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2013

Caracciolo, L., A. Orlando, S. Critelli, N. Kolios, P. Manetti, P. Marchev. 2013. The Tertiary Thrace basins of SE Bulgaria and NE Greece: a review of petrological and mineralogical data of sedimentary sequences. – *Acta Vulcanol.*, 25, 1–2, 21–41.

Sandstone petrology and detrital heavy mineral geochemistry have been widely used to investigate the post-collisional magmatism that followed the closure of the Vardar Ocean, the Alpine deformation and the orogenic collapse of the Rhodopian terranes, and its influence during the deposition of Upper Eocene–Oligocene sediments of the north and western portions of the Thrace basin. Beside the important amount of clastic sediments eroded from the Rhodope and Circum Rhodope terranes, volcanoclastic sediments are well represented in the area and offer a good opportunity to constrain the evolution of Thrace basin. Petrography of sediments allows discriminating among three distinct petrofacies reflecting multiple provenance from different tectonic settings as they evolve from quartzolithic to quartzofeldspathic to volcanoclastic compositions, corresponding to collisional orogen, crustal block uplift, and volcanic arc settings, respectively. Beside of the deposition of siliciclastic material, volcanic contributions from both, basic-intermediate and acid products represent an important source of sediments in the area. Despite of dominant intermediate to acid volcanic products, volcanic lithic fragments in sandstones (microlithic, lathwork and brown vitric textures) indicate main inputs from intermediate and basic products. Detrital amphibole and pyroxene chemistry is used to characterize the supply of volcanic material and understand the role played by basic and felsic volcanism in the infill of the north and western Thrace basin. This study demonstrates how Tertiary sandstone compositional shifts in the Thrace basin in NE Greece and SE Bulgaria are strictly related to various geodynamic stages.

Georgiev, S., P. Marchev, I. Peitcheva, A. von Quadt, O. Vaselli. 2013. Miocene extensional magmatic activity along Strymon valley and Doyran region, Bulgaria, Greece and the Former Yugoslav Republic of Macedonia. – *Acta Vulcanol.*, 25, 1–2, 153–168.

Limited occurrences of small and scattered subvolcanic bodies crop out along Strymon River Valley and Doyran region in the border area of Bulgaria, Greece and the Former Yugoslav Republic of Macedonia. The rocks are dated by zircon LA-ICPMS and ID-TIMS method at 12.235 ± 0.026 Ma (Kozhuh cryptodome) and 11.32 ± 0.099 Ma (subvolcanic body near Stoyakovo village), respectively. They are fractionated high-K trachytes to trachydacites, which exhibit adakite-like signatures most probably due to amphibole fractionation in a crustal chamber at depth of 12–8.6 km, and have relatively high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.70616–0.70648) and negative BND_i (–3.29 to

–3.46). The BND_i of the autocrystic zircons and zircon rims for the Kozhuh cryptodome fall into two groups (+5.46 to +8 and +0.83 to +1.18, respectively), whereas zircons from Stoyakovo trachyte exhibit values between +2.4 to +3.15. These elevated BND_i of zircons from the two bodies most probably indicate involvement of asthenospheric mantle melts in their genesis. The presence of xenocrystic zircons suggests contamination with crustal material in the formation of the rocks. Reverse zonation of the amphibole and dark mica, and sieve textures and Ca-overgrowth in plagioclase give a hint for recharge processes with more mafic magma(s). Altogether, the isotopic data and petrology imply complex evolution including mixing between asthenospheric mantle source and crustal magmas, fractionation in a crustal chamber and assimilation of basement lithologies. We argue that the formation of the Strymon River Valley and Doyran region magmatic rocks can be directly linked to the Miocene extensional tectonic regime and formation of the curvature of the Hellenide orogeny.

Kaiser-Rohrmeier, M. K., A. von Quadt, T. Dreisner, C. A. Heinrich, R. Handler, M. Ovtcharova, Z. Ivanov, P. Petrov, S. Sarov, I. Peitcheva. 2013. Post-orogenic extension and hydrothermal ore formation: high-precision geochronology of the Central Rhodopian metamorphic core complex (Bulgaria–Greece). – *Econom. Geol.*, 108, 691–718.

The late Alpine evolution of the Rhodope Massif in Southern Bulgaria and Northern Greece involved post-collisional extension, which generated detachment faults, syndeformational sedimentary basins, and exhumation of a large metamorphic core complex composed of gneisses and marbles: the Central Rhodopian dome. Closely associated with this complex, subvolcanic rhyolite dikes and extrusive rocks were emplaced, shortly followed by major swarms of epithermal to mesothermal Pb–Zn veins and carbonate replacement ore bodies. High-precision geochronology using complementary Ar–Ar, Rb–Sr, and U–Pb dating methods resolves how this process of tectonic denudation from deep crustal metamorphism to near-surface epithermal ore formation occurred within a period of about 12 Ma.

After an early Alpine phase of accretion, eclogite-facies metamorphism, and orogenic nappe stacking, the late Alpine postcollisional evolution of the Central Rhodopian dome started with the intrusion of granitic bodies at about 42 to 41 Ma, probably marking the beginning of extension and core complex formation. The early stages of extension were characterized by normal faulting, rotation of fault blocks, and thinning that caused cooling of the hanging wall through ~ 300 °C at about 40 to 38 Ma, as dated by Rb–Sr and Ar–Ar geochronology of metamorphic biotite. The main extensional phase occurred between 38 and 36 Ma and led to horizontal displacements of tens of kilometers in the hanging wall. In the footwall, high metamorphic temperatures and decompression persisted and resulted in partial melting and the formation of migmatites at 37 Ma and

vuggy pegmatites at about 36 Ma. Cooling of the footwall below ~300 °C occurred between 36 and 34 Ma, followed by emplacement of undeformed rhyolite porphyry dikes and the extrusion of volcanic products deposited onto the surface-exposed center of the dome at about 33 to 30 Ma. The hydrothermal ores were formed ca. 30.5 Ma in the south and ca. 29.3 Ma in the northern part of the dome during the last major event of focused heating from 270 to 330 °C of near-surface rocks by hydrothermal fluid advection. Ore formation and localized, later fluid processes caused disturbance and younging of some Rb-Sr ages in the footwall of the dome.

Field and geochronologic constraints indicate that the formation of the Pb-Zn deposits (~31–29 Ma) is up to 2 Ma younger than the local rhyolitic magmatism, which is volumetrically minor in the mineralized core complex. This contrasts with ore formation related to calc-alkaline magmatism in the Eastern Rhodopes, where polymetallic Cu-Au-Ag-Pb-Zn mineralization was found to be coeval with the latest phases of igneous activity (~32 Ma). The chemically simpler but considerably larger metamorphic-hosted Pb-Zn deposits of the Central Rhodopian dome were generated by large-scale hydrothermal fluid circulation, driven by the high heat flow attending core complex formation, exhumation, and final fracturing of a rapidly thinned crust.

Kostova, I., Ch. Vassileva, Sh. Dai, J. C. Hower, D. Apostolova. 2013. Influence of surface area properties on mercury capture behaviour of coal fly ashes from some Bulgarian power plants. – *Intern. J. Coal Geol.*, 116–117, 227–235; DOI: 10.1016/j.coal.2013.03.008.

In order to reveal the enrichment/depletion behaviour of Hg during coal combustion, a separation procedure was applied on three fly ash (FA) samples from two Bulgarian thermoelectric power plants, Maritza 3 TPP and Varna TPP, as follows: (1) FAs from the 1st and 3rd rows of the electrostatic precipitators (ESP) of Maritza 3 TPP; and (2) FA from the 5th row of ESP of Varna TPP. Five fractions were obtained from each bulk FA sample as a result of the sequential separation scheme applied, namely: water leachate of FA; water washed FA (FAW); char concentrate (FAC); magnetic fraction (FAM); and FA residue (FAR). Mercury content of bulk samples and separated fractions, Brunauer-Emmett-Teller (BET) specific surface area, Barrett-Joyner-Halenda (BJH) mesopore volumes, micropore surface area, monolayer capacity, and micropore volumes for porous texture characterization of the FAs and their respective char fractions were also measured.

