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MESOZOIC OPHIOLITES IN THE DINARIDES AND THE CARPATHIANS: A REVIEW

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Ophiolites and related rocks are important indicators in deciphering paleogeography and tectonic evolution of crustal segments. Despite a large variability and overlap in their lithological appearance, petrology and geochemistry it is generally possible to assign individual ophiolite bodies and related rocks to certain geotectonic environments such as MOR, SSZ, a transition from subcontinental to suboceanic mantle or intraplate environments (DILEK, 2003). In Europe the most widespread and complete Mesozoic ophiolites are found in the Balkan Peninsula, south and south-east of the Alps (ROBERTSON, 2002). Three ophiolite belts can be traced:

(1) From the northern Dinarides through Albania to western Greece;

(2) From the Transylvanian Depression along the inner Dinarides to north-eastern Greece;

(3) From the Western Carpathians through the Eastern Carpathians to the Southern Carpathians.

The westernmost ophiolites can be called Dinaride–Mirdita–Hellenide Ophiolite Zone (DMHZ). It extends from the vicinity of Zagreb in Croatia via Serbia and Albania (Mirdita Ophiolite) to the Beothian ophiolites in Greece. Geologically it is situated between the Drina–Ivanjica–Pelagonia microcontinent in the east and the Adriatic continental margin in the west (KARAMATA & KRSTIĆ, 1996; CHANNELL & KOZUR, 1997). The opening of the DMH oceanic realm is often related to the Middle Triassic fragmentation of the northern margin of the Gondwana supercontinent. A line of evidence, based on metamorphic sole ages (e.g. LANPHERE *et al.*, 1975; DIMO-LAHITTE *et. al.*, 2001; SPRAY & RODDICK, 1980) and Early Cretaceous overstep sequences suggest that it was closed in the Late Jurassic.

The DMHZ has a complex structure. In its central part, in Albania and north-western Greece, it consists of two belts, different in composition and origin but still related to each other. Above a mélange and a metamorphic sole the western belt is dominated by lherzolites, harzburgites are less abundant (BORTOLOTTI *et al.*, 1996; BORTOLOTTI *et al.*, 2004). The tectonites are overlain by a mantle-crust transition zone consisting of plagioclase-bearing peridotites, followed by ultramafic and mafic cumulates and intrusive gabbros. An occasionally developed thin MOR basalt cover, sometimes with a transition to SSZ basalts represents the extrusive section. In the eastern belt, harzburgites prevail followed by a mantle-crust transition zone, with ultramafic and mafic cumulates and intrusive gabbros including diorites and plagiogranites. A locally thick developed sheeted dyke complex follows, leading to the volcanics ranging from tholeiitic basalts to andesites, dacites and rhyolites.

Within the Dinarides the ophiolite belt consists, similar to the western belt in Albania, of a number of ultramafic bodies associated with a melange and it is characterized by a far-reaching lack of oceanic crust rocks (LUGOVIĆ *et al.*, 1991). The mélange is composed of a shaly-silty matrix, embedding different blocks of oceanic (ultramafics, gabbro-dolerite, pillow-lava, chert) and continental fragments (greywacke, limestone and granite). Larger ultramafic massifs (100–1000 km^2) represent thrust sheets that overlay the mélange. They are predominately lherzolitic in composition and usually associated with metamorphic rocks that are typical metamorphic soles, with additional HP/HT mafic granulites. The latter have an unusual thickness of up to 1000 m and are characterized by high pressure (up to 10 kbars) mineralogy. The thickness of the former is much smaller (up to 250 m) and they exhibit a low-pressure metamorphic zoning. The association of granulite facies metamorphic rocks with ultramafic massifs and the absence of upper oceanic crust led LUGOVIĆ *et al.* (1991) to question the ophiolitic nature of the Dinaride ophiolite belt. These observations allow a hypothesis that a large part of DMH ophiolite zone may represent a continental margin sequence.

