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Ophiolites of the Vardar Zone and Dinarides: Central and West Serbia

NADA VASKOVIĆ[1*] AND VESNA MATOVIĆ[2]

Faculty of Mining and Geology, Belgrade University, Djušina 7, 11 000 Beograd, Serbia
[1]nadavask@eunet.rs, *corresponding author; [2]vesnamat@beotel.net

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1. Introduction

As part of the Central Balkan Peninsula, Serbia is made up of very complex geological units extending from NNW to SSE. The Dinaridic-Alpine orogen composes the western and central parts of Serbia, while the Carpathian orogen, encompassing the Pannonian Basin, enters Serbia in the Danube Gorge extending further south along the Serbian–Bulgarian border to the Balkans (Fig. 1).

Generally speaking, the Central Balkan Peninsula represents a composite assemblage of Gondwana-related, oceanic and Eurasian units. These units were separated and underwent different development till the Late Cretaceous–Early Cenozoic period, when the steady northward movement caused their collision. The further development of these collided units during the Tertiary created the present geological framework.

The ophiolite originated mainly during Mesozoic convergence, and the collision processes in the Serbian part of the Central Balkan Peninsula offer an outstanding area to study the nature, origin and emplacement of Mesozoic Tethyan ophiolites. The basic feature of the geology of Serbia is a very complex geotectonic framework. The final closing of the Tethys Ocean during Late Mesozoic has been debated by many authors (*e.g.* Karamata, 2006; Schmid *et al.*, 2008; Robertson *et al.*, 2009), who question whether the Serbian ophiolites rep-

Fig. 1. Geographical position of Serbia.

resent relicts of one wide ocean (Dilek *et al.*, 2007; Schmid *et al.*, 2008; Robertson *et al.*, 2009) or several oceans (Dimitrijević & Dimitrijević, 1973; Karamata, 2006).

A simplified geotectonic framework of Serbia and its surroundings is presented in Fig. 2. In general, the following units are distinguished from east to west: the East Serbian Carpatho-Balkanides (CBES), the Serbo-Macedonian Massif (SMM), the Vardar Zone Ophiolite Belt (VZOB), accompanied by the basement units (the Kopaonik unit – KU; the Jadar unit – JU, and the Drina–Ivanjica unit – DIU), then the Dinaridic Ophiolitic Belt (DOB) and, further to the west, units of the External Dinarides. From Serbia the ophiolite belts extend northwest into Bosnia and Croatia and south into Albania and Greece where their mutual relationship, due to Tertiary (Palaeogene and Early Miocene) collision, are not continuous (Karamata, 2006).

The geological framework of Serbia and its neighbouring areas can be roughly defined as consisting of two clusters of continental units (*i.e.* the SMM and the DIU – JU – KU) separated by complex dismembered ophiolite belts (*i.e.* the VZOB and the DOB) (Fig. 3). These continental units once belonged to the southern/southwestern margin of Europe (Eurasia) and northern/northeastern margin of Africa (Gondwana) – margins that before the end of Mesozoic were separated by the wide Tethys Ocean. When the last parts of the Tethyan Ocean closed (probably at the end of the Mesozoic), the earlier widely separated continental margins started to share a common geological history.

Nowadays, as mentioned above, there is open debate about the nature of the Serbian ophiolites. This relates to ideas about the number of the oceans that existed during the Mesozoic period. Two theories dominate. The first (Schmid *et al.*, 2008) advocates the existence of only one Tethys Ocean between Eurasia and Gondwana, which was obducted onto the passive margin of Adria (Gondwana); in the current geotectonic framework the basement units (DIU and JU including the KU) represent tectonic windows beneath a single ophiolite thrust sheet. They infer a similarity in composition between the Vardar Zone and the Dinaride ophiolites. The alternative model, favoured by Karamata (2006) and Robertson *et al.* (2009) underlines the complexity of the Tethys Ocean and the existence of several ocean basins separated by several continental fragments. The identification of two suture zones (VZOB, DOB) supports the existence of more than one oceanic realm that separated Eurasia and Gondwana during the Mesozoic, where the basement rocks represent microcontinents.

In this field guide we will present the main geological features of the Vardar Zone and Dinaridic Ophiolite Belt of Serbia at the localities shown in Fig. 3. These localities highlight the results of research undertaken over the past three decades. The age data (still sparse) as well as open discussions emanating from several international symposiums related to the geology of the Dinarides and Vardar zone and published in several volumes of proceedings have greatly increased our knowledge as to the nature, evolution and time of Mesozoic events compared with

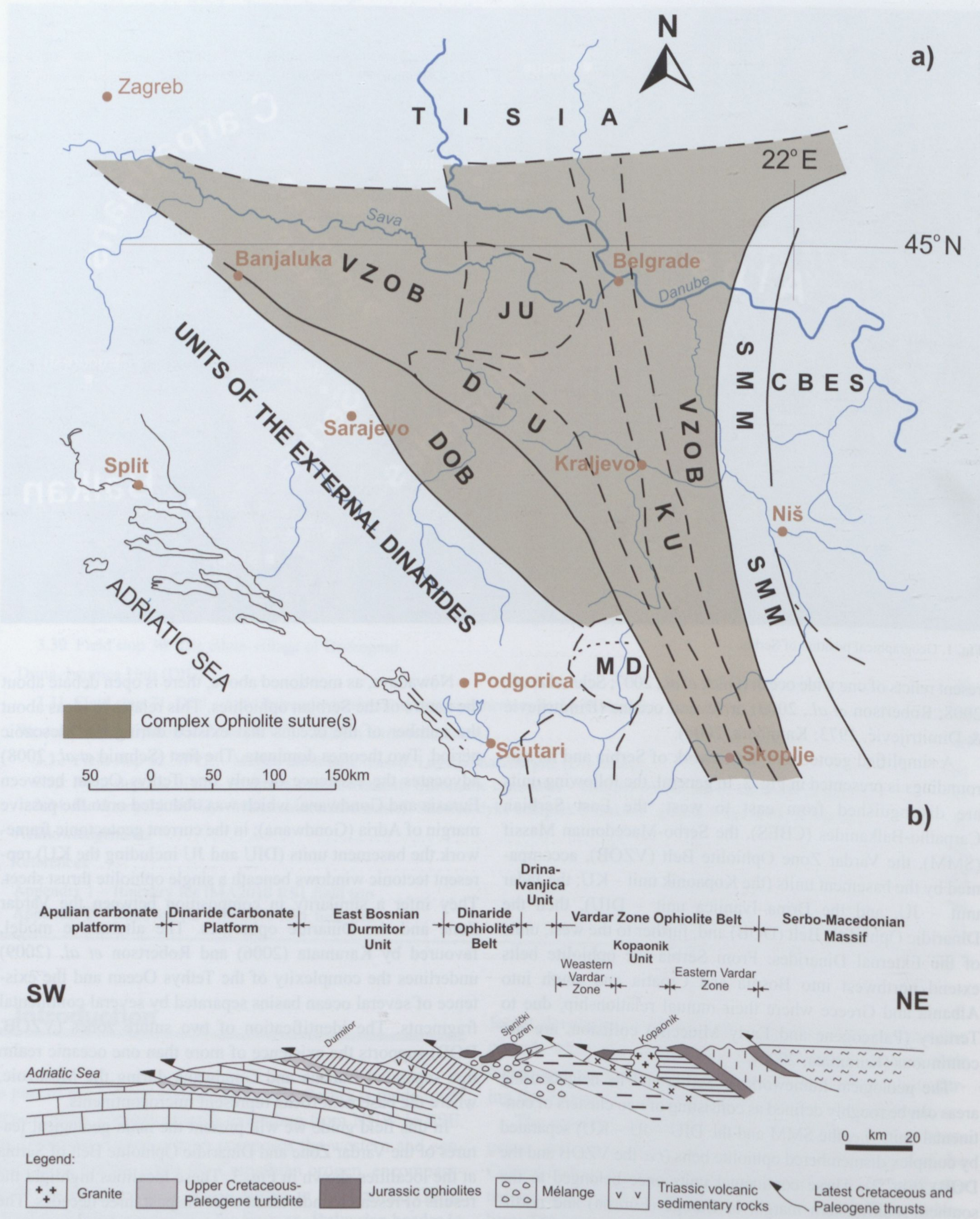

Fig. 2. a) Outline geotectonic framework of Serbia and adjacent regions according to Karamata & Krstić (1996), Karamata (2006) and Robertson *et al.* (2009); b) Simplified cross-section of central Serbia and Montenegro, modified from Dimitrijević (2001). (Redrawn from Robertson *et al.*, 2009). Key (in alphabetic order): CBES – Eastern Serbian Carpatho-Balkanides; DIU – Drina–Ivanjica Unit; DOB – Dinaride Ophiolite Belt; JU – Jadar Unit; KU – Kopaonik Unit; MD – Metohija Depression; SMM – Serbo-Macedonian Massif; VZOB – Vardar Zone Ophiolite Belt.

