones, in large number of observation points. Stress analysis shows very strong regime of stress field and indicates subvertical maximum principal stress with NNE – SSW trending, and local deviation with ENE –SWS direction. It relates maximum stress field distribution in horizontal plane. As a result, it is visible in a large number of normal faults. Although the stress field distribution is dominantly NNE – SSW oriented, it is noticed minor stress redistribution with NW –SE direction. This deformation stage probably took place for a long period during Late Cretaceous and ended in Paleocene time (?). Three phases of magmatic activities in eastern part of Carpatho-Balkanides is related for this period. The described stress distribution strongly indicates the opening of Timok Magmatic Complex, its evolution and position with NNW – SSE direction.

D3 – The youngest deformation stage is related to Laramian stage of Alpine orogenesis (Late Cretaceous – Paleocene, 64 Ma). Field stress distribution is very well exposed in N – S direction with dominant subhorizontal principal stress axis. Kinematic activity in Ravanica area shows sinistral strike-slip regime which is the consequence of major fault structures orientation (mostly NE – SW direction). The same kinematics in the eastern part of Carpatho-Balkanides shows dextral strike-slip regime, with dominant exposure in the area of Bor and Krivelj faults. It is most possible that under the influence of this stress activity started evolution of Extensional Duplex (Drew J.L., 2006)

New aspects of the relation between older nappes (metamorphic rocks and "flysch" sediments) and Neogene cover beds (including Quaternary) in Eastern Serbia

Petar Stejić[1], Rodoljub Gajić[1], Divna Jovanović[1], Darivojka Ljubović-Obradović[1]

[1] Geological Institute of Serbia, Rovinjska 12, 11000 Belgrade, Serbia; stejicpetar@hotmail.com; griva@ptt.yu; djdivna@gmail.com; darivojkaljo@hotmail.com

Paper deals with relationship of Paleozoic and Mesozoic rocks covered by transgressive Neogene sediments, often recognized as a currier of raw materials. In Eastern Serbia, between Kladovo and Negotin, different kind of sediments (limestones, sandstones, gravels and silts) lie over metamorphic rocks and "flysch" like limestones and clastites.

These older rocks are intersecting by young transgressive sediments, containing polymictic grains originated from mentioned older gneisses, granitoides, limestones, conglomerates and sandstones.

Re-sedimentated material represents very useful raw material applicable in civil engeneering and rarely in exploration of heavy minerals.

The region of Eastern Serbia is poorly investigated in terms of mentioned raw material deposits. It was researched locally for permanent needs and in earlier time for the Đerdap dam construction (1970-1980).

It is known that Carpatho-Balkan belt could be very perpective as tracer of heavy minerals in overlying Neogene sediments, especially in deposits of river origin.

In that sense, older Quaternary polycyclic river sediments are also very perspective for further investigations of heavy minerals. It is particularly related to high composition of garnets, ilmenite etc., known from previous investigations.

Lithology and Structural Features of the Trakia Unit, South Bulgaria

Stoyan Sarov[1], Kalin Naydenov[1, 2], Nikolay Petrov[1], Emilia Voynova[1], Krastina Kolcheva[1, 2]

[1]Geology and Geophysics Corp., 23 Sitnyakovo Blvd., 1505 Sofia, Bulgaria
[2]Sofia University, Dept. of Geology, 15 Tzar Osvoboditel Blvd., 1504 Sofia, Bulgaria
E-mail: k.naidenov@gmail.com; niky_geology@abv.bg; emili_voin@abv.bg

The Trakia unit is defined as an individual litho-tectonic unit by Sarov et al. (2006) during the new mapping of 1:50 000. It is outcropped in the northernmost slopes of the Rhodopes along Maritsa River valley from the town of Kostenets in the West to the area of Dimitrovgrad, Haskovo and Harmanly in the East. One of its main features is the low-metamorphic (greenschist facies) to anchi-metamorphic Late Alpine overprint of the rocks, which otherwise are with different age and origin. However, the degree of metamorphism in the volume of the unit increases from East to West.

The Southern boundary of Trakia unit is marked by subvertical dextral strike-slip faults considered as a part of Maritsa shear zone. They separate its rocks from the high-grade metamorphites of the Rhodopes. Deformations along the border of the unit are predominantly brittle or brittle-ductile but in some sections ductile shearings are observed. In the transtensional segments of these strike-slip faults pull-apart basins and rhomboidal grabens were formed. These structures are filled with Paleogene and Neogene sediments. There are also some sections of the zone where transpressional kinematic is dominating. The most common structures in the Southern border of the unit are subhorizontal mineral lineations or striations, S/C mylonites and millimeter- to meter-scale drag folds with subvertical hinges and dextral asymmetry.

In general we can distinguish three different sections in the structure of the Trakia unit.

1) The first section is represented by biotitic orthogneisses enriched in pegmatitic veins undergone metamorphism in upper amphibolite facies during Variscan time. During Alpine stage these rocks were reworked in lower metamorphic conditions causing pervasive retrogression. In general (based on the main lithological and structural features) these rocks refer to Balkanide type of metamorphites (Ivanov, 1989), which build up the basement of Srednogorie zone and Ograzhden complex. We suppose that these metamorphites constitute the basement of Trakia unit.

2) Mélange of low-grade metamorphic rocks containing metaophiolite fragments. This section is presented by calc-schists, green schists, quartzites, metabasites and ultramafic rocks affected by serpentinization. The rocks are folded in isoclinal folds and also in drag folds near the southern strike-slip boundary of Trakia unit. This section is correlated with the rim of the Sakar granites in the area of Bulgarin, Shishmanovo and Konstantinovo villages.

3) Fine-grained white marbles intercalated with white mica schists and calc-schists are widely spread in Besapara hills South of Pazardzhik town. White or bright-grey marbles crops out at South of the villages Brestovitsa, Markovo, Brestnik and Kuklen. The marbles are often strongly brecciated. In some outcrops are discovered brown-yellowish slightly metamorphosed limestones. The same succession is observed near the village of Klokotnitsa and between the towns of Dimitrovgrad and Haskovo, where it is already dated as Triassic-Jurassic sequence.

We suppose that in regional scale the whole volume of Trakia unit is strongly folded. The folds are south-verging. Their cores are built up by Variscan orthogneisses and by undated mélange of metapelites and metaophiolitic fragments. The limbs consist of Triassic and Jurassic carbonate fragments. In contrast to the section near Dimitrovgrad and Klokotnitsa, in the area of Parvenets, Brestovitsa, Markovo and Brestnik villages apparently the Variscan orthogneisses overthrusted the mélange and slightly metamorphosed the limestones.

Strike-slip deformation in the Trakia Unit along the Maritsa shear zone, northern border of the Rhodope Massif, southern Bulgaria

Kalin Naydenov[1, 2], Emilia Voynova[1], Nikolay Petrov[1], Stoyan Sarov[1], Krastina Kolcheva[1, 2]

[1]Geology and Geophysics Corp., 23Sitnyakovo Blvd., 1505 Sofia, Bulgaria, emili_voin@abv.bg; niky_geology@abv.bg
[2]Sofia University, Dept. of Geology, 15 Tzar Osvoboditel Blvd., 1504 Sofia, Bulgaria, k.naidenov@gmail.com

The studied area is situated between the towns Krichim and Kostenec along Maritsa River valley. The project is concentrated on the border between the northern parts of West Rhodopes and Central Srednogorie zone, which is part of the Trakia unit (Sarov et al., 2006). The present study gives data about the main features of this unit west of the Vucha River valley and also some new details about the deformation history of Maritsa shear zone.

Trakia unit consists of low grade metamorphic rocks. Marbles and mica schists containing albitic porphyroblasts (metasandstones) are widely spread in the eastern and central parts of studied area. In the western parts of the unit two-mica gneisses (probably orthogneisses), marbles and white mica schists in alternation with thin bodies of metabasites are well developed. The metamorphic mineral assemblages define upper greenschist facies of close to the amphibolite facies.

The whole volume of Trakia unit is affected by dextral strike-slip deformations along Maritsa shear zone. After a year of investigation it is possible to determine three different evolution stages. During the first stage the metamorphic rocks have been affected by strong synmetamorphic (ductile) deformations in strike-slip regime. This results in formation of subvertical mylonitic foliation trending to SE (120-140°) and clear subhorizontal or gently dipping to NW or SE stretching lineation (in some outcrops the rocks are turned into L-tectonites). During this period millimeter to meter-scale fold structures has been developed. Their hinges are parallel to the mineral lineation.

For the second phase of the shear zone evolution we presume a transtensional kinematics. The strain is decreasing, but temperatures are still comparatively high – about 450 to 500°C. During these p-T conditions and together with fluid transport within the systems a strong static recrystallization starts of the rock-forming minerals. The mylonitic fabric is overprinted and almost obliterated. The so-called “annealing” process can be observed in thin sections from all parts of the Trakia unit. Ductile deformations are localized in narrow shear zones. During this period Maritsa shear zone is intruded by several granitoids with late cretaceous age (84-78 Ma – Kamenov et al., 2002; Peytcheva and Von Quadt, 2003). Some of these igneous bodies are partly affected by ductile strike-slip shearing (Ivanov et al., 2001; Георгиев, 2003; Velichkova et al., 2004). The development of E – W elongated narrow sedimentary basins in the North Rhodopes is probably contemporaneous and cinematically linked whit the transtensional movements along Maritsa shear zone during Late Alpine time.

The third stage is dominated by the development of brittle strike-slip faults in transpressional regime. Directing 100-140° these dextral faults are better expressed in the South of studied area, building up the border between the Trakia unit and the high grade metamorphic units of the Rhodopes. In transpressional settings the sedimentary basins from the North slopes of the mountain are partly overtrusted by the low-grade metamorphic rocks of Trakia unit. Referring to the age of the sediments this tectonic event is defined as post-Oligocene.

Evolution of the Cretaceous magmatism from the Srednogorie zone to the Rhodopes: Constraints from isotope dating and tracing

Irena Peytcheva[1,2], Albrecht von Quadt[2], Kalin Naydenov[3,4], Stoyan Sarov[4], Emilia Voinova[4], Dimo Dimov[3]

1 - Central Laboratory of mineralogy and crystallography, Bulgarian Academy of Sciences, peytcheva@erdw.ethz.ch;
2– Institute of isotope geology and mineral resources, ETH-Zurich, Switzerland, quadt@erdw.ethz.ch;
3- Faculty of geology and geography, Sofia University;
4- "Geology and Geophysics" AD, Sofia;

The Srednogorie and the Rhodopes are the main ore-bearing Alpine tectonic zones in Bulgaria (e.g. Von Quadt et al, 2005; Marchev et al., 2005 and references therein). To understand the transition from one to the other zone and the change of the deposit style from Cu-porphyry (Au-Mo) to mainly Pb-Zn-Cu (-Au) we made a series of isotope-geochronological and geochemical studies in the border area from Central Srednogorie to Rila-Western Rhodopes and further to South.