The data obtained reveal that char, which contains mainly unburned organic matter, has an important role in the partial capture and retention of Hg in FAs. Fly ash char fraction (FAC) generated from lower rank lignites (Maritza 3 TPP) has greater enrichment in Hg compared to FAC originated from higher rank bituminous coals (Varna TPP). There is a strong positive correlation between Hg concentration and the BET/Langmuir specific surface area, BJH mesopore volume, micropore surface area and monolayer capacity of the char fraction derived from FA of the 3rd ESP row at Maritza 3 TPP, which suggests that Hg adsorbs on both the mesopores and micropores of the char particles and by volume filling of the pores for the lignite-derived fly ash char sample. In contrast, Hg concentration shows strong positive correlation with the micropore surface area and moderate positive correlation with micropore volume and monolayer capacity of the char fraction obtained from the FAs of the 5th ESP row in Varna TPP. Thus, the adsorption on the micropores of the char particles and subordinate volume filling of the char micropores can be expected as preferable mercury adsorption mechanisms for the bituminous-derived fly ash chars.

Lehmann, S., J. Barcikowski, A. von Quadt, D. Gallhofer, I. Peytcheva, C. A. Heinrich, T. Serafimovski. 2013. Geochronology, geochemistry and isotope tracing of the Oligocene magmatism of the Buchim-Damjan-Borov Dol ore district: Implications for timing, duration and source of the magmatism. – *Lithos*, 180–181, 216–233.

Timing, source and magmatic evolution of the intrusions in the Buchim-Damjan-Borov Dol ore district of the Former Yugoslav Republic of Macedonia (F.Y.R.O.M.) have been studied. They intrude the Circum Rhodope Unit close to the contact with the Vardar Zone and are a part of the Late Eocene–Oligocene Macedonian-Rhodope-North Aegean belt. The magmatism at Buchim-Damjan-Borov Dol occurred between 24.04±0.77 and 24.51±0.89 Ma, as indicated by chemical-annealing (CA)-LA ICP-MS zircon dating. Major element, trace and rare earth element analyses have been performed on the various intrusive rocks. All ore bearing magmas were classified as trachyandesitic, except the youngest intrusion which is not associated with mineralization; the Black Hill locality (24.04±0.77 Ma) shows a trachytic composition. The distribution of the trace elements, enrichment of large ion lithophile elements (LILE) and depletion in high field strength elements (HFSE), indicates subduction-related magmatism; most of the magmas follow a calc-alkaline fractionation trend with shoshonitic affinities; additionally, Sr/Y (10 to 90) and La/Yb values show some similarities to adakite-like magmas. Sr and Nd isotope ratios ($Sr_i = 0.70658$ to 0.70740 and $Nd_i = 0.512425–0.512497$) show that the magmatic products were slightly contaminated by continental crust material, e.g., the Variscan/Cadomian basement. In the Late Eocene–Oligocene belt the magmatism between 29 and 35 Ma is dominated by crustal melting with an increase in the mantle contribution between 20 and 27 Ma. We suggest the following scenario for the magmatic history of the Buchim-Damjan-Borov Dol ore district: a slab rollback of an oceanic slab located further to the SW which led to extensional and compressional features in upper levels of the continental crust. In the middle to upper crust three consecutive crystallization stages occurred at variable depths as indicated by amphibole zonation. Mixing of newly formed crust with mantle-like affinities and continental crust material in variable degrees during the ascent of the magma can explain all geochemical characteristics. The magma crystallized as dykes or stocks near the Earth's surface (>1 km) after its final emplacement and contemporaneous hydrothermal activity led to different mineralization styles depending on the lithology of the host rocks.

Marchev, P., A. Harkovska, Z. Pécskay, V. Panteva, M. Popov. 2013. Geology, petrology and K-Ar geochronology of Topolovo-Pilashevo dyke swarm (TPDS) and lavas from the NW Borovitsa volcano (Eastern Rhodopes, Bulgaria). – *Acta Vulcanol.*, 25, 1–2, 99–110.

The Topolovo-Novakovo dyke swarm (TPDS) consists of E-W to NE-SW striking intermediate to acid dykes, stocks and sills, interpreted as the northern boundary of the Borovitsa caldera. Geographically, it coincides with the Topolovo-Novakovo fault zone and a pronounced subequatorial linear lens-like magnetic anomaly. The dykes are intruded into Paleogene sediments, pre-caldera volcanic and volcanoclastic rocks, and pre-Paleogene crystalline basement. We present petrologic and K-Ar data for the dykes and the nearby lava flows, constraining the time span of the igneous activity in the TPDS and its relationship with the Borovitsa volcanism and caldera structure. The dykes and their host lavas have typical shoshonitic affinity, similar to the prevailing volcanic activity within the entire Borovitsa area. K-Ar dating of the rocks records an eruptive time interval between

~33.5–34.0 to 31.0 Ma, which is comparable to the span of the volcanic activity in the Borovitsa volcanic area constrained by the $^{40}\text{Ar}/^{39}\text{Ar}$ dating at 33.5–32.3 Ma. Collectively, these data show a much shorter duration of the volcanism when compared with previous K-Ar radiometric ages. Based on the large areal distribution of lavas and dykes with identical chemical and mineral composition over the entire volcanic area, along with their overlapping age, we argue that: (1) the dykes served as feeder structures; (2) Borovitsa area represents a single shield volcano structure with a common magma chamber, contradicting earlier ideas for the existence of numerous stratovolcanoes.

Nisi, B., O. Vaselli, P. Marchev, F. Tassi. 2013. Diffuse CO_2 soil flux measurements at the youngest volcanic system in Bulgaria: the 12.2 Ma old Kozhuh cryptodome. – *Acta Vulcanol.*, 25, 1–2, 169–178.

The output of CO_2 from diffuse soil degassing has been estimated in the surrounding areas of the Kozhuh sub-volcanic body, located along the Strymon Valley in SW Bulgaria. The rocks of this cryptodome are related to the latest volcanic event in Bulgaria, which occurred about 12.2 Ma years ago. To the best of our knowledge, these are the very first CO_2 measurements carried out in Bulgaria by the accumulation chamber method. In July 2014, 238 soil gas flux measurements east of the Kozhuh remnants were carried out covering a surface of about 173 000 m^2 . The study area also includes an artesian well and a spring discharging 35 L sec^{-1} of CO_2 -rich water at the temperature of about 75 °C. The total diffuse CO_2 output has been computed using a statistical approach and results to be 3.24 t day^{-1} , with the upper and lower limits at 95% confidence being of 3.71 and 2.9 t day^{-1} , respectively. The significantly high CO_2 flux values, mostly located in the eastern border of the study area, the CO_2 -rich thermal waters and the 150 m thick travertine deposit, presently non active, situated in the northern sector of Kozhuh can possibly suggest the presence of a long-lasting degassing hydrothermal system, which has been active since the emplacement of the Kozhuh cryptodome. This may suggest that the recorded anomalies of the diffuse CO_2 fluxes are partly fed by thermometamorphic CO_2 , similar to that discharging from the thermal waters.

Piccardi, L., N. Dobrev, G. Moratti, G. Corti, E. Tondi, G. Vannucci, M. Matova, V. Spina. 2013. Overview and new data on the active tectonics towards a comprehensive seismotectonic map of Bulgaria: – *Acta Vulcanol.*, 25, 1–2, 67–82.

This paper presents a discussion on some aspects of the active tectonics in Bulgaria based on available literature data as well as recent research mainly focused on the identification and characterization of active faults in selected key areas. In particular, through tectonic, GPS and remote sensing data, also coupling geological observations with seismological data, we present here: 1) a comprehensive map of major active faults in Bulgaria, although still in progress, and 2) a detailed study of various active structures, in particular in the Sofia Graben, Struma valley and surrounding regions. Our research highlights the occurrence in SW Bulgaria of several major active faults, the majority of which are normal faults accommodating a roughly N-S to NNE-SSW extension, in line with GPS data and analysis of the instrumental seismicity. The extensional stress field, with associated tectonic and seismic activity, is likely to be related to the northern extent of the Aegean extensional system and its recent evolution. In the Balkan mountains area the tectonic activity is somehow more complex, responding to the interplay of the northward propagation of the Aegean extension

and the influence of a roughly E-W compression, which determines local shear zones.

Trifonova, P., D. Solakov, S. Simeonova, M. Metodiev, P. Stavrev. 2013. Regional pattern of the Earth's crust dislocations on the territory of Bulgaria inferred from gravity data and its recognition in the spatial distribution of seismicity. – *Pattern Recogn. Phys.*, 1, 25–36.

