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88. Bonev, N., Marchev, P., Moritz, R., Filipov, P., 2015. Timing of igneous accretion, composition, and temporal relations 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. – *International Journal of Earth Sciences (Geol Rundsch)*, 104, 1837-1864.

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 to149 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 Chortiatis 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.

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87. Chatalov, A., **Bonev, N**., Ivanova, D., 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 Research,* **55**, 1-32.

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 Aliki 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 BerriasianeValanginian 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 longterm 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.

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86. Bonev, N., Marchev, P., Moritz, R., Collings, D., 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 Research*, **27**, 760-775.

In the Thrace region of NE Greece, the crystallization and post-solidification cooling below 600 °C of the intrusive suite of the Circum-Rhodope Belt arc-related Evros ophiolite spans from 176.4 ± 0.93 to 163.5 ± 3.85 Ma. In the underlying Rhodope high-grade metamorphic basement, (ultra-) high-pressure metamafic rocks are cross-cut by orthogneisses with granitoid protoliths and crystallization ages between 160 ± 0.69 and 154 ± 1.5 Ma. This new U-Pb LA-ICP-MS zircon geochronological data provides evidence that the timing of the evolution of the Evros ophiolite coincides, within analytical error, with granitoid magmatism in the underlying high-grade basement. One of the dated metagranitoid rocks cross-cuts amphibolitized eclogite, indicating that the high-pressure conditions have a maximum age of 160 Ma postdating one of the proposed ages of ultra-high pressure conditions in the Rhodope Massif. The currently earliest recognised Rhodope high/ultra-high pressure metamorphic event is therefore related to the subduction setting which formed the Evros ophiolite. Based on these new temporal constraints and the regional tectonic-geochronologic framework, we discuss and update the geodynamic context connected to the Jurassic subduction-collisional setting at the Rhodope continental margin of Eurasia.

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

The field relationships, biostratigraphic constraints and paleoenvironmental conditions of lowermost Cretaceous platform carbonates from the eastern part of the Vardar Zone and the Circum-Rhodope Belt are studied. Field data confirm the unconformable position of non-deformed and non-metamorphosed limestones over Upper Jurassic back-arc rift-spreading ridge Sithonia ophiolites of the Vardar Zone in the Chalikidiki Peninsula and deformed arc-related greenschists of the Circum-Rhodope Belt in Thrace region. The distinguished microfossil assemblages and foraminiferal morphogroups are compatible with deposition in a shallow-water environment adjacent to the continental margin of Eurasia. The morphogroup characteristics support such interpretation and newly discovered microfossils define the age of the limestones as Berriasian to early Valanginian. The microfossil data conform to available radiometric ages for the Late Jurassic ophiolite crystallization and time equivalent Circum-Rhodope Belt thrust tectonics. Hence, the obtained results provide sedimentary evidence for pre-Berriasian accretion of the eastern Vardar Zone ophiolites to the continental margin and completion of the Circum-Rhodope Belt tectono-metamorphic history. The earliest Cretaceous sedimentation extended along the whole length of the Circum-Rhodope Belt across

the north Aegean region implying a region-wide development of a carbonate platformwhich postdated the imprint of an important tectonic event. The sedimentation seals the Late Jurassic-Early Cretaceous Balkan orogenic event in the internal Hellenides at the Eurasian plate margin. This conclusion has strong implications for the geodynamic evolution of the Alpine Belt of the North Aegean region.

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84. Chatalov, A., Ivanova, D., **Bonev, N**., 2014. Transgressive Eocene clastic-carbonate sediments from the Circum-Rhodope Belt, northeastern Greece: implications for a rocky shore paleoenvironment. – *Geological Journal,* doi 10.1002/g.j.2598.

Locally exposed Middle to Upper Eocene conglomerates in the western part of the Cenozoic Thrace Basin are interpreted as products of continuous marine erosion of a rocky coast (consisting of Lower Cretaceous carbonates) and subsequent redeposition of the land-derived limestone material in a wave-dominated nearshore setting during a prolonged transgression. Contemporaneous biological activity in the warm-temperate marine environment contributed to the accumulation of mixed coarse-grained clastic–carbonate sediments on the upper shoreface. The formation of a relatively thick sedimentary succession was favoured by the interplay of several controlling factors as only shoreface deposits were preserved in the rock record. The results may help to elucidate the evolution of the hydrocarbon-bearing Thrace Basin and to assist with the regional correlation of its basal deposits.

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79. Bonev, N., Ovtcharova-Schaltegger, M., Moritz, R., Marchev, P., Ulianov, A., 2013. Peri-Gondwanan Ordovician crustal fragments in the high-grade basement of the Eastern Rhodope Massif, Bulgaria: evidence from U-Pb LA-ICP-MS zircon geochronology and geochemistry. – *Geodinamica Acta*, **26**, 3-4, 207-229.