The tectonic contact between the Srednogorie and Rhodopes is marked by the SW-SE to E-W orientated Maritsa fault zone (Bonchev, 1946; Ivanov, in press; Sarov et al., this volume). In the studied area it is followed on the northern slopes of Rila and West Rhodope Mountains and described as a dextral strike-slip zone, active from Cretaceous to Late Alpine time (Ivanov, in press). The Northern parts of the Rhodope zone are build up by the metamorphic rocks of the Assenitsa and Arda Units (Ivanov et al., 2000) and by the low-metamorphic Thracian Unit (Sarov et al., 2006), intruded by the granitoids of the Rila-West Rhodopes batholith. The latter consist of three main rock types: hornblend-biotite granodiorites (unit 1), biotite and two mica granites (unit 2) and leucogranites and aplitoid granites (unit 3) (Vulkov et al., 1989; Kamenov et al., 1999). Here we present data for the granodiorites of the Unit 1 (Belmeken and Gruntcharitsa bodies, AvQ159 and V3P), for the main Rila granite (AvQ230) and its strongly mylonitized parts in the fault zone, south of Dolna Banja village (second unit, AvQ164). Additionally we sampled an amphibolite and cross-cutting gneissic vein of the Arda Unit, east of the batholith and about 500 m from the contact to the Assenitsa Unit (AvQ155 and AvQ156), as well as deformed (metamorphosed?) dark (AvQ229) and light (AvQ228) metagranitoid parts of the same unit, closer to the batholith.

High-precision U-Pb single grain ID-TIMS dating of long-prismatic zircons from both granodiorite samples of unit 1 (AvQ159 and V3P) define concordant ages of 69.26 ± 0.26 Ma and 66.79 ± 0.29 Ma respectively, the majority of the analyzed grains lying on or close to the concordia line. Hf isotope characteristics of the dated zircons define mixed, but mantle dominated origin of the Cretaceous magma (εHf of +1.6 to +5.4, corrected for 67 Ma), and this conclusion is supported by the εNd of the whole rock samples between -3.3 to +0.6 and initial ($^{87}Sr/^{86}Sr$) of 0.7064-0.7066. Surprisingly the metagranodiorite AvQ229 from the "hosting metamorphic basement" revealed very close concordia age of 70.77 ± 0.09 Ma and same mantle-crust magma characteristics (initial εHf of +0.3 to +5.2). Compared with the Upper Cretaceous rocks of the adjacent Central Srednogorie these show less positive εHf values infer higher input of continental-crust materials in the magma.

Similar close age relations are defined for the main (second) unit of the batholith and the metagranitic veins and bodies of the metamorphic succession. The granite sample AvQ230 is dated at 39.39 ± 0.21 Ma by concordant zircons, whereas xenotimes are slightly younger (38 to 37 Ma) and magmatic monazites show lead loss with ages ranging between 26-30 Ma. The metagranitic veins from the "metamorphic basement" are dated in the range from 39 Ma (zircons from the closer outcrop AvQ228) to 40-43 Ma (AvQ156). All sampled granites reveal slightly negative to slightly positive εHf characteristics.

Based on *in situ* LA-ICP-MS dating and MC-LA-ICP-MS Hf-tracing the latter are explained mainly by the different origin of the crustal materials, generating and contaminating the granitic magma. The metadiorite (AvQ155) from the Arda unit is ~240 Ma old.

The new isotope data open new perspectives for prospecting of Srednogorie type ore deposits in the Rhodopes, related with Upper Cretaceous deformed/metamorphosed magmatic rocks.

Correlation of the Upper Cretaceous magmatism and the related Cu-Au mineralization in Bulgaria and Serbia: the status quo

Albrecht von Quadt[2], Irena Peytcheva[1,2], Svetoslav Georgiev[1] and C.A. Heinrich[1]

1– Institute of isotope geology and mineral resources, ETH-Zurich, Switzerland, quadt@erdw.ethz.ch;
2 - Central Laboratory of mineralogy and crystallography, Bulgarian Academy of Sciences, peytcheva@erdw.ethz.ch;

The Apuseni–Banat–Timok–Srednogorie (ABTS) belt, Europe's most extensive belt of calc-alkaline magmatism and Cu–Au mineralization, is related to the subduction of the Tethys ocean beneath the European continental margin during the Late Cretaceous phase. Economic deposits are restricted to certain segments along the belt, and all major porphyry-style and high-sulphidation ore deposits in Bulgaria are aligned on the Panagyurishte corridor, a narrow zone obliquely crossing the ABTS belt and in Serbia on the Timok unit.

This paper reviews the geology, geochemistry and geochronology of igneous events in three profiles extending from the European continental basement through the Srednogorie zone in Bulgaria (Central and Eastern part) and Timok unit in Serbia. U–Pb dating of single zircon grains from subvolcanic intrusions and major plutons, supplemented by published age data for magmatic rocks and hydrothermal ore deposits obtained by other methods, reveals a general younging of the magmatism from 92.1 Ma in the north (Elatsite) to 78.5 Ma in the south (Capitan Dimitrievo), in the Timok unit (east to west) from 86.29 Ma (first phase) to 78.6 Ma (third phase) and in Eastern Srednogorie from 86.6 Ma to 77.9 Ma with no magmatic time trend. Cu–Au deposits are restricted in Bulgaria in time from ~92 to ~86 Ma and in Serbia from 86 to 82 Ma, while the southernmost (Bulgaria)/westernmost (Serbia) part exposes more deeply eroded mid-crustal plutons devoid of economic mineralization. The time for epithermal deposits in Eastern Srednogorie can be estimated from Rb/Sr mineral isochrones between 81 and 79 Ma.

The age progression correlates in both profiles with the geochemical trend of decreasing crustal input into mantle-derived magmas. Magmatism and ore formation in individual magmatic–hydrothermal complexes along the profile is much shorter with life times between 0.6 and 0.9 Ma. The life time of the ore formation for the Timok, Central Srednogorie and Eastern Srednogorie is ranging between 3 and 6 Ma.

The age progression of calc-alkaline magmatism within the Srednogorie zone and Timok unit is explained as a consequence of slab retreat during oblique subduction. This led to transtensional block faulting and subsidence, and thus to the preservation of near-surface magmatic–hydrothermal products, including economic Cu–Au deposits.

The Cretaceous magmatism continued into the Rhodopian Massif (see Peytcheva et al., this volume) as well as further to West in Serbia into the Ridanj-Krepoljin belt. The magmatism outside the Timok unit and Srednogorie zone show a dramatic change in the geochemical and isotopic evolution, e.g. increasing of crustal assimilation. Theses observation lead to the question: what is the tectonic scenario of the Cretaceous magmatism on the Balkan Peninsula.

Mineral composition of the Late Cretaceous Breznik-Bardoto Au epithermal ore occurence (preliminary data), Western Srednogorie Belt, Bulgaria

Stanislav Stoykov[1], Strashimir Strashimirov[1], Robert Moritz[2], Dimitur Dimitrov[3], Jivko Todorov[3]
[1]Mining and Geology University 'St. Ivan Rilski', 1700 – Sofia, Bulgaria, sstoykov@mgu.bg, sbs@mail.mgu.bg
[2]University of Geneva, Geneva 1205, Switzerland, robert.moritz@terre.unige.ch
[3]Euromax, Resources Ltd, Sofia, Bulgaria, jikataa@abv.bg

The Bardoto prospect is a part of the Breznik epithermal gold occurrence, which is located in the Western Srednogorie zone, near the town of Breznik, approximately 35 km west from Sofia. The zone is part of the Late Cretaceous Apuseni-Banat-Timok-Srednogorie belt, which is a major copper and gold metallogenic province in southeastern Europe. This province is characterized mainly by porphyry-Cu and Au-Cu epithermal deposits, which are typically clustered in major mining districts, such as Bor-Madjanpek in Serbia and the Panagyurishte ore district in Bulgaria. The Breznik epithermal gold occurrence is hosted in hydrothermaly altered Late Crateceous volcanic and volcanoclastic rocks of andesitic, trachyandesitic and trachybasaltic composition. The Bardoto prospect is the central part of the ore occurrence. It is characterized by ore mineralisation typical for epithermal gold deposits formed at low temperatures.

The opaque assemblage consists of pyrite (including arsenian pyrite, As: 7-10wt%) chalcopyrite, galena, sphalerite, tennantite, tetrahedrite, pyrrhotite, native gold, electrum, magnetite, hematite, marcasite, ilmenite, chalcocite, covellite, malachite, cuprite and cerusite.

Pyrite is the most abundant opaque mineral. It forms mainly semi-euhedral, xenomorphic, euhedral or rarely colloform rounded grains and aggregates from 20 µm up to 2–3 cm. On the basis of its textures and chemical composition at least three varieties of pyrite are distinguished. The first one is related to pre-ore hydrothermal alteration and consists of fine disseminated grains of pyrite without any trace element contents over 0.0X wt%. The second variety is associated with other sulphide minerals, which generally replace or crosscut the pyrite. This pyrite has significant contents of Cu and lower contents of Ni. The most unusual is the third variety of pyrite forming rounded colloform aggregates with zonal textures. Their central parts have Cu and As concnetrationsabout 0.5 wt% and they are rimmed by layers of pyrite with extremely high contents of As and significant contents of Cu and Sb. The outermost part of the aggregates comprises very fine crystals of marcasite.

Chalcopyrite is associated with pyrite as irregular aggregates cutting early formed pyrite or fine nests among large pyrite aggregates. Chalcopyrite is typically associated with tennantite, in some cases tennantite rims chalcopyrite and in the marginal parts, chalcopyrite appears to be replaced by tennantite. The most probable is that both minerals are formed in narrow interval of mineralization process. Chalcopyrite also has high contents of As and low concnetrations of Sb.

Galena is present as fine, isometric slightly rounded inclusions in pyrite and asrare, irregularly shaped inclusions in chalcopyrite. Inclusions found in pyrite do not contain any trace elements while those in chalcopyrite are characterized by the presence of Se and Ag.

The obtained data show some differences in mineral composition with respect to ores reported in previous studies from the northern part of the area. The reported mineral association is more typical for intermediate to low sulphidation types of copper-gold deposits. The absence of enargite, luzonite, arsenosulvanite, colusite and other minerals usually found in the high sulphidation type are not observed here. Arsenic is present in high quantities in arsenian pyrite, which is one of the rare findings of this variety in Bulgaria. It is also registered in chalcopyrite and As-rich members of the tennantite-tetrahedrite series are distinctly dominant in the samples of this study. From this point of view, there is a misevaluation, and the prospect should be reclassified as a transitional type between intermediate to low sulphidation types of Au epithermal deposits.

