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REGIONAL GEOLOGY AND CORRELATION OF THE EASTERN CIRCUM-RHODOPE BELT, BULGARIA-GREECE

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Abstract: 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.

Keywords: regional geology, correlation, eastern Circum-Rhodope Belt, Bulgaria-Greece

1. Introduction

The Circum-Rhodope Belt (CRB) of continuous sedimentary successions was introduced by Kauffmann et al. (1976) as an isopic zone of the Internal Hellenides that surrounds the high-grade crystalline Serbo-Macedonian Massif and the Rhodope Massif in Greece and Bulgaria. This designation followed the works by Jaranov (1960) using the term Peri-Rhodope Zone and Kockel et al. (1971) for the same isopic zone of the Chalkidiki Peninsula. The CRB was discarded as continuous belt representing the sedimentary cover of the high-grade crystalline massifs (Ricou et al., 1998). Nevertheless, the CRB is widely used in the tectonic subdivision of the Hellenides, and the CRB concept is considered still vigorous (Brown and Robertson, 2004; Papanikolaou, 2009). The only attempt for correlation of the units in the eastern CRB was done by Boyanov et al. (1990) for the Mandritsa area in Bulgaria, based on the stratigraphic data presented by Papadopoulos et al. (1989) for the Drimos-Melia and Makri units in Greece. In this contribution, we review distinct units in the eastern segment of the CRB in the light of recent advances in their composition and structure, with the aim to better understand the regional context of this belt in the eastern Rhodope-Thrace region of Bulgaria and Greece.

The eastern CRB consists of greenschist-facies, very low-grade and unmetamorphosed rocks (Papadopoulos, 1982; Boyanov et al., 1990), including the Jurassic Evros ophiolite (Magganas et al., 1991) and associated Mesozoic sedimentary successions that span Middle Triassic-Lower Cretaceous interval as indicated by published biostratigraphic and radiometric ages in Bulgaria and Greece. We combined available stratigraphic data with own unpublished field observations and tectonic data, and published petrologic and geochemical data on distinct units to provide more comprehensive up-to-date regional synthesis with regard to the materials of eastern CRB.

2. Regional geology

Figure 1 shows the distribution of the Mesozoic low-grade metamorphic rocks of the CRB in the eastern Rhodope-Thrace region of Bulgaria and Greece. The low-grade rocks form the uppermost tectono-metamorphic unit occurring largely as inliers below the Tertiary sedimentary and volcanic cover successions. Partly, these rocks rest tectonically on the high-grade basement units, mostly through extensional detachments where they form part of the hanging wall and locally are limited by thrust contacts (Bonev and Stampfli 2003, 2008, 2009; Bonev 2006a; Bonev and Beccaletto 2007). We use available in the literature names for the distinct units in their description that follows from north to the south. The dispersed areal mode of occurrences of the low-grade successions requires an evaluation of the counterparts of the units, which to be put into a regional-scale frame.

The northernmost unit of the eastern CRB occurs in northern slope of the eastern Rhodope and was originally defined as the Kulidzhik nappe by Boyanov (1969), where Lower Cretaceous radiolarian assemblage (Boyanov and Lipman, 1973) subsequently re-examined as Jurassic in age (Boyanov et al., 1990) was reported in shales. The Kulidzhik nappe tectonically slices the high-grade basement orthogneisses with a greenschist series of arc-related meta-basalts and pyroclastics of IAT to MORB geochemical signature comparable to the similar rocks in the Mandritsa unit (Bonev, 2006b). The greenschist series record upper greenschist to epidote-amphibolite facies conditions, and is conformably overlain by a series consisting of weakly metamorphosed black argillaceous shales intercalated with thin limestone horizon, and phyllites. Both low-grade series are overlain by the Kulidzhik nappe orthogneissic allochthon that cooled in Late Jurassic time ($^{40}Ar/^{39}Ar$ mica ages of 154.23 ± 0.66 Ma and 156.7 ± 0.81 Ma), providing evidence for the Middle-earliest Late Jurassic metamorphism (following Early-Middle Jurassic ophiolite eruptive history) of the greenschist series coeval with a ductile to brittle NNE-directed nappe emplacement (Bonev et al., 2010).