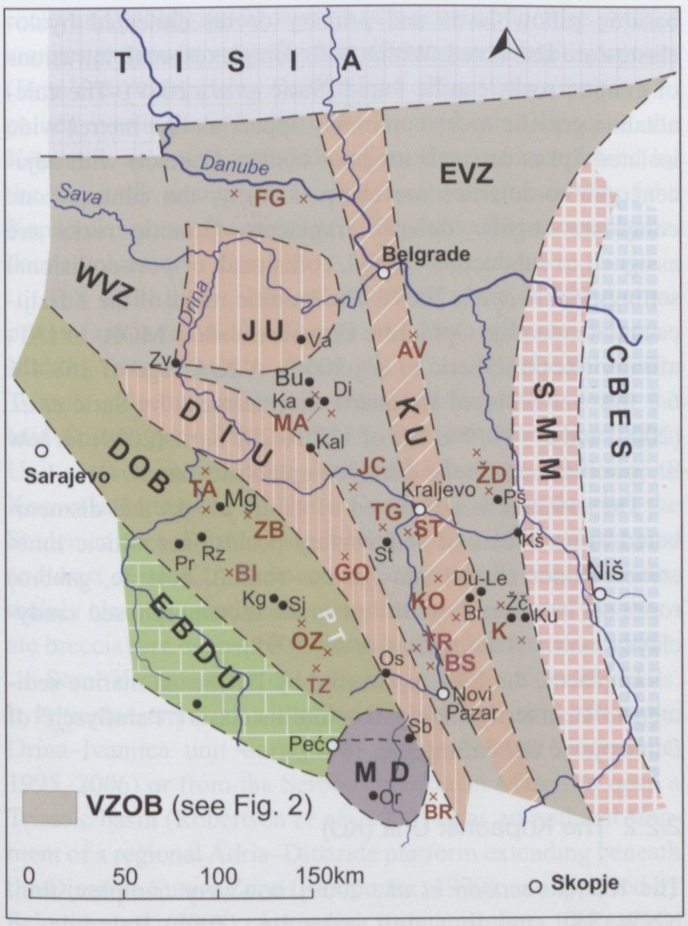

Fig. 3. Geotectonic framework of Serbia with location of places to be seen during the excursion and mentioned in the text. Key: **EVZ** (Eastern Vardar Ophiolitic Zone) × ophiolitic massifs: FG – Fruška Gora Mts.; AV – Mt. Avala; ŽD – Ždraljica (Pš – Prevešt; Kš – Kruševac; Du-Le – Dupci–Lepenac); K – Kuršumlija (Ku – Kuršumlija, Žč - Žuč); **KU** (Kopaonik Unit): KO – Kopaonik Mts. (St – Studenica, Br– Brus); **WVZ** (Western Vardar Ophiolitic Zone) × ophiolitic massifs: JC – Jelica Mts.; MA – Maljen Mts. (Ka – Kaona; Di – Divčibare; Bu – Bukovi; Va – Valjevo; Zv – Zvornik); TG – Troglav; BS – Banjska; TR – Trnava; **DIU** (Drina–Ivanjica Unit): GO – Golija Mts.; Os – Osanica; **DOB** (Dinaride Ophiolite Belt) × ophiolitic massifs: BR – Brezovica; TZ – Tuzinje; OZ – Ozren Mts.; BI – Bistrica (Pr – Priboj; Rz – River Rzav); ZB – Zlatibor Mts. Mélange: Kg – Krš pod Gradcem; Sj – Sjenica; **MD** (Metohija Depression): Or – Orahovac; Sb – Srbica; **SMM** – Serbo-Macedonian Massif; **CBES** – Eastern Serbian Carpatho-Balkanides; **EBDU** – East Bosnian–Durmitor Unit; other localities: TA – Tara; MG – Mokra Gora

what was known up to 1980, and have led to the improvement of previous models. Detailed geological and petrological-geochemical transects across the major ophiolite belts and lithostratigraphic units have also, to a certain degree, clarified the possible sources and tectonic settings of the Serbian ophiolites.

2. Geological setting

During this 5-day trip, participants will be able to see various parts of the Tethyan lithosphere: large, km-sized masses of obducted ophiolites, various types of metamorphic sole, gabbro-dolerite complexes, pillow basalts and mélanges with various olistoliths.

We will present here the basic features of the geotectonic units through which this excursion will pass.

2.1 The Serbo-Macedonian Massif (SMM)

The SMM (the Serbo-Macedonian composite unit in Robertson *et al.*, 2009) is situated between the Eastern Vardar Ophiolitic Zone and the western margin of the Carpatho-Balkanides (Figs. 2b, 3). Within this unit, the Lower and Upper complexes are separated according to metamorphic grade (Dimitrijević, 1959); they comprise a variety of medium to relatively high- and low-grade metamorphics. Some are of Pan-African age with Variscan and Alpine overprints (Dallmeyer *et al.*, 1996; Krstić *et al.*, 1996; Karamata, 2006). The Serbo-Macedonian Massif is generally believed to derive from the northern Eurasian margin of the Tethyan Ocean during the Mesozoic–Early Cenozoic period (see Robertson *et al.*, 2009). Its recent position and relation to the Eastern Vardar Ophiolitic Zone is still intensely debated.

2.2 The Vardar Zone Ophiolite Belt (VZOB)

The VZOB is a composite unit comprising three zones: a) the Eastern Vardar Ophiolitic Zone (EVZ), the remnant of the former larger Tethys Ocean; b) the Kopaonik unit (KU), a continental fragment; c) and the Western Vardar Ophiolitic Zone (WVZ), a marginal oceanic area that developed later (Figs. 2, 3).

The eastern and western boundaries of the VZOB are a system of westward-oriented thrusts (Fig. 2b). This suture encompasses the Jadar Unit (Figs. 2, 3). To the west the Drina–Ivanjica Basement Unit separates it from the Dinaride Ophiolite Belt. To the north the VZOB is covered by Neogene sediments of the Pannonian Basin and to the south it continues into Greece. Northeastward from Belgrade it emerges in the South Apuseni Mountains and the Transylvanian depression (Săndulescu, 1984; Săndulescu & Visarion, 1979; Saccani *et al.*, 2001; Bortolotti *et al.* 2002; Nicolae & Saccani, 2003; Ionescu & Hoeck, 2006; Ionescu *et al.*, 2009).

2.2.1 The Eastern Vardar Ophiolitic Zone (EVZ)

In the Serbian part of the Central Balkan Peninsula, the NNW–SSE-oriented Eastern Vardar Ophiolitic Zone is exposed between the Serbo-Macedonian Massif and the Kopaonik Unit to the west (Fig. 3). The thrusting of the EVZ onto the SMM during the Early Cretaceous period caused widespread nappe-stacking in the Carpatho-Balkanides (Săndulescu, 1984). The relationship between the EVZ with the KU in the west and with the SMM in the east arose from

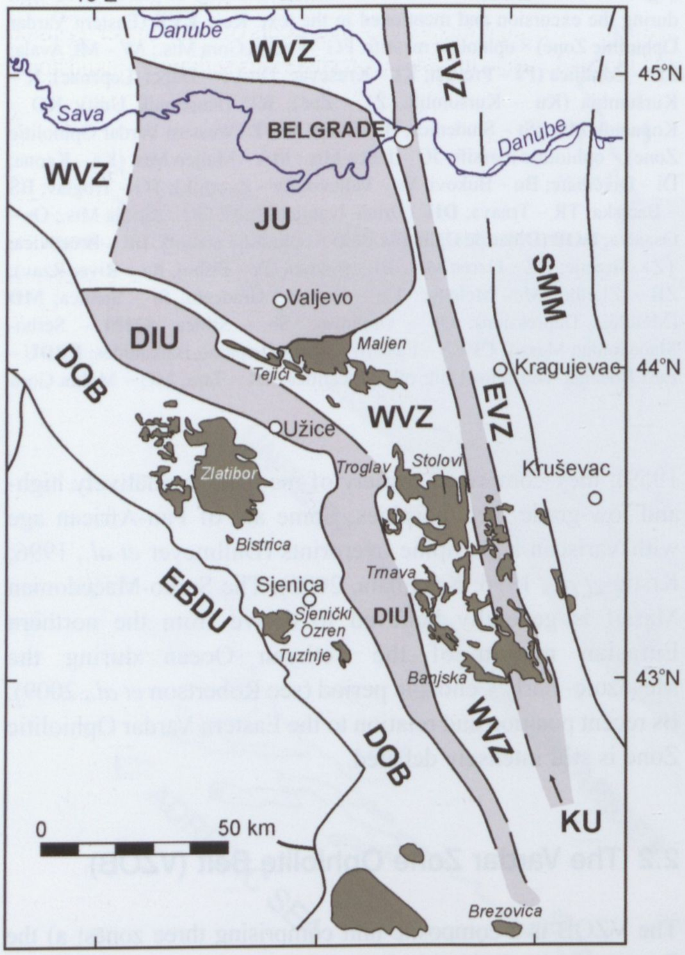

Fig. 4. Position of the ultramafic massifs of Serbia in the geotectonic framework of Karamata (2006). See Fig. 3 for the abbreviations.

Cenozoic high-angle normal faulting (see Karamata, 2006; Robertson *et al.*, 2009).

Ophiolitic rocks are well exposed south of Belgrade (Mt. Avala, Mt. Kosmaj), close to Kragujevac (the Ždraljica ophiolitic massif) and in the Kuršumlija area (the Kuršumlija ophiolitic massif) (Figs. 3, 4). The ophiolitic rocks mostly represent the upper part of the oceanic crust with occasional occurrences of serpentinised peridotites.

The EVZ is mainly built up of gabbro-dolerites and dolerites and rare basaltic pillow lavas. Discontinuous, relatively small isolated outcrops of mainly serpentinised harzburgites can be found near the eastern and western margins of the EVZ. The ophiolitic rocks are closely associated with intermediate and acid calc-alkaline granitic rocks and are overlain by Tithonian limestones.

The ophiolites from the Ždraljica and the Kuršumlija ophiolitic massifs (Resimić-Šarić *et al.*, 2000, 2006; Šarić *et al.*, 2009) form elongated dismembered bodies up to 20 km long and several km wide. These bodies are mainly composed of cumulitic and isotropic gabbros, gabbro-dolerite and dolerite dykes. Ultramafic rocks are generally rare. The gabbroic bodies are cut by isolated, locally sheeted dykes or associated with subduction-influenced volcanic rocks. Rare occurrences of basaltic pillow lavas and primary or resedimented hyaloclastite are also noted. Within both complexes small intrusions of granitic rocks can be found (Šarić *et al.*, 2009). The calc-alkaline granitic rocks commonly appear as few metres wide isolated dykes or small irregular bodies. Contacts with adjacent gabbro-dolerites are sharp. Locally, the contact zone comprises angular dolerite fragments. Granitic rocks are assigned to subduction-related, collisional, or post-collisional settings (Šarić *et al.*, 2009). The basaltic rocks of the Ždraljica and Kuršumlija Ophiolitic Complexes show MOR- or IAT-affinity (Resimić-Šarić *et al.*, 2006). A K/Ar age of 168.4 ± 6.7 Ma was reported for quartz dioritic rocks by Šarić *et al.* (2000) and a $^{207}Pb/^{235}U$ age of 170.16± by Šarić (2009) for low Sr_i granitic rocks in the Ždraljica ophiolitic massif.

The mélange is composed of exotic blocks and dismembered thrust sheets of sedimentary (sandstones, silicic limestones, minor cherts) and igneous (basalt, dolerite, gabbro) rocks set in a very low- to low-grade metamorphosed sandy-clayey matrix (Dimitrijević *et al.*, 1995).

In places, the EVZ is covered by Berriasian marine sediments rich in terrigenous and ophiolitic clasts ("Paraflysch" of Dimitrijević & Dimitrijević, 1987).