Deformations in the earth's upper layer can be mapped using a variety of methods and techniques. This paper examines the regional pattern of linear structures on the territory of Bulgaria using Bouguer gravity anomalies. The gravity data were analyzed using integrated gradient interpretation techniques, such as the Total Horizontal Gradient (THG) and Vertical Gravity Gradient (VGG). Derived gravity maps reveal persistent lateral changes in density caused by faults, thrusts or dislocated block borders. We thoroughly examine and describe the observed lineation pattern and relate it to the existing tectonostratigraphic information. Several decades after the earliest attempts of potential field data application for revealing first order faults and crustal blocks in the Bulgarian territory, we take advantage of improved techniques and high quality gravity and seismological data for more reliable estimation of the seismogenic potential of faults and thrust structures in the earth's crust. The interpreted structural elements are compared with the epicentral map and epicentral density function of the examined area, to evidence relations between the revealed structures and seismicity. The study indicates possible seismological significance of these lineations and motivates the interest of further quantitative investigations for the purposes of seismic hazard assessment.

2014

Antić, M., I. Peytcheva, A. von Quadt, A. Kounov, B. Trivić, T. Serafimovski, G. Tasev, I. Gerdjikov. 2014. Geochronological and geochemical studies on crystalline rocks from the central Serbo-Macedonian massif with implications on its pre-Alpine evolution. – In: *Proceedings of XX Congress of CBGA*. Tirana, Albania.

The Serbo-Macedonian Massif (SMM) represents a composite crystalline terrane situated between the two diverging branches of the Eastern Mediterranean Alpine orogenic system, the northeast-vergent Carpatho-Balkanides and the southwest-vergent Dinarides and the Hellenides. It is outcropping from the Pannonian basin in the north, to the Aegean Sea in the south, along the central and southeastern Serbia, southwestern Bulgaria, eastern Macedonia and central Greece. Its affiliation to European and/or African plate basement is still questionable due to the lack of reliable geochronological data and a detailed structural investigations. The SMM is the key area for understanding the bipolarity of the Alpine orogenic system, as well as the interaction of the Pannonian and Aegean back-arc extension during the Cenozoic time. The SMM is traditionally considered to comprise an Upper (low-grade) and a Lower (medium to high-grade) unit. The protoliths of both units are reported as volcano-sedimentary successions, which have been intruded by magmatic rocks during several pulses. Here we present the results of our 4-year project aimed at discerning the main magmatic episodes and the geodynamic evolution of the SMM and its environs. In order to obtain the protolith ages, LA-ICP-MS analyses were carried out on zircon grains from 24 ortho- and para-metamorphics as well as undeformed ig-

neous rocks. Additionally, we were able to constrain the geotectonic settings of formation for the total of 30 whole-rock samples by obtaining the main oxide and trace element measurements. The new geochronological constraints coupled with the field evidence, allowed us to conclude: a) The Lower complex of the SMM consists of Cadomian (569–558 Ma) volcano-sedimentary sequences and magmatics, which were consequently intruded by igneous rocks from late Cambrian to Early Silurian (528–439 Ma); b) The Upper SMM (i.e. Vlasina or Morava unit) represents a volcano-sedimentary sequence, which is intruded by the Cadomian (562–550 Ma) and Cambrian (521±4 Ma) magmatic rocks; c) No evidence of Ordovician and Silurian magmatism in the Upper complex were revealed by our research; d) The Upper complex is structurally overlain by a deformed Silurian–Devonian sedimentary sequence; e) Additional pulses of magmatism, represented by Carboniferous (328–304 Ma), and Late Permian (255–253 Ma) weakly deformed rocks constrain the lowest age for the penetrative high-strain ductile deformation. This conclusion is in accord with the reports from the Lower complex in Bulgaria (i.e. the Ograzhden block); and f) The youngest magmatic event in the SMM recorded by our study took place in the Late Eocene (35–32 Ma) related to the intrusion of Surdulica granodiorite and associated latitic volcanism. However, even younger (Oligocene to Quaternary) volcanic activity is known at periphery of the SMM.

Georgiev, N., B. Henry, N. Jordanova, D. Jordanova, K. Naydenov. 2014. Emplacement and fabric-forming conditions of plutons from structural and magnetic fabric analysis: A case study of the Plana pluton (Central Bulgaria). – *Tectonophysics*, 629, 138–154; DOI: 10.1016/j.tecto.2014.02.018.

The relationship between intensity parameters, such as the corrected anisotropy degree P' and mean susceptibility K_m for plutons with similar magnetic mineralogy, yields a criterion to determine the origin of their magnetic fabric: for a same mineralogy, the higher the P' values for the same mean susceptibility K_m (irrespective of its absolute value) the higher tectonic effect was possible. Using this criterion, comparison of the magnetic fabric of the Upper Cretaceous mid- to shallow crustal level Plana pluton with that of other small Upper Cretaceous plutonic bodies in Sredna Gora Zone (Central and Southeast Bulgaria) highlights the structural evolution of the Plana pluton. The central part of Plana pluton and its southwest, west and east margins have preserved their emplacement fabric. Along its northern contact the pluton is affected by the last movements within the Okol Shear Zone where high-temperature S/L mylonites developed. The fabric of the pluton at its southeastern border was disturbed during the intrusion of the neighboring Gutsal pluton. The similarity in the orientation of magmatic and magnetic structures preserved in the central and southern parts of the Plana pluton and the transition from magmatic to high-temperature superimposed foliations and lineations at its north contact point to a composite superimposed shear-induced and emplacement-related magmatic-magnetic fabric. Nearly vertical orientation of magnetic and magmatic foliations and lineations from the undeformed parts of the pluton shows a process of vertical magma rising and emplacement. The sub-vertical high-temperature solid-state mylonitic foliation and dip-parallel stretching lineation in the pluton along its northern contact reveals the transpression nature of the deformation in the vicinity of Okol Shear Zone with a strong pure shear component. The smooth transition between the deformed and undeformed parts of Plana pluton reveals the syn-kinematic character of the emplacement.

Filipov, P., P. Marchev, I. Peytcheva, C. Münker, M. Kirchenbauer. 2014. Comparison between $^{176}\text{Hf}/^{177}\text{Hf}$ of zircon and whole rock samples from Mesta Volcanic Complex, West Rhodopes: Evidence for crustal contamination. – In: *Proceedings XX Congress CBGA*. Tirana, Albania.

Mesta Volcanic Complex (MVC) from the Central Rhodope Magmatic Zone (CRMZ) is located on tectonically thickened crust. Unlike the East Rhodope Magmatic Zone (ERMZ), CRMZ only comprises a limited variety of mainly felsic rocks with strong crustal characteristics. The comparison between $^{176}\text{Hf}/^{177}\text{Hf}$ of zircon and whole rock provides a new insight into magma generating processes in Mesta Volcanic Complex and can help to distinguish anatectic melting from wall-rock assimilation.

Froitzheim, N., S. Jahn-Awe, D. Frei, A. N. Wainwright, R. Maas, N. Georgiev, Th. J. Nagel, J. Pleuger. 2014. Age and composition of meta-ophiolite from the Rhodope Middle Allochthon (Satovcha, Bulgaria): a test for the maximum-allochthon hypothesis of the Hellenides. – *Tectonics*, 33, 1477–1500; DOI: 10.1002/2014TC003526.

The metamorphosed thrust stack of the Rhodopes comprises a level with ophiolites (Middle Allochthon) under- and overlain by continent-derived allochthons. The Upper Allochthon represents the European margin but the origin of the Lower Allochthon remains controversial, with suggestions that it may be derived from an inferred microcontinent (Drama) or from the margin of Adria. Trace element compositions and Sr and Nd isotope ratios of metagabbroic amphibolites and enclosed meta-plagiogranites from the Satovcha Ophiolite, Middle Allochthon, show that they are cogenetic and represent supra-subduction-zone ophiolites. U-Pb dating using LA-SF-ICP-MS of zircons from two meta-plagiogranites and a metagabbro yielded identical Jurassic ages (160±1 Ma, 160.6±1.8 Ma, and 160±1 Ma, respectively), similar to ophiolites in the eastern Vardar Zone bordering the Rhodopes to the SW. The trace element patterns also closely resemble those of the Vardar ophiolites. The association with Late Jurassic arc-type granitoids is another feature that applies both to eastern Vardar and Satovcha. This strongly suggests that the Middle Allochthon comprises the metamorphosed northeastward continuation of the Vardar zone. The Jurassic age of the Satovcha Ophiolite contradicts the hypothesis of Early Jurassic suturing between Europe (Upper Allochthon) and the assumed Drama microcontinent (Lower Allochthon) but is in line with the “maximum allochthon hypothesis”, i.e. the assumption that the Lower Allochthon represents Adria and that the “root” of the Vardar-derived thrust sheets is at the NE boundary of the Rhodopes.