The Mandritsa area is the second large exposure of the CRB rocks in Bulgaria, straddling the Greek-Bulgarian border. This area is usually referred as the Mandritsa unit (e.g. Ricou et al., 1998), whose meta-sedimentary lower section is largely correlated with the Makri unit in Greece (Boyanov et al., 1990). The Mandritsa unit is floored by a horizon of recrystallized limestones that grade into marbles occurring in basal direct contact with the ductile-brittle orthogneiss mylonites of the Byala reka extensional detachment (Bonev, 2006a). The marble horizon contains greywacke knockers and mafic lenses (Bonev, 2005a), and is intruded by boninitic affinity diorite dyke (Bonev and Stampfli, 2008). This horizon is gradually overlain by greenschist unit consisting of meta-sedimentary (common quartz-chlorite-white mica ± garnet) and meta-volcanic (common chlorite-actinolite ± epidote) rocks having arc-related boninitic-tholeiitic affinity. Both lithologies depict an internal NW–NE-directed ductile shear deformation in greenschist-facies conditions (Bonev and Stampfli, 2003). Up-section the greenschist unit is gradually overlain by thin lava flows of arc-related boninitic-tholeiitic affinity basalts to andesites that are geochemically undistinguishable from the greenschists (Bonev and Stampfli, 2008). The lavas are interstratified by chert layers that yielded Lower Jurassic radiolarians (Tikhomirova et al., 1988). Stratigraphically uppermost is mélange-like unit consisting of intercalated conglomerates, gravels, sandstones and black shales. This intercalation contains in olistostromic context reworked blocks and clasts of Late Permian and Middle-Late Triassic shallow-water limestones and siliciclastics (Boyanov and Trifonova, 1978; Boyanov and Bodurov, 1979; Trifonova and Boyanov, 1986; Bonev, 2005b). The subdivided by Boyanov et al. (1990) in the Mandritsa area topmost Late Cretaceous sedimentary-volcanogenic Meden Buk Formation that contains Campanian foraminifera recovered only in drill cores is not considered here because it can not be seen in the field. Instead, we assign the terrigeneous components included in the Meden Buk Formation as belonging to the mélange-like unit. Internal north-directed thrusts locally juxtapose greenschists with very low-grade rocks in the Mandritsa unit.