Field, geochemical, and geochronologic data of high-grade basement metamafic and evolved rocks are used to identify the nature and timing of pre-Alpine crustal growth of the Rhodope Massif. These rocks occur intrusive into clastic-carbonate metasedimentary succession. Petrography and mineral chemistry show compositions consistent with Alpine amphibolite-facies metamorphism that obliterated the original igneous textures of the protoliths. Bulk-rock geochemistry identifies low-Ti tholeiitic to calc-alkaline gabbroic-basaltic and plagiogranite precursors, with MORB-IAT supra-subduction zone signature and trace elements comparable to modern back-arc basalts. The U-Pb zircon dating revealed a mean age of 455 Ma for the magmatic crystallization of the protoliths that contain inherited Cambrian (528–534 Ma) zircons. Carboniferous, Jurassic, and Eocene metamorphic events overprinted the Ordovician protoliths. The radiometric results of the metamorphic rocks demonstrate that Ordovician oceanic crust was involved in the buildup of the Rhodope high-grade basement. Dating of Eocene-Oligocene volcanic rocks overlying or cross-cutting the metamorphic rocks supplied Neoproterozoic, Ordovician and Permo-Carboniferous xenocrystic zircons that were sampled en route to the surface from the basement. The volcanic rocks thus confirm sub-regionally present Neoproterozoic and Paleozoic igneous and metamorphic basement. We interpret the origin of the Middle-Late Ordovician oceanic magmatism in a back-arc rift-spreading center propagating along peri-Gondwanan Cadomian basement terrane related to the Rheic Ocean widening. The results highlight the presence of elements of Cadomian northern Gondwana margin in the high-grade basement and record of Rheic Ocean evolution. The eastern Rhodope Massif high-grade basement compared to adjacent terranes with Neoproterozoic and Cambro-Ordovician evolution shares analogous tectono-magmatic record providing a linkage among basement terranes incorporated in the Alpine belt of the north Aegean region.

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77. Bonev, N., Spikings, R., Moritz, R., Marchev, P., Collings, D., 2013. $^{40}Ar/^{39}Ar$ age constraints on the timing of Tertiary crustal extension and its temporal relation to ore-forming and magmatic processes in the eastern Rhodope Massif, Bulgaria. – *Lithos*, **180-181**, 264-278.

We quantify the timing of the Tertiary crustal extension in the eastern Rhodope Massif of south Bulgaria using 40Ar/39Ar geochronology to constrain the temporal evolution of exhumation of the metamorphic domes. 40Ar/39Ar analyses of mineral phases with different closure temperatures extracted from metamorphic rocks collected in the footwall and the hanging wall of the extensional system reveal the low-temperature cooling history towards shallow crustal levels. The results reveal that subsequent to regional amphibolite facies metamorphism (i) the hanging wall gradually cooled between 500 and 300 °C during the Paleocene to Late Eocene (64–34 Ma), starting at a low rate of 25 °C/Ma and increasing to 50–67 °C/Ma during 38–34 Ma, (ii) cooling below 400–300 °C of the footwall beneath the extensional detachments occurred in the Middle–Late Eocene (39–35.5 Ma) at an average rate of 35 °C/Ma. 40Ar/39Ar data from the metamorphic basement has been combined with 40Ar/39Ar data from the volcanic and hydrothermal rocks in the vicinity to the extensional domes, to determine the temporal relationships between extensional tectonics, ore-forming and magmatic processes in the region. Extension of the high-grade basement, the ore-formation and volcanism overlaps within a 5 Ma lasting time interval, especially during the cooling and exhumation of the footwall. The eastern Rhodope Massif records an early stage of Eocene extension within the Aegean extensional province, where distinct crustal-scale processes occurred simultaneously implying the presence of cause and effect processes, and thus represents a key example of coeval continental extension, magmatism and hydrothermal activity in the late-stage evolution of the orogens.

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76. Marchev, P., Georgiev, S., Raicheva, R., Peytcheva, I., von Quadt, A., Ovtcharova, M., **Bonev, N**., 2013. Adakitic magmatism in post-collisional setting: An example from the Early-Middle Eocene magmatic belt in South Bulgaria and North Greece. – *Lithos*, **180-181**, 159-180.

Post-collisional (56.0–40.4 Ma) adakiticmagmatismin the RhodopeMassif and the Kraishte region, including W. Srednogorie, in South Bulgaria followed the collision of the Rhodope and Pelagonian Massifs. It forms a 250 km NWtrending beltwhich continues into the 1000 kmlong belt of Eocenemagmatism in northern Turkey and Iran. The rocks are represented by felsic subvolcanic dykes and sills in the Kraishte and plutons in the Rhodopes. Here, we synthesize new chemical (whole-rock major and trace elements, and Sr and Nd isotopes) and LA–ICP/MS mineral and U–Pb zircon age data along with published similar data in order to constrain the genesis of this magmatism and the early Cenozoic geodynamic evolution of the central Balkan Peninsula. The rocks display typical subduction-related characteristicswith enrichment in LILE and LREE and depletion in HFSE (Nb, Ta and Ti). In the Kraishte and western Srednogorie Zones these are calc-alkaline to high-K calc-alkaline rhyolites, displaying a typical adakitic signature, i.e. high La/Yb and Sr/Y ratios. The studied Rhodope Massif rocks are predominantly high-K calc-alkaline and subordinate calc-alkaline granites and granodiorites with a minor amount of tonalites. Petrographically, they are H2O- and accessory-rich (allanite, epidote, titanite, apatite) rocks, showing geochemical affinities fromnon-adakitic tonalites and mafic granodiorites to adakitic granodiorites and granites. Similarity of Sr and Nd isotopic compositions of the Kraishte subvolcanic and Rhodope intrusive adakitic rocks with the neighboring and coeval NW Anatolian basaltic to dacitic volcanics and plutons suggests that the most likely source for the South Bulgarian adakitic rocks is the subduction-enriched depleted lithosphericmantle. The nearby and contemporaneous East Serbian alkaline basalts are isotopically and compositionally different and, probably, originate from an OIB-like mantle source. Subsequent fractionation within an isotopically similar lower or middle crust in the Kraishte and interaction with the mid- to lower part of collision- and underplating-induced thickened crust in the Rhodopes can explain their isotopic variations. Transition from non-adakitic tonalities and granodiorites into adakitic granodiorites and granites in the Rhodopes was developed in response to amphibole fractionation accompanied by trace-