2.2.2 The Kopaonik Unit (KU)

The KU (Robertson *et al.*, 2009) is a very complex, thin, NNW–SSE trending unit extending from Belgrade to FYROM. (Figs. 2, 3). Its continuity north of Belgrade beneath the Pannonian Basin up to the Tisia Unit is presumed by Pamić *et al.* (2002) on the basis of findings from drill cores. To the east, the KU is tectonically overlain by the EVZ (Lower Cretaceous Paraflysch of Dimitrijević & Dimitrijević, 1987). The western boundary of the KU towards the Dinaridic Ophiolitic belt is marked by a narrow strip of ophiolitic mélange (Dimitrijević, 2000).

The northern and western parts of the KU (Belgrade–Studenica–Kosovska Mitrovica) comprise a succession of low-grade metaclastites (partly of Carnian age) with rare basalts and Upper Triassic limestones. The Triassic succession is covered by a Jurassic mélange consisting mainly of an admixture of clasts and olistoliths of sandstone and chert with rare limestone and igneous rocks set in a silty matrix, which sometimes predominates. The southeastern flanks of the KU (Kosovo area), besides low-grade metaclastites, also comprise Upper Triassic low-grade meta-siliceous limestones (Sudar & Kovács, 2006) overlain by Middle Triassic "Gutenstein Limestone". The age of this metamorphism is still unknown (Jurassic or Early to Mid-Cretaceous?).

The central part of the Kopaonik Unit (Kopaonik Mts. area) is composed of a succession of low-grade metamorphosed arenites, siltstones, pelites and carbonate rocks as well as basaltic rocks. This metamorphic complex is overlain by a Late Jurassic mélange (with olistoliths and fragments of limestones, serpentinised peridotites, basalts, cherts, metamorphic rocks and pebbly mudstones set in a matrix of coarse-grained arenites and mudstones). The Late Cretaceous turbiditic deposits (Brus area) comprising fine-grained siliciclastic arenites and pelites overlie the ophiolites. During the Early Oligocene, the Kopaonik area was intruded and contact metamorphosed by the Kopaonik granitoid body. Southward and westward of the Kopaonik area a large complex of Oligocene–Miocene andesite-dacite volcanics is exposed.

The small thrust sheet of Studenica (west of Ušće) comprises Lower to Middle Triassic clastites, neritic carbonates, Middle Triassic basalts (Memović *et al.*, 2004) and Upper Triassic siliceous limestones (Dimitrijević, 1997). From the Mid-Triassic period, the Studenica slice and the Drina–Ivanjica Unit showed conspicuous similarities. To the south, close to Kosovska Mitrovica, an Upper Cretaceous flysch overlies the Studenica slice (Dimitrijević & Dimitrijević, 1987). To the east and west of the KU, Cretaceous (Senonian) flysch sediments, mainly clastites (sandstone, aleurolite, marl and rarely carbonate breccia) are deposited (Dimitrijević & Dimitrijević, 1987).

Some disagreement over the origin of the KU still exists. It is treated either as a continental fragment rifted from the Drina–Ivanjica unit during the Upper Triassic (Karamata, 1995, 2006) or from the Serbo-Macedonian Massif to open a Triassic basin (Robertson *et al.*, 2009) or as an upthrust fragment of a regional Adria–Dinaride platform extending beneath the Dinaride Suture Zone (Rampnoux, 1970), as supported by Schmid *et al.* (2008). According to later authors, the eastern margin of the Kopaonik Unit is similar to the most easterly preserved part of the Adriatic Platform, which was overthrust by ophiolitic rocks during the Late Jurassic–Early Cretaceous age. Due to the presence of non-conforming overlying Upper Cretaceous clastic sediments (Dimitrijević & Dimitrijević, 1987), it is very difficult to evaluate this assumption.

2.2.3 The Western Vardar Ophiolitic Zone (WVZ)

The WVZ represents a complex zone comprising ophiolites and mélange. It is a relatively narrow belt in central and southern Serbia between the Drina–Ivanjica Unit and the Kopaonik Unit, becoming broader towards the northwest, where it surrounds the Jadar Unit (Figs. 2, 3). It proceeds further northwest (close to Zagreb; the Sava Zone of Pamić, 2002). In the areas northwest from Belgrade (Pannonian Basin), the WVZ crops out in isolated mountains (Fruška Gora, Požeška Gora and Prosara). To the south, the WVZ extends between the Pelagonian Zone and the Paikon Unit of the Vardar (Axios) Zone.

The main feature of the WVZ is the presence of various dismembered ophiolitic masses (Maljen, Troglav, Stolovi, Trnava and Banjska; Fig. 4) with metamorphic soles (mainly amphibolites, gneisses, mica schists and greenschists) at their base. The range of K/Ar age from 160 to 123 Ma found in the metamorphic soles (Karamata *et al.*, 2000; Milovanović *et al.*, 1995) suggests emplacement of the ophiolites during the Late Jurassic and Early Cretaceous periods.

The mélange is exposed throughout the WVZ and comprises mostly huge blocks and fragments of Mid-Upper Triassic and Upper Jurassic limestones, terrigenous sediments (sandstone, mainly greywacke), basalts, cherts with Carnian to Norian and Upper Jurassic radiolarians, with smaller fragments and clasts of gabbros and ultramafic rocks also being noted. The matrix of the mélange is argillaceous–silty. It should be noted that the mélange from the NE part of the Fruška Gora Mts. comprises a Barremian crossite schist (123 Ma, K/Ar age) as fragments and blocks. Pebbles of these rocks are also found in basal conglomerates of the Upper Cretaceous (Maastrichtian) sandstone sequence near the top of the Fruška Gora ridge (Milovanović *et al.*, 1995). Outcrops of ophiolitic rocks (serpentinised harzburgite, gabbro, dolerite and basaltic pillow lava) are also present within the Fruška Gora Mts. Early Oligocene to Miocene latite and dacite-andesite intrude the highest tectono-stratigraphic levels of Fruška Gora (Karamata *et al.*, 2000a, b, 2006).

The basic features of the main ultramafic massifs within the WVZ (Fig. 4) are as follows: The *Maljen Massif* is a large peridotite massif (50×15 km) mostly composed of spinel harzburgites; cumulate sequences (sometimes layered) are exposed at the western and northwestern margin of the massif and, from bottom to top, comprise dunites, plagioclase lherzolites, troctolites, pyroxenite, gabbro norite and ends with sheeted dykes. The ultramafic mass exposed further west from the Maljen Massif, *i.e.* between the Drina–Ivanjica Unit and the Jadar units (the Tejići area, Srećković-Batoćanin *et al.*, 2006) also comprise spinel harzburgite. The metamorphic sole at its base is composed of garnet mica schist, gneisses, amphibolites and low-grade metamorphics (phyllites, metasandstones). Srećković-Batoćanin & Vasković (2000) calculated a peak temperature of nearly 550 °C for a pressure of 5 kbar using the Grt-Ms thermometer (Hynes & Forest, 1988).

The *Troglav Massif* (12×10 km) mainly consists of spinel harzburgites. Dunite is subordinate and appears in the harzburgites as veins with a varying thickness of several tens of centimetres to tens of metres. Spinel lherzolites are rare. Contact between the dunites and harzburgites is sharp. Chromitite veins and chromite segregations occur within the dunites (Popević, 1971, 1978).

The *Stolovi Massif* (27×15 km) is located to the east of the Troglav Massif and mainly comprises spinel harzburgites. It is supposed that Stolovi and Troglav represent parts of one large massif separated by the Ibar River valley (Popević, 1978).

The *Trnava massif* (15×8 km) is located to the south of the Troglav Massif and mainly consists of spinel harzburgites and spinel lherzolite (Bazylev *et al.*, 2009). Occasionally, dunites with chromitite segregations are also found (Popević, 1971). Cumulate peridotites (plagioclase lherzolite, Bazylev *et al.*, 2009) are found only in the talus at its southern margin in the vicinity of the spinel harzburgite (and are possibly related to them).

The *Banjska Massif* is a relatively large body (20×8 km) composed of clinopyroxene-poor spinel lherzolites (Bazylev *et al.*, 2009). The metamorphic sole developed at the base of this ultramafic massif comprises clinopyroxene and/or hornblende (± clinozoisite) amphibolites with thin bands of garnet-cordierite-sillimanite gneiss. These rocks metamorphosed according to the Grt-Bt and Grt-Crd thermometer (Perchuk, 1989) and Grt-Crd-Sill-Qtz barometer (Aranovich & Podlesskii, 1989) in a temperature range of 780–650 °C at a pressure of 6.7–6.9 kbar. (Korikovsky *et al.*, 2000b).

According to geochemical data, the WVZ is interpreted as a supra-subduction zone (Bazylev *et al.*, 2009). The ophiolitic sequences of the WVZ are unusually overlain by "Upper Senonian–Palaeogene flysch" (Dimitrijević, 2001; Ustaszewski *et al.*, 2006, 2009).

2.2.4 The Drina–Ivanjica Unit (DIU)

A thin N–S to NW–SE trending belt, the Drina–Ivanjica Unit separates the DOB from the WVZ (Figs. 2, 3). It is 20 km wide and more than 250 km long. The NE and E boundaries of the DIU are marked by a system of westward-oriented thrusts called the "Zvornik Suture" (Dimitrijević, 2007). According to Schmid *et al.* (2008), the "Zvornik Suture" represents the northwestern continuation of the Senonian flysch, that marks the tectonic boundary between the Drina–Ivanjica and Jadar–Kopaonik thrust sheets. The southwestern border with the DOB is mostly covered by Triassic limestone megablocks (gravitationally moved southwest from the DIU). The northwestern part of the DIU is covered by Eocene sediments and its further continuation is uncertain.

Many authors agree that the DIU represents a microcontinent that rifted from the Adria block (Dimitrijević, 1982; Robertson & Karamata, 1994; Dimitrijević & Sikošek, 1997; Dimitrijević, 1997, 2001). By contrast, Schmid *et al.* (2008) concluded that the DIU is a part of the Adria block, which extends right beneath the Dinaridic Ophiolite Belt (*e.g.* Aubouin *et al.*, 1970; Bernoulli & Laubscher, 1972).

The DIU comprises Paleozoic and Triassic sequences (Fig. 5). The lower Upper Cambrian to Middle Carboniferous sequence is composed of low-grade metamorphosed terrigenous and carbonate sediments and basic to intermediate volcanics and their pyroclastics (mostly phyllites, metasandstones, greenschists and marbles, while meta-quartzose conglomerates are subordinate). Over these rocks, a sequence of very low-grade metamorphosed to non-metamorphosed psammitic to clayey and carbonate rocks with red to black cherts (Visean in age) follows. These Paleozoic lithologies are unusually overlain by Triassic red continental clastites called "Kladnica" and "Seiss" strata, followed by the shallow marine Bioturbate Formation and the Ravni Formation from the Anisian period and finally by Bulog Limestone (Fig. 6). Lower to Middle Triassic neritic carbonates and silicic volcanic rocks are found as detached thrust slices and blocks within the southern margin of the DIU intercalated with ophiolitic rocks and mélange (*e.g.* between Duga Poljana and Sjenica).