Georgiev, S., I. Peytcheva, A. von Quadt. 2014. Petrology and zircon U-Pb geochronology of trachytes from Kozhuf paleovolcano, FYROM – adakite-like signatures by amphibole fractionation. – In: *Proceedings XX Congress CBGA*. Tirana, Albania.

Kozhuf paleovolcano is a part from the Late Miocene to Pleistocene rifting magmatic activity in the Vardar zone. The U-Pb zircon LA-ICPMS dating yielded an age of 5.638±0.025. The rocks studied are trachytes which represents one of the most widespread varieties in the area. The phenocrysts are presented by plagioclase, rare sanidine, amphibole, clinopyroxene and phlogopite. The rocks exhibit geochemical adakite-like features with weak Eu (0.79–0.93) anomaly, high La_N/Yb_N ratio ranging from 28 to 39, high Sr (1200–1800 ppm) and

low Y (12–13.5 ppm) content and listric-like profile of REE chondrite normalized pattern. This is probably due to amphibole fractionation of water saturated magmas in upper crustal levels (6.1–8.3 km) with almost suppressed weak plagioclase fractionation.

Ivanov, Zh., R. Nedialkov, K. Bogdanov. 2014. Magmatic and ore-related breccias in the Elatsite porphyry-copper deposit (PCD), Bulgaria. – In: *Proceedings XX Congress CBGA*. Tirana, Albania.

Various ore-related breccia types associated with porphyric granodiorite type intrusions in the Elatsite Cu-porphyry deposit, Bulgaria include: 1) magmatic breccias, 2) magmatic hydrothermal injection breccias, 3) collapse breccias, 4) mosaic breccias, 5) crackle breccias, and 6) pebble dike breccias. Both clast supported and matrix supported breccias are widespread. All of them occur as single or clusters of pipe-like bodies with steep (65–800) to vertical dips, ranging from centimeter to meter scale and rarely to 5 x 30 m in size. Pre-, syn- and post-mineralization breccias have also been recognized.

Moritz, R., C. Noverraz, I. Márton, P. Marchev, R. Spikings, D. Fontignié, J. E. Spangenberg, T. Vennemann, K. Kolev, S. Hasson. 2014. Sedimentary rock-hosted epithermal systems of the Tertiary Eastern Rhodopes, Bulgaria: new constraints from the Stremtsi gold prospect. – In: Garofalo, P. S., J. R. Ridley (Eds.). *Gold-transporting Hydrothermal Fluids in the Earth's Crust*. Geological Society London Special Publications, 402, 207–230; DOI: 10.1144/SP402.7.

Precious metal epithermal, sedimentary rock-hosted prospects constitute a new class of ore deposits recently described in the Tertiary Eastern Rhodopes of Southeastern Bulgaria. The Stremtsi prospect investigated in this contribution is located in a distal location with respect to the main cluster of sedimentary rock-hosted Ada Tepe and Rosino gold prospects of the Eastern Rhodopes. The Stremtsi prospect is hosted by a Priabonian clastic sedimentary rock sequence, overlaying metamorphic rocks of the Central Rhodopean dome. The eastern part of the Stremtsi prospect contains high gold grades, and is characterized by a strongly silicified zone, including adularia and silicified dolomite blades, diagnostic for boiling conditions during ore formation in such low-sulphidation epithermal systems. The western part of the Stremtsi prospect consists of a barite, sphalerite and galena mineralisation, associated with silicification, and illite and carbonate alteration. Both parts are underlain by subvertical quartz-carbonate-pyrite veins. Primary and secondary fluid inclusions, respectively, in dolomite and barite yield homogenisation temperatures ranging between 90 and 247 °C. The salinity of primary inclusions in dolomite falls between 1.9 and 5.1 wt% NaCl equivalent, whereas the one of secondary fluid inclusions in barite ranges between 0 and 3.1 wt% NaCl equivalent. The variable homogenisation temperatures reflect post-entrapment reequilibration of the fluid inclusions, whereas the salinities were preserved and the inclusions in dolomite are interpreted in terms of dilution of a saline fluid in the western part of the Stremtsi prospect. Sulphur isotope compositions of sulphides from Stremtsi range mainly between –4 and +4‰. They are not diagnostic and can be attributed to magmatic, metamorphic and sedimentary sources. They overlap with the main compositional range of sulphides from other sedimentary rock-hosted epithermal systems and reveal the existence of hydrothermal fluids with common characteristics during ore formation throughout the Eastern Rhodopes. In addition at Stremtsi, negative $\delta^{34}\text{S}$

values between –42.6 and –8.8‰ combined with framboidal pyrite and elevated $\delta^{34}\text{S}$ values of +7.0 to +19.5‰ support locally derived sulphur, generated, respectively, by bacterial and thermochemical sulphate reduction. Modelling of O, C and Sr isotope data of dolomite support the above ore-forming processes. A positive correlation between $\delta^{18}\text{O}$ (+12.7 to +19.7‰ V-SMOW) and $\delta^{13}\text{C}$ (–2.8 to +1.5‰ V-PDB) values for dolomite from the eastern, silicified and gold-enriched zone of the Stremtsi prospect is satisfactorily modelled by boiling between 140 and 180 °C of a deeply circulating fluid characterized by $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of +5.5‰ V-SMOW and –1.5‰ VPDB, respectively, and radiogenic strontium leached from the metamorphic basement rocks or its clastic counterparts in the Priabonian host rocks. By contrast, negative correlations of $\delta^{18}\text{O}$ values (+13.4 to +23.3‰ V-SMOW) with $\delta^{13}\text{C}$ values (–0.6 to –3.9‰ V-PDB) and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of dolomite from the western, barite and base metal-rich zone are adequately modeled by a shallow, low temperature (70 °C), intra-formational fluid recharged by meteoric water, which interacted with organic matter, i.e. coal layers, and carbonate rocks from the Priabonian host sequence, mixing with a deep, moderate temperature (190 °C), ^{87}Sr -enriched fluid characterized by $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of +5.5‰ V-SMOW and –1.5‰ V-PDB, respectively. Disequilibrium conditions revealed by sulphur isotope thermometry of two galena-barite pairs yielding discrepant temperatures of 190 and 306 °C are consistent with fluid mixing. A plateau age of 37.57 ± 0.31 Ma obtained by $^{40}\text{Ar}/^{39}\text{Ar}$ dating of adularia from Stremtsi is interpreted as a maximum age because of the saddle-shaped age spectrum. Combined with $^{40}\text{Ar}/^{39}\text{Ar}$ age data from previous studies, it reveals that the sedimentary rock-hosted epithermal prospects constitute an independent, regional and older ore-forming hydrothermal system, distinct from the younger volcanic rock-hosted epithermal deposits of the Bulgarian and Greek Eastern Rhodopes.

Nachev, I., D. Sinnyovsky. 2014. Eocene Varna reefs in NE Bulgaria. – *Geoheritage*, 6, 4, 271–282.

Начев, И., Д. Синьовски. 2014. Варненските еоценски рифове в СИ България.

Варненските микробиални карбонатни рифове, известни като „Побити камъни“, са варовикови колони от естествен произход, образувани в еоценските пясъци близо до гр. Варна, СИ България. Тези уникални геоложки образувания са сред най-впечатляващите природни феномени в България и обхващат защитена територия от 253,3 ha, която включва 18 геотопа с естетическа и научна стойност. Някои от тези забележителности са част от природен парк „Златни пясъци“. Побитите камъни са бактериално-водораслови рифове, образувани в безкарбонатните ипрески пясъци и алеврители на Дикилиташката свита. Те са с геоморфоложка, седиментоложка и палеонтоложка стойност. Човешкият интерес към колоните е резултат от тяхната уникална морфология, поради което първоначално са считани за останки от древни храмове и замъци. Според различните теории те са атмосферни или инфилтрационни образувания, конкреции, коралови рифове, вкаменени гори и т.н. В края на XX в. техният генезис е изучен в контекста на фитогенната хипотеза и се стига до заключението, че са бактериално-водораслови биохерми, подобни на съвременните атоли и миниатоли в сегашните океани и морета. В подкрепа на тази хипотеза е присъствието на микробиални староматолитни пластини и текстури, тръбни тела и останки от водорасли в колоните, които не се намират в седиментите извън тях. Варненските рифове са атрактивна туристическа дестинация за посетителите на

българското черноморско крайбрежие. Те са включени в Програмата на ЮНЕСКО за опазване на геоложкото наследство с научна стойност. Бъдещето на тези уникални геоложки образувания зависи от тяхната закрила на национално и европейско ниво.

