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GEOLOGY OF THE VARDAR ZONE OPHIOLITES OF THE MEDVEDNICA MOUNTAIN AREA LOCATED ALONG THE ZAGREB-ZEMPLIN LINE (NW CROATIA)

DAMIR SLOVENEC[1] and JAKOB PAMIĆ[2]

[1]Institute of Geology, Sachsova 2, HR-10 000 Zagreb, Croatia
[2]Croatian Academy of Science and Art, Ante Kovačića 5, HR-10 000 Zagreb, Croatia

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Abstract: The ophiolite mélange of the Medvednica Mountain area, located in the southwestern parts of the Zagorje-Mid-Transdanubian or Sava Zone, is included within the Vardar Zone (VZ) of the Dinarides. The mélange represents the northwesternmost parts of the Dinaridic ophiolites, the origin of which was related to the Alpine evolution of the Dinaridic part of the Tethys. The Dinaridic ophiolites represent fragments of Mesozoic oceanic crust generated over 150 Ma starting with a) Late Triassic (?) to Late Jurassic oceanization of the Tethys, Late Jurassic/Early Cretaceous subduction, obduction and formation of the Dinaride Ophiolite Zone (DOZ) to b) Cretaceous–Early Paleogene back-arc basin final subduction and obduction, that is the formation of the VZ. The main Alpine compressional-collisional event, which took place in the Eocene (55–45 Ma) gave rise to the final structuration of the Dinarides and their uplift, and backthrusting of the VZ onto the DOZ. The Medvednica ophiolite mélange represents a chaotic complex in which primary sedimentary sequences are rarely preserved due to subsequent tectonism. The mélange is characterized by pervasively sheared and fine-grained shaly-silty matrix in which are included smaller (centimetre to hektometre) and larger (kilometre) fragments of various rocks. These are most commonly greywackes, ophiolites, cherts and exotic limestones, the youngest blocks of which are Late Cretaceous and Paleocene in age. For that reason the VZ ophiolite mélange is of post-Paleocene age as distinguished from the Jurassic ophiolite mélange of the DOZ. The Medvednica ophiolites are represented by tectonic and cumulate serpentinized peridotites, gabbro-diabases and basalts, transformed by postmagmatic processes, into serpentinites, metagabbros, metadiabases and metabasalts. The Medvednica ophiolites can be correlated to the ophiolites from the northwestern part of the Zagorje-Mid-Transdanubian (or Sava) Zone and the Bükk area in northern Hungary. The present position of all these ophiolites can be best explained by the mechanism of extrusion tectonics, for example strike slip faulting as a result of Oligocene and Neogene indenting of Apulia into Eurasia.

Key words: Late Cretaceous–Paleogene, Medvednica Mt, Zagorje-Mid-Transdanubian (Sava) Zone, Vardar Zone, ophiolite mélange, subduction, obduction, extrusion tectonics.

Introduction

The Dinarides, which can be traced along strike for about 700 km, represent a complex fold, thrust and imbricate belt which developed along the northeastern margin of the Adriatic microplate or Apulia (Dewey et al. 1973). Spatially, the Dinarides are not precisely defined but, generally, it is believed that they merge in the southeast with the Hellenides and in the northwest with the Alps. In the north, the Dinarides are bounded by the Pannonian Basin, that is, the Tisia (Fig. 1).

The Dinaridic ophiolites and genetically related sedimentary formations have fixed geotectonic position by their occurrence in the Dinaride Ophiolite Zone (DOZ) and Vardar Zone (VZ). Kossmat (1924) first defined the VZ, restricting its occurrence to southern Serbia, Macedonia and northern Greece; this is the VZ *sensu stricto*. Afterwards it was recognized that the zone continues further northward and northwestward (Aubouin 1974) into the area south of the Sava River up to the Zagorje-Mid-Transdanubian (or Sava) Zone. This extended zone is the VZ *sensu lato*, although the more adequate term would be the Sava-Vardar Zone (Pamić 2001).

Genetically, the ophiolites from the DOZ were probably related to the Tethyan open ocean realm, whereas the ophiolites from the VZ were related to the North Tethyan active continental margin, that is, the back-arc basin. Due to these different settings, ophiolites from the two zones have their pecularities regarding their ages, relations with genetically related sedimentary formations and some other aspects (Pamić et al. 2001).

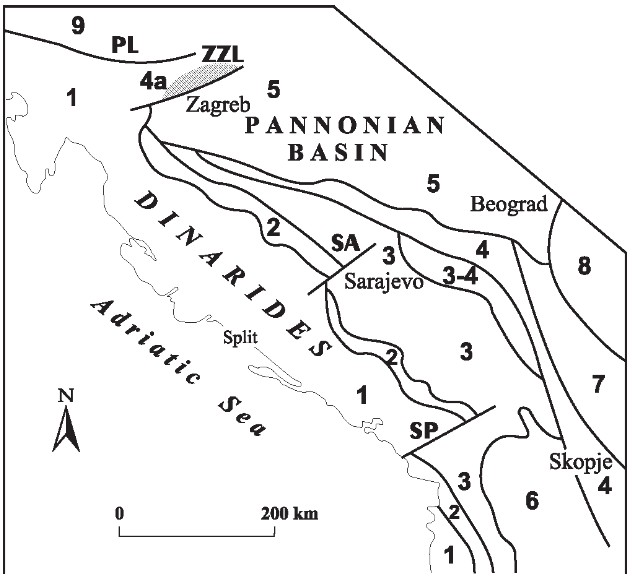
The northwesternmost outcrops of the Dinaridic ophiolites occur in the Medvednica Mt and the adjacent Ivanščica and Kalnik Mts (Pamić 1997) located in the Zagorje-Mid-Transdanubian (or Sava) Zone (Pamić & Tomljenović 1998). Numerous papers have been published on these ophiolites and they have been summarized elsewhere (Crnković 1963; Šikić 1995a,b; Tomljenović 1995; Pamić 1997; Halamić 1998; Slovenec 1998).