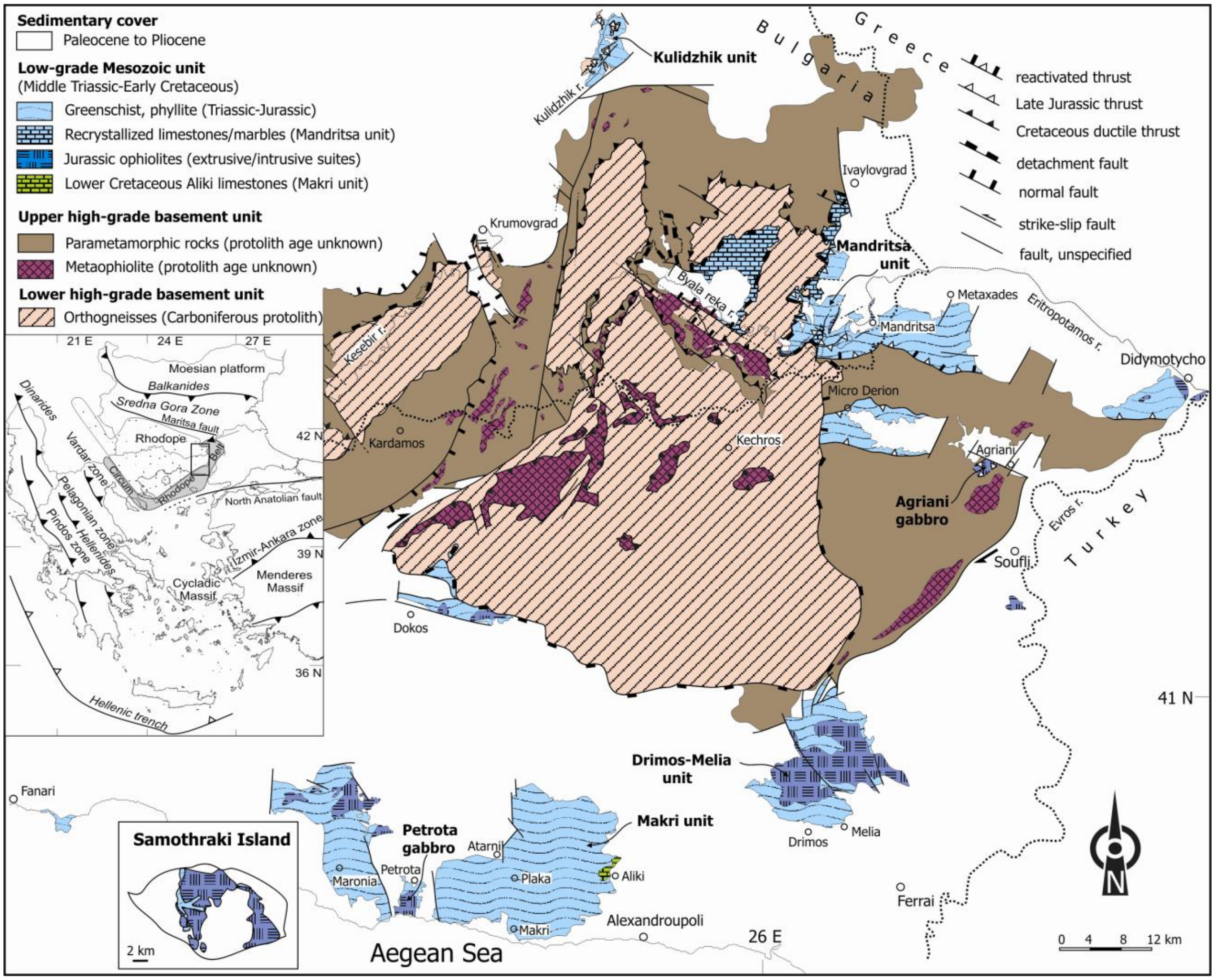

Fig. 1. Geologic sketch map of the eastern Rhodope-Thrace region in Bulgaria-Greece (modified from Bonev and Stampfli, 2008).

The Metaxades-Micro Derion area represents laterally continuous exposure of the greenschist unit from the Mandritsa area. In this area, the meta-lavas and meta-pyroclastics of same lithologic context and metamorphic grade to the Mandritsa greenschist unit belongs to the upper and lower meta-volcanics having an arc-related tholeiitic signature (Magganas, 2002). Field observations in Metaxades-Micro Derion area have shown that the greenschist unit locally exposes a basal N-directed ductile thrust contact with the high-grade basement, which contact is re-activated as normal fault during the Tertiary extensional deformation.

Further east (Fig. 1), a gabbroic body at the village Agriani and the mafic lavas and plagiogranite intrusion at Didymotycho area belongs to the section of the Evros ophiolite (Magganas et al., 1991; Magganas, 2002, 2007; Bonev and Stampfli, 2009). The Agriani isotropic gabbro of tholeiitic affinity is intruded by boninitic basalt dykes and overlain by mafic lava flow. The gabbro lies on the high-grade basement with an inferred thrust contact. The plagiogranite stock at Didymotycho is intruded by microgabbroic and coarse-grained gabbroic dykes, as well as by tholeiitic and boninitic affinity basalt dykes. The massive, rarely pillowed mafic lavas at Didymotycho belong to the upper meta-volcanics of the Evros ophiolite (Magganas, 2002). The basal ductile thrust contact of the ophiolite at Didymotycho, yet locally observed, demonstrates intensely folded thin horizon of the Makri unit-specific meta-sediments with pronounced NE-directed fold asymmetry and tectonic transport direction on top of the high-grade basement.

Southwards, the main exposures of the Mesozoic low-grade rocks encompass the Drimos-Melia and the Makri units (Papadopoulos, 1982). The former unit, which is better exposed between the Drimos and Melia villages, consists therein of massive basalt to andesite lava flows lying usually above the basalt pillow lavas intercalated with rare sheeted-like dykes. This extrusive ophiolite suite is interfingering-with flysch rhythmic shale and sandstone alternation. These relationships imply mutual flysch depositional and ophiolite eruptive history. The flysch supplied find of Callovian-Oxfordian ammonite (Trikkalinos, 1955) and prints of Middle-Upper Triassic bivalve (Dimadis et al., 1996). Detrital zircons in the sandstones cluster at ca. 315-285 Ma, with youngest zircon at ca. 160 Ma providing maximum depositional age of the flysch (Meinhold et al., 2010). Easterly, south of Soufli (Fig. 1), an isolated basaltic andesite lava flow occurs below the Tertiary cover, showing similarity to massive lava flows of the Drimos-Melia unit and at Didymotycho.