element rich accessory minerals. Data fromthe literature showthat the adakitic signature of the Early–Middle Eocene rocks disappeared in the following Late Eocene–Early Oligocene (35–26 Ma) magmatic episode. Our interpretation is that adakitic magmatism is related to a deep (N250 km) slab break-off, followed by asthenospheric upwelling, heating, fast exhumation and formation of core complexes in the Rhodopes and Kraishte in the interval 42–35 Ma. The process was followed by thinning of the crust, orogenic collapse, steep faulting and extensional magmatism.

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70. Bonev, N., Dilek, Y., Hanchar, J.M., Bogdanov, K., Klain, L. 2012. Nd-Sr-Pb isotopic composition and mantle sources of Triassic rift units in the Serbo-Macedonian and the western Rhodope massifs (Bulgaria-Greece). – *Geological Magazine,* **149**,1, 146-152.

We report on the field occurrence and isotopic compositions of metamafic rocks exposed in the Serbo-Macedonian (Volvi and Therma bodies) and western Rhodope (Rila Mountains) massifs of Bulgaria and Greece. These metamafic units consist of high- and low-Ti gabbroic and basaltic rocks, whose Nd–Sr–Pb isotopes are compatible with mantle derived MORB and OIB components with a small amount of crustal material involved in their melt source. These isotopic features combined with the field observations are consistent with an intra-continental rift origin of the metamafic rocks protolith, and are comparable to those of the Triassic riftrelated mafic rocks in the northern Aegean region.

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68. Bonev, N., Stampfli, G. 2011. Alpine tectonic evolution of a Jurassic subduction-accretionary complex: Deformation, kinematics and $^{40}Ar/^{39}Ar$ age constraints on the Mesozoic low-grade schists of the Circum-Rhodope Belt in the eastern Rhodope-Thrace region, Bulgaria-Greece. – *Journal of Geodynamics,* **52**, 2,143-167.

Deformation of the Circum-Rhodope Belt Mesozoic (Middle Triassic to earliest Lower Cretaceous) low-grade schists underneath an arc-related ophiolitic magmatic suite and associated sedimentary successions in the eastern Rhodope-Thrace region occurred as a two-episode tectonic process: (i) Late Jurassic deformation of arc to margin units resulting from the eastern Rhodope-Evros arc–Rhodope terrane continental margin collision and accretion to that margin, and (ii) Middle Eocene deformation related to the Tertiary crustal extension and final collision resulting in the closure of the Vardar ocean south of the Rhodope terrane. The first deformational event D1 is expressed by Late Jurassic NW-N vergent fold generations and the main and subsidiary planar-linear structures. Although overprinting, these structural elements depict uniform bulk north-directed thrust kinematics and are geometrically compatible with the increments of progressive deformation that develops in same greenschist-facies metamorphic grade. It followed the Early-Middle Jurassic magmatic evolution of the eastern Rhodope-Evros arc established on the upper plate of the southward subducting Maliac-Meliata oceanic lithosphere that established the Vardar Ocean in a supra-subduction back-arc setting. This first event resulted in the thrust-related tectonic emplacement of the Mesozoic schists in a supra-crustal level onto the Rhodope continental margin. This Late Jurassic-Early Cretaceous tectonic event related to N-vergent Balkan orogeny is well-constrained by geochronological data and traced at a regional-scale within distinct units of the Carpatho-Balkan Belt. Following subduction reversal towards the north whereby the Vardar Ocean was subducted beneath the Rhodope margin by latest Cretaceous times, the low-grade schists aquired a new position in the upper plate, and hence, the Mesozoic schists are lacking the Cretaceous S-directed tectono-metamorphic episode whose effects are widespread in the underlying high-grade basement. The subduction of the remnant Vardar Ocean located behind the colliding arc since the middle Cretaceous was responsible for its ultimate closure, Early Tertiary collision with the Pelagonian block and extension in the region caused the extensional collapse related to the second deformational event D2. This extensional episode was experienced passively by the Mesozoic schists located in the hanging wall of the extensional detachments in Eocene times. It resulted in NE-SW oriented open folds representing corrugation antiforms of the extensional detachment surfaces, brittle faulting and burial history beneath thick Eocene sediments as indicated by

42.1–39.7Ma 40Ar/39Ar mica plateau ages obtained in the study. The results provide structural constraints for the involvement components of Jurassic paleo-subduction zone in a Late Jurassic arc-continental margin collisional history that contributed to accretion-related crustal growth of the Rhodope terrane.