There is a lot disagreement over the nature and age of the deformation and metamorphism within the DIU: Karamata & Krstić (1996) presume that it took place between Mid-Carboniferous and Mid-Triassic; Filipović & Sikošek (1999) reported pre-Devonian age and Dimitrijević & Dimitrijević (1970) Upper Paleozoic age. Milovanović (1984) reported Early Cretaceous age (139–129 Ma, K/Ar radiometric dating on muscovite) for the lowest part of the Drina–Ivanjica unit and attributed the metamorphism in greenschist facies to the northeastward subduction of a spreading ocean ridge beneath the Drina–Ivanjica Continental Unit. Recently, Schmid *et al.* (2008) proposed a mid-Cretaceous regional tectonic event resulting in the upthrust of the Drina–Ivanjica unit above the Dinaride ophiolites and mélange. More detailed investigation should be carried out to test this assumption.

2.2.5 The Jadar Unit (JU)

The Jadar Unit is exposed in the northern part of the WVZ (Figs. 2, 3). It is bounded by deep faults and by the WVZ mélange. Its southwestern boundary represents a NW–SE trending deformed zone, whereas its eastern boundary is

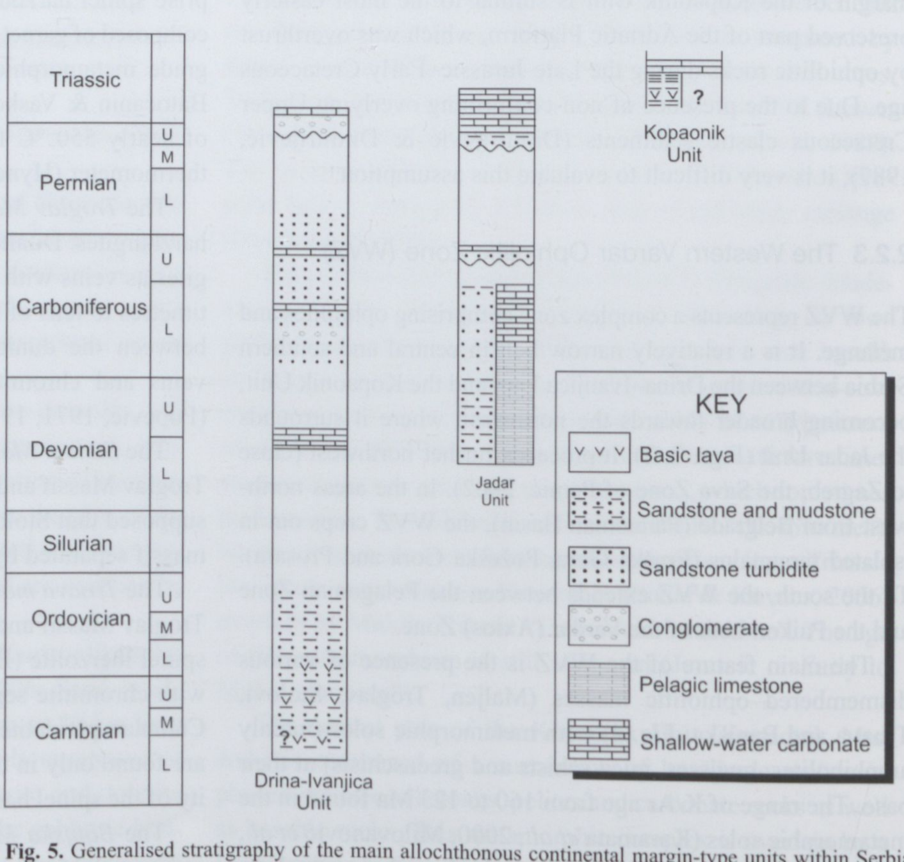

Fig. 5. Generalised stratigraphy of the main allochthonous continental margin-type units within Serbia according to Karamata (2006). Redrawn from Robertson *et al.*, 2009 (a part of Fig. 5 on p. 6). Key: U – Upper; M – Mid-; L – Lower.

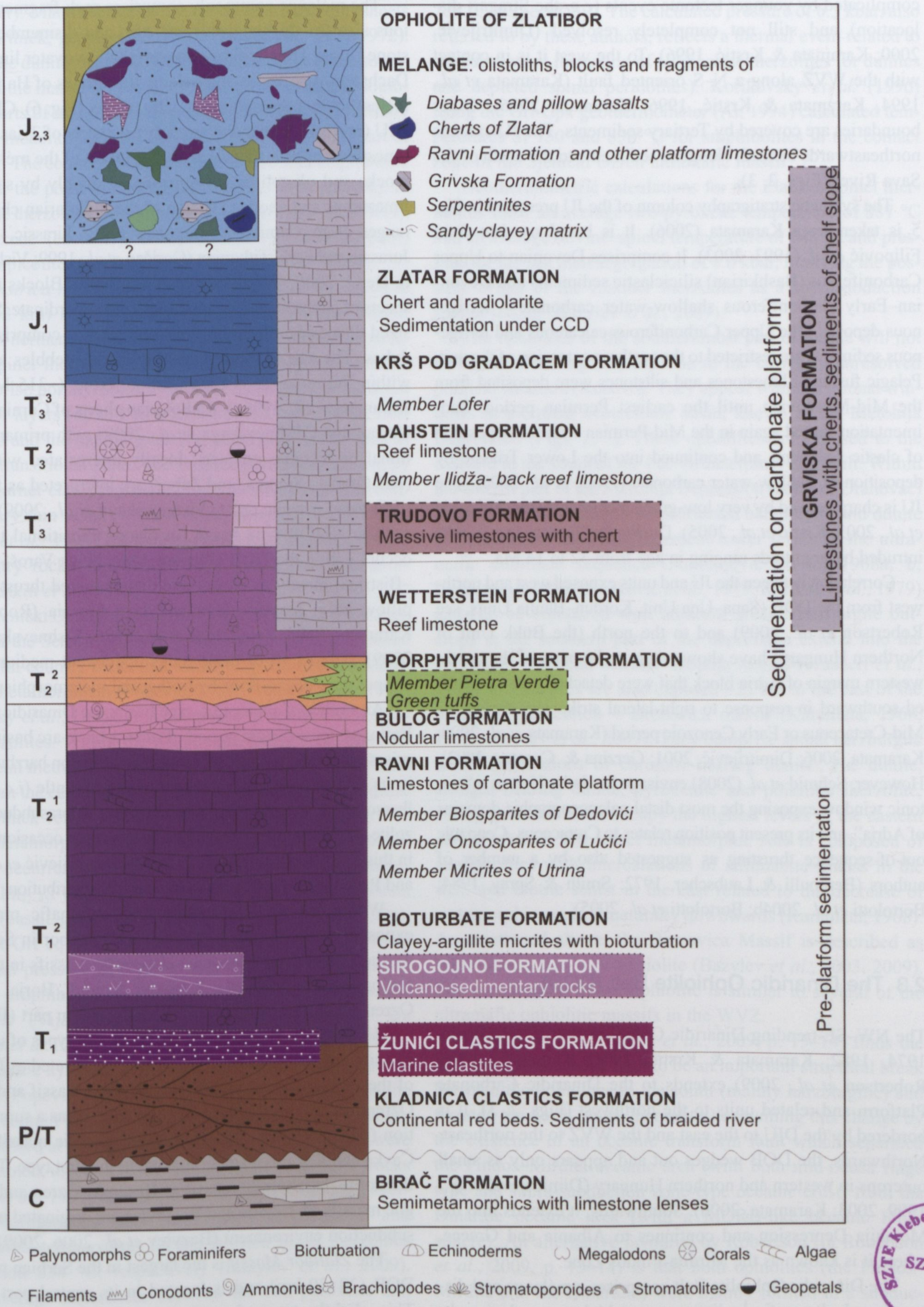

Fig. 6. Lithostratographic column of Zlatibor Mts. (data according to Dimitrijević & Dimitrijević, 1991; Dimitrijević *et al.*, 1996).

complicated by younger tectonic events (*e.g.* the Stragari dislocation) and still not completely resolved (Dimitrijević, 2000; Karamata & Krstić, 1996). To the west it is in contact with the WVZ along a N–S oriented fault (Karamata *et al.*, 1994, Karamata & Krstić, 1996; Karamata, 2006). Other boundaries are covered by Tertiary sediments. The JU extends northeastwards beneath Neogene sediments to the north of the Sava River (Figs. 2, 3).

The synthetic stratigraphy column of the JU presented in Fig. 5 is taken from Karamata (2006). It is based on data from Filipović *et al.* (1993, 2003). It comprises Devonian to Upper Carboniferous (Bashkirian) siliciclastic sediments and Devonian–Early Carboniferous shallow-water carbonate – terrigenous deposits. The Upper Carboniferous calcareous and terrigenous sediments are restricted to the northern extension of the unit. Pelagic fusulinid limestones and siltstones were deposited from the Mid-Moscovian until the earliest Permian period. Sedimentation started again in the Mid-Permian with the deposition of clastic sediments and continued into the Lower Triassic by deposition of shallow-water carbonate (Protić *et al.*, 2000). The JU is characterised by very low-grade metamorphism (Filipović *et al.*, 2003; Krstić *et al.*, 2005). During the Tertiary the JU was intruded by granitoids ranging in age from 32 to 14 Ma.

Correlation between the JU and units exposed west and northwest from the DOB (Sana–Una Unit, Kordun–Banija Units, see Robertson *et al.*, 2009) and to the north (the Bükk Unit of Northern Hungary) have shown them to be parts of the northwestern margin of Adria block that were detached and transported southward in response to right-lateral strike–slip during the Mid-Cretaceous or Early Cenozoic period (Karamata *et al.*, 2000; Karamata, 2006; Dimitrijević, 2001; Gerzina & Csontos, 2003). However, Schmid *et al.* (2008) envisage the Jadar Unit as a "tectonic window exposing the most distal paleogeographic domains of Adria", and its present position relates to Cretaceous–Cenozoic out-of-sequence thrusting as suggested also by a number of authors (Bernoulli & Laubscher, 1972; Smith & Spray, 1984; Bortolotti *et al.*, 2004b; Bortolotti *et al.*, 2005).