The largest development of the Makri unit occurs north of the village Makri and extends into the Maronia area westwards. These two areas are separated by the Tertiary Petrota graben, which exposes in its central part the Petrota gabbroic complex (Biggazzi et al., 1989). According to the latter authors, the Petrota complex consists of cumulitic and isotropic gabbros, gabbro-norites and anorthosites having tholeiitic to calc-alkaline arc-related, supra-subduction zone affinity. Our field observations in the area identified also the presence of tholeiitic basalt dykes. U-Pb zircon SHRIMP age of 169 ± 2 Ma (Koglin et al., 2007) and apatite fission-track ages in the range 161-140 Ma (Biggazzi et al., 1989) were reported for the Petrota gabbro, implying respectively its crystallization or uplift/shallow-crustal emplacement. The contact of the Petrota complex with the surrounding rocks is intrusive (Bigazzi et al., 1989) or tectonic (Frass et al., 1989). In the field, the contact with the Makri unit is uncertain, marked by late faults limiting the graben or traced by gabbro-contact zone altered rocks, but virtually the Petrota complex occurs below the Marki unit. The unit itself includes metasedimentary series consisting of shales, phyllites, quartz-chlorite schists, sandstones and recrystallized limestone horizons overlain by greenschists and greenstone series (commonly chlorite-actinolite) (Kopp, 1969; Papadopoulos et al., 1989), presumably of volcanic and pyroclastic origin. In between greenschists layers of the Makri unit and metasomatic contact zone with them, small serpentinite olistostromic occurrences are found nearby the villages Atarni and Plaka. The greenschists, which form the tholeiitic back-arc-related lower metavolcanics of Magganas (2002), are intruded by gabbroic and minor plagiogranitic rocks. The lower limestone horizon yielded Triassic corals (Maratos and Andronopoulos, 1964), whereas chlorite schists supplied Tithonian-Berriassian ammonite (Dimadis and Nikolov, 1997). The uppermost limestone horizon of the Makri unit, the so-called “Aliki limestones”, supplied Lower-Middle Cretaceous foraminifers (Kopp, 1969) which are considered pertaining to Lower Cretaceous (Maratos and Andronopoulos, 1964). The Aliki limestones are debatable because of claimed transgressive superposition onto the Makri unit (Kopp 1969), tripartite intercalation within its higher levels (Maratos and Andronopulos, 1964) or lying with tectonic contact (von Braun, 1993). Our field observations around the hill that only exposes the Aliki limestones revealed no tripartite intercalation with the underlying greenschists that always show very weak shear deformation and the limestones in turn are undeformed. These features indicate that the Aliki limestones unconformably overlie the greenschists. Detrital zircons in the sandstones of the Makri unit cluster at ca.310-290 Ma and at ca. 240 Ma (Meinhold et al., 2010) providing at least Middle Triassic depositional age.

In the Maronia area, both series of the Makri unit are present with same metamorphic grade lithologic assemblage, in turn overlain by forearc tholeiitic basalt to andesite pillow-lavas and flows, boninitic dykes and flysch that exhibit characteristics analogous to the volcanic and clastic sedimentary rocks of the Drimos-Melia unit.

A small area near the village Dokos (Fig. 1) exposing analogous to the Makri unit low-grade successions occur in the hanging wall of an extensional detachment (Bonev and Beccaletto, 2007). All areas exposing the Makri unit provide evidences for an internal N-directed deformation depicted by fold asymmetry, thrust fault propagation in the fold hinges and ductile shearing.

An isolated coastal outcrop east of the village Fanari exposes shale-sandstone rhythmic flysch alternation (Fig. 1). The flysch shows NW-vergent refolded patterns associated with hinge thrusts propagation in the direction of fold overturning. The Fanari flysch strongly resembles the Drimos-Melia unit flysch, despite the later is weakly deformed.