Magmatic to hydrothermal transition at the Elatsite porphyry Cu-Au-(PGE) deposit, Srednogorie zone, Bulgaria

Elitsa Stefanova[1], Zoltán Zajacz[1], Thomas Driesner[1],Paraskev Petrov[2]

[1]ETH Zurich, IGMR, Switzerland, stefanova@erdw.ethz.ch, zajacz@erdw.ethz.ch, driesner@erdw.ethz.ch
[2]Sofia University "St. Kliment Ohridski", Bulgaria, parp@geo.uni-sofia.bg

It has been known for a long time that the formation of porphyry-type copper deposits is related to volatiles released from upper crustal magma reservoirs. Primary magmatic volatiles are highly efficient in sequestering economic metals from the crystallizing magma and transporting them to the place of ore mineral precipitation. In the Elatsite deposit, assemblages of co-existing silicate melt inclusions, saline brine inclusions and vapor inclusions in early magmatic-hydrothermal quartz veins offer a unique chance to reconstruct the compositional evolution of the melt and volatile phase. Co-existence of fluid inclusions with silicate melt inclusions suggests that they represent the primary magmatic volatile phase released from the crystallizing magma.

Scanning electron microprobe cathodoluminescence (SEM-CL) was used for the textural correlation of successive quartz types and fluid inclusion assemblages. Recrystallized silicate melt inclusions, brine and vapor inclusions occur as primary and pseudosecondary assemblages. Brine inclusions consist of liquid (50-70 vol%), vapor, crystal of halite and sylvite. Additionally, they may contain another transparent grain (anhydrite) and 2 opaque phases (typically a triangular plate of chalcopyrite and a small red plate of hematite). Vapor inclusions consist of at least two phases (liquid and vapor) with a dominating vapor bubble and an opaque daughter phase. The calculated salinities of the brine inclusions are up to 55 wt% NaCl equivalent. No microthermometry data could be obtained from the vapor inclusions because of their small liquid content. In order to rehomogenize the silicate melt inclusions, quartz crystals were heated to 730°C under 150 MPa confining pressure for 120 hours and quenched subsequently. After the heating experiments several composite inclusions consisting of silicate glass and brine or vapor were observed in numerous assemblages. We interpret these to be formed by heterogeneous entrapment of silicate melt and brine or silicate melt and vapor. This provides a clear evidence for the co-existence of the three immiscible phases in the system.

LA-ICPMS data of brine inclusions show that they are Cu-rich, Cu concentrations reach maxima of 9122 ppm. Pb and Zn content are up to 2000 ppm and 3300 ppm, respectively. The concentration of Cu, Pb and Zn in the recrystallized silicate melt inclusions are highly variable (Cu 3-3657 ppm; Pb 11-797 ppm; Zn 5-1153 ppm). The elevated concentrations of these fluid compatible elements in the SMI can be explained by the heterogeneous entrapment of fluid with the melt.

Tectonic and structural controls on intrusion-related deposits (Elatsite and Praveshka Lakavica) in the Northern part of Sredna Gora zone, Bulgaria.

Nikolay Petrov[1], Kamelia Nedkova[2]

[1]*Sofia University "St. Kliment Ohridski", 15 Tsar Osvoboditel Bd., 1504 Sofia, Bulgaria; niky_geology@abv.bg*
[2]*Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; kamelia_geology@abv.bg*;

The Cu-Au deposits of the Sredna Gora tectonic zone are spatially and temporally related to Late Cretaceous plutonic and volcanic rocks. The plutonic suites were generated by arc-trench-related magmatism. They represent a series of orogen-oblique magmatic centers stepped progressively southward between 92 and 78 Ma, possibly in response to ongoing subduction and collision of the African plate. More specifically, Elatsite and Praveshka Lakavica deposits situated in the northern part of the zone are associated with intermediate intrusions of Srednogorie Plutonic Suite.

Mechanical modeling of the Northern part of Sredna Gora zone combined with regional observations show that strain is unevenly distributed across the orogen. There are zones of extension parallel and perpendicular to the zone axis. The locally extensional domains in an otherwise generally contractional settings, facilitates magma and fluids migration from depth. These local extensional sites are associated with regional scale fault intersection zones between the oblique reverse Kashana and Placalnica shear zones and a set of brittle strike-slip faults. This is the most pronounced magma and fluid flow zone in this part of the orogen.

Relationships between the geometry of the granitoid stocks and the fault/fracture network indicate that the faults may have been important in the localization of stocks. More specifically, the NW and E– striking line of granodiorite stocks and dykes suggests that NW and E - striking dextral strike-slip fault system exerted control on emplacement of these intrusions. In the Elatsite and Praveshka Lakavica deposits, however, magma emplacement and mineralization controlling faults are regionally extensive but are not linked to any regional-scale (>5km length) faults or shear zones.

The observation that these faults (NW – striking) cut earlier compressional fabrics indicates that they probably developed late-syn or post movement along the major thrusts (Kashana and Placalnica) in the end of Early Cretaceous. Dextral reactivation of the NW- striking faults occurred in association with magmatism and hydrothermal activity at 92 Ma. This tectonic-magmatic event may be representing a transitional stress-regime between Early Alpine compressional tectonics and initiation of major movements of the Late Alpine Srednogorie strike-slip system.

Elatsite and Praveshka Lakavica deposits are similar to a porphyry style systems in that mineralization has a close spatial and temporal relationship to intrusions. However, porphyry systems commonly have variably-oriented stockwork and/or breccias at their centers. In porphyry intrusion-related systems concentric and radial vein arrays are common, and reflect magmatic processes.

The critical difference in structural style of Elatsite and Praveshka Lakavica deposits to porphyry systems is that there are regionally consistent stock, dyke, vein and fault orientations both within and outside areas of influence of intrusions and their hydrothermal centers. The hall-marks of true porphyry systems, multidirectional quartz-veinlet stockworks generated as a result of hydraulic fracturing, are absent. Such deposits seem to have formed during relatively passive ascent of magma and magmatic fluids through fracture systems related to district-wide stress regimes.

The Magmatic Sulfide Inclusion in some Intrusions from the Metaliferi Mountains, Romania (preliminary data)

Emilian Rosu[1], Marcel Guillong[2], Christoph A. Heinrich[2], Thomas Pettke[3], Paul Ivascanu[1], Caroline R. Harris[2]

[1]Geological Institute of Romania, str. Caransebeş 1, 012271, Bucharest 32, Romania ; e_rosu@yahoo.com; paul_im@yahoo.com
[2]Dept. of Earth Sciences, IGMR, ETH Zurich, 8092 Zürich, Switzerland; guillong@erdw.ethz.ch; heinrich@erdw.ethz.ch; harris@erdw.ethz.ch
[3]Institute of Geological Sciences, University of Bern, Baltzerstrasse 1 +3, 3012 Bern, Switzerland; thomas.pettke@geo.unibe.ch

In the South Apuseni Mountains (SAM) area, the Miocene-Quaternary magmatic activity evolved in three episodes. The earliest volcanic rocks are Lower Badenian (ca. 15 Ma old) dacitic tuffs, the age is inferred from stratigraphic relationships with paleontologically dated Miocene sediments. The main episode, developed in Upper Badenian-Pannonian is represented by an early volcanogenic sedimentation in newly created pull-apart basins, followed by two magmatic activity events. The first, between 14.8–11 Ma, (calc-alkaline medium-K quartz andesites with amphibole, pyroxene ± biotite) is spatially restricted to Zarand-Barza-Zlatna-Rosia Montana-Bucium areas. This area shows a progressive clockwise rotation of 70º between 14.5 Ma and 12 Ma. The second, between 12.6–7.4 Ma (calc-alkaline medium to high-K quartz andesites with amphiboles, biotite ± pyroxene), covers largely areas in the Deva-Sacaramb-Hartagani and Baia de Aries-Rosia Montana zones. The main products here are "adakite-like" calc-alkaline rocks. Small bodies with alkaline features (trachyandesites, microdiorites; 10.5 Ma) in Sacaramb-Hartagani area and basaltic andesites (7.4 Ma) in Rosia Montana-Bucium area, with distinct geochemical signature, are the latest products in the respective districts. Paleomagnetic data indicate no rotations. The last episode (Early Pleistocene) displays an alkaline character and occurs on a different geostructural context after a gap of about 6 Ma only in Uroi Hill (1.6 Ma) at the east to Deva zone.

The Neogene ore-deposits of the SAM are related to "normal" and "adakite-like" calc-alkaline intermediate magmatic complex structures generated under extensional regime in a non-subduction setting. Despite of some mineralogical and geochemical differences existing between "normal" and "adakite-like" calc-alkaline andesites, the whole area of SAM is characterized by numerous porphyry copper systems (Cu+Au, Mo), base metal-gold and telluride epithermal ores: veins, breccia pipes or replacement bodies. There are three main episodes for mineralization processes: the first, at the Badenian/Sarmatian boundary in Rosia Montana area (13.6 Ma), the second, (largely developed at regional scale) after the cessation of the clockwise rotation, between 12.5-10 Ma (Middle Sarmatian-Upper Pannonian) and the third, in Pannonian, between 9.5-8.5 Ma at Baia de Aries.

Based on the field observations, geochronological, geochemistry and isotopic data of the rocks and according to pre-ore and post-ore setting of some intrusions from "volcano-plutonic" structures that generated porphyry copper (Deva, V. Morii, Bucium Tarnita) or epithermal gold mineralizations (Sacaramb, Rosia Montana, Baia de Aries) we have selected the samples for investigations. We have analyzed these samples and measured by LA-ICPMS the unexposed primary sulfide melt inclusions (MIS) enclosed in phenocrysts of plagioclase, amphibole and sometimes magnetite. Petrographic observations on polished surfaces show that MIS has varied shapes. They are represent as monophases sulfide minerals (pyrrhotite, chalcopyrite, and bornite) or are composed of several phases of these sulfide minerals associated sometimes with Fe-oxides, accounting for variations in fO_2, fS_2 and iron activity in the host magma. Sulfide MIS were analyzed for their Fe, Cu, Ni, Au, Ag and Te contents. At regional scale, the contents of these elements and theirs ratios present important values according to the type of MIS and the type of mineralization, too. The Cu contents are usually up to 10wt%, with frequent values between 10wt.%-20wt.% and sometimes up to 40wt.%. Gold concentrations are approximately constant between 0.5 and 2 ppm.

Petrogenesis of the Hercynian Rkvia-Beretisa intrusion, Dzirula Massif, Georgia

Rusudan Chagelishvili.
Geological Institute of Georgian Academy of Sciences, Tbilisi, Georgia
Ruso_chagelishvili@yahoo.com

The geology of Georgia consists of two major thrust belts: the Great Gaucasus and the Achara-Trialeti belt, separated by two foreland basins named Rioni and Kartli, with one intervening basement culmination, the Dziruli Massif. The Rkvia intrusion is located to the west of the Dziruli Massif. This intrusion was never studied before by modern analytical methods.

Based on field investigations, petrographic and petrochemical investigations, it was concluded that the Rkvia intrusion and outcrops of porphyry granites and pegmatites on the eastern edge of the intrusion (V.Beretisa) represent one genetic type. According to the petrographic characteristics of the rocks, their spatial distribution, petrochemical and geochemical features and their geodynamic position, these two bodies are considered as one intrusive complex called Rkvia-Beretisa.