Peytcheva, I., D. Dimitrova, P. Marchev, A. Hikov, E. Stefanova, L. Metodiev, A. von Quadt, K. Kouzmanov, R. Creaser. 2014. Tran Au-Ag±W deposit in Western Bulgaria: a new intrusion-related gold system in the Variscan belt of Europe. – In: *Proceedings XX Congress CBGA*. Tirana, Albania.

New data for the magmatism, hydrothermal alteration, mineralization styles, isotope geochronology, mineralogy, fluid-inclusions and elemental geochemical associations are combined in the present study to characterize the Tran Au-Ag±W deposit in Western Bulgaria. The main features of the deposit define it as intrusion-related gold system (IRGS): its association with reduced plutons; well-defined structural control on intrusion and mineralization; diverse mineralization styles, including veins, stockworks, dissemination; wide range of gold grades; approximately coeval magmatism and mineralization at 330–333 Ma; low sulfide content; apparent correlation of Au and Bi; and the presence of CO₂ in hydrothermal fluids. These characteristics are useful for further prospecting for IRGS in the Variscan belt of Eastern Europe.

Raicheva, R., P. Marchev. 2014. Mineral diversity, melt inclusions and gabbroic xenoliths of the Upper series of Zvezdel volcano (Eastern Rhodopes): Evidence for mush chamber recharge and magma differentiation. – In: *Proceedings XX Congress CBGA*. Tirana, Albania.

This study demonstrates the importance of the process of mafic recharge in the genesis of the Zvezdel volcano and the mechanism of mixing on the basis of detailed study of mineral chemistry, melt inclusions and troctolite xenoliths. We show that variations in mineral chemistry are the result of repeated injection of basaltic magmas in an evolving andesite to dacite mush magma chamber, whereas troctolite xenoliths and melt inclusions provide information about lower to mid and upper crustal evolution of Zvezdel lavas.

Yossifova, M. G. 2014. Petrography, mineralogy and geochemistry of Balkan coals and their waste products. – *Intern. J. Coal Geol.*, 122, 1–20.

The samples studied include raw coal from five mines, coal concentrate, coal slurry, associated rock, and waste water. Collodetrinite comprises the dominant portion in raw coals and waste products while collotelinite and telinite/cryptotelenite dominate in the CC. The sulphide, particularly that of a syngenetic origin, cannot be completely separated out after coal crushing and flotation. The major minerals are pyrite, quartz, and kaolinite; the minor minerals – illite, muscovite, plagioclase, K-feldspar, gypsum, calcite, dolomite, and siderite; and the additional mineral species as gold, sulphur, Fe_{1,24}S_{0,76}, pyrrhotite, galena, hematite, magnetite, hercynite, Cr-spinel, Ti-bearing minerals, biotite, halloysite, zircon, apatite, stilbite, celestine, Mn-calcite, Fe-dolomite, CaFe(CO₃)₂, ankerite, biogenic minerals, volcanic ash, and possible cosmogenic dust are present in the samples as accessory phases. The modes of occurrence of the authigenic minerals suggest that this coal has undergone a series of syngenetic, epigenetic, and exogenic mineralisation. The origin of the epigenetic framboidal pyrite and neoform phases

of microbial activity and water treatment is also discussed. The elements Te, S, Cd, U, Cs, V, Mo, W, and Cr are enriched in the coal concentrate compared with worldwide Clarke values of hard coal. Most of the elements have an mixed mode of occurrence. The Br, S, U, and Ge display a strong affinity to organic matter, whereas the Al, K, Si, Rb, Li, Ti, P, and Se display a distinctly inorganic pattern of distribution. Certain of the trace elements (e.g., Sr, Ba, P, Mn, Mo, As, Pb, Sb, Tl, Li, Nb, Be, Y, Ti, Yb, and Cd) are present as impurities in various minerals, whereas other trace elements (e.g., La, Ba, Cu, Re, Pb, Gd, Nd, Sr, Sn, and Cr) are present as discrete phases. It is suggested that the main sources of the trace elements were mineral and mixed sea waters, the basement rocks, and the Sliven U-polymetallic ore deposit. It was also revealed that a number of elements (S, Li, Cs, F, Br, NH₄⁺, NO₃⁻, and V) in the Balkan coals are mobile in water and may pose certain environmental concerns. The coal slurry could be used as a form of fuel.

Şahin, S. Y., N. Aysal, Y. Güngör, I. Peytcheva, F. Neubauer. 2014. Geochemistry and U–Pb zircon geochronology of metagranites in Istranca (Strandja) zone, NW Pontides, Turkey: Implications for the geodynamic evolution of Cadomian orogeny. – *Gondwana Res.*, 26, 755–771.

New zircon U–Pb dating and whole-rock geochemical analysis were carried out on meta-intrusive rocks (Çatalca and İhsaniye metagranites) of the Istranca Zone, Western Pontides, with the aim of constraining the magmatic evolution of the Cadomian orogeny of the northern Gondwana margin during Late Precambrian–Early Paleozoic times. The Istranca zone is composed of metamorphic basement intruded by large granitic bodies and overlain by a Paleozoic–Mesozoic meta-sedimentary cover. The metamorphic rocks of the Istranca zone extend from Bulgaria, Istranca Mountains to NW Turkey and reach the area near Istanbul (Çatalca region). The Çatalca and İhsaniye metagranites have a subalkaline, high-K calc-alkaline and peraluminous character. Trace element geochemistry displays decreasing normalized concentrations from large-ion lithophile (LIL) elements to high field strength (HFSE) elements and from light (LREE) to heavy rare earth elements (HREE). A negative Eu anomaly is both types of metagranites. On tectonic discrimination diagrams, the samples from both metagranites plot in the subduction-related fields. The SHRIMP-II U–Pb zircon ages of the Çatalca metagranite range from 534.5±4.7 Ma to 546.0±3.9 Ma and LA-ICP-MS U–Pb zircon dating yields 535.5±3.6 Ma age for the İhsaniye metagranite. The new ages together with the geochemical constraints allow a new geodynamic interpretation for the Istranca zone and we compare these metagranites with other Upper Ediacaran to Lower Cambrian granitoids of Turkey and Alpine-Himalayan orogenic belt. We deduce an origin of these elements from the northern Gondwana-Land margin.

2015

Antić, M. D., A. Kounov, B. Trivić, A. Wetzel, I. Peytcheva, A. von Quadt. 2015. Alpine thermal events in the central Serbo-Macedonian Massif (southeastern Serbia). – *Intern. J. Earth Sci.*; DOI: 10.1007/s00531-015-1266-z.

The Serbo-Macedonian Massif (SMM) represents a crystalline belt situated between the two diverging branches of the Eastern Mediterranean Alpine orogenic system, the northeast-vergent Carpatho-Balkanides and the southwest-vergent Dinarides and the Hellenides. We have applied fission-track analysis on apatites and zircons, coupled with structural field observations in order to reveal the low-temperature evolution of the SMM.

Additionally, the age and geochemistry of the Palaeogene igneous rocks (i.e. Surdulica granodiorite and dacitic volcanic rocks) were determined by the LA-ICPMS U–Pb geochronology of zircons and geochemical analysis of main and trace elements in whole-rock samples. Three major cooling stages have been distinguished from the late Early Cretaceous to the Oligocene. The first stage represents rapid cooling through the partial annealing zones of zircon and apatite (300–60 °C) during the late Early to early Late Cretaceous (ca. 110–ca. 90 Ma). It is related to a post-orogenic extension following the regional nappe-stacking event in the Early Cretaceous. Middle to late Eocene (ca. 48–ca. 39 Ma) cooling is related to the formation of the Crnook-Osogovo-Lisets extensional dome and its exhumation along low-angle normal faults. The third event is related to regional cooling following the Late Eocene magmatic pulse. During this pulse, the areas surrounding the Surdulica granodiorite (36±1 Ma) and the slightly younger volcanic bodies (ca. 35 Ma) have reached temperatures higher than the apatite closure temperature (120 °C) but lower than ca. 250 °C. The geochemistry of the igneous samples reveals late- to post-orogenic tectonic setting during magma generation.

Antić, M. D., I. Peytcheva, A. von Quadt, A. Kunov, ..., A. Wetzel. 2015. Pre-Alpine evolution of a segment of the North-Gondwanan margin: Geochronological and geochemical evidence from the central Serbo-Macedonian Massif. – *Gondwana Res.*; DOI: 10.1016/j.gr.2015.07.020.