The southernmost occurrence of the eastern CRB units is found in the Samothraki Island. Low-grade meta-sedimentary rocks consisting mostly of meta-conglomerates and mica-chlorite schists of Late Jurassic age (Heimann et al., 1972) are intercalated by rhyodacitic to andesitic metavolcanics, forming the lower unit in the island. It has been suggested that most rocks from this unit correspond to the Makri unit rocks and constitutes a flyschoid formation deposited in a continental rift (Tsikouras and Hatzipanagiotou, 1998). Ophiolitic rocks of Late Jurassic age (154±7 and 155±7 Ma) tectonically overlay the lower unit. From base to top, the Samothaki ophiolite consists of gabbro, hornblende-diorite with plagiogranite pods and veins, dolerite in massive layers and dykes and basaltic pillow-lavas and flows, almost all showing strong MORB signatures. The diorites intrude locally schists of the lower unit. The ophiolite is unconformably overlain by Eocene sediments, covered by Oligocene to Miocene volcanics and a Miocene granitic body intruded into the ophiolite and the lower unit (Davis, 1963; Eleftheriadis et al., 1989).

3. Correlation and synthesis

Figure 2 summarizes the stratigraphic and tectonic features of the distinct units or studied areas of the eastern CRB, allowing their correlation and establishing corresponding counterparts. Starting from the base of eastern CRB, the meta-sedimentary series of the Makri unit is comparable with the lower meta-sedimentary levels of the Mandritsa unit, both only having relatively thick limestone horizons. The variations in the latter units include the higher abundance of calcareous rocks in the Makri unit, with reminder that the Mandritsa unit lays above an extensional detachment that accounts for stratigraphic omissions. These meta-sedimentary successions stands for the near Rhodope Triassic-Jurassic continental margin shallow-water environment (e.g. Papadopoulos et al., 1989) located adjacent to the Jurassic island arc system that created the supra-subduction zone Evros ophiolite. The very low-grade (prehnite-pumpellyite facies, Magganas, 2005) massive and pillow lavas of the ophiolite extrusive suite, together with its me-