The aim of this paper is to present geological data on ophiolites from the Medvednica Mt and adjacent mountains and give correlation with the ophiolites from the surrounding parts of the Dinarides and Zagorje-Mid-Transdanubian (or Sava) Zone in Hungary.

Geotectonic position

The Medvednica Mt is included in the southwestern part of the Mid-Transdanubian Zone (Fülöp & Dank 1978) recently renamed the Zagorje-Mid-Transdanubian Zone — ZMTZ (Pamić & Tomljenović 1998) and the Sava Zone, respectively (Haas et al. 2000). In northwestern Croatia, the ZMTZ can be traced along strike for about 120 km, stretching in a NE-SW direction which is nearly perpendicular to the NW-SE strike of the Dinaridic structures (Fig. 1). With its southwesternmost boundary the ZMTZ is thrust onto the northeastern margin of the External Dinarides (Mesozoic carbonate platform), whereas westwards the zone continues in the system of the Sava and Julian-Savinja nappes (Mioč 1984; Pamić 1993; Haas et al. 2000). In the east the zone is bounded by the Zagreb-Zemplin Line (Grecula & Varga 1979). In some geotectonic schemes the ZMTZ continues for about 400 km in the northeastern direction as the Igal and Bükk Unit (Árkai et al. 1991).

The ZMTZ is characterized by mixed Alpine-Dinaridic tectonostratigraphic units (Pamić & Tomljenović 1998; Haas et al. 2000). This is best exemplified by the Medvednica Mt which can be traced along a NE strike for about 40 km. The mountain is composed of numerous Paleozoic, Mesozoic-Paleogene and Neogene formations (Šikić et al. 1995a,b) which can be grouped into four main tectonostratigraphic units (Fig. 2). The present-day thrust succession from the bottom to the top is as follows: (1) Tectonized ophiolite mélange; (2) Paleozoic-Triassic metamorphic complex overprinted by Early Cretaceous metamorphism; (3) Late Cretaceous-Paleocene flysch, and (4) Triassic sequences mainly of carbonate platform facies (Pamić & Tomljenović 1998).



1 External Dinarides and Southern Alps; 2 carbonate-clastic formations of the passive continental margin (flysch bosniaque); 3 Dinaride Ophiolite and Mirdita zones; 3-4 Golija Zone; 4 Vardar Zone; 4a Zagorje-Mid-Transdanubian (Sava) Zone; 5 Pannonian Basin; 6 Pelagonide; 7 Serbo-Macedonian Massif; 8 Carpathians and Balkan; 9 Eastern Alps; Major faults: PL Periadriatic Lineament; ZZL Zagreb-Zemplin Line; SA Sarajevo Line; SP Scutari-Peć Line. The Mt. Medvednica area is shaded.

Fig. 1. Major paleogeographical and structural units of the Dinarides (simplified after Aubouin 1974).

The relationship of these units with the basement is ambiguous. In the northeastern part of the Medvednica Mt, Triassic clastics and carbonates crop out in a way suggesting that they might have been originally the basement of the ophiolite mélange. A similar ambiguous structural relationship is known between the ophiolite-bearing and underlying units composed of Late Paleozoic and Triassic clastics, carbonates and volcanics in adjacent Ivanščica Mt (Šimunić et al. 1982).

Basic geological data

The ophiolite mélange of the Medvednica Mt is a chaotic lithological unit in which primary depositional sequences are rarely preserved due to subsequent tectonic activity. The ophiolite mélange is characterized by pervasively sheared and fine-grained shaly-silty matrix in which fragments of various rocks are included (Fig. 3). The size of the fragments varies from small (centimetre–decimetre–metre–hektometre) to large (kilometre) mappable dimensions.

The most common fragments embedded in the matrix are greywackes and arenites in the form of flow-balls, 4–150 cm, locally up to 10 m in diametre, and slumps. These formations originated by tectonic deformation which finally resulted in the formation of chaotic fabric, for example “block-in-matrix texture” (Raymond 1984). Originally interlayered sediments are mutually mixed and included into sheared silty-pelitic matrix and thus correspond to “autoclastic rocks”. According to Raymond (1984) this is a **broken formation** (beta-unit which has signatures of the stratigraphic unit) and locally **incoherent complex** (gamma-unit — without signatures of the stratigraphic unit). Undisturbed sequences with alternating graywackes and shales are very rarely preserved. The shale is mainly composed of quartz and a mixture of illite and highly illitic interlayered illite-smectite and, to a lesser extent, of chlorite and some plagioclase. In some places, shales are strongly silicified. Greywackes are composed of quartz (23–54 %), feldspars (11–25 %), and biotite, muscovite and chlorite (1–12 %); the most common rock fragments are quartzites, cherts, volcanics and pyroclastics.