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63. Moritz, R., Márton, I., Ortelli, M., Marchev, P., Voudouris, P., **Bonev, N.**, Spikings, R. Cosca, M., 2010. A review of age constraints of epithermal precious and base metal deposits of the Tertiary Eastern Rhodopes: coincidence with Late Eocene-Early Oligocene tectonic plate reorganization along the Tethys. – Scientific Annals, School of Geology, Aristotle University of Thessaloniki, *Proceedings XIX Congress CBGA*, Special volume **100**, 351-358.

The Tertiary Eastern Rhodopes are a major ore province within the Tethyan metallogenic belt. 40Ar/39Ar age data obtained in the past ten years are overviewed and discussed. It allows us to address some of the open questions and shed some new light on the sequence of ore-forming, magmatic and tectonic processes throughout the Eastern Rhodopes. Small to moderately sized ore deposits and prospects in the Rhodope Massif are hosted by high-grade metamorphic, continental sedimentary and igneous rocks. Sedimentary rock-hosted gold epithermal prospects are the earliest hydrothermal systems, hosted by Maastrichtian-Paleocene clastic rocks. Their 40Ar/39Ar ages vary between 37.55 ± 0.44 Ma and 34.71 ± 0.16 Ma, with the waning hydrothermal activity overlapping with the start of the oldest volcanism in the Eastern Rhodopes yielding 40Ar/39Ar ages ranging between 34.62 ± 0.46 Ma and 32.97 ± 0.23 Ma. Within a very short time between 32.13 ± 0.20 and 31.2 ± 0.4, Pb-Zn-dominated and Cu-Audominated epithermal prospects, respectively in the northern and the southern parts, were formed, and coincide with rhyolitic dikes emplaced at about 31.5 Ma. The Late Eocene-Early Oligocene postorogenic magmatic and ore-forming evolution of the Eastern Rhodopes coincides with the time of collision at about 30-35 Ma of the African and Eurasian plates in the Caucasus and the Rif-Betic belts, when a dominantly subduction-dominated tectonic regime changed to a collision-dominated system, and the northward motion of the African plate slowed down, accompanied by an increasing southward slab retreat velocity in the Aegean Sea.

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62. Bonev, N., Magganas, A., Klain, L., 2010. Regional geology and correlation of the eastern Circum-Rhodope Belt, Bulgaria-Greece. – Scientific Annals, School of Geology, Aristotle University of Thessaloniki, *Proceedings XIX Congress CBGA*, Special volume **100**, 157-164.

We review on a regional-scale the distinct units of the eastern Circum-Rhodope Belt (CRB) in Bulgaria and Greece, with the aim to provide an up-to-date synthesis and correlation. The eastern CRB consists of Early-Middle Jurassic supra-subduction zone Evros ophiolite, the MORB related Late Jurassic Samorthaki ophiolite and Middle Triassic-Jurassic clastic, pelitic, carbonaceous and Cretaceous(?) flysch sedimentary successions. Lower Cretaceous shallow-water Aliki limestones seal part of these sedimentary successions already metamorphosed in greenschist-facies. Bulk stratigraphy in ascending order comprises a meta-sedimentary series overlain by a meta-volcanic series. The metamorphic grade increases towards the high-grade basement northwards reaching upper greenschist to epidote-amphibolite facies, and decreases to very low-grade (prehnite-pumpellyite facies) and non-metamorphic stratigraphically up-section. Trace element and REE comparison of the ophiolite basalts and underlying greenschist-facies meta-volcanics of same composition reveals similar geochemistry within the distinct units, implying a regional-scale chemical continuity. The allochthonous eastern CRB units show N-directed internal shear deformation and thrust emplacement, evidently along rarely preserved thrust contacts, and record tectonic overprint by Tertiary collision and extensional tectonics in the region. Collectively, the onshore eastern CRB is a region-wide (180 km long along strike × 80 km wide along meridian) tectonic zone including correlative units with regard to their coherent and

comparable stratigraphy, tectonics and geochemistry. These units testify for three paleogeographic domains that include Triassic-Jurassic near Rhodope continental margin shallow-water environment, adjacent to this margin Early-Middle Jurassic intra-oceanic arc system responsible for the generation of the supra-subduction zone Evros ophiolite and related to the ophiolite Middle-Late Jurassic trench-slope environment. Another MORB-related paleogeographic domain is indicated by the Samothraki back-arc ophiolite offshore.

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61. Bonev, N., Spikings, R., Mortiz, R., Marchev, P. 2010. The effect of early Alpine thrusting in late-stage extensional tectonics: Evidence from the Kulidzhik nappe and the Pelevun extensional allochthon in the Rhodope Massif, Bulgaria. – *Tectonophysics*, **488**, 256-281.