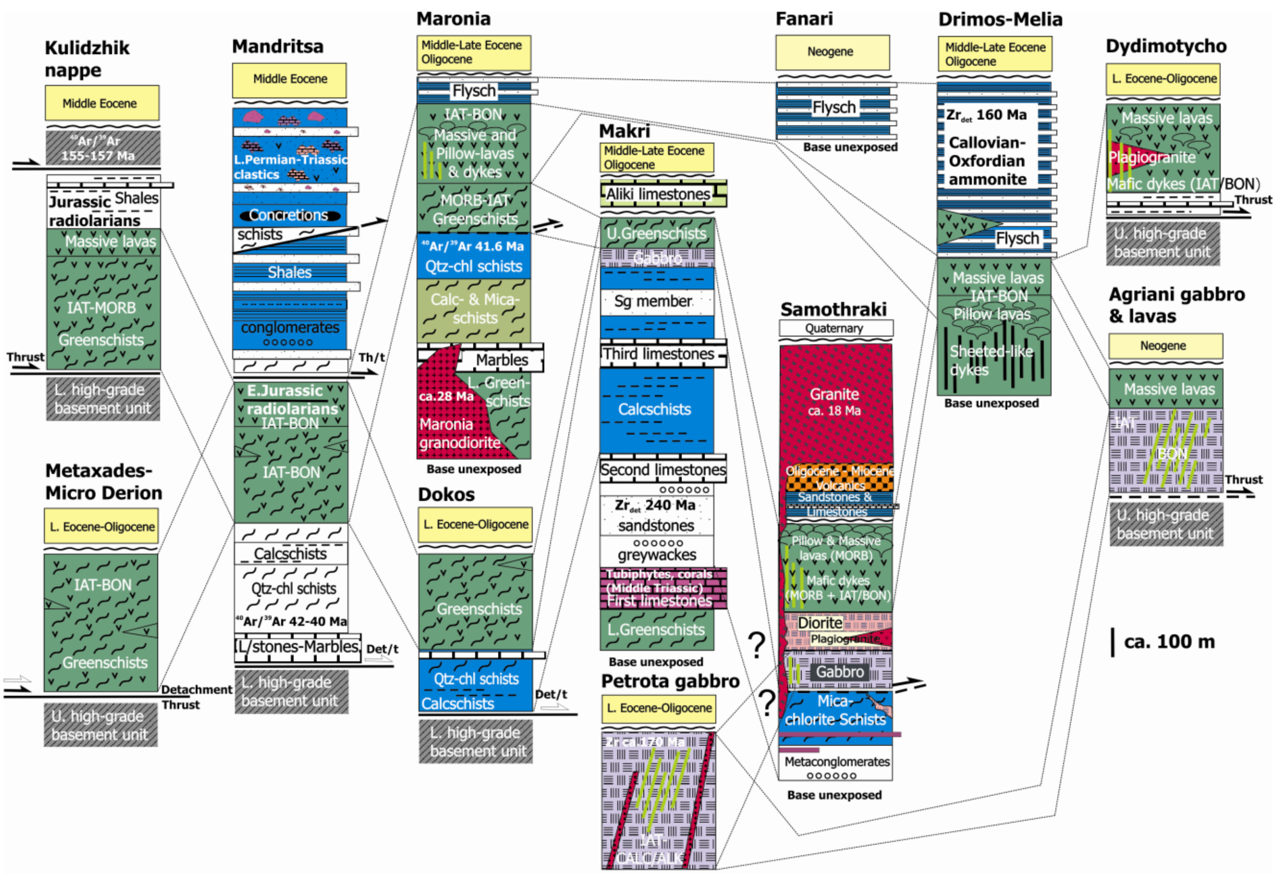

Fig. 2. Tectono-stratigraphic columns for the units or areas of the eastern CRB. The Makri unit stratigraphy after Kopp (1969). $^{40}Ar/^{39}Ar$ ages for the Kulidzhik nappe from Bonev et al., (2010). Unpublished $^{40}Ar/^{39}Ar$ ages for the Mandritsa unit and Maronia area testify respectively for extensional tectonic overprint and burial beneath 5 km thick Middle Eocene sediments (e.g. Ivanov and Kopp, 1969).

tamorphosed members in the greenschist series, both are traced in almost all eastern CRB units. Geochemical comparison of the greenschists and the ophiolite basaltic lavas of same composition show chemical consistency of the trace element and REE patterns in the distinct units, implying common magmatic origin clearly related to a SSZ environment (Fig. 3). Weak MORB and strong IAT and boninitic signatures are revealed, with the latter two compositions depicted mostly in the relatively younger ophiolitic rocks of the Drimos-Melia unit in Greece and the equivalent units in Bulgaria. The deepest crustal section of the ophiolite is represented by Petrota and Agriani gabbroic bodies. Cumulate rocks in the Petrota complex may represent deep magma chamber elements, whereas Makri and Didymotycho gabbroic and plagiogranitic stocks and dykes presumably belong to upper magma chamber layers. The sheeted-like dykes of the Drimos-Melia unit and the basaltic dykes crosscutting plagiogranitic rocks in Didymotycho are forming the likely transition to the extrusive suite in a bulk ophiolite "pseudostratigraphy". Mantle section of the ophiolite is almost absent. However, the serpentinite bodies occurrences at Atarni and Plaka, which are found in close spatial-contact relationship with the greenschists of the Makri unit, showing depleted chemistry and harzburgitic composition can be considered as small slices of the tectonitic part of the ophiolite (Magganas, 2002). The proximal flysch of the Drimos-Melia unit and in Fanari indicates trench-slope environment, which in the Drimos-Melia unit is intimately related to the ophiolite extrusive suite. From a tectonic view point, the Late Jurassic N-directed thrust displacement of the eastern CRB units is recorded elsewhere by internal shear deformation and locally preserved thrust contacts (Bonev et al., 2010; Bonev and Stampfli, 2010), with the strong overprint by the Tertiary final collision and extensional tectonics in the region (Bonev and Stampfli, 2003; Bonev, 2006a; Bonev and Beccaletto, 2007). From a geodynamic view point, the eastern CRB reveals intimately related four paleogeographic environments, namely the Triassic-Jurassic continental margin of the Rhodope, the Early-Middle Jurassic intra-oceanic arc system (including magmatic products specific for the proto/fore-arc and arc regions) responsible for the generation of the Evros ophiolite and the Jurassic trench-slope environment adjacent to the arc-related ophiolite. The last paleogeographic environment is clearly indicated by MORB affinities recognized in most mafic rocks of the Samothraki Island ophiolite. This back-arc extensional setting was active southwards during Late Jurassic (Tsikouras and Hatzipanagiotou, 1998).