Based on modern petrochemical, geochemical and isotope data, the magmatic source of the complex is interpreted as being generated within an island arc geodynamic regime and that it is of a collisional nature. Rocks of the main phase of the complex are normal granites. Their magmatic melt belongs to calc-alkaline series. The intrusive complex is an upper crustal anatectic S type (Initial 87Sr/86Sr=0.7083; Epsilon Nd=-5.9517) with 5-25% of mantle material in the initial melt.

Based on microprobe analyzes of plagioclases, K-feldspars, biotites and muscovites and using different geothermobarometers, it is concluded that crystallization of the Rkvia-Beretisa magmatic system started under temperatures of 670-690^{0}C and pressures of 7.5-8.5 kbars. The final crystallization stages took place at 400-450^{0}C and 3.5-4.5 kbars.

^{40}Ar / ^{39}Ar ages of the complex are 302±2 Ma.

The Rkvia – Beretisa intrusion is one of the largest granitic complexes in Georgia. It is valuable for Georgian industry as a building and facing materials. On the edge of the central part of the intrusion, silicified rocks of the main intrusive phase were recognized. In the canyon of the river Budja, a basic and ultrabasic young intrusive body (Buja intrusive) was discovered, which according to its decorative nature can replace gabbros imported to Georgia from Ukraine.

The place of the Bolnisi ore district, Georgia in the Tethyan-Eurasian metallogenic belt and peculiarities of its mineralization

Vladimir Gugushvili, Nino Popkhadze, Tamar Beridze, and Rusudan Chagelishvili
Geological Institute of Georgian Academy of Sciences, Tbilisi, Georgia
gugushvili34yahoo.com, nino_popkhadze yahoo.com, r_chagelishvili yahoo.com

The Tethian-Eurasian metallogenic belt (TEMB) consists of the Apuseni-Banat-Timok-Srednegorie (ABTS) belt on the west and the Pontide-Lesser Caucasus (PLC) belt on the east. Both of them belong to the same geodynamic setting and are mainly linked to Late Cretaceous calk-alkaline volcanic activity. During Late Cretaceous, the Tethyan ocean closed and volcanic activity and mineralization were related to the last stage of subduction and to slab destruction as well. The various character and slab transformation along TEMB is the differences in the mineralization and character of volcanism in the western and eastern belts and within each of them.

Thus in the western belt, in the Bulgarian Panaguyrishte and Serbian Timok regions, gold-copper high-sulfidation epithermal (Chelopech, Elshitsa, Radka, Krassen, Coka Marin, Lipa), and porphyry-copper (Medet, Elatsite, Assarel, Petelevo, Tsar Assen, Vlaikov Vruh, Madjanpek, Bor) were formed. In the eastern belt, there are Kuroko-type deposits at Madenkoy (Chaeli) and Lahanos (East Pontides), Turkey, as well as one epithermal copper-polymetallic deposit (Murgul), gold-bearing low sulfidation deposits at Cerattepe, Mastra (Gumushane) and one porphyry-copper deposit at Guzeliayla, Turkey.

In the Bolnisi district, Georgia, which belongs to the PLC, the gold-copper epithermal deposits consist of two levels: the lower gold-copper porphyry and upper gold-bearing quartz-barite veins. The Bolnisi ore district consists of two clusters with deposits and occurrences of similar styles of mineralization. Such a similar alternation of ores is known at the Turtei deposit, Sardinia, Italy, where gold-bearing quartz vein mineralization was developed above the epithermal copper-base metal ores.

The character of volcanic activity and mineralization was different along the Tethyan-Eurasian metallogenic belt, and varied within the limits of Late Cretaceous. The volcanic-hosted porphyry-copper mineralization the Timok and Panagyurishte regions is andesitic, whereas in the Bolnisi ore district the volcanism linked to mineralization is rhyolitic-dacitic. In the Panagyurishte region, the north to south younging of magmatism is accompanied by a change in chemical and isotopic characteristics (Von Quadt et al, 2005). In the Bolnisi ore district, the same situation occurs, however here the younging of magmatizm and mineralization is observed from the south to the north and is characterized by a concomitant increase of the mantle source during volcanism. It may be explained by slab detachment during subductiuon. (Gugushvili; et al. 2002).

The gold bearing quartz-chalcedony and low temperature quartz-barite mineralization must be linked to acid magmatism. The reason of poor gold content in Timok region (Bor and Madjanpek) as well as in Kuroko type Pontide deposits (Madenkay and Lahanos) need farther investigations.

The Bolnisi mining district, southern Georgia: present knowledge and open questions about volcanism, geodynamics and ore formation

Nino Popkhadze[1], Robert Moritz[2] & Vladimir Gugushvili[1]

[1]Geological Institute of the Georgian Academy of Sciences, Tbilisi, Georgia,
nino_popkhadze@yahoo.com, gugushvili34@yahoo.com
[2]University of Geneva, Switzerland, robert.moritz@terre.unige.ch

The Bolnisi mining district represents consists of gold-copper-polymetallic stockworks and vein as well as low sulfidation epithermal gold deposits. It lies within a larger metal rich, Late-Cretaceous tectonic zone of the Alpine Tethyan Belt stretching from south Georgia and northern Armenia into northern Turkey (Pontides), Bulgaria (Srednegorie), Serbia and Romania (Balkan Region). This tectonic zone developed during subduction and collision of the Afro-Arabian (southern) plate beneath the Euro-Asia (northern) plate resulting in the closure of the northern branch of Tethys ocean.

Mineralization within this corridor includes such deposits as Chelopech, Elshitsa, Medet, (Bulgaria), Murgul, Artvin-Borchka, Gerat Jape and Madenkoy (NE Turkey), Alaverdi, Kafan (Armenia), Madneuli, and Sakdrisi (Georgia). The deposit types in this tectonic zone are Kuroko-Cu, Pb, Zn-Ag-Ba, Au ores, porphyry Cu-Au, stock work and vein of copper-polymetallic gold-bearing deposits, and low sulfidation Au vein deposits.

The Bolnisi mining district includes various types of mineralization characteristics of the belt. The host rocks are Upper Cretaceous acid, intermediate and basic volcanic rocks unconformably overlying the Paleozoic basement.

The Madneuli deposit is one of the most significant deposits within the Bolnisi mining district and we are at the first stage in our study of the whole district.

In spite of the long history of investigations of the Madneuli copper-gold deposits, questions are still open about its origin. Some researchers consider Madneuli as an epigenetic deposit and its formation was attributed to Tertiary geological processes (Nazarov, 1966; Tkemaladze, 1982). Other researchers think, that there is a genetic relationship between ore generation and Cretaceous volcanism, although they consider that ore mineralization was epigenetic (Bachaldin and Tkvarchelidze, 1963; Malinovski, 1987; Gugushvili and Omiadze, 1988; Kekelia, 1993). In the Bolnisi mining district, gold-copper-polymetallic mineralization as well as epithermal mineralization are located along cauldron subsidence ring structures and are related to the tuminescence stage of their development. Mineralization preceded the ignimbrite ejection and cauldron subsidence (Gugushvili 2004). The existence of syngenetic volcanogenic ore mineralization is also supported by several authors. A hybrid genetic character of the Madneuli deposit has been proposed, as well as a close similarity with transitional volcanogenic-sedimentary –epithermal types of ore deposits (Migineishvili, 2001).

Our aim is to use modern analytical data (isotope geochemistry and absolute dating), to reinvestigate in detail the volcano-sedimentary setting of the Madneuli deposit, to undertake lithogeochemistry of magmatism of the district and of the hydrothermal alteration of the volcanic-sedimentary rocks, in order to try to characterize the ore deposit typology at Bolnisi-Madneuli. In addition, the aim is to clarify some of those open questions about the character of the volcanism in the district, and its geological setting (submarine or subaeral).

The Uraveli sequence: implication for basin formation during the Middle-Upper Eocene, Achara-Trialeti basin, Georgia

T.Beridze, V.Alania, S. Khutsishvili, N.Popkhadze, & R.Chagelishvili
Geological Institute of Georgian Academy of Sciences, Tbilisi, Georgia
nino_popkhadze@yahoo.com , viktoralania@yahoo.com, sofio_sofi@yahoo.com, ruso_chagelishvili@yahoo.com

Studies of modern back-arc basins demonstrate that the history of their formation and evolutions is reflected in the sedimentary fill of the basins, their structure, composition and texture of volcanic and volcano-clastic components. This history can be deciphered in ancient back-ark basin sequences.

The Achara-Trialeti fold and thrust belt is a major tectonic unit located in the eastern part of the Caucasus in Georgia. Eocene volcano-sedimentary sequences within Achara-Trialeti are folded and thrust-faulted as a result of a compressional-contractional tectonic regime during post-upper Eocene time. From Jurassic to Paleogene, the present Achara-Trialeti area was a back-arc basin, as a result of northward subduction of the Tethys Ocean under the Eurasian active margin. Sedimentary successions, and the composition and textures of volcanic and volcanoclastic components reflect a two-phase subsidence history (fault controlled and thermal) and are divided into syn-rift and transitional mega-sequences. The Lower-Middle Eocene sedimentary rocks consist of thin and thick bedded turbidities, pyroclastic flows and volcanoclastic turbidites, and they filled the basin during an extentional tectonic regime accompanied mostly by low K-tholeitic and calk-alkaline volcanic activity. The Upper Eocene sedimentary rocks are thin bedded turbidities, and filled the basin during a transitional regime accompanied by alkaline (shoshonites) volcanic activity.

Based on sedimentary, stratigraphic and structural analyses within the Akhaltsikhe basin (riv. Uraveli and Mtkvari), during the Middle-Upper Eocene, the Uraveli sequence consist of thin and thick bedded turbidities, volcanogenic turbidities and conglomerates separated from each other by syn-rift and transitional mega-sequences. Formation of this sequence is attributed to a transpressional-extentional tectonic regime. During Late Middle-Early Upper Eocene, there was a deepening along northern normal faults, related to half-graben structures, which resulted in the formation of asymmetrically shaped depocenters. Such kind of tectono-sedimentation is common for pull-apart type basins.

Ore-forming fluids associated with Pb-Zn-Ag-sulfide mineralization at Rogozna and in the South Kopaonik mineral belt

Sabina Strmic Palinkas[1], Sibila Borojevic Sostaric[1], Milica Veselinovic Williams[2], Vladica Cvetkovic[3], Ladislav Palinkas[1], Andy Rankin[2] and Peter Treloar[2]

1. Institute of Mineralogy and Petrography, Faculty of Science, University of Zagreb, Croatia
2. Centre for Earth and Environmental Science Research, Faculty of Science, Kingston University, UK
3. Faculty of Mining and Geology, University of Belgrade, Serbia

Rogozna and Kopaonik Mountains are a part of the Western Vardar zone (WVZ), situated between the Drina-Ivanjica block on the West and the Kopaonik Ridge on the East. The WVZ is composed mainly of a Jurassic ophiolite complex, placed within a mélange formation. It is sporadically cross-cut by Tertiary volcanic rocks. Volcanic rocks in the area consist of Oligocene-Miocene basalt-andesites, latites, quartz-latites and associated pyroclastite rocks. The Neogene syncollisional volcanism produced numerous Pb-Zn-Ag mineral deposits, which extend northward from Kosovo and southern Serbia (Trepča, Belo Brdo, Crnac) along the Kopaonik Ridge. The metallogenic district hosts skarns, hydrothermal replacements and vein type deposits. The on-going studies on Trepča, Belo Brdo and Crnac mines are focused on the P-T-X formation conditions and refinement of genetic models in order to improve exploration on similar deposits in the region.