In the northeastern Rhodope Massif, the Kulidzhik nappe exposes a unique juxtaposition of a high-grade basement allochthon onto a low-grade Mesozoic unit, and the counterpart Pelevun extensional allochthon belonging to the same unit. The Kulidzhik nappe tectonostratigraphy comprises structurally upward: (i) a lower unit consisting of high-grade basement orthogneisses; (ii) a low-grade greenschist-phyllite unit consisting of Jurassic extrusive rocks and metasedimentary rocks; (iii) the nappe allochthon built by the lower high-grade basement unit orthogneisses; and (iv) Eocene sedimentary rocks and Oligocene volcanic cover rocks. The Pelevun extensional allochthon is heterogeneous, and consists of Mesozoic low-grade unit marbles and greenschists and the upper high-grade basement unit. We have combined structure and kinematics, with lithological information and 40Ar/39Ar geochronology to constrain the tectonic evolution and regional significance of the Kulidzhik nappe and the Pelevun extensional allochthon. Mineral chemistry reveals igneous phases of the granitic protolith of the allochthonous orthogneisses with textures related to ductile deformation and metamorphism higher than 500 °C. Their trace element patterns are indistinguishable from the high-grade basement orthogneisses in the eastern Rhodope. Mineral chemistry of the metamorphic assemblage in the underlying greenschists is consistent with medium-grade greenschist-facies metamorphism at temperatures well below 450 °C, whose geochemistry defines transitional MORB to IAT affinities with a strong arc imprint. The greenschist's composition is extremely similar to the composition of a supra-subduction zone Jurassic arc extrusive suite that occurs in the low-grade unit of the eastern Rhodope. The structural elements in all of the tectono-metamorphic units and the nappe surface indicate top-to-the NNE tectonic transport. Deformation evolved from ductile to brittle conditions coevally with a progressive decrease from lower amphibolite to weak greenschist-facies metamorphismtowards the structural top. Two klippen gave plateau 40Ar/39Ar mica ages of 154.23±0.66 Ma and 156.70±0.81 Ma, respectively, which reflect cooling following the greenschist-facies event below 350 °C, during shallow crustal level thrust emplacement and exhumation of the Kulidzhik allochthon. The hanging-wall Pelevun extensional allochthon preserves an internal NNE-directed ductile tectonic transport trend, but is underlain by a SSW-directed ductile–brittle extensional detachment and has experienced NE-SW brittle extension on high-angle normal faults. An amphibole 40Ar/39Ar inverse isochron age of 156.58±0.60 Ma constrains a Late Jurassic upper greenschist-facies tectono-metamorphic event, whereas a white mica plateau age of 39.66±0.47 Ma provides evidence for Middle Eocene cooling and exhumation of the Pelevun extensional allochthon in the hanging wall of the detachment. We relate the Kulidzhik nappe to Late Jurassic crustal deformation during arc-continental margin collision that involved NNE-directed nappe staking and metamorphism of continental margin basement and island arc units. The nappe shares a tectono-metamorphic history with the nappes of the adjacent Strandzha Massif, implying a region-wide early Alpine orogenic system. Our results reveal a record of early Alpine thrust tectonics and show the significance of crustal accretion-related assembly for the tectonic evolution of the Rhodope Massif. Both the Late Jurassic thrusting event and the subsequent Cretaceous thrusting event thickened the Rhodope crust creating crustal instability, which influenced Tertiary crustal extension.

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60. Bonev, N., Dilek, Y. 2010. Geochemistry and tectonic significance of proto-ophiolitic metamafic units from the Serbo-Macedonian and western Rhodope massifs (Bulgaria-Greece). – *International Geology Review*, **52**, 2/3, 298-335.

Dispersed Triassic (?) metamafic rocks occurring in the Serbo-Macedonian and western Rhodope massifs of southern Bulgaria and northern Greece are important crustal components of early Mesozoic oceanic crust formation in the Tethyan realm. The Volvi and Therma metamafic bodies of the Serbo-Macedonian Massif and metamafic rocks at RilaMountain of the western RhodopeMassif consist mainly of gabbros and basalts that show a strong overprint of Alpine amphibolite-facies metamorphism and deformation. Only clinopyroxenes in the Volvi body represent preserved primary phases. High-Ti and low-Ti groups have been identified geochemically within the metamafic rocks. The incompatible trace-element and REE-enriched high-Ti group displays an E-MORB signature consistent with a riftspreading centre tectonic setting; in contrast, the low-Ti group exhibits geochemical features largely comparable to the high-Ti group as well asHFSE andREE depleted compositions and an arc-related signature. Comparison with Triassic rift-related volcanic suites in adjacent tectonic zones show that these metamafic rocks are fully comparable in terms of their trace elements, REE ratios, and normalized patterns, suggesting that collectively they represent the remnants of a regionwide Triassic rifting event. Enriched mantle components, together with an arc component likely influenced by the late Palaeozoic-early Mesozoic Palaeotethyan subduction, were involved in the petrogenesis of the metamafic rocks. Based on regional geology and geochronology, we interpret the metamafic rock suites as the products of intracontinental rifting within the Serbo-Macedonian/Rhodope continental margin. Thus, these proto-ophiolitic mafic rock assemblages represent precursors of the Neotethyan early crust formation along the Eurasian plate boundary following the closure of Palaeotethys.