The Serbo-Macedonian Massif (SMM) represents a composite crystalline belt within the Eastern European Alpine orogen, outcropping from the Pannonian basin in the north, to the Aegean Sea in the south. The central parts of the massif (i.e. southeastern Serbia, southwestern Bulgaria, eastern Macedonia) consist of the medium- to high-grade Lower Complex, and the low-grade Vlasina Unit. New results of U–Pb LA-ICP-MS analyses, coupled with geochemical analyses of Hf isotopes on magmatic and detrital zircons, and main and trace element concentrations in whole-rock samples suggest that the central SMM and the basement of the adjacent units (i.e. Eastern Veles series and Struma Unit) originated in the central parts of the northern margin of Gondwana. These data provided a basis for a revised tectonic model of the evolution of the SMM from the late Ediacaran to the Early Triassic. The earliest magmatism in the Lower Complex, Vlasina Unit and the basement of Struma Unit is related to the activity along the late Cadomian magmatic arc (562–522 Ma). Subsequent stage of early Palaeozoic igneous activity is associated with the reactivation of subduction below the Lower Complex and the Eastern Veles series during the Early Ordovician (490–478 Ma), emplacement of mafic dykes in the Lower Complex due to aborted rifting in the Middle Ordovician (472–456 Ma), and felsic within-plate magmatism in the early Silurian (439±2 Ma). The third magmatic stage is represented by Carboniferous late to post-collisional granites (328–304 Ma). These granites intrude the gneisses of the Lower Complex, in which the youngest deformed igneous rocks are of Early Silurian age, thus constraining the high-strain deformation and peak metamorphism to the Variscan orogeny. The Permian–Triassic (255–253 Ma) stage of late- to post-collisional and within-plate felsic magmatism is related to the opening of the Mesozoic Tethys.

Bonev, N., P. Marchev, R. Moritz, D. Collings. 2015. Jurassic subduction zone tectonics of the Rhodope Massif in the Thrace region (NE Greece) as revealed by new U–Pb and ⁴⁰Ar/³⁹Ar geochronology of the Evros ophiolite and high-grade basement rocks. – *Gondwana Res.*; dx.doi.org/10.1016/j.gr.2014.08.008.

Бонев, Н., П. Марчев, Р. Мориц, Д. Колингс. 2015. Юрска субдукция на Родопския масив в Тракийския район (СИ Гърция), установена с нови U–Pb и ⁴⁰Ar/³⁹Ar геохронологички изследвания на офиолитите Еврос и високометаморфните скали на фундамента.

В област Тракия на СИ Гърция кристализацията и пост-кристализационното охлаждане под 600 °C на интрузивната последователност на островнодъговите офиолити Еврос от Циркумродопския пояс се разпростира във възрастовия интервал от 176,4±0,93 до 163,5±3,85 Ма. В отдолулежащия Родопски високостепенен фундамент (ултра-) високобаричните метаморфични скали са пресечени от ортогнайси с гранитоидни протолити и възраст на кристализация между 160±0,69 и 154±1,5 Ма. Тези нови U–Pb LA-ICP-MS цирконови геохронологички данни осигуряват доказателства за съвпадение на времевата еволюция на офиолитите Еврос (в рамките на аналитичната грешка) с гранитоидния магматизъм в отдолулежащия високостепенен фундамент. Един от датиранияте метагранитоиди пресича амфиболитизиран еклогит, като сочи максимална възраст от 160 Ма на високобаричния метаморфизъм. Тази възраст последва една от предлаганите възрасти на ултра-високобарични условия в Родопският масив. Ето защо, така установеното понастоящем най-ранно разграничимо родопско високо/ултрависокобарично метаморфно събитие се свързва със субдукционната обстановка, образувала офиолитите Еврос. Въз основа на тези нови времевы ограничения и регионалната тектонска-геохронологичка рамка, ние обсъждаме и осъвременяваме геодинамичния контекст във връзка с юрската субдукционно-колизийна обстановка в Родопската континентална окрайнина на Евразия.

Bonev, N., P. Marchev, R. Moritz, P. Filipov. 2015. Timing of igneous accretion, composition, and temporal relation of the Kassandra-Sithonia rift-spreading center within the eastern Vardar suture zone, Northern Greece: insights into Jurassic arc/back-arc systems evolution at the Eurasian plate margin. – *Intern. J. Earth Sci.*, 104(7); DOI: 10.1007/s00531-015-1172-4.

In the Hellenides of Northern Greece, the Kassandra-Sithonia and Central Chalkidiki ophiolites constitute the Vardar suture zone against the Serbo-Macedonian margin of Eurasia. The mafic-intermediate to acid members in the crustal section of the Kassandra-Sithonia ophiolites have N- and E-MORB signatures compatible with an origin in a back-arc spreading centre. The MORB mantle source has received subduction zone input from the nearby Paikon arc system as revealed by LILE and LREE enrichment. A diorite from the Gerakini complex presumably belonging to the Central Chalkidiki ophiolites shows more enriched HFSE and REE patterns relative to MORB and Na-rich character compared to the Kassandra-Sithonia ophiolites. The Sithonia ophiolite crystallization spans from 159 to 149 Ma and the Gerakini complex diorite crystallized at 173 Ma as derived from new U–Pb zircon geochronology. The main cluster of Permo–Carboniferous, a small cluster of Neoproterozoic–Cambrian and few Proterozoic, Ordovician, Devonian, Triassic and Middle Jurassic inherited zircons derive from the Serbo-Macedonian margin units. Thus, a Late Jurassic ca. 10 Ma lasting igneous accretion of the Kassandra-Sithonia back-arc crust within the eastern Vardar zone is now well-constrained, and corroborated by Berriasian–Early Valanginian supra-ophiolite cover limestones. Instead of an affinity to the Central Chalkidiki ophiolites, the Gerakini diorite exhibits chemical similarity to the Chortiatiss arc magmatic suite of the Circum-Rhodope belt

within the eastern Vardar zone. The Gerakini diorite predates the Sithonia ophiolite in which the Chortiatis arc suite supplied Middle Jurassic inherited zircons. The Chortiatis arc compared with arc-related Evros ophiolites of the Circum-Rhodope belt in Thrace region shows the same 173–160 Ma life span and tectonic setting, implying the extension of the arc systems across the north Aegean Sea. Based on these new temporal constraints, a tectonic scenario of Jurassic subduction settings and arc/back-arc systems development in the Maliac and Vardar oceanic basins is proposed that also accounts for continental magmatism in the Serbo-Macedonian margin of Eurasia.

Chatalov, A., N. Bonev, D. Ivanova. 2015. Depositional characteristics and constraints on the mid-Valanginian demise of a carbonate platform in the intra-Tethyan domain, Circum-Rhodope Belt, northern Greece. – *Cretaceous Res.*, 55, 84–115.

Two platform-type carbonate successions of Berriasian to Early Valanginian age are exposed in the eastern Circum-Rhodope belt which extends from the Chalkidiki Peninsula to the Thrace region in northern Greece. On the basis of new sedimentological and biostratigraphic results and analysis of published palaeomagnetic data, the Porto Koufos Limestones and Aliko Limestones are interpreted as deposits of a formerly unknown earliest Cretaceous carbonate platform in the Western Tethys realm. This Circum-Rhodope carbonate platform existed in tropical latitudes of the intra-Tethyan domain on the northern shelf area of the small Vardar oceanic basin. It was characterized by limited regional extent, remoteness from land, and short lateral transitions into deeper basin areas. Predominantly skeletal sediments with various microencrusters were produced along with variable amounts of lime mud, marine cements, peloids, intraclasts, aggregate grains, ooids and microbialites. The microfacies analysis of limestones formed around the Berriasian–Valanginian boundary indicates the configuration of a rimmed shelf with restricted lagoon, open lagoon, reef margin, fore-reef and upper slope depositional environments. During the early Valanginian a change from photozoan to heterozoan mode of carbonate production occurred mainly as a result of climate cooling. Deposition continued in protected lagoon, shoal and near-shoal settings implying a ramp-like morphology of the platform. Finally, a shift from skeletal to non-skeletal carbonate deposition took place as a consequence of high seawater carbonate saturation and possibly coeval increase of the marine trophic levels. A major sea level fall and climate cooling were the prime palaeoenvironmental controls that caused decline of the shallow-water carbonate factory and subsequent demise of the Circum-Rhodope carbonate platform in mid-Valanginian time that was followed by a long-term subaerial exposure and karstification which continued at least until the middle Eocene. The new results can be used for correlation with other shallow marine carbonates deposited in the intra-Tethyan domain during the earliest Cretaceous. Also, they appear to be of critical significance to decipher the Mesozoic geodynamic evolution of the Circum-Rhodope belt and adjacent tectonic zones.