East of the Drina–Ivanjica–Pelagonia microcontinent, a second ophiolite zone known as Vardar Zone (VZ) occurs. One subzone (Eastern VZ) ranges from north-eastern Greece via Macedonia and Serbia (BÉBIEN, 1983; RESIMIĆ-ŠARIĆ *et al.*, 2000) to Romania, where it is found in the Apuseni Mtns. (NICOLAE; 1995; SACCANI *et al.*, 2001) and the basement of the Transylvanian Depression, (IONESCU & HOECK, 2004). A second subzone (western VZ) can be followed from southern Serbia to Croatia (KARAMATA *et al.*, 2000). The former ophiolites differ from those in the DMHZ in that they contain (1) only little mantle tectonites but a well developed crustal section, (2) the ophiolites are often overlain by an island arc sequence and (3) the crustal rocks are intruded by granites and granodiorites. Radiometric age determinations and palaeontological evidence of overlying sediments suggest Middle to Late Jurassic age for the ophiolites and the intruding granites and granodiorites. The most prominent examples are the Guevgueli ophiolites at the Greece – Macedonian border (BÉBIEN, 1983) and the Apuseni ophiolites in the Mureş Nappe (SACCANI *et al.*, 2001) in Romania. The latter is discussed here in some details as an example.

The ophiolites contain ultramafic and mafic cumulates, gabbros, sheeted dykes and basalts, but no mantle tectonites. Basalts, rarely basaltic andesites and even andesites, display mainly a MOR geochemistry with a high amount of Fe-Ti gabbros and Fe-Ti basalts (SACCANI *et al.*, 2001). Nevertheless, transitional compositions from MORB to SSZ and intraplate basalts occur. The ophiolites are overlain and intruded respectively by an island arc plutonic (?) and volcanic sequence (BORTOLOTTI *et al.*, 2002), which is widely distributed in the eastern part (Trascău Mts.). The volcanic rocks range from basalts to rhyolites forming dykes, massive lava flows and pillow lavas. Volcaniclastics are common. By contrast to the ophiolites, they exhibit clear signs of a SSZ genesis with low content of HFSE, a negative Nb anomaly and enrichment of LREE over the HREE. They are in turn overlain by thin radiolarite beds and Upper Jurassic limestones. Palaeontological evidence and K-Ar as well as U-Pb data indicate Middle to Late Jurassic age of the formation of the ophiolites and the island arc sequence (PANA *et al.*, 2002). To what extent granites, granodiorites and diorites represent the plutonic part of the island arc sequence or are alternatively independent Jurassic intrusions, remains a matter of debate.

The Transylvanian Depression was drilled by a large number of boreholes, from which some reached the pre-Cretaceous basement and consequently basaltic rocks. In particular the deep well Deleni-6042 and Zoreni-1 drilled each several hundred metres of basaltic and andesitic rocks. The Deleni borehole drill cores form approximately 10% of the whole length of the basalt drilling, *i.e.* approximately 40 m drill cores. Basalts and andesites from the drill cores can be grouped in three petrographic and geochemical entities. All of them, despite small geochemical differences, resemble strongly basalts and andesites on top of the ophiolites of the Apuseni Mtns. and the Trascău Mts. (IONESCU & HOECK, 2004). From the drill-hole Zoreni-1 a few core remnants are available for investigation. They show boninitic affinities with high SiO_2 and MgO, Cr and Ni but low to very low Ti, Zr, Y and Sm. The REE are depleted, the chondrite-normalised pattern is slightly U-shaped. All these features highlight the suprasubduction zone character of these rocks.

In the Eastern Carpathians (EC) basalts and ultramafics are found in the Transylvanian nappes (TN) in the tectonic highest position above the Bucovinian Nappe (SĂNDULESCU, 1984; RUSSO-SĂNDULESCU *et al.*, 1983) closely associated with the Wildflysch. The major occurrences are from N to S: Rarău, Hăghimaş and Perşani. The ophiolites occur often as olistoliths, partly as tectonic slivers (?). Among the smaller blocks (hundred of meters) larger continuous occurrences of basalts or ultramafics are regarded as remnants of the Transylvanian nappes. How far these larger units can be interpreted as mega-olistoliths remains to be discussed. Such an interpretation would disregard the existence of a separate Transylvanian Nappe.