The shaly-silty matrix also includes fragments of ophiolites. Incorporation of solid and detached blocks of igneous and sedimentary rocks can probably be explained, at least partly, by the olistostrome mechanism. This took place on the trough slope and was subsequently stimulated by subduction processes in the growing zone of the accretion prism. The only exception is a large volcanic body (10 km^2), about 400 m thick, which is interlayered with sediments and pyroclastics (volcanic breccias and lapilli tuffs). All these data point to polyphase submarine and synsedimentary volcanic activity. Sediments included in the volcanics are represented by fragments of greywacke, arenite, and chert, 3–40 cm in diametre, mixed with sandy mudstone and lithic greywacke with 35 % illite, 33 % quartz, “amorphous matter” and chlorite. In a smaller basaltic body in the Orešje Quarry in Bistra Valley, pillow lavas include xenoliths of Middle Triassic limestones (Halamić et al. 1998; Fig. 3).

Besides the fragments mentioned above, the ophiolite mélange also contains large, frequently mappable fragments com-

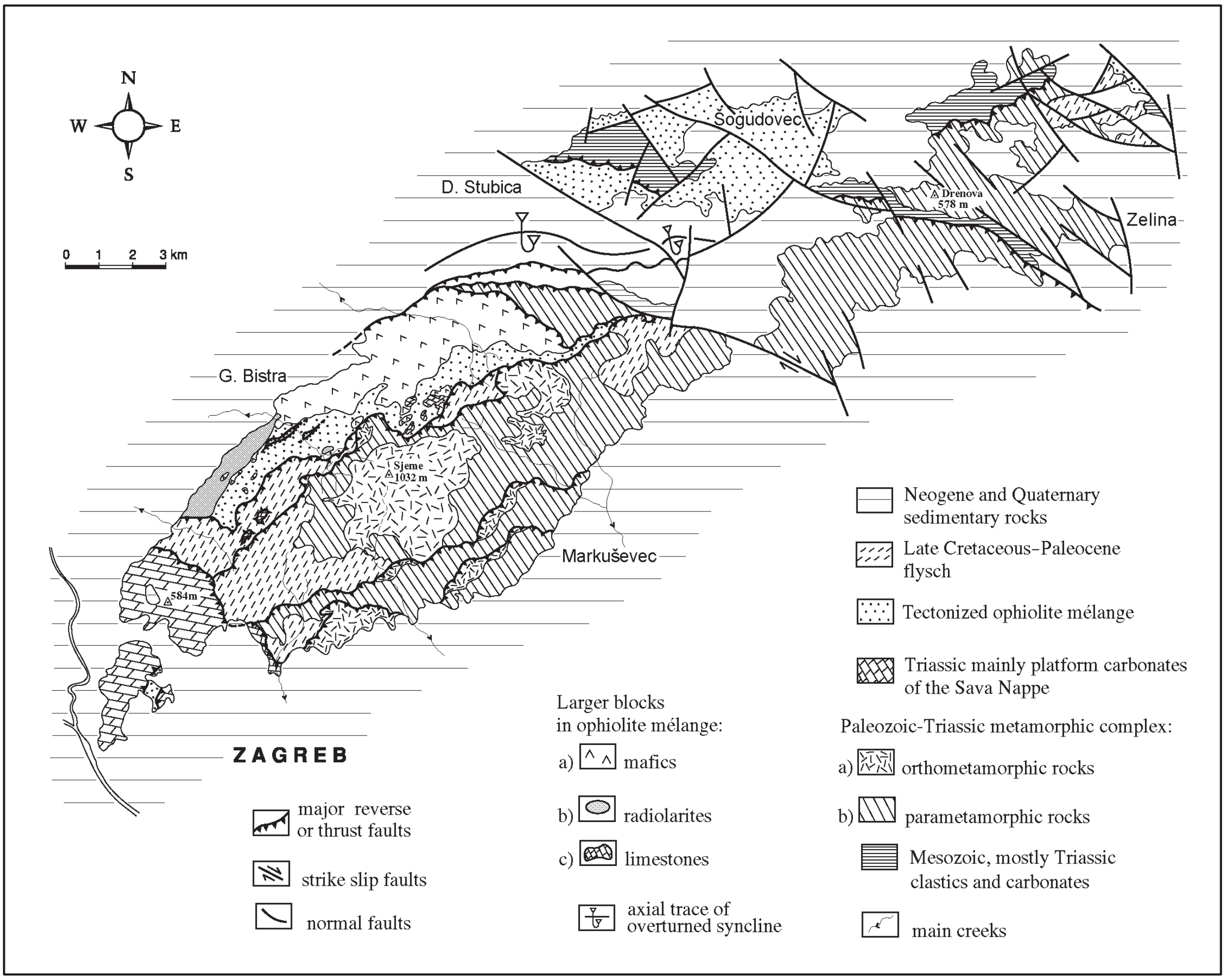


Fig. 2. Simplified geological map of the Medvednica Mt with the main tectonostratigraphic units (Pamić & Tomljenović 1998).

posed of greyish and reddish cherts, shales, siltites and micrites interlayered with volcanics. In chert fragments from the area between the Bistra and Poljanica Creeks, Ladinian-Norian radiolarians were determined (Fig. 3; Halamić 1998). In the same area Middle and Upper Jurassic fossiliferous radiolarites occur, in which Middle to Upper Triassic carbonate olistoliths, metres in diameter are included (Halamić et al. 1999). In the area of Drenovec Creek greyish platy micrites with chert lenses and interlayers crop out.