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59. Bonev, N., Moritz, R., Marton, I., Chiaradia, M., Marchev, P. 2010. Geochemistry, tectonics, and crustal evolution of basement rocks in the eastern Rhodope Massif, Bulgaria. – *International Geology Review*, **52**, 2/3, 269-297.

Orthogneisses derived from granitoids with Variscan protolith ages dominate the lower unit of high-grade metamorphic basement of the Eastern Rhodope Massif in south Bulgaria. We present whole-rock geochemistry and Sr–Pb isotopic composition of these orthogneisses, which are compared with Pb isotopes of parametamorphic rocks, and hydrothermal ore deposits and associated rocks, to better constrain their composition, origin, and contribution to late Alpine hydrothermal processes. The igneous mineral assemblage is partly preserved, and the field textures and microstructures of the orthogneisses are consistent with a ductile, amphibolite-grade tectono-metamorphic overprint during Alpine time, when they were involved in the metamorphic nappe stack. Whole-rock geochemistry revealed compositions of the orthogneisses largely unaffected by the amphibolite-grade metamorphism, displaying a magmatic differentiation trend of the igneous protoliths. The protoliths are peraluminous medium-K calcalkaline S-type granitoids, whose tectono-magmatic setting discrimination consistently indicates a continental volcanic arc origin. The orthogneisses present trace element and rare-earth elements (REE) patterns based on which a group of high-field strength elements-depleted and REE fractionated orthogneisses and a group of LREE-enriched orthogneisses can be distinguished. Both geochemical groups show compositions similar to the bulk and upper continental crust and its sedimentary counterparts. Crustal Pb isotope ratios (206Pb/204Pbi518.24–18.66) of the orthogneisses are comparable to the paragneisses (206Pb/204Pbi518.31–18.93) and uniform in both (207Pb/204Pbi515.64–15.72) and 208Pb/204Pbi ratios in the paragneisses (38.23–38.60) and the orthogneisses (38.32–38.56). The trace element data and 87Sr/86Sri isotopes of the orthogneisses (0.7050–0.7117) overlap those of the parametamorphic rocks (0.7039–0.7144), and confirm the supracrustal origin of the igneous precursors. A heterogeneous crustal source region is suggested in which melting and crustal contamination during magma genesis with subsequent

fractional crystallization was involved in the petrogenesis. Comparative Pb isotope systematics suggests that a significant crustal Pb input to ore-forming hydrothermal fluids was derived primarily from the metamorphic basement, implying that the brittlly deformed basement during crustal extension acted as an immediate environment for fluid leaching during late Alpine hydrothermal ore-forming processes.

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56. Bonev, N., Beccaletto, L., Robyr, M, Monié, P. 2009. Metamorphic and age constraints on the Alakeçi shear zone: implications for the extensional exhumation history of the northern Kazdağ Massif, NW Turkey. – *Lithos*, **113**, 331-345.

The Kazdağ Massif exposes an extensional metamorphic dome in the Biga Peninsula of northwest Turkey, bounded on both flanks by detachments and/or shear zones. The northern flank is marked by the extensional Alakeçi shear zone (ASZ), with poorly known P–T–t path.We therefore focus on metamorphic conditions and temporal history of the ASZ to determine its tectono-metamorphic evolution. ASZ mylonites were derived from both the footwall Kazdağ Massif core metamorphic rocks and the hanging wall Çetmi mélange lithologies. The mylonitic fabrics in the ASZ depict a top-to-the NNE shearing, parallel to the NNE-plunging stretching lineation and NNW-dipping mylonitic foliation. This geometry implies normal sense movement i.e. north-side down-dip extensional displacement along this flank of the Kazdağ Massif. The northward transition from ductile to brittle–ductile shear regime through the ASZ shows that the non-coaxial deformation occurred at decreasing temperatures and degree of metamorphism. The paragenesis in equilibrium of the mylonitic gneisses and schists contains quartz+feldspar+muscovite+biotite+garnet±staurolite, with late retrogressive chlorite after biotite and garnet. Calculated thermo-barometric conditions for ASZ rocks yielded pressures between 6.9 and 5.7 kbar and temperatures between 706 and 587 °C, which constrain the peak metamorphism. The mylonitic rocks supplied isochron 39Ar/40Ar mica ages between 26.97 and 24.19 Ma, which we interpret to date the cooling of the mylonites following the P–T decrease across the ASZ. The metamorphic data support the structural record and strengthen the extensional character of the ASZ. The transition from sillimanite-bearing footwall Kazdağ Massif core gneisses in the deeper structural levels to chlorite schists towards the shallow structural levels at the top of the ASZ, is consistent with an extensional exhumation of the metamorphic pile. These data allow us to determine the peak P–T conditions and the temporal evolution in the northern flank of the Kazdağ Massif, where Late Oligocene extensional exhumation was assisted by NNE-directed ductile–brittle ASZ, which had operated from amphibolite to greenschist facies. The ASZ, together with similar time-constrained ductile–brittle activity of SW-directed detachment along the southern flank of the massif, collectively indicates a bivergent mode of extension in the western Kazdağ Massif. The latter is likely influenced by magmatic activity spatially and temporally related to these extensional zones. At the regional scale, the bivergent tectono-metamorphic pattern of the Kazdağ Massif is similar to those observed on other places of the north-central Aegean domain.