The age of the ophiolites from the Eastern Carpathians is debatable. At least a large part is Triassic in age, inferred from the close connection to Mid-Triassic sediments with well preserved original interfaces among basalts and sediments. The ophiolitic fragments consist mainly of lherzolitic ultramafics, serpentinites and various basalts. Gabbros and related rocks such as diorites and plagiogranites as well as fragments of sheeted dikes are rare. The most frequent rocks are basalts. In the northern parts (Rarău and Hăghimaş) lherzolites prevail, in the Perşani Mtns. harzburgites are more common. In the Rarău, MORB-type volcanics with a variable subduction component are common. They also show a certain variation towards andesitic (trachyandesitic) compositions. However, according to RUSSO-SĂNDULESCU *et al.* (1983) intraplate basalts are likely to occur. They seem to be more widely distributed in Hăghimaş and are common also in Perşani. It should be noted however, that except for one occurrence no remnants of an ophiolitic sequence could be detected so far. Trachytes are additionally common in the Perşani Mtns. Until now no similar rocks were found in Rarău or Hăghimaş.

Compared with other ophiolites, in particular with those in the Southern Apuseni Mtns. a number of differences can be noted:

(1) Intraplate compositions of basalts or their differentiation products are missing in the Apuseni Mtns.
(2) The Apuseni ophiolites have an almost complete ophiolite sequence ranging from ultramafic cumulates over gabbros and sheeted dykes to basaltic extrusives. Gabbros, dykes and basalts show often Fe-Ti enrichment trend. By contrast, the Eastern Carpathians MOR-type basalts have a slight subduction component, but no Fe-Ti enrichment. There are almost no ophiolite sections, but isolated ultramafic bodies. Gabbros are almost missing.
(3) The Apuseni ophiolites are overlain by island arc sequence. No such equivalents could be found so far in the Eastern Carpathians.
(4) Inferred from the depositionally overlying Late Jurassic limestones, the Apuseni ophiolites are regarded to be Late Jurassic in age. Contrary, Late Jurassic limestones are not reported to be spatially associated with the Eastern Carpathians basalts and ultramafics. Strong relations to Mid to Late Triassic sediments are more common.

Within the Southern Carpathians the Severin Nappe, sandwiched between the Danubian unit below, and the Getic nappes above, contains Mesozoic ophiolites. They are believed to be Jurassic in age and consist of serpentinized peridotites (mainly lherzolites), rare gabbros and basalts (SAVU, 1982). The latter display geochemically a MOR characteristic and are accompanied by enriched intraplate basalts. In this respect the Severin Nappe ophiolites resemble those from Rarău in the Transylvanian nappes, notwithstanding the different tectonic position. The ophiolites from the Severin Nappe are thought to have a continuation in the Ceahlău and Black Flysch nappes in the Eastern Carpathians. There, blocks of basic volcanic material are found embedded in coarse grained clastic sediments of Late Jurassic and Cretaceous age. Larger, mappable units occur in the north of Romania and in the Ukraine in the continuation of the Ceahlău–Black Flysch units. The Severin–Ceahlău ophiolites and basalts respectively are regarded as remnants of an intracontinental oceanic basin situated within the European continental margin.

The relation among the ophiolite belts and their according oceanic basins in south-eastern Europe remains enigmatic. The rhetoric question “How many oceans?” put forward by CHANNELL & KOZUR (1997) is not satisfactorily answered yet. To envisage their three “Meliata, Vardar and Pindos” oceans is most likely not enough. The Upper Cretaceous MOR-type basalts and sediments in the western Vardar Zone require a separate marginal or back-arc basin (*cf.* PAMIĆ *et al.*, 2002). Additionally, the Severin ophiolites in the Southern Carpathians and their possible continuation (?) in the Eastern Carpathians, the mafic volcanic remnants in the Ceahlău and Black Flysch nappes are probably formed in a small intra-continental oceanic basin E of the Vardar Zone. Based on the lithological, petrological, geochemical and geochronological differences, we propose here that the ophiolites in the Transylvanian nappes of the Eastern Carpathians represent the continuation of the Triassic Meliata Ocean from the Western Carpathians (CHANNELL & KOZUR, 1997) rather than the north-eastern most continuation of the eastern Vardar Ocean (SĂNDULESCU, 1984), which we believe has terminated at the northern end of the Transylvanian Depression (HOECK *et al*., 2004).

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