The Medvednica ophiolite mélange also includes exotic metre–hektometre and kilometre mappable fragments composed of limestone, calcarenite grading into siltite, calcareous sandstone, sandstone and shale succession of Albian–Cenomanian age (Gušić 1971, 1974). The fragments themselves do not include any ophiolite. These formations were fragmented and transported along parallel thrust faults during the generation of the olistostrome mélange, and as exotic blocks were incorporated, partly gravitationally, into the frontal parts of the accretionary prism in the chaotic matrix of the subducted complex. For that reason such a structural complex corresponds to the **tectonic ophiolite mélange** (delta-unit) as proposed by Raymond (1984) or to an olistostrome deformed within the shear zone of the accretionary prism, that is the increasing zone of the subducted complex (Orange & Underwood 1995). Large exotic blocks, decimetre–metre–hektometre in size, also occur. They are composed of Rhaetian-Liassic limestones and dolomitic limestones. The blocks were subsequently cemented by fossiliferous pelmicrite and clay of Senonian age forming polymicte breccias (Babić et al. 1973). Contact between syngenetic and exotic fragments is mainly disconformable (tectonic) in character. Triassic-Jurassic carbonate formations, together with parts of rocks incorporated in the subduction complex (sandstones, cherts and orbitolina limestones) were redeposited during Late Jurassic/Early Cretaceous tectonic processes by submarine sliding mechanism from the marginal parts into the basin characterized by pelagic sedimentation. Afterwards they were incorporated, together with Senonian breccias, into the ophiolite mélange. The fact that the Senonian breccias are the youngest fragments ("olistoliths") included in the Medvednica ophiolite mélange indicates its post-Senonian, e.g. Paleogene age. In the adjacent Kalnik Mt the youngest exotic limestone fragments included in the ophiolite mélange are of Paleocene age (Šimunić & Šimunić 1992).

The Medvednica ophiolite mélange is thrust by Late Cretaceous/Paleocene flysch composed of conglomerates, sandstones, thin-bedded siltites and laminated shales grading into

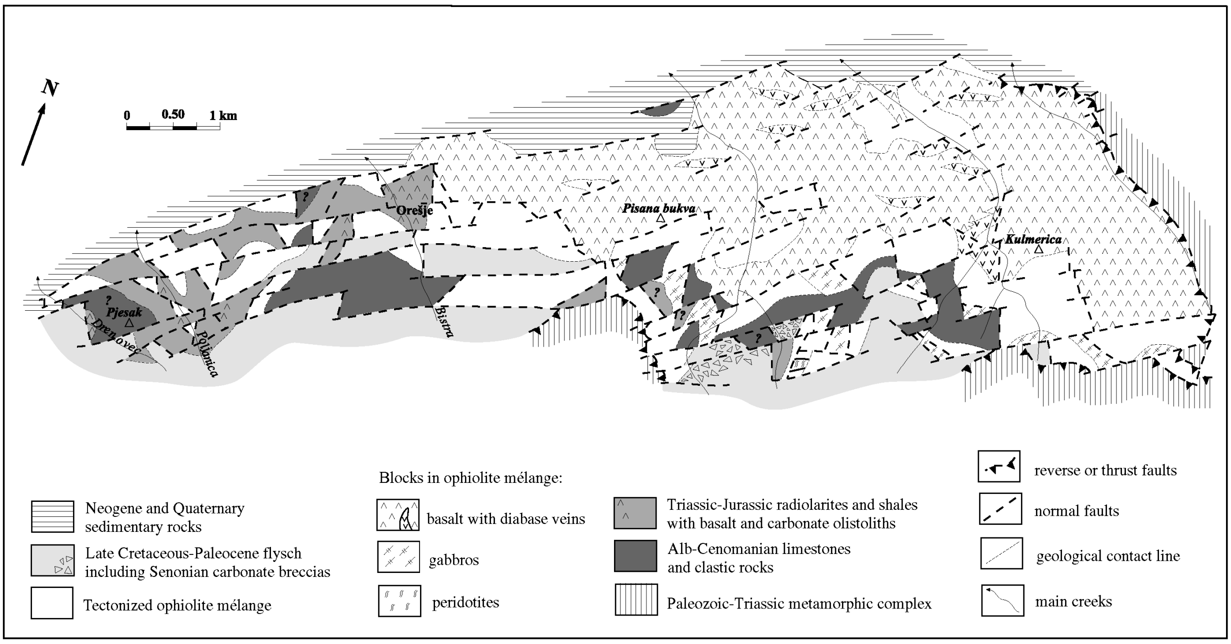


Fig. 3. Simplified geological map of the part of the Medvednica Mt composed mainly of tectonized ophiolite mélange (modified after Halamić 1998).

hemipelagic *Scaglia-type* micrites originating in a trench of the back-arc basin (Tomljenović 1995). By contrast, the ophiolite mélange of the DOZ is disconformably overlain by Late Jurassic/Early Cretaceous Urgon-type (?) clastic and subordinate carbonate formations, for example the Pogari Series (Jovanović 1957; Pamić et al. 2001).