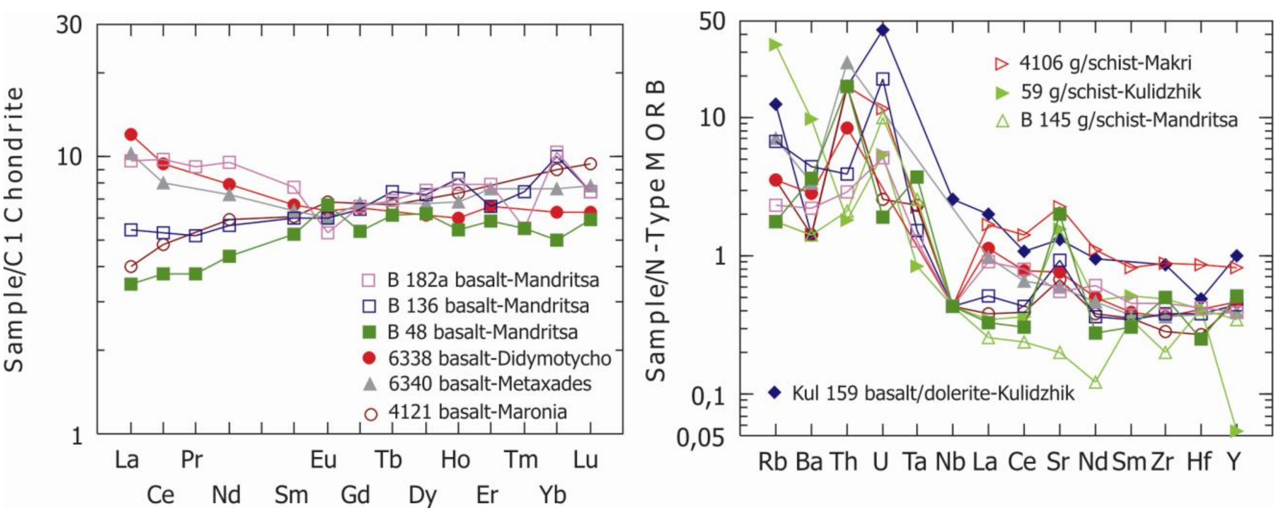

Fig. 3. Comparative geochemistry of the greenschists and ophiolite basalt lavas in the units of the eastern CRB. Data compiled from Magganas (2002), Bonev et al., (2010) and Bonev and Stampfli (2008). Normalization values after Sun and McDonough (1989).

4. Conclusions

- The onshore eastern CRB is a regional-scale tectonic zone including coherent units that can be followed for more than 180 km along the strike from Fanari to Didymotycho and is 80 km wide from the front of the Kulidzhik nappe to the Aegean coast. Offshore element is Samothraki Island ophiolite. The various units contained in this belt show correlative stratigraphy, similar chemical compositions of the ophiolite suites and analogous tectonic features related to their Late Jurassic thrust emplacement onto the Rhodope margin and the Tertiary Rhodope collisional and extensional overprint. Metamorphic grades are highest northwards close to the high-grade basement in the meta-sedimentary and greenschist series, and generally decrease stratigraphically upwards to ocean-floor metamorphism of the ophiolite and unmetamorphosed flysch.

- The Early-Middle Jurassic supra-subduction zone Evros ophiolite (constrained by radiolarians within the lavas of the Mandritsa unit and the crystallization of the Petrota gabbro) presents mostly an extensive extrusive suite and limited intrusive crustal section, essentially lacking the mantle section. Geochemically, the ophiolite has regionally coherent arc-related dominant IAT signature, with similar affinity greenschist series that systematically underlie the ophiolite in various eastern continental CRB units. In opposite, Jurassic Samothraki ophiolite shows mostly MORB features.

- The weakly or unmetamorphosed sedimentary successions represent deposits related to the supra-subduction zone ophiolite, both depicting three consistent paleogeographic domains of near continental margin shallow-water environment, trench-slope environment and intra-oceanic arc system. A forth setting is indicated by a mid-ocean ridge system developed further south in the marginal basin.

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