The Trepča mine: Mineralization is hosted by limestones with paleokarst, covered by Triassic schists. The ore forming process is related to a phreatomagmatic event (maar type). Commonly skarn minerals (ilvaite, hedenbergite, garnet) precede sulfide mineralisation. Fluid inclusion (FIs) studies were carried out on skarn (hedenbergite: Th=385-410°C, 14.8-16.5 wt% NaCl equ.), sulfide (sphalerite: Th=240-305°C, 8.0-14.6 wt% NaCl equ.) and gangue minerals (quartz: Th=295-355°C, 4.5-12.0 wt% NaCl equ.; carbonates: Th>295, 4.5-11.0 wt% NaCl equ.).

The Belo Brdo mine: Mineralization is located on and close to the tectonic contacts of Cretaceous carbonates with volcanoclastic rocks and/or serpentinite. The additional hydrothermal veins are located within Tertiary andesites. The preliminary FIs study was applied to quartz from a hydrothermal replacement ore body (Th=135ºC-350ºC, with mode value at 230ºC and two weaker maxima at 150ºC and 320ºC, 1.0-14.0 wt% NaCl equ.). The bivariate Th vs. salinity diagram may indicate a mixing trend of magmatic and meteoric fluids.

The Crnac mine: There are two types of mineralization: vein type, hosted by Jurrassic amphibolites, and listwaenite mineralization developed at the contact between amphibolites and overlying serpentinites. A FIs study on quartz from the listwaenite mineralization reveals the presence of a high-temperature – low-salinity fluid (Th=249 - 324ºC, 2.9 – 6.7 wt% NaCl equ.). Primary fluid in late stage carbonates ($CaCl_2$-NaCl±KCl-H_2O, Th=247-325ºC, 5.1 – 7.0 wt% NaCl equ) overprinted by a lower temperature fluid ($CaCl_2$-NaCl-H_2O-CO_2, Th=219-268ºC, 4.3 – 11.7 wt% NaCl equ.) suggests an influence of meteoric water.

Despite the variations between ore types and host-rock characteristics, major similarities are recognized in the fluid inclusion data, structural controls and sulfide mineralogy. It appears that the spectrum of mineralization styles, shown by these deposits represents different responses to the same magmatic events.

Geochemistry and geochronology of the Eastern Srednogorie zone, Bulgaria

Svetoslav Georgiev[1], Albrecht von Quadt[1], Irena Peytcheva[1], Peter Marchev[2]

[1] ETH Zurich, IGMR, Switzerland, georgiev@erdw.ethz.ch; vonquadt@erdw.ethz.ch; peytcheva@erdw.ethz.ch
[2]Geological Institute, BAS, Sofia, Bulgaria, pmarchev@geology.bas.bg

Eastern Srednogorie zone is situated in southeastern Bulgaria and is part of the ABTS magmatic and metallogenic belt. Compared to other parts of the ABTS belt the magmatism in Eastern Srednogorie is the most voluminous and compositionally diverse manifestation of the Late Cretaceous magmatic activity. Characteristic features of the magmatism are the elevated alkalinity and the predominance of basic to intermediate volcanics. The available geochemical data consists mostly of major element analyses for separate volcano-intrusive centers.

In this study we present our geochemical and isotope data for a broad representative set of samples, with the aim to characterize the magmatism, and to put new constraints on the geodynamic evolution of Eastern Srednogorie zone.

Single zircon LA-ICP-MS dating and high precision TIMS U-Pb dating reveals that magmatism commenced at ca. 86 Ma, and the peak of the magmatic activity was from 81 to 78 Ma. Basement granitoids are dated as Permian.

All rocks from the studied area display typical MORB-normalized patterns of arc magmas: elevated contents of fluid mobile LILE, negative Nb-Ta trough, increase of Th and LREE compared to HREE. The HFSE ratios of the most primitive magmas suggest that the mantle source of Eastern Srednogorie had the characteristics or a slightly enriched N-MORB source. Our attempt to model the degree of melting following the ideas of Pearce and Patterson, 1993, suggest that the melting took place in a spinel lherzolite field, the calculated degrees of melting are rather high (25-35%), and the oxidizing conditions were around QFM +1.

Hf isotopes of the dated zircons suggest a mantle-dominated source of the magmas. The elevated Th/La ratios (0.24), the LREE to HREE enrichment (La/Yb_n=6.9) and the isotope ratios of the primitive volcanics with MgO > 8 wt% require addition sedimentary material to the mantle source Modeling of the whole-rock isotopic compositions suggests that the initial $^{87}Sr/^{86}Sr$ (0.70403) and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ $^{208}Pb/^{204}Pb$ (18.43, 15.58, and 38.37, respectively) ratios in the most primitive rocks can be achieved by addition of less than 1 wt% of sediment, plus some input of radiogenic Sr from slab-released fluids.

The more evolved compositions most probably resulted from crystal fractionation mainly of clinopyroxene ± olivine ± plagioclase ± Fe-oxides. In the process of differentiation, the rocks assimilated various proportions of crustal material, which is reflected in their elevated Pb and Sr initial ratios

References: Pearce and Parkinson, 1993. Geological society of London special publication No 76, 737-403

Magmatic petrology and ore generating potential of the Zidarovo center, Eastern Srednogorie, Bulgaria.

Rossen Nedialkov[1], Robert Moritz[2] & Denis Fontignie[2]
[1]Sofia University "St Kl. Ohridski",, Bulgaria, rned@gea.uni-sofia.bg
[2]University of Geneva, Switzerland, robert.moritz@terre.unige.ch, denis.fontignie@terre.unige.ch

The Zidarovo magmatic center is situated 15-20 km southward of the Bourgas town, Bulgaria. The magmatic center is in the easternmost part of the Apuseni-Banat-Timok-Srednogorie Late Alpine belt. The center is close to the border between the Strandja Collage Unit (SCU – to the south) and the Eastern Srednogorie Volcanic Zone (ESVZ – to the north). The Zidarovo volcanic edifice is asymmetric, with a larger and SE-elongated eastern part and a smaller and isometric western part. The eastern part of the volcano is subsided and is built up mainly by basaltic to trachybasaltic lavas (with abundant pillow lavas) and a small amount of pyroclastic and epiclastic rocks. The western part consists of a relatively larger part of pyroclastic and epiclastic rocks (up to 30-40%) generally with red colouring, evidence for a higher oxygene potential during the subaerial or shallow water volcanic activity. The subvolcanic dyke rocks occupy a large horse-tail splay structure probably due to the westward moving of the SCU, which was a dextral strike-slip in transpressional tectonic event. The dyke swarm was the main magmatic conduit for lava effusions in the eastern part of the volcano. The volcanic and subvolcanic rocks are crosscut by the multi-phase Zidarovo differentiated small intrusion, exposed over an area of 3-4 km^2, and elongated in a SE direction.

Major elements in volcanic and subvolcanic rocks display similar trends, and indicate that the rocks belong to the medium-K to high-K series. The trends of Na_2O and K_2O for the intrusive rocks differ from those of the volcanic and subvolcanic rocks. Two trends are distinguished in the intrusive rock samples: a low-K and a high-K to medium-K one. The potassic trend for volcanic and subvolcanic rocks shows a steep increasing of K_2O in a narrow SiO_2 interval. A similar magmatic evolution is interpreted by Meen (1987) by a differentiation mechanism due to the fractionation of Ol and Px from a relatively anhydrous melt at 10 kbars (30 km depth) in a Moho level chamber. The derived magmatic liquids are strongly enriched in K_2O. During this evolution the evolved magmas were also enriched in water, to a level to form amphiboles in the more evolved basic subvolcanic rocks (more than 4 wt% water for basalts when amphiboles appear). The magmatic evolution of the intrusive complex occurred at a shallower depth with respect to relatively hydrous melts. Water contents in the more primitive basaltic magmas were about 0-2 wt% according to the geohydrometer of Merzbacher and Eggler (1984). The more evolved magmas of the volcanic rocks (latites and trachytes) have water contents up to 5 wt%.

The temperature of clinopyroxene phenocryst crystallization was 1185-1140^{o}C. Crystallization of CPx from the ground mass was at 1100-1110^{o}C (approximately the temperature of the basaltic lava at the earth surface). The hornblende-bearing intrusive rocks (monzodiorite, diorite, monzogabbro) crystallized at temperatures of 820-890^{o}C and at pressures of 4.5 – 5.4 kbars.

Small sulfide magmatic inclusions of pyrrhotite and chalcopyrite are present in the pyroxenes of the volcanic and subvolcanic rocks. The calculated fS_2 is 3.5-5 at the respective magmatic temperatures. Interstitial anhydrite (late magmatic (?)) is present in monzodiorites and in quartz-diorites, which is evidence for the high S potential of the magma and the relatively high fO_2 (oxidized intrusive magma). Magmatic activity evolved in a volcanic arc tectonic setting.

Isotopic compositions ($^{86}Sr/^{87}Sr$ and $^{143}Nd/^{144}Nd$) of the basalts and monzogabbros from the Zidarovo magmatic center plot in the mantle array between the fields of BSE and HIMU, closer to HIMU and PREMA. Those are pure $^{86}Sr/^{87}Sr$ mantle characteristics (0.70370-0.70378) without crustal contamination.

High-K ankaramitic and high-Al magmas in the Eastern Srednogorie continental arc: Comparison between melt inclusion geochemistry and lavas

Peter Marchev[1], Svetoslav Georgiev[2], Zoltán Zajacz[2], Simone Tomassini[3], Piero Manetti[3], Albrecht von Quadt[2]

[1]Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria, pmarchev@geology.bas.bg
[2]University of Florence, Italy, toms@unifi.it; manetti@unifi.it
[3]ETH Zurich, IGMR, Switzerland, georgiev@erdw.ethz.ch; zajacz@erdw.ethz.ch; vonquadt@erdw.ethz.ch

Two olivine and clinopyroxene-rich high-Mg cumulitic rocks (24. 5 wt. % and 12.0 wt%, respectively) from the Upper Cretaceous Srednogorie continental arc, Bulgaria, contain melt inclusions with much less mafic compositions. Olivine (Fo_{91-85})- and clinopyroxene (Mg#89-69)-hosted melt inclusions in the more mafic rock are characterized by high-calcium, nepheline-normative compositions (MgO=7.5 - 10.8 %, CaO/Al_2O_3>1), with high total alkalis and K_2O/Na_2O>1, which can be classified as shoshonitic ankaramites. The inclusions in olivine ($Fo_{84.2-83}$) and clinopyroxene (Mg#86.9-75.3) in the less mafic rock are also nepheline-normative, but with lower (MgO=3.1 - 5.6 wt.%, CaO/Al_2O_3 <1), with similar high K_2O/Na_2O ratio, but at 2-3 times higher alkali contents. Chemical composition of this magma can be determined as high-K trachybasalts. Major and trace element composition of the ankaramitic melt inclusions are similar to the bulk rock compositions of some lavas and dykes, from the central part of the Eastern Srednogorie, indicating that they have been formed from melts of similar composition. These rocks are strongly porphyritic, composed by phenocrysts of olivine and large clinopyroxene, resembling the high-potassic ankaramites from several other continental and oceanic arcs. Rocks with compositions, similar to the high-K trachybasltic melt inclusions were not found, although more evolved ultra-K magmas are largely distributed in the area. Isotopic (Sr and Pb) similarity of the cumulitic rocks containing ankaramitic and trachybasaltic melt inclusions indicate derivation from similar source and progressive fractionation of olivine and clinopyroxene from ankaramitic parental (in proportions similar to those in the cumulitic rocks) can result in production of high-K trachybasalts. The most likely source of the Eastern Srednogorie primitive high-calcium, silica-undersaturated magmas is a clinopyroxene-rich, phlogopite-bearing mantle source. Garnet-bearing peridotites and clinopyroxenite cumulates are alternative but less realistic sources.