Gallhofer, D., A. von Quadt, I. Peytcheva, S. M. Schmid, Ch. A. Heinrich. 2015. Tectonic, magmatic, and metallogenic evolution of the Late Cretaceous arc in the Carpathian-Balkan orogen. – *Tectonics*; DOI: 10.1002/2015TC003834.

The Apuseni-Banat-Timok-Srednogorie Late Cretaceous magmatic arc in the Carpathian-Balkan orogen formed on the European margin during closure of the Neotethys Ocean. It was subsequently deformed into a complex orocline by continental collisions. The Cu-Au mineralized arc consists of geologically

distinct segments: the Apuseni, Banat, Timok, Panagyurishte, and Eastern Srednogorie segments. New U-Pb zircon ages and geochemical whole rock data for the Banat and Apuseni segments are combined with previously published data to reconstruct the original arc geometry and better constrain its tectonic evolution. Trace element and isotopic signatures of the arc magmas indicate a subduction-enriched source in all segments and variable contamination by continental crust. The magmatic arc was active for 25 Myr (~92–67 Ma). Across-arc age trends of progressively younger ages toward the inferred paleo-trench indicate gradual steepening of the subducting slab away from the upper plate European margin. This leads to asthenospheric corner flow in the overriding plate, which is recorded by decreasing $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70577 to 0.70373) and increasing $^{143}\text{Nd}/^{144}\text{Nd}$ (0.51234 to 0.51264) ratios over time in some segments. The close spatial relationship between arc magmatism, large-scale shear zones, and related strike-slip sedimentary basins in the Timok and Panagyurishte segments indicates mild transtension in these central segments of the restored arc. In contrast, the Eastern Srednogorie segment underwent strong orthogonal intra-arc extension. Segmental distribution of tectonic stress may account for the concentration of rich porphyry Cu deposits in the transtensional segments, where lower crustal magma storage and fractionation favored the evolution of volatile-rich magmas.

Ivanova, D., N. Bonev, A. Chatalov. 2015. Biostratigraphy and tectonic significance of lowermost Cretaceous carbonate rocks of the Circum-Rhodope Belt (Chalkidiki Peninsula and Thrace region, NE Greece). – *Cretaceous Res.*, 52, 25–63.

Иванова, Д., Н. Бонев, А. Чаталов. 2015. Биостратиграфия и тектонско значение на най-долните кредни карбонатни скали в Циркумродопския пояс (п-в Халкидики и Тракийски район, СИ Гърция).

Изследвани са теренните взаимоотношения, биостратиграфските граници и условията на палеообстановката на карбонатна платформа от самото начало на Кредата в източната част на Вардарската зона и Циркумродопския пояс. Теренните данни потвърждават несъгласната позиция на недеформираните и неметаморфозирани варовици върху горноюрските задлъгови офиолити Ситония на Вардарската зона, Халкидически полуостров и върху свързаните с островна дъга деформирани зелени шисти на Циркумродопския пояс в област Тракия. Установените микрофосилни съобщества и фораминиферни морфогрупи са съвместими с отлагане в плитководна обстановка в съседство с континенталната крайнина на Евразия. Характеристиката на морфогрупите подкрепя тази интерпретация и новооткритите микрофосили определят възрастта на варовиците като Бериас до Ранен Валанжин. Микрофосилните данни са в съзвучие с радиометричните възрасти за късноюрска възраст на кристализация на офиолитите и еквивалентна времево навлачна тектоника в Циркумродопския пояс. Ето защо получените резултати осигуряват седиментни доказателства за доверлива акция към континенталната крайнина на офиолитите в източната част на Вардарската зона и приключването на тектоно-метаморфната история на Циркумродопския пояс. Раннокредната седиментация се е разпростирила по цялата дължина на Циркумродопския пояс през Северноегейската област. Това означава развитие на регионална по обхват карбонатна платформа, която следва отпечатъка на важно тектонско събитие. Седиментацията запечатва късноюрско-раннокредното Балканско орогенно събитие във Вътрешните Елениди в крайнината на Евразийската плоча. Това заключение има важно зна-

чение за геодинамичната еволюция на Алпийския пояс в Северноегейската област.

Lazarova, A., K. Naydenov, N. Petrov, V. Grozdev. 2015. Cambrian magmatism, Variscan high-grade metamorphism and imposed greenschist facies shearing in the Central Sredna Gora basement units (Bulgaria). – *Geologica Carpathica*, 66(6), 443–454; DOI: 10.1515/geoca-2015-0037.

Gneisses from the deep structural levels of the European Variscan Belt are well exposed in the Central Sredna Gora in Bulgaria. In general, migmatites predominate, but unmigmatized domains (or domains with incipient migmatization) are also documented in this area. This paper presents new structural, petrographic and U-Pb isotope geochronological data from such an unmigmatized part of the Variscan high-grade metamorphic basement (the Koprivshitsa Unit). A predominant part of this unit represents an alternation of metagranitoids and metabasites. The protolith crystallization age of the metagranitoids is constrained at 491.5 ± 7.6 Ma by U-Pb laser ablation method on zircons. This age coincides with the previously available Late Cambrian protolith ages of metabasic rocks that crop out within the adjacent migmatitic unit. The Koprivshitsa Unit comprises also lesser orthogneisses with Late Neoproterozoic protoliths. Based on the available local and regional paleogeographic reconstruction schemes, we suggest that the Late Cambrian magmatic rocks intruded Late Neoproterozoic crust during the initial opening stages of the Rheic Ocean or a related basin. Subsequently, both were involved in the Variscan high-grade deformation. The contact of the Koprivshitsa Unit with the migmatitic part of the metamorphic complex coincides with a north-vergent greenschist facies thrust zone – the Chuminska Shear Zone. The exact time of the shearing is still not well constrained but it clearly postdates the Variscan high-temperature metamorphism of the gneisses.

Machev, Ph., V. Ganev, L. Klain. 2015. New LA-ICP-MS U-Pb zircon dating for Strandja granitoids (SE Bulgaria): evidence for two-stage late Variscan magmatism in the internal Balkanides. – *Turkish J. Earth Sci.*, 24, 230–248; DOI: 10.3906/yer-1407-21.

The Strandja Massif (Sakar-Strandja Zone) forms an important link between the Balkan Zone (external Balkanides) of Bulgaria, which is commonly correlated with the Variscan orogen in Central Europe, and the Western Pontides of Turkey. The Bulgarian part of the massif is composed of a metamorphic basement (various granite gneisses, paragneisses, and schists) traditionally interpreted as having Precambrian age, Triassic–Jurassic metasedimentary cover, and Upper Cretaceous volcano-sedimentary sequences. The basement is intruded by large granitic plutons of Variscan age that are widespread mostly across Turkish territory. New LA-ICP-MS data support the suggestion of Variscan granitoid magmatism in the studied area but do not confirm the presence of Precambrian rocks. Furthermore, two stages of magmatism are determined in relation to the Variscan metamorphism and deformation. The first one (301.9 ± 1.1 Ma) is represented by strongly deformed metagranites and thus is interpreted as syntectonic, while the second one is relatively younger (293.5 ± 1.7 Ma) and postmetamorphic.

Sinnyovsky, D. 2015. *Upper Cretaceous Calcareous Nannoplankton Biostratigraphy in Bulgaria*. Saarbrücken, LAP Lambert Academic Publishing, 142 p.

Синьовски, Д. 2015. *Биостратиграфия на Горната Креда в България по варовит нанопланктон*.

Книгата представлява второ допълнено и преработено издание на издадената под същото име монография в България през 2013 г. Тя е посветена на зоналната подялба на Горната Креда в България и прилежащия ѝ черноморски шелф по варовит нанопланктон. Разработена е въз основа на данни от 70 разреза и разкрития на различните фациални типове Горна Креда, разкриващи се на територията на България: епиконтиненталната пишеща креда в Северна България, карбонатните последователности в Предбалкана, преходните теригенно-карбонатни отложения между епиконтиненталния и медитеранския тип Горна Креда в Западния Балкан, варовиково-мергелните периодити и турбидитните последователности в Източния Балкан, алевролитово-мергелните отложения в Карпатската зона, теригенно-карбонатните и вулcano-седиментни последователности от Медитеранския тип Горна Креда в Средногорската зона и варовиково-мергелните отложения в Черноморския шелф. Разработената нанофосилна зонална схема включва 19 широко използвани нанофосилни зони и 15 нови подзони, отделени въз основа на надеждни нанофосилни събития, проследени на територията на цялата страна. Тя не съответства на известните „стандартни“ горнокредни схеми, защото нито една от тях не е напълно приложима за различните фациални типове Горна Креда в България. Монографията обединява нанофосилни данни от авторски разреза и ключови разкрития на горнокредните отложения в различни фациални обстановки с цел да изгради една надеждна регионална схема, корелирана с най-разпространените и широко използвани горнокредни „стандартни“ схеми по варовит нанопланктон в света, но освободена от техните индекси. Материалът е илюстриран с 19 палеонтоложки таблици с изображения на над 130 вида варовити нанофосили, заснети на обикновен петрографски микроскоп и сканиращ електронен микроскоп.