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52. Bonev, N., Beccaletto, L. 2007. From syn- to post-orogenic Tertiary extension in the north Aegean region: constraints on the kinematics in the eastern Rhodope-Thrace, Bulgaria-Greece and the Biga Peninsula, northwest Turkey, In: Taymaz, T., Yilmaz, Y., Dilek, Y. (eds.). The Geodynamics of the Aegean and Anatolia. – *Geological Society, London, Special Publication,* **291,** pp. 113-142.

The Aegean region experienced back-are extension related to the Hellenic subduction system at least from the latest Oligocene to the present. We document Tertiary extension-related kinematics in the north Aegean, in the eastern Rhodope–Thrace of Bulgaria–Greece and the Biga Peninsula of NW Turkey. A regionally consistent NNE–SSW- to NE–SW-oriented kinematic direction, delineated in both areas by stretching lineations and associated ductile–brittle shear fabrics in exhumed

metamorphic domes beneath detachments, suggests that they were kinematically coupled during the Tertiary extension. This kinematic framework, combined with regional geochronological data and the stratigraphic record in hanging-wall supradetachment basins, defines an extensional history that includes syn- and post-orogenic episodes from Paleocene to Miocene times. Paleocene–early Eocene synorogenic extension in the Kemer micaschists of the northern Biga Peninsula and in the Kesebir–Kardamos dome in Rhodope–Thrace accommodated gravitationally induced hinterland-directed exhumation of the orogenic stack, coeval with the closure of the Vardar Ocean. Then, following collision within the region, it was succeeded by latest Oligocene–Early Miocene extension as recorded in the Kazdagˇ Massif in the southern Biga Peninsula, which overlaps the Aegean back-arc post-orogenic extension, widely recognized in the central Aegean and southern Greek Rhodope. The protracted record of extension is interpreted to reflect progressive exhumation of the orogenic wedge along the Eurasian plate margin. Southward migration of extension and magmatism across the study areas accounts for sequential shift and roll-back of the subduction boundary at that margin, from the latest Cretaceous in the Rhodope to its present position at the Hellenic trench. The results allow recognition of the investigated areas as an important extensional domain in the north Aegean region, which underwent Tertiary syn- and post-orogenic extension.

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51. Beccaletto, L., **Bonev, N**., Bosch, D., Bruguier, O. 2007. Record of a Paleogene syn-collisional extension in the north Aegean region: Evidence from the Kemer micaschists (NW Turkey). – *Geological Magazine,* **144**, 2, 393-400.

In NW Turkey, the medium-grade Kemer micaschists of the Biga Peninsula record NEdirected extension related to ductile to brittle–ductile shearing during the Palaeogene period: a lower limit for their exhumation is given by the Late Maastrichtian age of the HP–LT metamorphism of a similar nearby area (Camlıca micaschists); an upper limit is given by the Early Eocene intrusion age of the post-kinematic Karabiga granitoid, dated as 52.7±1.9 Ma using the U–Pb LA–ICP–MS method on xenotime. Correlations with the northeasterly Rhodope region and integration into the geodynamic regional frame indicate that the Kemer micaschists experienced an extensional deformation connected to a collisional context in latest Cretaceous–early Tertiary times. The Kemer micaschists therefore represent a new area (the first in Turkey), which suffered synorogenic extension in the north Aegean domain at the very beginning of Tertiary times.

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47. Bonev, N. 2006. Cenozoic tectonic evolution of the eastern Rhodope massif (Bulgaria): Basement structure and kinematics of syn- to postcollisional extensional deformation, In: Dilek, Y., Pavlides, S., (eds.) Post-collisional tectonics and magmatism in the Mediterranean region and Asia. – *Geological Society of America Special Paper* **409**, pp. 211-235.

This article contributes to a better understanding of the structure and extensional tectonics in the eastern part of the Rhodope massif. The eastern Rhodope high-grade metamorphic basement includes a lower and an upper unit of continental and mixed continental-oceanic affinity, respectively. Both high-grade basement units are tectonically overlain by a low-grade Mesozoic unit representing a Late Jurassic–Early Cretaceous subduction-accretion complex, and altogether the metamorphic units are covered by a sedimentary unit of Late Cretaceous to Miocene syn- to post-tectonic sequences. Low-angle extensional detachments and mylonitic zones separate the lower high-grade unit in the footwall from the hangingwall consisting of the upper highgrade unit, a low-grade Mesozoic unit, greenschists, and a sedimentary unit lying in fault contact with the detachments. The high-grade basement structure consists of large-scale metamorphic domes, the Kesebir and the Byala reka domes, characterized by an overall dome-shaped regional foliation pattern and associated northwest-southeast-to northeast-southwest-trending stretching lineation. The Kesebir dome internally consists of distinct submassifs—namely, the Kesebir (s.s.), the Makaza, and the Veykata domes—distinguished from one another on the basis of structural and kinematic patterns. Asymmetric ductile fabrics and metamorphic