2.3 The Dinaridic Ophiolite Belt (DOB)

The NW–SE-trending Dinaridic Ophiolite Belt (Dimitrijević, 1974, 1982; Karamata & Krstić, 1996; Karamata, 2006, Robertson *et al.*, 2009) extends to the Dinaridic Carbonate Platform and related units to the northwest (Figs. 2, 3). It is bordered by the DIU to the east and the WVZ to the northeast. Northwards, the DOB wedges out and appears only as small outcrops in western and northern Hungary (Dimitrijević *et al.*, 1999, 2003; Karamata, 2006). Southwards, it extends into the Metohija Depression and continues to Albania and Greece, where it is known as the Mirdita-Pindos Zone.

The Dinaridic Ophiolite Belt comprises a mélange and dismembered ultramafic bodies among which some show subcontinental mantle origin (Bazylev *et al.*, 2003, 2006, 2009)

The mélange commonly comprises rock fragments of various size (m- to km-sized) and age, and dismembered limestone Upper Triassic thrust sheets (shallow-water limestone of Dachstein-type facies and pelagic limestones of Hallstatt-type facies) set in a sheared sandy-silty matrix (Fig. 6). Close to the DIU (northwest) dismembered thrust sheets of Triassic neritic limestones appear mostly at higher levels of the mélange. The blocks and olistoliths are represented mainly by sandstones, limestones and cherts. The age of the radiolarian chert blocks ranges from Carnian–Norian, late Early Jurassic, Mid–Late Jurassic and Early Tithonian (Goričan *et al.*, 1999; Vishnevskaya & Đerić, 2006; Vishnevskaya *et al.*, 2009). Blocks and thrust sheets of gabbroic and granitic rocks are subordinate. Some km-sized dismembered thrust sheets of gabbros comprise sheeted dykes. The age of the red granite blocks, pebbles and sheets within the mélange is Late Carboniferous (~315 Ma; U-Pb; Karamata *et al.*, 1996a). Radiolarian cherts of Carnian to early Norian age (Vishnevskaya *et al.*, 2009) with primary depositional or tectonic contacts, locally intercalated with basalts (Krš Gradac, Sjenica, and Zaboj) are interpreted as fragments of Triassic oceanic crust (Vishnevskaya *et al.*, 2009).

The NMOR-type basalt, in places transitional to E type, occurs within the DOB (Zlatibor Mts.; Nova Varoš–Prijepolje –Bistrica) mostly as blocks and dismembered thrust sheets of pillow lava, massive lava and lava breccia (Robertson & Karamata, 1994; Zakariadze *et al.*, 2006; Vishnevskaya *et al.*, 2009). Almost all of these rocks underwent medium to low-temperature ocean-floor hydrothermal metamorphism.

As a relict of an oceanic-type basin, the Dinaridic Ophiolite Belt was, for a certain period of time, a back-arc basin. It comprises ultramafic massifs of the suprasubduction harzburgite type in its southern part and a subcontinental mantle (*i.e.* orogenic lherzolite) in its central and northern parts. Suprasubduction lherzolite–harzburgite and lherzolite massifs occur occasionally within this segment (Bazilev *et al.*, 2009). Dimitrijević *et al.* (2000) and Pamić *et al.* (2002) reported a similar distribution.

Within the DOB the following ultramafic massifs are exposed: Sjenički Ozren, Bistrica and Zlatibor in Serbia (Fig 4); the Tuzinje and Brezovica ultramafic massifs in the southern part of the DOB (*i.e.* Kosovo); Konjuh, Borja, Bosanski Ozren, Čavka and Kozara in its northwestern part (Bosnia).

Within the Serbian part of the DOB two types of ultramafic massifs are distinguished. The first is interpreted as fragments of the subcontinental mantle (the Bistrica massif and Sjenički Ozren) and the second (the Zlatibor Massif) as a suprasubduction (back-arc) type. The Bosnian ultramafic massifs (Borja, Čavka and Kozara) also correspond to the first type. The spinel lherzolite–harzburgite massif of Bosanski Ozren and harzburgite massifs of Tuzinje and Brezovica are originated in a suprasubduction environment (Bazylev *et al.*, 2006, 2009).

The *Zlatibor Massif* is the largest in the Serbian part of the DOB (20×30 km) and is located in its central part (Fig. 4). This slightly to moderately serpentinised lherzolitic body comprises cumulates and gabbros at the top of the section (the

Rzav River). Mantle tectonites occur as relatively thin sheets (<2–3 km thick; geophysical data of Roksandić, 1971/1972). Subordinate dunites with chromite schlieren occur in the southern part of the massif (Popević, 1971). The southern and southwestern parts of massif are composed of harzburgite. Partially preserved metamorphic sole occurs beneath the central part of the massif. The country rocks metamorphosed into amphibolite facies near the point of contact (Korikovsky *et al.*, 2000a). In general, the lherzolites are composed of olivine (Mg# 90.0–90.9), orthopyroxene (enstatite), clinopyroxene (Fe- and Al-poor) and chrompicotite (Cr# 0.13-0.50) (Bazylev *et al.*, 2009).

The *Bistrica massif* represents a small isometric tectonic block (2×2 km) located to the south of the Zlatibor Massif (Fig. 4). Its northern part is mainly composed of massive, coarse-grained spinel lherzolites. The lherzolites from the southern part comprise porphyroblastic spinel harzburgites in the form of veins or layers (up to 1 m thick). Contact between the host lherzolites and the harzburgites is gradual and can be seen as a narrow transitional zone. The Bistrica peridotites are cut by veins of garnet clinopyroxenite (1–5 cm thick) and occasionally by very thin veins (< 1mm thick) of spinel hornblendite (Popević *et al.*, 1993) containing rare grains of green spinel. The country rocks experienced high temperature metamorphism (Fedkin *et al.*, 1996).

The Sjenički Ozren Massif (10×15 km) is located in the central part of the Serbian DOB (Fig. 4). The massif is in tectonic contact with country rocks that locally experienced high-temperature metamorphism (Popević, 1985; Popević *et al.*, 1996; Korikovsky *et al.*, 1996). It is composed of spinel and plagioclase lherzolites. Within the plagioclase lherzolites, gabbroic veins several metres thick and intrusions occur. The spinel lherzolites from the central and western part of the massif comprise relatively thick veins or bodies (tens of meters) of dunites.

The metamorphic sole of the Bistrica Massif is characterised by occurrences of unusual garnet clinopyroxene amphibolites ($Alm_{42-45}Pyr_{42-45.6}Grs_{15-23}$) formed by the metamorphism of mafics (basalt, gabbro). For these rocks Fed'kin *et al.* (1996), using Cpx-Grt equilibria, calculated a temperature of 740 to 830 °C and pressure of 8 to 10 kbar The corundum-bearing pargasitic amphibolite was interpreted as part of a regional-scale unit (Vijaka–Bistrica amphibolite complex, see Robertson *et al.*, 2009) possibly originating from the subduction of basaltic hyaloclastite, which was first transformed into bentonite (Popević & Pamić, 1973). The ultramafics in the northeast contain local dykes of garnet pyroxenite that probably crystallised at pressures of ~16 kbar at ~1400 °C and were later exhumed together with the adjacent ultramafic rocks (Popević *et al.*, 1993; Bazylev *et al.*, 2006). Preliminary average geothermometry data based on two-pyroxene and olivine–spinel temperatures for the Bistrica spinel lherzolites are 886 and 834 °C, respectively (Bazylev *et al.*, 2009). Greater average differences between the two-pyroxene and olivine–spinel temperatures were found by the same authors for the spinel lherzolites of the Sjenički Ozren massif (940 and 784 °C, respectively). The calculated pressure of 6.3 kbar, also referred to by these authors, reflects a thermal event related to the subsequent formation of plagioclase lherzolites (or dunites and depleted spinel peridotites). Korikovsky *et al.* (1996) using the Grt-Cpx geothermometer (Ai, 1994) calculated temperatures of 750 and 830 °C for amphibolites in the contact zone of the Sjenički Ozren ultramafic massif.

Geothermometric calculations for the Zlatibor spinel lherzolites show an average two-pyroxene temperature of 887 °C and an average olivine–spinel temperature of 748 °C and pressure for the last melt segregation of 8.0 kbar, implying the possible origin of the Zlatibor lherzolites as a suprasubduction spread setting (Bazylev *et al.*, 2009).

The ophiolites of the southernmost part of Serbia will not be observed during this trip due to the currently unresolved political situation (Kosovo). They appear within erosional windows in a critical neotectonic basin, known as the Metohija Depression (Figs. 2, 3). These ophiolites are exposed to the east and to the south of the Peć–Srbica transverse fault. Within the eastern part of the Metohija Depression (north of Orahovac) small outcrops of mainly serpentinised harzburgite and dunite (with poikilitic wehrlite) represent lower levels of the ultramafic cumulate sequence (Antonijević *et al.*, 1968a, b; Lončarević, 1978; Menković *et al.*, 1979, Karović *et al.*, 1979) and can be compared with adjacent areas. Harzburgite outcrops in the southern part of the depression extend into the very large Albanian Mirdita–Tropoja Massif (Frasheri *et al.*, 1996). Ultramafics are also exposed ~25 km to the east of the Metohija Depression – Brezovica massif (Karamata, 1968, 1985; Bazylev *et al.*, 2003). They comprise spinel harzburgite with intercalations of chromite-bearing dunite. The dunite, feldspar-bearing dunite, pyroxenite and poikilitic lherzolite, cut by gabbroic rocks occupy the highest levels of the eastern part of massif. The intact metamorphic sole is composed of amphibolites with intercalations of sillimanite–gneiss in the west and biotite schist in the east related to the decrease of metamorphic grade structurally downwards (Karamata, 1968). As mentioned above, the Brezovica Massif is described as supra-subduction-type ophiolite (Bazylev *et al.*, 2003, 2009). The composition of the ophiolite is similar to several of the ultramafic ophiolitic massifs in the WVZ.

Karamata (in Robertson *et al.*, 2009, p. 13–14) finds the Peć–Srbica transverse fault to be an important structural break between the ophiolites to the south (mainly harzburgitic) and those to the north (more lherzolitic) explaining this change by the existence of an oceanic transform fault which separated the Pindos–Mirdita oceanic area (with both mid-ocean ridge type and supra-subduction zone-type oceanic crust) from the Dinaride oceanic area (with a MORB-like oceanic lithosphere). An alternative favoured by Robertson (in Robertson *et al.*, 2009, p. 13–14) is that both ophiolites (the Pindos–Mirdita and the Dinaridic) were mainly formed in a subduction-related setting, according to the chemical and mineralogical evidences.