Age of mélange and ophiolites

The precise age of ophiolite mélange cannot be determined due to its chaotic nature and large stratigraphic span of the exotic limestone blocks included in it. The youngest limestone blocks are of Late Cretaceous age, in the adjacent Kalnik Mt even of Paleocene age (Šimunić & Šimunić 1992), indicating that the ophiolite mélange as a whole is of Paleocene or post-Paleocene age (Pamić 1997). Consequently, the Medvednica ophiolite mélange and the mélange of the entire VZ is distinctly different from the DOZ ophiolite mélange in which the youngest exotic limestone blocks are Tithonian indicating post-Tithonian age of the mélange (Pamić et al. 2001).

In the shaly-silty matrix of the Medvednica ophiolite mélange, as well as in the rarely preserved profiles with alternating shales and greywackes to date no characteristic fossils were found. Only on one outcrop on the greywacke bedding surface well preserved angiosperm leaves were found, suggesting that they are not older than Early Cretaceous (Koch, pers. comm.).

This conclusion is compatible with the K-Ar ages of 94.3 and 85.4 Ma (Turonian–Senonian) which were obtained on two fresh basalt samples taken from the largest volcanic body in the Medvednica Mt. On a fresh basalt sample interlayered with Cretaceous sediments from the adjacent Kalnik Mt K-Ar ages of 86.8 Ma were measured. These radiometric ages can be correlated with those ranging from 109.6 to 62 Ma (Albian–Cenomanian) which were obtained on gabbro and diabase samples taken in several deep oil-wells in the neighbouring Sava Depression (Pamić 1997).

In this respect the ophiolites of the Medvednica Mt and the whole VZ differ from the ages of ophiolites from the DOZ ranging most commonly between 174±14 and 136±15 Ma (Pamić et al. 2001). However, in the adjacent Kalnik Mt K-Ar ages of 189–185 Ma (Lias) were measured on two fragments of dolerite-gabbros included in the ophiolite mélange. This indicates that in some places the ophiolite mélange of the northwesternmost parts of the VZ Jurasic ophiolite fragments are also preserved. The ophiolite mélange of the Medvednica and Kalnik Mts also include fragments of Anisian-Carnian non-ophiolite related tholeiitic basalts interlayered with penecontemporaneous sediments (Halamić & Goričan 1995; Halamić et al. 1998). Hence, besides preserved fragments of Jurassic ophiolites, the ophiolite mélange of the ZMTZ includes fragments of Triassic, probably rift-related, volcanics.

Two groups of K-Ar ages were also obtained for the Darnó-Hill ophiolites from the northeasternmost parts of the ZMTZ in Hungary. The first group includes K-Ar ages of 175–152 Ma obtained on gabbros and in the second one K-Ar ages of 110–100 Ma measured on basalts (Árva-Sós & Józsa 1992). The ophiolites are associated with radiolarites of Ladinian–Carnian and Bajocian–Callovian ages (Dosztály & Józsa 1992; Dosztály 1994).

Basic petrological data

The ophiolite rocks of the Medvednica Mt are not different from the ophiolites of the whole Alpine-Himalayan belt, for example they include Alpine-type peridotites, gabbros and diabase-basalts.

Ultramafic rocks are represented by tectonic and cumulate peridotites (Šimunić & Pamić 1989; Slovenec 1998). The peridotite tectonites are characterized by metamorphic fabric, for example porphyroblastic texture, massive and parallel structure shown in foliation. They are represented most commonly by harzburgite composed of recrystallized enstatite porphyroblasts (Fs_{10}) embedded into a matrix of serpentinized olivine (Fo_{90}). The harzburgites are most commonly completely serpentinized. Cumulate peridotites are represented by amphibole- and plagioclase-bearing harzburgite, cortlandite, plagioclase-hornblende lherzolite and quite subordinate hornblende websterite. All these rocks have magmatic fabric; their major minerals are olivine ($Fo_{81.5-80.1}$), diopside, bronzite, amphibole (both primary edenite-pargasite and secondary uralite), and calcic plagioclase, commonly completely altered into hydrogarnet (Crnković 1963; Slovenec 1998).

Mafic intrusive rocks are represented by amphibole gabbro, uralitized metagabbro, scarce olivine metagabbro, leucocratic metagabbro, and gabbro-diabase/metagabbro-metadiabase. These rocks are medium- to coarse-grained, partly poikilitic, and massive in structure. The major minerals are plagioclase (commonly bytownite), clinopyroxene (augite-diopside), amphibole (hornblende and uralite) and olivine, all of them accompained by secondary minerals.

Mafic vein rocks occur in the form of chilled dykes, metre to decametre thick, within the main Medvednica volcanic body (Fig. 3). They are represented commonly by altered diabase-dolerites. These rocks have the same mineral and chemical composition as the associated volcanic rocks. Within gabbro blocks incorporated in the mélange, rare decimetre-thick veins of gabbro-aplite and gabbro-pegmatite occur.

Mafic extrusive rocks build up the Medvednica main volcanic body and occur as metre–hektometre fragments in the ophiolite mélange (Fig. 3). The main volcanic body is the product of polyphase volcanic activity as indicated by multiple occurrence of pillow lavas interlayered with sediments. These rocks are represented by fresh basalts and more commonly by metabasalts and spilites.