crystallization/deformation relationships indicate that the basement rocks experienced two distinct events of Alpine deformation: SSE-SSW-oriented contraction related to nappe stacking and top-tothe-SSW and/or -NNE extension. Top-to-the-SSE-SSW ductile fabric elements are coeval with the main metamorphism in amphibolite facies and are associated with synmetamorphic thrust imbrication of the high-grade basement units. This contractional event occurred before intrusion of the latest Late Cretaceous–Paleocene granitoids (70–53 Ma) and is also indicated by the radiometric ages of metamorphism. The southdirected kinematics of this contractional event continued in lower metamorphic grade and temperature conditions, with top-to-the-SSW ductile to brittle extension in the Byala reka dome and top-to-the-NNE ductile rather than brittle extension in the Kesebir dome. Extension developed partly coeval and concurrent with the earlier stacking event through the operation of ductile to semiductile shear zones under a lowangle brittle detachment that led to tectonic denudation and exhumation of the lower high-grade unit of the footwall in the cores of large-scale metamorphic domes. The extensional exhumation was accompanied by widespread cooling of the footwall rocks in both large-scale domes between 42 and 37 Ma, followed by late faulting at 36–35 Ma. The kinematic pattern in the high-grade basement units is interpreted to reflect spatially and vertically partitioned shear sense and kinematic direction defined by stretching lineations in a metamorphic pile. This pattern formed in response to transition from crustal thickening to late orogenic extension. The syn- to postcollisional extension described herein was broadly coeval with and followed closure of the Vardar Ocean. Extension has accommodated tectonic denudation during the late stage of the collisional evolution of the Alpine orogenic belt in the eastern Mediterranean region. The structural and kinematic results indicate that the eastern Rhodope region represent an Early–Middle Tertiary extensional domain in the northernmost part of the late Alpine Aegean extensional province.

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42. Bonev, N., Burg, J.-P., Ivanov, Z. 2006. Mesozoic-Tertiary structural evolution of an extensional gneiss dome – the Kesebir-Kardamos dome, eastern Rhodope (Bulgaria-Greece). – *International Journal of Earth Sciences (Geol. Rundsch.)*, **95**, 2, 318-340.

The tectonic evolution of the Rhodope massif involves Mid-Cretaceous contractional deformation and protracted Oligocene and Miocene extension. We present structural, kinematic and strain data on the Kesebir–Kardamos dome in eastern Rhodope, which document early Tertiary extension. The dome consists of three superposed crustal units bounded by a low-angle NNEdipping detachment on its northern flank in Bulgaria. The detachment separates footwall gneiss and migmatite in a lower unit from intermediate metamorphic and overlying upper sedimentary units in the hanging wall. The highgrade metamorphic rocks of the footwall have recorded isothermal decompression. Direct juxtaposition of the sedimentary unit onto footwall rocks is due to local extensional omission of the intermediate unit. Structural analysis and deformational/metamorphic relationships give evidence for several events. The earliest event corresponds to top-to-the SSE ductile shearing within the intermediate unit, interpreted as reflecting Mid-Late Cretaceous crustal thickening and nappe stacking. Late Cretaceous–Palaeocene/Eocene late-tectonic to post-tectonic granitoids that intruded into the intermediate unit between 70 and 53 Ma constrain at least pre-latest Late Cretaceous age for the crustal-stacking event. Subsequent extension-related deformation caused pervasive mylonitisation of the footwall, with top-to-the NNE ductile, then brittle shear. Ductile flow was dominated by noncoaxial deformation, indicated by quartz c-axis fabrics, but was nearly coaxial in the dome core. Latest events relate to brittle faulting that accommodated extension at shallow crustal levels on high-angle normal faults and additional movement along strike-slip faults. Radiometric and stratigraphic constraints bracket the ductile, then brittle, extensional events at the Kesebir–Kardamos dome between 55 and 35 Ma. Extension began in Paleocene–early Eocene time and displacement on the detachment led to unroofing of the intermediate unit, which supplied material for the syn-detachment deposits in supra-detachment basin. Subsequent cooling and exhumation of the footwall unit from beneath the detachment occurred between 42 and 37 Ma as indicated by mica cooling ages in footwall rocks, and extension proceeded at brittle levels with high-angle faulting constrained at 35 Ma by the age of hydrothermal adularia crystallized in open spaces created along the faults. This was followed by Late

Eocene–Oligocene post-detachment overlap successions and volcanic activity. Crustal extension described herein is contemporaneous with the closure of the Vardar Ocean to the southwest. It has accommodated an earlier hinterland-directed unroofing of the Rhodope nappe complex, and may be pre-cursor of, and/or make a transition to the Aegean back-arc extension that further contributed to its exhumation during the Late Miocene. This study underlines the importance of crustal extension at the scale of the Rhodope massif, in particular, in the eastern Rhodope region, as it recognizes an early Tertiary extension that should be considered in future tectonic models of the Rhodope and north Aegean regions.