3. Field stops

The geology of the Serbian ophiolite framework is based on a recent summary of all the northern Balkan Peninsula ophiolite belts (Robertson *et al.*, 2009). In addition, the work of Karamata (from the early 1970s till now) should be stressed. It must be mentioned that the summary presented here contains the results of work still in progress that will be tested through further studies based on mapping, geochemistry and geochronology.

Day 1

Eastern Vardar Ophiolitic Zone (EVZ)

Most authors, even those who advocate the "single ocean story", agree that the EVZ differs from the Western Vardar Zone ophiolites in the dominant gabbro-dolerite sequences cut by Upper Jurassic calc-alkaline granitic rocks (Šarić *et al.*, 2009) and basaltic rocks. Sheeted dykes appear locally (the Ždraljica Massif). The main characteristic of the EVZ is the rare appearance of small, generally highly serpentinised harzburgitic bodies.

The mélange comprises exotic blocks and dismembered thrust sheets of sedimentary (sandstones, silicic limestones, minor cherts) and igneous (basalt, dolerite, gabbro) rocks set in a very low- to low-grade metamorphosed sandy-clayey matrix (Dimitrijević *et al.*, 1995).

The western part of the EVZ is covered by Lower Cretaceous (Berriasian) marine sediments abundant in terrigenous and ophiolitic material ("Paraflysch" of Dimitrijević & Dimitrijević, 1987).

3.1 Field stop 1. EVZ – Western part of the northern branch of the EVZ (south of Belgrade): Serpentinised harzburgite (Bubanj Potok, Mt. Avala)

The first larger outcrops of the western part of the northern branch of the EVZ occur at about 20 km south of Belgrade on the southern flank of Mt. Avala and continue as a NNW–SSE trending zone with smaller or larger elongated exposures close to the eastern flanks of Mts. Kosmaj and Bukulja to Kragujevac following the Stragar fault zone (Fig. 7). All of them are harzburgitic in composition and partly to completely serpentinised. The relationship between the serpentinised harzburgite bodies and the surrounding rocks is tectonic. The mélange is only developed in the Ripanj area (Fig. 7), where the major part is covered by Neogene sediments. It crops out only in deep streams. This mélange is composed of olistoliths, blocks and clasts of Jurassic limestones, cherts, sandstones, shales and marls set in a clayey-marly matrix, occasionally schistose. Its Kimmeridgian–Portlandian origin was determined on the basis of the foraminifera-rich carbonate blocks.

On our way to Kruševac the first outcrop of Mt. Avala (serpentinised harzburgites) appears on the left side of the highway (close to Bubanj Potok). It will not be possible to stop due to the very heavy road and rail traffic. Observation will be available only from the bus.

The serpentinised harzburgites of Mt. Avala are composed of serpentinised olivine, orthopyroxene (enstatite) partly or completely transformed into bastite ranging in size from 0.5 to 2 cm, chromite, chrompicotite and mostly secondary magnetite. Among the serpentine minerals, the most frequent is chrysotile, freqently in asbestiform habit. Thin magnesite veins (up to 2 cm thick) and calcitic veins occur sporadically.

Due to high hydrothermal activity related to Oligocene volcanism, silicic and silico-carbonatic masses up to 40-80 m in diameter as well as listvenitic masses and mercury deposits (Šuplja Stena) formed within some serpentinised harzburgitic bodies.

The bodies of serpentinised harzburgites in the western part of the EVZ, in the area between Belgrade and Kragujevac, have not been studied in detail since the time of Dimitrijević (1936), Luković (1958) and Pavlović *et al.* (1980).

We will drive southeast through the area of the EVZ mostly covered by Neogene sediments. At the exit to Mladenovac we will turn to east to Ralja, and from there to south towards Stalać and Kruševac along the eastern margin of the EVZ, which is also covered by Neogene sediments. From Velika Plana (the valley of the Južna Morava river) we will enter the Serbo-Macedonian Massif mostly overlain by Quaternary and Tertiary sediments. Its first outcrops (various types of mica schists and gneisses) can be observed after we turn southwest off the highway, in the area between Ćićevac and Belušić.

3.2 Field stop 2. EVZ – Ždraljica ophiolitic massif: Sheeted dyke complex of Prevešt

The Ždraljica ophiolitic massif is exposed east of the Gledići Mountains (Fig. 8). This is one of the best-investigated ophiolitic complexes within the EVZ (Resimić-Šarić *et al.*, 2000; Resimić-Šarić *et al.*, 2006; Šarić *et al.*, 2009). It is in tectonic contact with the Barremian–Aptian flysch sediments to the west and slightly metamorphosed Upper Jurassic mélange (so-called "Diabase-Chert Formation") and Mid-Jurassic low grade metamorphics (mostly greenschists, rarely metasandstones, calcschists and marbled limestones). The massif is composed of tholeiitic and calc-alkaline sequences of various types of gabbros and dolerite with subordinate MOR pillow basalts, plagiogranites and small granitic to dioritic intrusions of VA-affinity. Massive or cumulate gabbros occur as irregular blocks. Dolerites appear as single dykes or dyke swarms intruding the gabbros or as irregular massive bodies. Some pillow basalts

Fig. 7. Position of some serpentinised harzburgites bodies and their relationship with surrounding lithologies within the western part of the EVZ. Data according to Ivković *et al.* (1975); Brković *et al.* (1980); Dolić *et al.* (1981) and Marković *et al.* (1968) – Basic Geological Map of Yugoslavia, scale 1: 100 000, sheets Beograd, Obrenovac, Kruševac and Paraćin.

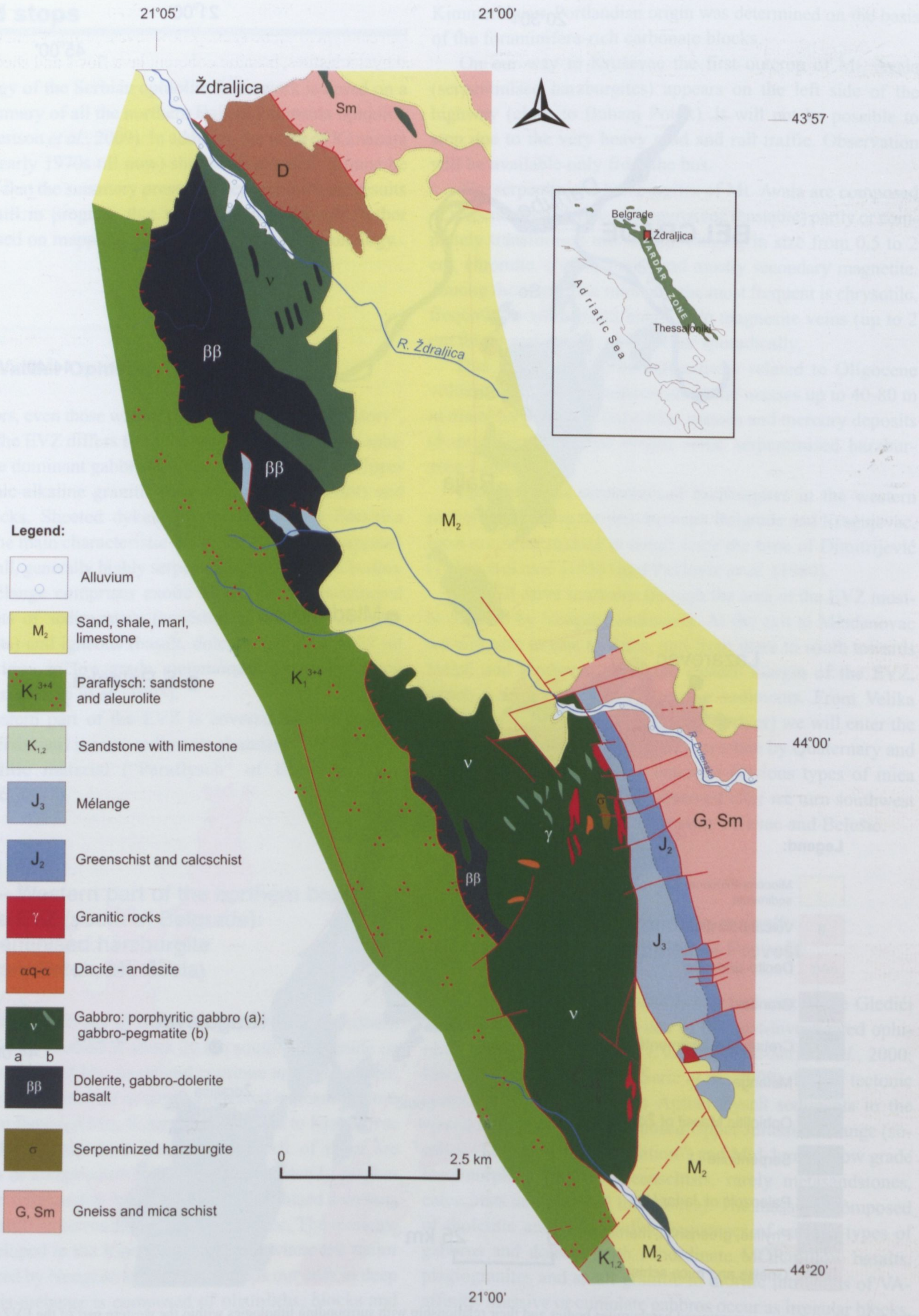

Fig. 8. Simplified geological map of the Ždraljica Ophiolitic Sequence. According to data of Dolić *et al.* (1981) and Marković *et al.* (1968) – Basic Geological Map of Yugoslavia, scale 1:100 000, sheets Kruševac and Paraćin.

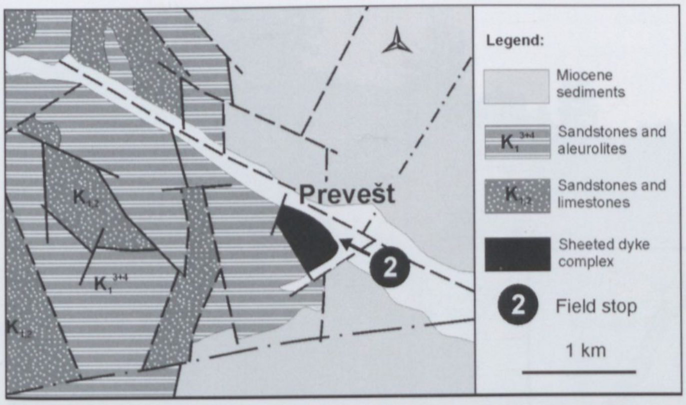

Fig. 9. Simplified geological map of the Prevešt locality according to Marković *et al.* (1968) – Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Paraćin.

are either primary or redeposited hyaloclastites. Within the massive dolerite and some fine-grained gabbro bodies, dykes several metres thick or irregular bodies of granites, locally with foliated and/or milonitised margin can be seen.