Suc, J.-P., S.-M. Popescu, D. Do Couto, G. Clauzon, J.-L. Rubino, M. C. Melinte-Dobrinescu, F. Quillévéré, J.-P. Brun, N. Dumurdžanov, I. Zagorchev, V. Lesić, D. Tomić, D. Sokoutis, B. Meyer, R. Macalet, H. Rifelj. 2015. Marine gateway vs. fluvial stream within the Balkans from 6 to 5 Ma. – *Marine and Petrol. Geol.*, 66(1), 231–245.

Since the discovery of calcareous nannofossils, dinoflagellate cysts and planktonic foraminifers in deposits from the Dacic Basin, intensive research has been performed in order to evidence which gateway this microplankton used to connect Paratethys and the Mediterranean prior and after the Messinian Salinity Crisis (MSC). Such a gateway is also to be regarded at the origin of successive influxes of Paratethyan organisms (molluscs, ostracods, dinoflagellates) into the Mediterranean Basin (“Lago Mare” events). Observing that the Istanbul area, usually proposed for this purpose, was inefficient, we examine the succession of marine well-dated pre-MSC and post-MSC deltaic deposits through the Balkans, from northern Greece to southern Romania, that constitutes a reliable candidate for such a marine corridor, the origin of which was caused by the regional tectonic extension. The reconstructed palaeogeography for high sea level episodes that encompassed the MSC clarifies the context of the so-called North Aegean Lake. This marine gateway probably evolved as a powerful river during the peak of the MSC, contributing to the deposition of clastics in the hydrocarbon Prinos Field. A tectonically controlled subsidence to the north and south of the Skopje region caused the closure of such a gateway.

Sheng, Y., A. Benderev, D. Bukolska, K. I. Eshiet, C. Dinis da Gama, T. Gorka, M. Green, N. Hristov, I. Katsimpardi, T. Kempka, J. Kortenski, N. Koukouzas, N. Nakaten, V. Sarhosis, R. Schlueter, V. Navarro Torres, A. C. Verissimo, V. Vesselinov, D. Yang. 2015. Interdisciplinary studies on the technical and economic feasibility of deep underground coal gasification with CO₂ storage in Bulgaria. – *Mitigation and Adaptation Strategies for Global Change*. Springer, 1–33; DOI: 10.1007/s11027-014-9592-1.

This paper presents the outcome of a feasibility study on underground coal gasification (UCG) combined with direct carbon dioxide (CO₂) capture and storage (CCS) at a selected site in Bulgaria with deep coal seams (>1200 m). A series of state-of-the-art geological, geo-mechanical, hydrogeological and computational models supported by experimental tests and techno-economical assessments have been developed for the evaluation of UCG-CCS schemes. Research efforts have been focused on the development of site selection requirements for UCG-CCS, estimation of CO₂ storage volumes, review of the practical engineering requirements for developing a commercial UCG-CCS storage site, consideration of drilling and completion issues, and assessments of economic feasibility and environmental impacts of the scheme. In addition, the risks of subsidence and groundwater contamination have been assessed in order to pave the way for a full-scale trial and commercial applications. The current research confirms that cleaner and cheaper energy with reduced emissions can be achieved and the economics are competitive in the future European energy market. However the current research has established that rigorous design and monitor schemes are essential for productivity and safety and the minimisation of the potential environmental impacts. A platform has been established serving to inform policy-makers and aiding strategies devised to alleviate local and global impacts on climate change, while ensuring that energy resources are optimally harnessed.

Zagorchev, I., C. Balica, E. Kozhoukharova, I. C. Balintoni, G. Săbău, E. Negulescu. 2015. Cadomian and post-Cadomian tectonics west of the Rhodope massif – the Frolosh greenstone and the Ograzhdenian metamorphic supercomplex. – *Geologica Macedonica*, 29, 2, 101–132; UDC: 553.52/.53:551.73]:556.4(497).

The Frolosh Greenstone Belt (FGB) is traced at a distance of more than 200 km in the territories of Bulgaria, Macedonia and Serbia. It consists of various greenschist-facies rocks (actinolite schists, phyllites, calcareous schists, impure marbles, metasandstones, metadiabases, massive green rocks, etc.) of the Frolosh metamorphic complex with bodies of metabasites (including lherzolites), and inliers (retrogressed mica gneisses and migmatites) from the Ograzhdenian supercomplex. The complex is intruded by bodies of gabbro (occasionally with ultramafic cumulates), diorites to granites (Struma diorite formation). U-Pb studies on zircons yielded Cadomian ages within the time span between ca. 574 and 517 Ma. The Frolosh complex covers the ultrametamorphic (migmatized gneisses and amphibolites; tourmaline- biotite schists; quartzo-feldspathic gneisses; lensoid bodies of metaperidotites to norites) of the Ograzhdenian

supercomplex. The Ograzhdenian rocks are intersected by diatectic metagranites overprinted by amphibolite-facies metamorphism. Dominant U-Pb ages vary between 470 and 430 Ma. The contact between the Frolosh complex and the Ograzhdenian supercomplex has been subject of long discussion and controversial interpretations. Now we emphasize on the multistage developments of both complexes as demonstrated both by field evidence and isotopic dating. The Ograzhdenian supercomplex has been subject of Precambrian tectonometamorphism witnessed by Rb-Sr whole-rock isochron data and relict U-Pb zircon data. Ordovician to Silurian anatexites (metatectic migmatization, diatexis) are intruded by Permo–Triassic granites. The contact between the Ograzhdenian supercomplex and the covering Frolosh complex is regarded as a thick complex zone of multistage tectonometamorphic development rather than a “razor-blade” surface of one-stage origin. As a boundary between suprastructure and infrastructure, it played an important role throughout the Phanerozoic, and acted as a screen with a steep thermal gradient during the Ordovician–Silurian anatexis and metamorphism in the Ograzhdenian supercomplex. For to verify this hypothesis, new detailed structural and isotopic studies are needed.

Zdravkov, A., A. Bechtel, S. Ćorić, R. F. Sachsenhofer. 2015. Depositional environment, organic matter characterization and hydrocarbon potential of Middle Miocene sediments from northeastern Bulgaria (Varna-Balchik Depression). – *Geologica Carpathica*, 66(5), 409–426; DOI: 10.1515/geoca-2015-0034.

The depositional environments and hydrocarbon potential of the siliciclastic, clayey and carbonate sediments from the Middle Miocene succession in the Varna-Balchik Depression, located in the south-eastern parts of the Moesian Platform, were studied using core and outcrop samples. Based on the lithology and resistivity log the succession is subdivided from base to top into five units. Siliciclastic sedimentation prevailed in the lower parts of units I and II, whereas their upper parts are dominated by carbonate rocks. Unit III is represented by laminated clays and biotrititic limestone. Units IV and V are represented by aragonitic sediments and biomicritic limestones, correlated with the Upper Miocene Topola and Karvuna Formations, respectively. Biogenic silica in the form of diatom frustules and sponge spicules correlates subunit IIa and unit III to the lower and upper parts of the Middle Miocene Euxinograd Formation. Both (sub)units contain organic carbon contents in the order of 1 to 2 wt% (median: 0.8 for subunit IIa; 1.3 for unit III), locally up to 4 wt%. Based on Hydrogen Index values (HI) and alkane distribution pattern, the kerogen is mainly type II in subunit IIa (average HI=324 mg HC/g TOC) and type III in unit III (average HI=200 mg HC/g TOC). TOC and Rock Eval data show that subunit IIa holds a fair (to good) hydrocarbon generative potential for oil, whereas the upper 5 m of unit III holds a good (to fair) potential with the possibility to generate gas and minor oil. The rocks of both units are immature in the study area. Generally low sulphur contents are probably due to deposition in environments with reduced salinity. Normal marine conditions are suggested for unit III. Biomarker composition is typical for mixed marine and terrestrial organic matter and suggests deposition in dysoxic to anoxic environments.