Plagioclases (andesine, labradorite) occur as phenocrysts in fresh basalts and diabases and more commonly in groundmass. Albite (An_{3-5}), which originated by albitization of primary calcic plagioclase, is a major mineral in more common metabasalts and metadiabases. Clinopyroxene (augite, titanoaugite) is frequently transformed into chlorite and cryptocrystalline mixture of clinocoizite, epidote and leucoxene. Volcanic rocks are cross-cut by veinlets and lenses and permeated by amygdules filled by chlorite, epidote, coizite, prehnite and zeolite (natrolite?). Pumpellyite and volcanic glass build up the peripheral parts of pillows, 0.5–1.0 cm thick; they probably represent the product of devitrification which took place during the hydrothermal activity. The accessory minerals are ilmenite, sphene, anatase, rutile, leucoxene, magnetite, chromite (?), pyrite, and apatite (Slovenec 1998).

Discussion and conclusion

The ophiolite complex of the Medvednica Mt and the surrounding Kalnik and Ivanščica Mts has a prominant Dinaridic affinity and thus distinctly differs from the Penninic ophiolite complex from the adjacent Alps. Outcrops of ophiolites positioned along the Zagreb-Zemplin fault system and within the ZMTZ, represent the last northwesternmost parts of the Dinaridic ophiolites (Pamić 1997).

According to the model proposed by Pamić et al. (1998a) and Pamić et al. (2001), the origin of the Dinaridic ophiolites was related to the geodynamic evolution of the Dinaridic parts of the Tethys. Generation of the Mesozoic oceanic crust was taking place from the Late Triassic (?) to Late Jurassic over the period of 60–70 Ma of oceanization of the Tethys. Along its northern margin started by the end of Jurassic processes of north-dipping subduction, e.g. “suprasubduction” (Pearce et al. 1984) which were accompained by penecontemporaneous south-verging obduction and dismembering of the oceanic crust. This was incipient Late Jurassic generation of the DOZ (Pamić et al. 2001).

The obducted and tectonically dismembered ophiolite complex of the DOZ was partially uplifted and affected by weathering and erosion and detritus of ophiolites and genetically related sediments redeposited during the Early and Late Cretaceous in the surrounding marine shoals and depressions. And thus the ophiolite complex was disconformably overlain by Cretaceous clastic and carbonate sequences of the Urgonian-type (?) Pogari Series (Jovanović 1957).

Late Jurassic (Tithonian–Berriasian) oceanic subduction initiated gradual narrowing and closure of the Dinaridic Tethys. Along its northern margin a magmatic arc was generated, in the back-arc basin (BARB) where deposition of clastic and carbonate flysch succession occurred during the Cretaceous and Early Paleogene (Jelaska 1978). In the BARB environments persisting subduction made possible continuous generation of oceanic crust. This is documented by radiometric ages of 110–62 Ma obtained on mafic ophiolite fragments included in the VZ ophiolite mélange (Pamić et al. 2001).

Subduction processes terminated during the Eocene (50–45 Ma) when the main Alpine compression-collision took place. These processes gave rise to final structuring of the Dinarides and their uplift. The ophiolite mélange originating during the first Tithonian-Berriasian oceanic obduction was recycled and the recycled mélange incorporated ophiolite fragments, generated during the Cretaceous–Early Paleogene, together with exotic fragments of Upper Cretaceous and Paleocene limestones. Consequently, the second Paleogene obduction of the oceanic crust gave rise to the second emplacement of ophiolites and genetically related sedimentary formations. These geodynamic processes taking place during the Cretaceous and Early Paleogene in BARB environments produced the main tectonostratigraphic units of the VZ, which were backthrusted during the Eocene main deformational event onto the DOZ.

In such an interpretation, the Dinaridic ophiolites represent fragments of Mesozoic oceanic crust generated over a period of ca. 150 Ma. They are the product of a two-stage evolution: 1) Older ophiolites included in the DOZ originating in open-ocean environments were obducted during the Tithonian-Berriasian oceanic subduction. 2) Younger ophiolites, originating in BARB environments and their obduction was related to the main Eocene deformational event, that is, the Eurasian (Tisia and Moesia)-African (Apulia) continental collision.

Despite the complex structure of the Dinarides, the DOZ and VZ can be almost continuously traced along their strike for about 700 km. On the basis of the available outcrops and seismic and deep drilling data the VZ units, although mainly covered by sediments of the South Pannonian Basin, can be traced along strike up to the northwesternmost parts of the Dinarides. The outcrops of the VZ lithologies are only a few tens of kilometres from the easternmost Periadriatic Lineament (Pamić 1993; Pamić & Tomljenović 1998).

In this geodynamic interpretation of the Dinaridic ophiolites, it is not easy to explain the present position of the ophiolites of the Medvednica Mt and the whole ZMTZ. An undocumented opinion prevailed that these ophiolites have their root in the northwestern part of the Internal Dinarides from where they were tectonically transported along the Zagreb-Zemplin transcurrent fault system during the Tertiary post-orogenic tectonic phases (Tomljenović 1995; Pamić 1997 and others).