The sheeted dyke complex of Prevešt occupies the extreme southeastern part of the Ždraljica ophiolitic massif (Fig. 9). At the crossroads, from Kamidžor creek to the quarry, the following rock types can be seen: pillow lavas, primary and redeposited hyaloclastites, basaltic coherent lava flows and sheeted dyke. This zone was strongly tectonised and rocks have been altered. Basalts and dolerite dykes commonly comprise pale veins composed of epidote, quartz, calcite, with subordinate albite.

The sheeted dyke complex is well exposed in the active quarry of Prevešt (Fig. 10). The thickness of the dykes ranges from a few cm to around 50 cm. In places, some dykes are characterised by glassy chilled margins (asymmetric dykes are also noted). Usually, their texture is fine-grained to ophitic, occasionally intergranular or intersertal. The main minerals are plagioclase (65–85% An), augite, magnetite and ilmenite. The plagioclase is mostly albitised or epidotised, while the pyroxene is chloritised or transformed into a very fine-grained aggregate of actinolite, epidote and chlorite. Within some dykes, very fine-grained accumulations or veins of quartz or calcite are found. Disseminated pyrite is also presented as a secondary phase in the altered groundmass.

From Prevešt we will drive to Trstenik and further south to Kuršumlija.

Fig. 10. Prevešt Quarry: sheeted dykes complex. (Photo courtesy of Kristina Šarić)

3.3 Field stop 3. EVZ – Kuršumlija ophiolitic massif: Granites

Gabbros and dolerites and granites of the Kuršumlija ophiolitic massif can be found south of the Ždraljica ophiolitic massif on the southeastern margin of the EVZ (Fig. 11).

The section exposed along the Kuršumlija–Žuč road consists of outcrops of fine- to coarse-grained (locally porphyritic or pegmatitic) or ophitic gabbros and dolerites which are composed of altered plagioclases (saussurite, prehnite) and clinopyroxene (uralite, very rarely calcite) and Fe±Ti oxides. So far there has been no analysis of the geochemistry of these rocks.

A relatively small leucocratic granite intrusion into the gabbro-dolerite mass can be observed on the eastern part of the Kuršumlija–Žuč section (Figs. 11, 12). Generally speaking, this low-Sr$_i$ granite (Sr$_i$ = 0.70330 – 0.70767; e_{Nd} (T) = –5.1 – 1.5) is composed of quartz, alkali feldspar, plagioclase, and chloritised biotite (< 5 vol%, with accessory zircon, apatite and magnetite (Šarić *et al.* (2009). The melting of (meta)sedimentary and immature volcanoclastic rocks was responsible for the generation of low-Sr$_i$ granites (Šarić *et al.*, 2009).

3.4 Field stop 4. EVZ – Kuršumlija ophiolitic massif: Pillow basalts

The profile of the Kuršumlija–Žuč road ends with outcrops of basaltic pillow lavas associated with dolerite dykes (Fig. 13). The diameter of the pillows ranges from 30 to 70 cm. In structure, they vary from massive (mostly at the core) to vesicular. The pillow basalts are intersertal and microophitic in texture

Fig. 11. Simplified geological map of the Kuršumlija ophiolitic massif and location of field stops. Based on Malešević *et al.* (1980) – Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Kuršumlija.

Fig. 12. Intrusion of Low-Sr_i granite into gabbro. (Photo courtesy of Kristina Šarić)

and are composed of albite, uralite and chlorite and rare relics of primary clinopyroxenes. The dolerite dykes show chilled margins and tiny normal joints – typical features of shallow emplaced feeder dykes. The dykes are intersertal and ophitic in texture with a composition similar to the adjacent basaltic lava.

From Kuršumlija to Kopaonik Mts. we will first pass Kuršumlija. Then, on the road via Blace to Razbojna, we will drive through the SMM, mostly composed of gneisses and micaschists and covered by Miocene–Pliocene sediments and Upper Cretaceous flysch. At Razbojna we will re-enter the EVZ with its mélange (called the "Diabase-Chert Formation"), the ophiolite complex of Kuršumlija (its northern part) and the Lower Cretaceous paraflysch, which extends from the area west of Kuršumlija as far as Brus and further to the north (Fig. 14).

Fig. 13. Pillow basalts at the road section Žuč–Kuršumlija. (Photo courtesy of Kristina Šarić)

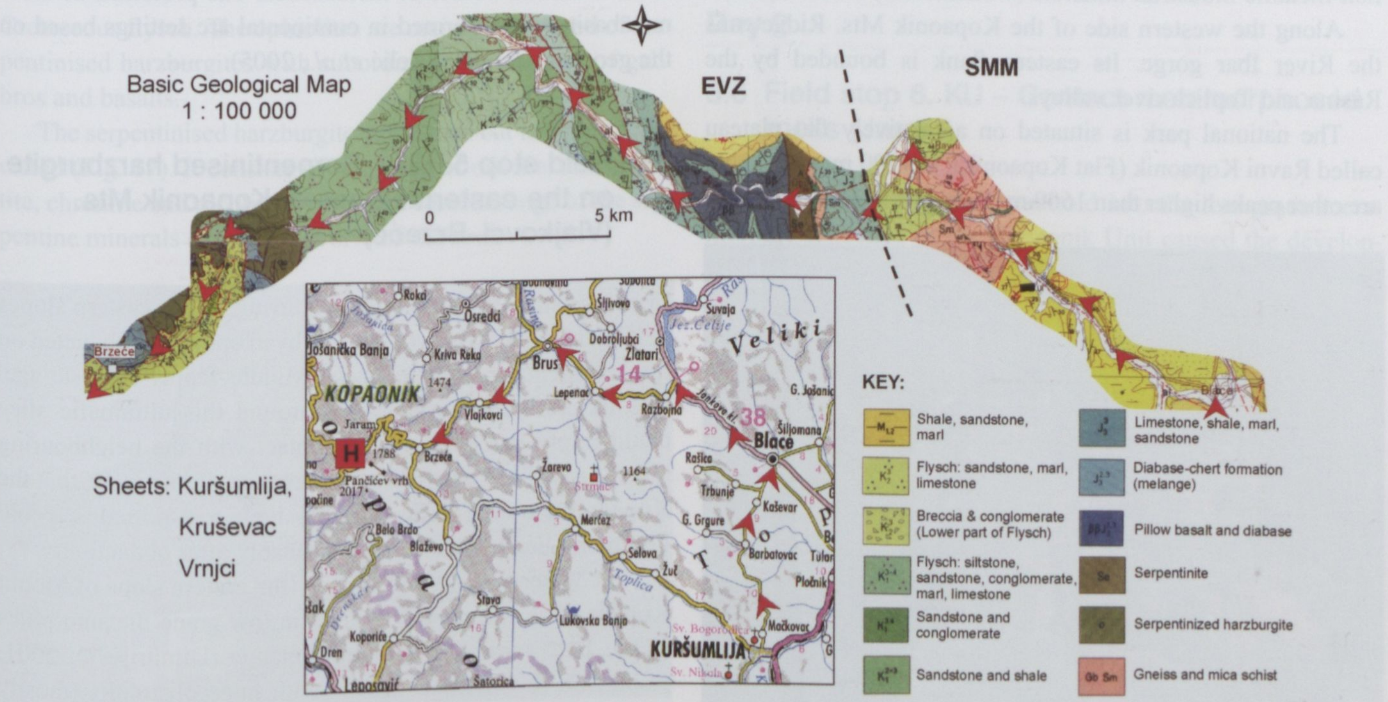

Fig. 14. Geology of the area between Blace and Brzeće (based on Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Kruševac: Rakić *et al.*, 1976; sheet Kuršumlija: Malešević *et al.*, 1980 and sheet Vrnjci: Urošević *et al.*, 1973a)

One of the main features of this part of the EVZ is a trough (basin) at least 160 km long with Lower Cretaceous paraflysch deposits (Dimitrijević & Dimitrijević, 1987). It spreads south from Kragujevac via Kuršumlija to Podujevo (Kosovo). The succession begins with coarse-grained clastites transgressive over Paleozoic (?) crystalline schists, ophiolitic mélange or rarely over the uppermost Jurassic limestones. Conglomerates are composed of pebbles of the underlying rocks. The paraflysch succession comprises two megasequences with coarse-grained clastites in the lower part and fine-grained clastic-calcareous sediments in the upper part.

From the village of Lepenac to Brus, the mostly Barremian –Aptian horizon of the paraflysch (arenitic siltstone) is exposed.

After Graševci, driving towards Kopaonik Mts., we will cross the western flank of the EVZ before entering the Kopaonik Unit (KU)

The Mount Kopaonik National Park

Kopaonik Mts. is one of the largest mountain ranges in Serbia located in its central part. It is more than 100 km long and spreads over 118.1 km^2. The highest peak (2017 m) was named "Pančićev Vrh" (Pančić Peak) after the famous 19th century Serbian botanist. A national park was established in 1981 due to its natural beauty, extraordinary flora and fauna and rich historical heritage, including pre-medieval and medieval churches, monasteries and fortresses built by Serbian dynasties (Fig. 15). It was an important mining centre during medieval times with many Saxon miners. On its highest peak an old iron mine named Suvo Rudište is located (see Fig. 22 below). Apart from metal ores (iron, lead and zinc, Ag, Au) there are also non-metallic industrial minerals (wollastonite, asbestos, etc).

Along the western side of the Kopaonik Mts. Ridge runs the River Ibar gorge. Its eastern flank is bounded by the Rasina and Toplica river valleys.

The national park is situated on a relatively flat plateau called Ravni Kopaonik (Flat Kopaonik), at 1700 metres. There are other peaks higher than 1600 m: Gobelja (1934 m), Karman Vučak (1936 m), Suvo Rudište (1976 m) etc. The Jošanička Banja spa with powerful natural springs reaching a temperature of 88 °C is located on its northwestern side. Starting directly below the plateau is the attractive and picturesque gorge of the River Samokovska with its steep cliffs runs, rapids and falls.

Fig 15. The 13th century medieval fortress of Maglić in Ibar gorge, Kopaonik Mts.

Nowadays Kopaonik is a very famous tourist centre, especially during wintertime. It has more than 200 days of sunshine annually. The snow cover stays from November to May. The resort offers hotels, apartments, ski lifts and excellent ski slopes.