Morphological features and genesis of fluid inclusions in quartz crystals from the chamber pegmatites of Upper Cretaceous monzonites, eastern Bulgaria

Paraskev Petrov[1]

[1]*Sofia University "St. Kliment Ohridski", 15 Tsar Osvoboditel Bd., 1504 Sofia, Bulgaria;*
parp@gea.uni-sofia.bg

Smoky quartz crystals that were formed during the post-magmatic stage of the evolution of the monzonitic magma have been studied. The crystals have grown in elongated cavities. Aggregates of feldspars, individual biotite crystals and epidote geodes were growing together with the quartz. After this typical pegmatitic parageneses chalcopyrite, molybdenite, zeolites and calcite were formed.

The quartz crystals are trigonal, up to 3 cm in length. They have well-preserved primary growth forms of the walls. The crystals are transparent, especially in their outer parts. In the base parts, however, variable amount of fractures with the same orientation as the R and r walls of the crystals can be observed.

Microscopically, the different fractures contain considerable variety of multi-phase and two-phase fluid inclusions. Typical are cross-cutting relationships and refilling of earlier from later fluids. Some of the fluid inclusions have accidentally trapped earlier minerals. The studied inclusions in the chamber pegmatites share similar features with the well-characterized inclusions in Cu-porphyry deposits.

Primary fluid inclusions in the studied quartz crystals are very rare. They are observed only in cases of concomitant growth of smoky quartz crystals with zonal growing epidote aggregates within the quartz. It should be emphasized that the primary inclusions are low salinity two-phase (L+V).

Diversity of epithermal gold ore formation events in southeastern Europe: a record of a protracted 60 m.y.-long geodynamic and metallogenic evolution of the Tethyan arc

Robert Moritz[1], Istvan Marton[1], Isabelle Chambefort[1], Cécile Noverraz[1],
Peter Marchev[2], Rumen Petrunov[2], Richard Spikings[1] & Nikolay Bonev[3]
[1]University of Geneva, Switzerland, robert.moritz@terre.unige.ch, istvan.marton@terre.unige.ch
[2]Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria, pmarchev@geology.bas.bg
[3]Sofia University "St. Kliment Ohridski", Bulgaria, niki@gea.uni-sofia.bg

The Bulgarian Late Cretaceous Srednogorie belt and the adjoining Tertiary Rhodope massif to the south record a sequence of tectonic, magmatic and metallogenic events during a protracted, ~60 m.y. long geological evolution. A diversity of epithermal gold deposits is associated with this geological environment, which reflects changing regional tectonic and magmatic conditions over time of this segment of the Tethyan metallogenic belt, in combination with local variations of structural and lithological controls, and variable evolutionary trends of the ore-forming fluids.

The Late Cretaceous Srednogorie belt is an Andean-style, calk-alkaline magmatic arc, with dominantly andesitic-dacitic rocks, where the Panagyurishte district is the main Cu and Au producing center, with spatially associated porphyry-Cu and high-sulfidation Cu-Au epithermal deposits. Ore formation was located along belt-parallel pull-apart basins, and occurred during changes in principal stress axe orientations. Many studies were focused on the world-class high-sulfidation epithermal Chelopech deposit, which is located in the northern, more fertile part of the Panagyurishte district. These studies reveal both structural and lithological controls during or formation. Combined isotope data (O-H-S-Sr-Pb) indicate a magmatic origin for the epithermal deposits, which are roughly coeval with spatially associated porphyry-Cu deposits. Fluid inclusion salinities are mostly below 5 wt% NaCl throughout the paragenetic evolution for all epithermal deposits from the Panagyurishte district, including enargite from the main ore forming stage, and are compatible with a vapor-transport model of Au and Cu. Post-ore basin sedimentation and tectonics, and different erosion levels explain variable preservation states of the Late Cretaceous ore deposits. Preliminary fluid inclusion studies at the Breznik prospect, Western Srednogorie, suggest that local drastic changes of pressure conditions (due to volcanic collapse structures?) may locally explain porphyry-epithermal transitions, and the juxtaposition of apparently different styles of ore forming conditions (high- vs low-sulfidation fluid states).

With progressive plate convergence and collision, the ore forming activity moved southward into the Rhodope massif. Renewed, major gold deposition took place during Late Eocene-Oligocene extension of the Rhodope massif, and was related to metamorphic core complex exhumation. New and published $^{40}Ar/^{39}Ar$ age data (Stremtsi, Ada Tepe, Rosino pospects) reveal that sedimentary rock-hosted, low-sulfidation epithermal deposits were formed between 37.5 and 35 Ma, and pre-date local magmatism. Textural, fluid inclusion and isotope data indicate that gold deposition was related to different processes, including boiling, fluid mixing and/or fluid-rock interaction. The dominant sulfur isotopic composition of sulfides, between –6 and +4 ‰ in all prospects, reveals a similar ore fluid in the different localities. Based on oxygen isotope data, the fluids were dominated by meteoric water, partly reequilibrated with metamorphic and magmatic basement rocks. The origin of the dilute ore-forming fluids, with salinities mostly below 2.2 wt%, and rarely as high as 5 wt%, is still open to question. The sedimentary-rock hosted gold event, was followed at 32-29 Ma by the formation of magmatic-associated Pb-Zn±Cu deposits with subsidiary Ag and/or Au in the Bulgarian part of the Rhodopes (e.g. Madan and Madjarovo districts), and by porphyry and epithermal Cu-Au occurrences in the Greek Eastern Rhodopes, with transitional high- to intermediate sulfidation states of the epithermal fluids based on previous studies.

Petrology and Geochronology of Iran Tepe volcano, Eastern Rhodopes, Bulgaria: Age relationship with the Ada Tepe gold deposit (preliminary data).

Peter Kibarov[1], Peter Marchev[1], Maria Ovtcharova[2], Raya Raycheva[1] & Robert Moritz[2]
[1]Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria
, p.kibarov@abv.bg; pmarchev@geology.bas.bg; raya@geology.bas.bg
[2]Institute of Earth Sciences, University of Geneva, Geneva, Switzerland,
maria.ovtcharova@terre.unige.ch; robert.moritz@terre.unige.ch

The Iran Tepe paleovolcano is situated in the Eastern Rhodopes, immediately N-NE of Krumovgrad, 3-4 km N of the35 Ma-old sedimentary-hosted Ada Tepe gold prospect. On the basis of stratigraphic relationships and available K-Ar data (35-39 Ma), Iran Tepe has been considered as one of the oldest volcanic structures in the region. The proximity of the volcano with the Ada Tepe prospect makes it a possible candidate for the source of fluids and metals for the Ada Tepe hydrothermal system. We report results of detailed petrological and geochemical investigations undertaken on the Iran Tepe volcano, along with the first reliable U-Pb zircon age, in order to constrain the genesis of the magmas and their relationship with the Ada Tepe prospect.

The volcano is built up of massive and brecciated lava flows, epiclastic rocks and rare tuffs. A swarm of WNW striking dykes and subvolcanic bodies are the most likely vent structure. The lavas are porphyritic, with phenocrysts mineralogy dominated by normally and reversely zoned plagioclase, clinopyroxene, orthopyroxene, and amphibole, with biotite in the more evolved compositions. Ti-magnetite is ubiquitous as pheno- and microphenocrysts. Accessory minerals are apatite and zircon. The groundmass consists of same minerals, set in a feldspar or glassy mesostasis. Small metamorphic xenoliths or xenocrysts of quartz and garnet have been observed in some samples. The topmost lava flows are characterized by abundant amphibole-biotite andesitic enclaves. Crystallization temperature, using amphibole-plagioclase geothermometry is between 920 and 990ºC, slightly lower than that obtained by two-pyroxene thermometry (980º-1080ºC). Calculated pressures are between 3.5 and 9 kb.

Lavas are basaltic andesites to dacites (55 - 66 wt% SiO_2). The rocks are medium- to high-K calc alkaline, except a later shoshonitic dike. FeOt, MgO, TiO_2, and CaO generally decrease with increasing SiO_2 and K_2O, whereas Na_2O has a flat distribution. Trace elements display a negative correlation with silica and Sr, V, Co, Ni, Cr and weak positive trends for Ba, Ce. LREE patterns are fractionated LREE, whereas HREE are flat. The Eu anomaly is weak. $^{87}Sr/^{86}Sr$ ratios between 0.7075 and 0.7068 and $^{143}Nd/^{144}Nd$ ratios between 0.51244 and 0.51255 decrease and increase with increasing SiO_2., respectively.

U-Pb zircon dating from a stratigraphically low lava flow demonstrates that the volcanic activity began at *c*. 33 Ma. The lower intercept of the discordia yields an age of 32.7 ± 1.4 Ma and the upper intercept an age of 307.8 ± 1.1 Ma. The latter is interpreted as the age of inherited zircons from the Variscan basement.

Petrographic observation along with the major, trace element and isotopic variations and zircon geochronology data reveal multistage polybaric evolutionary processes for the Iran Tepe magmas. Magma mixing and crystal-liquid fractionation processes determined many of the petrological and geochemical characteristics of the volcanic rocks. Isotopic data, metamorphic xenocrysts along with the complex zircon morphology and age data suggest that magma with more primitive characteristics underwent crustal contamination during their ascent to the surface.

The recent more reliable U-Pb age data show that ore formation at Ada Tepe was 1.7-2.5 my older than igneous activity at Iran Tepe, thus indicating that Iran Tepe was not the source of hydrothermal activity at AdaTepe.