However, emplacement of the ophiolites of the Medvednica Mt and the surrounding mountains must have been related to the geodynamic evolution of the ZMTZ in which they are included. The ZMTZ is a transitional zone composed of mixed allochthonous units of the Alps and Dinarides. According to the current widely accepted opinion, it is believed that the transitional ZMTZ originated by extrusion (escape) tectonics (Kázmér & Kovács 1985; Ratschbacher et al. 1991) during the post-orogenic evolution of the Dinarides and Alps. According to this interpretation after Eocene compression and collision, and uplift of the Dinarides and Alps started the NNW rotation of Apulia and its indenting into the southern Eurasian margin. These tectonic movements gave rise to strong N-S shortage of the Alpine tectonostratigraphic units in the adjoining area of the Southern and Eastern Alps, e.g. Periadriatic Lineament region amounting to 200–500 km (Coward & Dietrich 1989; Laubscher 1971; Ziegler et al. 1996). The Apulian indenting is reflected in transpression processes manifested in strong dextral strike slip faulting, that is, the horizontal eastward tectonic transport toward the western parts of the Pannonian Basin. According to such an interpretation the allochthonous Paleozoic and Mesozoic blocks of the Medvednica Mt and the whole ZMTZ might have had their roots in the wider Periadriatic area. It is very probable that in the same root area, before the mechanism of escape tectonics started to operate, lithologies of the VZ were also included.

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References

Árkai P., Lantai Cs., Forizs I. & Lelkes-Felváry Gy. 1991: Diagenesis and low-temperature metamorphism in a tectonic link between the Dinarides and the Western Carpathians; the basement of the Igal (Central Hungarian) Unit. *Acta Geol. Hung.*, 34, 81–100.

Árva-Sós E. & Józsa S. 1992: Tectonic appraisal of K-Ar data of Mesosoic ophiolitic mafic rocks of Darnó Hill, northern Hungary. *Terra Abstracts*, 4, 3–4.

Aubouin J. 1974: Des tectoniques superposées et de leur signification par rapport aux modéles géophysiques: l'exemple des Dinarides; paléotectonique, tectonique et tarditectonique. *Bull. Soc. Géol. France* 7, 11, 426–460.

Babić Lj., Gušić I. & Nedela-Devidé D. 1973: Senonian breccias and overlying deposits on Mt. Medvednica (Northern Croatia). *Geološki Vjesnik (Zagreb)* 25, 11–27 (in Croatian, English summary).

Coward M. & Dietrich D. 1989: Alpine tectonics — an overview. In: M.P. Coward, D. Dietrich & R. G. Park (Eds.): Alpine tectonics. *Spec. Publ. (Geol. Soc. London)* 45, 1–29.

Crnković B. 1963: Petrography and petrogenesis of the magmatites of the northern part of Mt. Medvednica. *Geološki Vjesnik (Zagreb)* 16, 63–160 (in Croatian, English summary).

Dewey J.F., Pitman W.C., Ryan W.B.F. & Bonnin J. 1973: Plate tectonics and the evolution of the Alpine system. *Geol. Soc. Amer. Bull.* 84, 3137–3170.

Dosztály L. 1994: Mesozoic radiolarian investigations in Northern Hungary. *Unpubl. PhD Thesis*, *Budapest Univ.*, Budapest 1–108.

Dosztály L. & Jósza S. 1992: Geochronological evaluation of Mesozoic formations of Darnó Hill at Recsk on the basis of radiolarians and K-Ar age data. *Acta Geol. Hung.* 35, 4, 371–393.

Fülöp J. & Dank V. 1978: Geological map of Hungary without the Cenozoic. *MAFI*, Budapest.

Grecula P. & Varga I. 1979: Main discontinuity belts on the inner side of the Western Carpathians. *Miner. Slovaca* 11, 5, 389–404.

Gušić I. 1971: About existence of the Early Cretaceous in Mt. Medvednica (Northern Croatia). *Geološki Vjesnik (Zagreb)* 24, 197–200 (in Croatian, German summary).

Gušić I. 1974: Taxonomy and biostratigraphy of the Upper Triassic, Liassic and Early Cretaceous microfossils from Mt. Medvednice. *PhD Thesis*, *University of Zagreb*, Zagreb, 1–190 (in Croatian, German summary).

Haas J., Mioč P., Pamić J., Tomljenović B., Árkai P., Bérczi-Makk A., Koroknai B., Kovács S. & Felgenhauer E. R. 2000: Complex structural pattern of the Alpine–Dinaridic–Pannonian triple junction. *Int. J. Earth Sci.* 89, 377–389.

Halamić J. & Goričan Š. 1995: Triassic Radiolarites from the Mts. Kalnik and Medvednica (Northwestern Croatia). *Geol. Croatica* 48, 2, 129–146.

Halamić J. 1998: Lithostratigrapy of Jurassic and Cretaceous sediments with ophiolites from the Mts. Medvednica, Kalnik and Ivanšćica. *PhD Thesis, University of Zagreb*, Zagreb, 1–188 (in Croatian, English summary).

Halamić J., Slovenec Da. & Kolar-Jurkovšek T. 1998: Triassic basalt-carbonate peperite from Mt. Medvednica, Northwestern Croatia (Orešje Quarry). *Geol. Croatica* 51, 1, 33–45.

Halamić J., Goričan Š., Slovenec Da. & Kolar-Jurkovšek T. 1999: A Middle Jurassic Radiolarite-Clastic Succession from the Medvednica Mt. (Northwestern Croatia). *Geol. Croatica* 52, 1, 29–57.

Jovanović R. 1957: Overview on the Mesozoic development and some new data on the stratigraphy of Bosnia and Hercegovina. *2nd Congr. Yugosl. Geol., Sarajevo*, 38–63 (in Serbian, German summary).

Kázmer M. & Kovács S. 1985: Permian-Paleogene paleogeography along the eastern part of the Insubric-Periadriatic Lineament system: evidence for continental escape of the Bakony-Drauzug. *Acta Geol. Hung.* 28, 71–84.

Kossmat F. 1924: Geologie der zentralen Balkanhalbinsel. Mit einer Übersicht des dinarischen Gebirgsbaues. *Die Kriegsschauplätze 1914-1916. Gebrüder Bornträger*, Berlin, 1–198.

Laubscher H. 1971: Das Alpen–Dinariden Problem und die Palinspastik der südliche Tethys. *Geol. Rdsch.* 60, 813–833.

Jelaska V. 1978: Stratigraphy and sedimentology of Senonian-Paleogene flysch of Mt. Trebovac area in North Bosnia. *Geol. Vjesnik, (Zagreb)* 30, 95–117 (in Croatian, English summary).

Mioč P. 1984: Geology of the Transitional Area between the Southern and Eastern Alps in Slovenia. *PhD Thesis, University of Zagreb*, Zagreb, 1–214 (in Slovenian, English summary).

Orange D.L. & Underwood M.B. 1995: Patterns of thermal maturity as diagnostic criteria for interpretation of mélanges. *Geology* 1144–1148.

Pamić J. 1993: Eoalpine to Neoalpine magmatic and metamorphic processes in the northwestern Vardar Zone, the easternmost Periadriatic Zone and the southwestern Pannonian Basin. *Tectonophysics* 226, 503–518.

Pamić J. 1997: The northwesternmost outcrops of the Dinaridic ophiolites: a case study of the Mt. Kalnik (North Croatia). *Acta Geol. Hung*. 40, 1, 37–56.

Pamić J. 2001: The Vardar Zone of the Dinarides and Hellenides versus the Vardar Ocean. *Eclogae Geol. Helvetiae*, in press.

Pamić J. & Tomljenović B. 1998: Basic geological data on the Croatian part of the Mid-Transdanubian Zone as exemplified by Mt. Medvednica located along the Zagreb-Zemplen Fault Zone. *Acta Geol. Hung*. 41, 4, 389–400.

Pamić J., Gušić I. & Jelaska V. 1998a: Geodynamic evolution of the central and northwestern Dinarides. *Tectonophysics* 297, 251–268.

Pamić J., Tomljenović B. & Balen D. 2001: Geodynamic and petrogenetic evolution of Alpine ophiolites from the Central and Northwestern Dinarides; an overview. *Lithos*, in press.

Pearce J.A., Lippard S.J. & Roberts S. 1984: Characteristics and tectonic significance of suprasubduction zone ophiolites. In: B.P. Kokelaar & M.F. Howells (Eds.): Marginal basin geology. *Spec. Publ. (Geol. Soc. London)* 16, 77–94.

Ratschbacher L., Frisch W., Linzer H.G. & Merk O. 1991: Lateral extrusion in the Eastern Alps. Part I: boundary conditions and experiments scaled for gravity. *Tectonics* 10, 245–256.

Raymond L.A. 1984: Classification of mélanges. In: Raymond L.A. (Ed.): Mélanges: their nature, origin and significance. *Spec. Pap. (Geol. Soc. Amer.)* 198, 7–20.

Slovenec Da. 1998: Ophiolitic rocks in the area of the Bistra Creek on the northern slopes of Mt. Medvednica. *MSc Thesis, University of Zagreb*, Zagreb, 1–104 (in Croatian, English summary).

Šikić K. 1995a: Geology of Mt. Medvednica. In: Šikić K. (Ed.): Geological field guidebook. *Institute of Geology,* Zagreb, 7–30 (in Croatian).

Šikić K. 1995b: Tectonics and tectonogenesis of Mt. Medvednica and the surrounding area. In: Šikić K. (Ed.): Geological field guidebook. *Institute of Geology,* Zagreb, 31–40 (in Croatian).

Šimunić An., Najdenovski J. & Šimunić Al. 1982: Geology of the north-western part of the Drava Depression and eastern slopes of Mt. Kalnik. *Zbor. rad. Jug. geol. kongresa*, Budva, 1, 107–122 (in Croatian).

Šimunić An. & Pamić J. 1989: Ultramafic rocks from the neighbourhood of Gornje Orešje on the northwestern flanks of Mt. Medvednica (Northern Croatia). *Geološki Vjesnik (Zagreb)* 42, 93–101 (in Croatian, English summary).

Šimunić A. & Šimunić Al. 1992: Mesozoic of the Hrvatsko Zagorje area in the southwestern parts of the Pannonian Basin (Northwestern Croatia). *Acta Geol. Hung*. 35, 2, 83–96.

Tomljenović B. 1995: Stratigraphy and tectonics of the sedimentary complex with basic magmatic rocks of the north-western slopes of Mt. Medvednica. *MSc Thesis, University of Zagreb*, Zagreb, 1–68 (in Croatian, English summary).

Ziegler P., Schmid S.M., Pfiffner A. & Schönborn G. 1996: Structure and evolution of the Central Alps and their northern and southern forland basins. In: Ziegler P. & Horváth F. (Eds.): Peri-Tethys. *Mém. 2. Mém. Mus. nat. Hist. Natur*. 170, 211–233.