Ductile and brittle structures, and kinematics related to crustal extension in the Central Byala Reka Dome, Eastern Rhodopes, Bulgaria

N. Bonev[1], K. Peychev [1] & R. Moritz [2]

[1]Sofia University "St. Kliment Ohridski", Bulgaria, niki@gea.uni-sofia.bg, kokoeverest@yahoo.com
[2]University of Geneva, Switzerland, robert.moritz@terre.unige.ch

The N-S oriented Byala Reka dome represents an extensional metamorphic dome in the Eastern Bulgarian Rhodopes. It is limited along the flanks by a detachment and high-angle fault, whose central part is tectonically overlain by metamorphic basement allochtonous rocks. An open questions still concerns the contractional vs extensional origin of these allochtonous rocks and their related structural record. In this contribution, we focus on the structures and kinematics in the central Byala Reka dome in order to clarify its tectonic evolution, which provides important clues relative to ore-forming and magmatic processes, also involved during the extensional evolution of the area.

A lower high-grade basement unit, consisting mainly of orthogneisses, constitutes the footwall, which is separated by a detachment fault from the marble-dominated allochton of an upper high-grade basement unit in the hanging wall. The Eocene-Oligocene sedimentary rocks, which fill a fault-bounded graben in the south supra-detachment hanging wall, represent syn- and post-tectonic cover sequences. The flat-lying regional foliation in the footwall rocks progressively grades to a mylonitic foliation in a shear zone underlying the detachment. The mylonitic foliation contains a NNE-SSW trending stretching lineation with shallow plunges. Penetrative fabrics and strain gradient from protomylonites to mylonites depict intense ductile non-coaxial deformation in the shear zone. This deformation becomes increasingly brittle towards the detachment, in turn marked by cataclasite and fault breccia. The sense-of-shear criteria in the footwall shear zone and detachment consistently demonstrate a top-to-the SSW tectonic transport, parallel to the ductile-brittle fabrics. Scarce top-to-the S kinematic indicators in the hanging wall associated with a N-S oriented lineation. Intense folding of the hanging wall has produced early intrafolial folds with WNW-ESE oriented axes and southeast verging closed folds with ENE-WSW trending axes, lying oblique or orthogonal to the lineation. Boudins and clasts used as strain markers in the hanging wall yielded a finite strain with $K \geq 1$. A set of WNW-ESE to E-W striking normal faults and small-scale brittle shears with retrogression to chlorite are developed in the hanging wall orthogonal to the shear direction and fabrics in the footwall, implying a NNE-SSW oriented brittle extension. As sedimentary strata in supra-detachment graben dips south towards the bounding high-angle fault, this suggests hanging wall sedimentation accompanied by faulting.

The ductile-brittle shear regime in the detachment and underlying shear zone shows that the localized deformation occurred at decreasing temperatures and metamorphic grade from amphibolite- to greenschist-facies. Kinematic continuity of ductile then brittle deformation, the decrease in metamorphic grade towards the detachment and associated hanging wall sedimentation, are all characteristics consistent with exhumation and an extensional origin of the basement allochton. These new results allow to constrain the tectonic evolution of the central Byala Reka dome, where the basement exhumation was accommodated by south-southwestward ductile-brittle extension. Cooling ages of the hanging wall and fault assisted sediment-hosted mineralization in the graben (ca. 40-36 Ma), together with stratigraphic ages of the sedimentary fill, constrain a mid-Eocene age for extensional deformation.

Geochemistry and Sr isotopes of the rocks of the Plana pluton, Srednogorie zone, Bulgaria

L.S.Bidzhova[1], R.N. Nedialkov[1], A. von Quadt [2], S.V. Georgiev[2]

[1] SU „St. Kliment Ohridski“, bvd „Tzar Osvoboditel“- 15, Sofia 1504, lora.bidzhova@gmail.com, rned@gea.uni-sofia.bg
[2] ETH Zurich, IGMR, vonquadt@erdw.ethz.ch; georgiev@erdw.ethz.ch

The Plana pluton represents a large intrusive body (about 400 km^2), located ca. 60 km SE from Sofia and belongs to the Apuseni-Banat-Timok-Srednogorie Late Alpine belt (ABTS). The rocks of the pluton range gradually from small volumes of gabbroic rocks in the periphery, to granitoids (mainly granodiorites) in the central parts of the body. The rock varieties are gabbro-pyroxenites, gabbro, monzogabbro, monzodiorites, quartz-diorite, quartz monzodiorite, quartz monzonite, to granodiorite and granite as well as granite-aplites and pegmatites. The pluton is probably a result of *in situ* crystallization that led to the formation of cumulative gabbroic rocks in the periphery and the consecutive increasingly more evolved rock types within the center. Magmatic enclaves were found in the whole intrusion area, indicating the magma mixing processes.

The geochemical characteristics of the rocks of the Plana pluton demonstrate the typical signature of subduction related magmas. The ORG normalized patterns for the granitoids exhibit all the distinctive characteristics for Ca-alkaline VA granites [1]. The samples are enriched in K, Rb, Ba, Th, Ce and Sm relative to Ta, Nb, Hf, Zr, Y, Yb. The degree of LILE and LREE enrichment relative to HFSE correlates with SiO_2 and alkali content. On the Rb – (Yb+Ta) and the Rb-Hf-Ta discrimination diagrams the granitoids plot unequivocally in the VAG field.

All the rocks (except some cumulative gabbroic rocks and aplites) exhibit general enrichment in LREE relative to HREE. The more evolved the sample, the higher the La/Sm and La/Yb ratios, which could be attributed to CPx and Hb fractionation. A negative Eu anomaly appears with the formation of monzonites due to Pl fractionation while further differentiation keeps the Eu anomaly relatively constant.

Aplitic granites strikingly differing from all of the other rocks were established in the pluton. They exhibit large negative Ba anomalies, strong Rb enrichment and raised Nb and Ta abundances. They have characteristic “V”-shaped normalized REE patterns with HREE enrichment, low La/Yb values, very steep increase in LREE/MREE, and a large negative Eu anomaly. Their characteristics could account both for WP and syn-COL granites, but their $^{87}Sr/^{86}Sr$ values of 0.7185 are high and favoured a crustal origin and thus a syn-COL tectonic setting is rather more appropriate. The syn-COL origin is further supported by the position of the rocks on a Rb – (Yb+Ta) discrimination diagram and the Rb-Hf-Ta plot. However, their actual mode of formation still remains uncertain, and further investigations are to be made.

The $^{87}Sr/^{86}Sr$ isotope measurements are in the range of 0.7043-0.7050 which supports a mantle source for the rocks of the Plana pluton with slight crustal contamination. The results are similar to those obtained for other Late Cretaceous bodies in the Srednogorie zone. The $^{87}Sr/^{86}Sr$ values for the geochemically different aplites is 0.7185, indicating crustal dominated source for this rock type

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Mineralogy of rock-forming minerals in Vitosha pluton, Western Srednogorie, Bulgaria

Stela Atanasova-Vladinirova[1], Albrecht von Quadt[2], Kalin Kouzmanov[2,3], Irena Peytcheva[2,4], Bozhidar Mavrudchiev[5]

1. Earth and Man National Museum, stelaatanasova@hotmail.com
2. ETH Zurich, IGMR, vonquadt@erdw.ethz.ch
3. Section des Sciences de la Terre, University of Geneva, kalin.kouzmanov@terre.unige.ch
4. Central Laboratory on Mineralogy and Crystallography - BAS, irena.peytcheva@erdw.ethz.ch
5. Sofia University "St Kliment Ohridski"

The Vitosha pluton is situated in the western part of the Srednogorie zone. The Srednogorie unit is characterized by mafic to felsic rocks association (volcanic, plutonic and dyke rocks) of ultrabasic, basic, intermediate and acid composition. The rocks belong to the normal, subalkaline and alkaline series.

The pluton is composed of abyssal gabbros, anorthosites, hypoabyssal monzonites, syenites and late veins of granosyenitic composition. The pluton is intruded in Late Cretaceous volcanic rocks.

Clinopyroxene is a characteristic mineral for all rock types of the Vitosha pluton with Mg# values of 58-80. It forms deep resorption nuclei or single grains with automorphous contours. The composition plots into the augite and diopside fields. The clinopyroxenes from Vitosha pluton have low REE abundances. The clinopyroxenes show (chondrite-normalized REE diagram) show a general trend of LREE enrichment and HREE depletion. Chondrite-normalized values of La are commonly less than Ce and Nd. Negative Eu anomaly still persists, and the HREE show limited fractionation. Moreover, the negative Eu anomaly in this pattern requires a much larger fraction of pyroxenes.

Amphiboles are present in all upper cretaceous rocks with Mg# values of 58 – 85. The amphibole contains higher REE content than clinopyroxene, and may be important carrier for REE and other trace elements, e.g. in samples with high modal amphiboles. The LREE of the amphiboles from Vitosha pluton are relatively higher, the HREE abundances are essentially the same as those in the clinopyroxene.

Biotites are abundant minerals in the monzogabbro and monzonites, but less abundant or absent in gabbro and syenites. The composition changes from Mg# values of 69 to 43. Biotites are xenomorphic and they altered into chlorites.

Plagioclases occur in all rock varieties of the pluton and they form idiomorphic, polylamellae twinned crystals. The anorthite composition decreases with increasing fractionation of the magmas. Chondrite-normalized REE diagram for plagioclase shows higher LREE/HREE ratio. These relationships help to distinguish the effects of fractionation of trace elements in plagioclase and their primary abundances due to intrinsic concentrations in their magma sources.

The potassium feldspars are weakly altered into clay minerals. They are high sanidine low anortoklase. BaO contents are low, being less than about 0.5 wt%. It is difficult to establish some trend in the Ba distribution in individual crystals. The chondrite-normalized REE spectra consistently follow a decreasing slope from La to Sm, show a strong positive Eu-anomaly, and feature a flat or slightly increasing HREE spectrum. Partitioning of REE into K-feldspar is buffered by fractional crystallization of REE-phases.

A mature arc chemistry of the parental magma suggests similarity with the other plutonic suites from the axial part of the Western Srednogorie area. The observed compositional variations of amphibole, biotite, titanite, magnetite, and ilmenite have been tentatively used as indicators of magmatic evolution of the calc-alkaline I-type for Vitosha pluton. Estimated temperatures of crystallization are between 834° and 579°C, based on the Blundy and Holland (1990) geothermometer. The depth of final crystallization of the pluton is considered to be of about 7 km.

Low-sulfidation, 'non-magmatic' epithermal AuAg deposits of the eastern Rhodopes mountains, Bulgaria

Dimitar L. Dimitrov
Euromax Resources Inc ; e-mail :jikataa@abv.bg

ABSTRACT: The eastern part of Bulgaria's Rhodope mountains host at least 10 documented low-sulfidation epithermal AuAg occurrences and deposits, most of which were unrecognized by modern exploration until the 1990's, though many were worked in Thracian and later times. The deposits display a wide range of morphology, host rocks and variable geochemical signatures including Au:Ag ratios and relative enrichments or deficiencies in typical epithermal elements As, Sb, Hg, but show no enrichment in base metals. Many deposits occur at or immediately below the unconformity of basal Tertiary conglomerates and underlying metamorphic rocks, and are demonstrably older than most Tertiary volcanism in the region. Notably, none of the low-sulfidation systems appear to be related to magmatic rocks, and most appear to be older than the numerous adjacent Tertiary magmatic-related PbZn systems, some of which have economic AuAg grades in their upper and peripheral portions.

Bulgaria's most recently discovered Au orebody is Ada Tepe, perhaps a "classic" low-sulfidation vein/stockwork system, developed at the contact of lower Tertiary sedimentary rocks, and underlying metamorphic rocks. Ada Tepe is one of many low-sulfidation AuAg occurrences throughout the adjacent Rhodopes Mountains that have been identified and explored within the last fifteen years. However unlike most low-sulfidation AuAg epithermal deposits worldwide, which are either hosted in or clearly connected to contemporaneous volcanic/intrusive rocks, most of the Rhodopes occurrences have no such direct spatial or genetic tie to magmatic rocks. This paper summarizes basic geologic and geochemical information on several of these deposits, their spatial distribution, and their morphology. It is hoped that further study will use this basis as a stepping stone toward clarifying their genesis and spatial distribution

Fig. 1 Location of E. Rhodopes low-sulfidation AuAg province

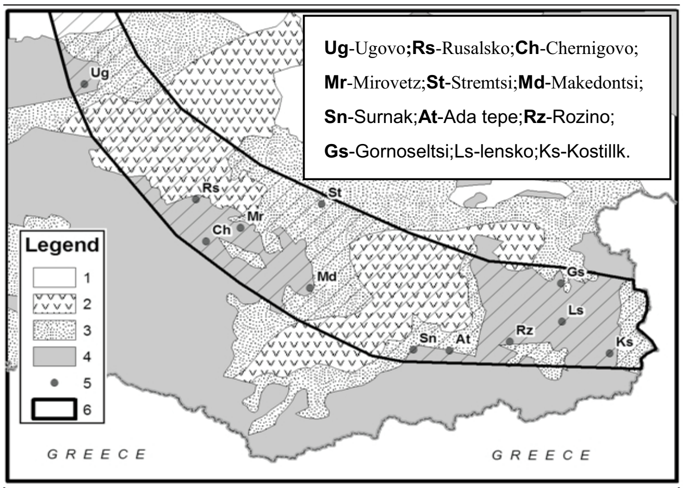

Fig. 2 Generalized map of E Rhodopes low- sulfidation Au-Ag province: **1** *Pliocene-Quaternary sediments;* **2** *Upper Eocene-Miocene volcanic areas;* **3** *Palaeocene-Eocene sediments;* **4** *Metamorphic basement;* **5** *Low-sulfidation Au-Ag deposits and occurrences;* **6** *Eocene low-sulfidation Au-Ag belt.*

The low-sulfidation AuAg deposits occur over an area of approximately 2000 km² (Figure 2). Roughly half are hosted in conglomerate-breccias, conglomerates and sandstones, presumably of Palaeocene - Eocene age. The remainder are hosted in gneiss, calc-schists, and marbles of ages ranging from Proterozoic to Palaeozoic age which forms the underlying basement rocks to the lower Tertiary sediments. Although Ada Tepe and Makedontzi occur in sediments directly at the Tertiary/basement unconformity, at Stremtsi, the mineralization is hosted in sandstone-conglomerate at least 300m above metamorphic basement rocks. At many occurrences, Tertiary sediments are often removed by erosion or were never present. The age of mineralization has not been directly dated but at Surnak is well-constrained by the age of overlying post-ore limestones, of Priabonian age. In places, there is suggestion that early ore-related structures which controlled early Tertiary low-sulfidation Au mineralization, which is it devoid of base metals, may have been reactivated during Tertiary magmatic-related PbZnAg systems of Oligocene age. At Rozino, localized PbZn veinlets were intersected in basement rocks but do not appear to represent a continuous zoning pattern from adjacent Au mineralization. At Stremtsi, a silicified limestone unit which occurs at least 150m stratigraphically above the ore-hosting sandstone-conglomerate, and which may be younger than the Stremtsi Au mineralization itself, contains very high Ag values and is virtually devoid of Au.

The deposits have textural and alteration features typical of low-sulfidation AuAg systems, including banded veins, cavernous carbonate-replacement textures, local adularia, massive silicification, and silica-white mica-chlorite alteration. Morphologies of the mineralized zones vary from roughly stratiform bodies of disseminations and strata-confined vein stockworks in sandstone-conglomerate (Stremtsi), to slab-like low-angle veins and adjacent overlying vein stockworks in basal sandstone-conglomerate (Ada Tepe), steeply-dipping wide stockworks/breccias (Spoluka-Mirovetz), to discreet, wide banded to massive quartz veins (Spoluka-Chernigovo).

Occurrence	**Hostrock**	**Morphology**	**Ag:Au etc**	**Ancient workings?**
Ada Tepe	Tertiary congl> gneiss/schist	Stratiform replacement; steep veins	1:1	Large
Surnak-Kuklitza	Gneiss/schist; marble	Breccia-sockwork and carbonate replacement	10:1 As, Co, Ni	None
Stremtsi	Tertiary conglom.	Dissem. and stratabound veinlets	5:1 Mo, Sb	Large
Lensko-Kostilkovo	Marble; schist	Veins parallel schistosity and carbonate replacement	2:1 As,Sb	Large
Rozino	Tertiary conglom.; granite; gneiss	Disseminated and stockwork	2:1 As,Sb,Mo	Limited
Spoluka: Mirovetz	Gneiss	Breccia-stockwork	>10:1	None
Spoluka: Chernigovo	Gneiss	Large vein	1:1	None
Makedontzi	Tertiary conglom.	Breccia and disseminated, steep veins	5:1 As,Ba	None
SpolukaRusalsko	Gneiss	Brecciasstockwork; veins,	5:1, As,Sb	None
Gornoseltsi/Dolnoseltsi	Tertiary conglom>schists	Disseminated, veins parallel schistosity	5:1, Sb,As	Limited

Table 1: Summary characteristics of eastern Rhodopes low-sulfidation epithermal Au(Ag) systems

The deposits are characterized by varying Ag:Au ratios and concentrations of As, Sb, Hg, locally Co and Ni, where ofiolite blocks are presented in the underlying basement. CONCLUSIONS: The epithermal low-sulfidation hydrothermal systems of the east Rhodopes are emplaced along tectonic boundaries of Early Palaeogene post-collision grabens and are hosted in the Precambrian metamorphic basement, and in the basal conglomerate-sandstone levels of lower Tertiary sedimentary units. These basic geologic data suggest that the early Tertiary Au(Ag) deposits and occurrences are more likely connected to the metamorphic core complexes than Eocene-Oligocene magmatic activity. The Upper Cretaceous collision-related metamorphism is a possible heat source for the widespread low-sulfidation epithermal systems, developed in post-collision extension environments together with the extension of the early Tertiary graben depressions.

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Evolution of the Malko Tarnovo plutonism and its significance for the formation of the ore deposits in the region, Bulgaria

R.Nedialkov[1], B. Kamenov[1], B. Mavroudchiev[1], E. Tarassova[2] & M. Popov[3]

[1]Sofia University "St. Kl. Ohridski", Bulgaria, rned@gea.uni-sofia.bg , b.kamenov@gmail.com
[2]CLMC - BAS,
[3]Bulgarian Academy of Sciences, Sofia, Bulgaria

The pluton is situated southward of the town Malko Tarnovo, at the border between Bulgaria and Turkey and a half of it is exposed in the Turkish territory. It covers an area of 12 km^2 in Bulgaria. The pluton is intruded into low grade metamorphosed terrigenous and carbonate rocks of Upper Triassic and Lower Jurassic age. The magmatic intrusion resulted in the formation of magnesian and calcic skarns. Three Cu-Au-base metal vein- and skarn-hosted deposits (Gradishte, Propada and Mladenovo) and one porphyry type Cu-Mo deposit (Bardtze) are located within the Malko Tarnovo pluton area. The Malko Tarnovo pluton is composed of four intrusive phases: I) Basic rocks (pyroxenites, gabbro-pyroxenites, gabbros, monzogabbros); II) Monzonitoids (monzodiorites, quartz-monzodiorites, monzonites and quartz-monzonites); III) Quartz-syenites; and IV) Porphyry rocks (quartz-diorite porphyrites, granodiorite porphyrites, quartz-monzonite porphyrites and quartz-syenite porphyries).

The rocks from the first phase are low-K to high–K. Rocks from the second and third phases are high-K. The rocks of the fourth phase are medium-K to high-K with potassic alkalinity clearly lower than the rocks of the two previous phases. The rocks of the first three phases form an isometric plutonic body. K-Ar dates are in the interval 77-74 Ma (for I and II phases). The rocks of the IV phase are formed in a different stress regime and form subequatorially elongated intrusive porphyritic bodies. The K-Ar age of the porphyritic rocks is 66 Ma.

The magmatic evolution of the first three monzonitoid phases is characterized by decreasing contents of TiO_2, $FeO+Fe_2O_3$, MgO, CaO, V, Cr, Ni, Co and Sr and increasing contents of K_2O, Na_2O, Ba, Zr and Rb. The trends for Al_2O_3, P_2O_5, Cu, Y, Li, Au and Nb are characterized by a maximum during the second monzonitoid phase. The fractionation of Ol, CPx, Mt, and probably Pl is the likely explanation for this peculiarity. Geochemical and textural features of the mafic rocks indicate a cumulative (mainly for Cpx) origin of the pyroxenites and gabbro-pyroxenites.

The complex of the porphyritic intrusive rocks shows the same tendencies for the evolution trends for most of the elements except for K_2O, Zr, Nb, Rb, and Y which are with lower contents.

The Malko Tarnovo magmatism is related to a normal arc tectonic setting. In the diagram Rb vs Y+Nb the samples fall in the fields of VAG and WPG. This peculiarity is due to the fluid factor influence and the increased K-alkalinity. ORG-normalized spiderdiagrams for all magmatic rocks are similar but with lower contents of the less incompatible HFSE for the porphyritic rocks of the IV phase. They have distinct negative Nb and Zr anomalies, typical for VAG. The chondrite-normalized REE patterns show enrichments of LREE and a very slight decrease of the Eu negative anomaly with the magmatic evolution of monzonitoidic magma of the first three phases.

Crystallization temperatures of zircons are 620 to 730^{o}C for porphyritic rocks and 750 to 900^{o}C for monzonitoids. The pressure of crystallization of amphiboles according to the geobarometer of Schmidt (1992) is 5.4 to 8.8 kb for monzonitoids and 3.7-5.6 kb for porphyrites.

The chemical composition of monomineral biotite separates allow us to estimate roughly the fO_2 at1-2 units below the Mt-Hm buffer, which corresponds to oxidising conditions during magma crystallization in the Malko Tarnovo pluton, favourable for ore element leaching from the magma by hydrothermal fluids exsolving from the melt.

The initial $^{87}Sr/^{86}Sr$ ratio of the Malko Tarnovo plutonic rocks varies between 0.7044 and 0.7078, indicating different degrees of crustal contamination in the mantle derived magma. This ratio varies with around 0.0003 even in a single phase, suggesting crustal assimilation during the magmatic evolution and crystallization in the intrusive chamber.