The Kopaonik Unit (KU)

As already mentioned in the introductory chapter, one of the most vital questions relates to the number of Mesozoic oceans that existed in the Vardar Zone Ophiolite Belt. This question is certainly associated with the nature of the basement rocks found inside this belt. One such basement unit is the Kopaonik Unit (Figs. 2, 3). It is situated between the EVZ and WVZ.

Kopaonik Mts. is anticlinal in shape with Triassic metamorphic rocks at its core. These metamorphics are tectonically overlain by ophiolites. The margins of the KU are unusually covered by Upper Cretaceous flysch. During the Oligocene period, the anticline core was intruded by a large granitoid body and contact metamorphosed (Fig. 16). At present, the KU is assumed to be a microcontinent that separated two oceanic realms (Karamata, 2006; Robertson *et al.*, 2009) or simply a tectonic window beneath the Western Vardar ophiolites (*e.g.* Schmid *et al.*, 2008).

The geological framework of Kopaonik Mts. and the location of the field stops are shown in Fig. 16.

In the Kopaonik area, the KU is composed of a succession of low-grade metapelites and metacarbonate rocks and 30–200 m thick lenticular bodies of metabasites. The protoliths of these metabasites were formed in continental arc settings based on the geochemical data (Zelić *et al.*, 2005).

3.5 Field stop 5. KU – Serpentinised harzburgite on the eastern slopes of Kopaonik Mts. (Vlajkovci–Brzeće)

The serpentinised harzburgite occurring on the eastern slopes of Kopaonik Mts. is part of the Tethyan ophiolites obducted on the continental basement in the Middle–Upper Jurassic age. The lack of metamorphic sole around this ultramafic slice could imply that present-day contact with the neighbouring units is related to later tectonic events or alternatively, that the Kopaonik ultramafic slice was passively transported as a cold ultramafic body from the east, probably after obduction.

The wider area around Brzeće (the eastern slope of Mount Kopaonik) is composed of Triassic low grade metamorphics (KU), Late Jurassic ophiolitic mélange (Dimitrijević, 2001; Robertson & Karamata, 1994) with huge olistoliths (mostly serpentinite, gabbro, platform carbonates and metamorphic rocks of the KU) set in a sandy-clayey matrix and Upper

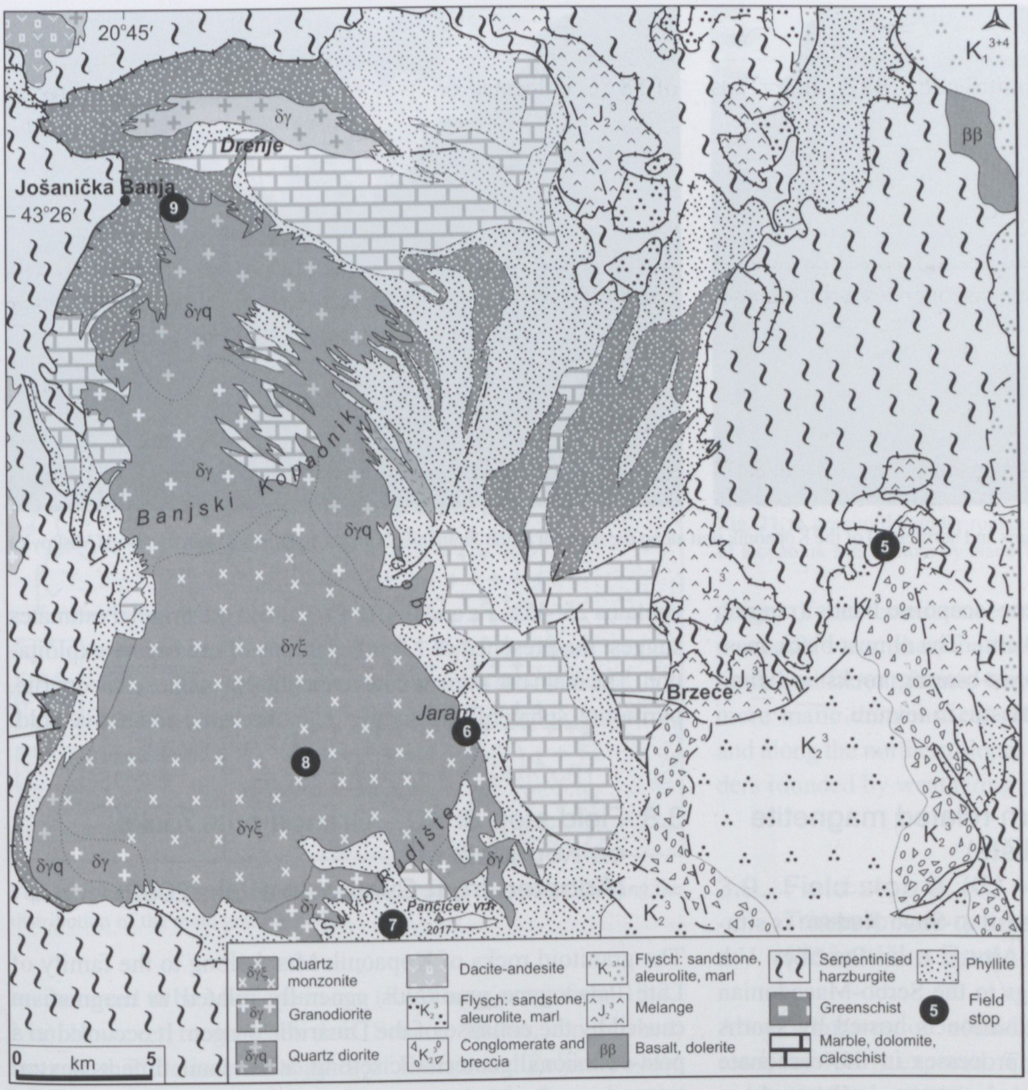

Fig. 16. Simplified geological map of the Kopaonik Unit (Kopaonik Mts.) according to the Basic Geological Map of Yugoslavia, scale 1:100 000, sheets Vrnjci and Novi Pazar (Urošević *et al.*, 1973a, 1973b).

Cretaceous flysch. The ophiolites are mainly composed of serpentinised harzburgites with subordinate occurrences of gabbros and basalts.

The serpentinised harzburgite at the road cut is highly brecciated (Fig. 17). It consists of remnants of olivine, and enstatite, chromite and picotite. The modal content range of the serpentine minerals exceeds 60 vol% of the rock.

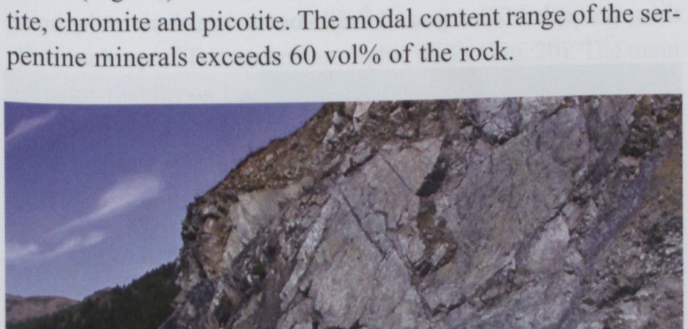

Fig. 17. Outcrop of serpentinites at the road cut Vlajkovci–Brzece (Photo curtesy of Kristina Šarić).

Day 2

3.6 Field stop 6. KU – Contact-metamorphosed rocks (Jaram)

Intrusion of an Oligocene granitoid into the low-grade metamorphic sequence of the Kopaonik Unit caused the development of an extensive contact metamorphic aureole. The direct contact with the granitoid rocks is not exposed. Hence, these contact metamorphic rocks most probably represent a hanging wall of rock above the plutonic body.

The contact metamorphic aureole is best exposed in the area of Jaram on the southern slopes of Kopaonik Mts. (Figs. 16, 18). Here, the lower part of the KU is composed of phyllites intercalated with thin layers of calcschists, metasandstones and marls. Its upper part comprises limestones and dolostone. Within both parts frequent alternations of pelitic and carbonate material can be found.

The contact metamorphic zone in the locality of Jaram (Knežević-Đorđević *et al.*, 1995) is composed of fine-grained cordierite- to biotite-bearing hornfelses and calc-silicate hornfelses and skarns showing alternations of wollastonite, diop-


Fig. 18. Contact metamorphosed rocks (skarns and hornfelses) of the Kopaonik unit along the road cut in the Jaram area. (Photo by Kristina Šarić and Nada Vasković)

side, diopside–garnet and pyroxene–scapolite bands (ranging in thickness from a few mm to 50 cm). The almost black massive to slightly schistose cordierite-bearing rocks are fine-grained granoblastic to porphyroblastic in texture.

3.7 Field stop 7. KU – Skarn-related magnetite ore deposit (Suvo Rudište)

The abandoned magnetite ore deposit at Suvo Rudište is situated on the top of the Kopaonik Mts., *i.e.* on Pančićev Vrh (2017 m) – Figs. 16, 19. It belongs to the Serbo-Macedonian Metallogenetic Province. Mineralisation is hosted by skarns formed by contact metamorphic processes in the carbonate rocks of the Kopaonik Unit. These skarns are similar to those observed in the Jaram area and comprise garnet of andradite–grossular composition, diopside, wollastonite, scapolite and epidote (Vasković & Knežević, 1995).

The ore bodies are lens-shaped or nest-like. Some elongated lenses (~100 m long) were found to occur at depths of around 120 m. Mineralization is of the massive or impregnation type. The ore contains 25–45% Fe and 0.4–0.8% Cu and the original estimates suggest the presence of 1.5 million tons of ore before exploitation. The main ore minerals are magnetite, hematite, chalcopyrite, pyrrhotite, sphalerite, arsenopyrite, molibdenite and native gold.

3.8 Field stop 8. KU – Granodiorite rocks on Kopaonik Mts. (Adopted from Cvetković et al., 2009)

The granitoid rocks of Kopaonik Mts. belong to the family of Late Palaeogene granitoids generally related to magmatism caused by the collapse of the Dinaridic orogen. It occurred in a post-collisional geotectonic setting, at the same time as dextral transcurrent movements, wrench tectonics and the formation of lacustrine basins along the central axis of the Balkan Peninsula.

The main granitoid mass is accompanied by smaller masses to the west and east (Fig. 20). Available K/Ar data indicate an Oligocene age ranging from 29 to 35 Ma. This age has long been adopted as the age of the main Kopaonik granitoid while the granitoids of Drenje and Željin occurring more to the north

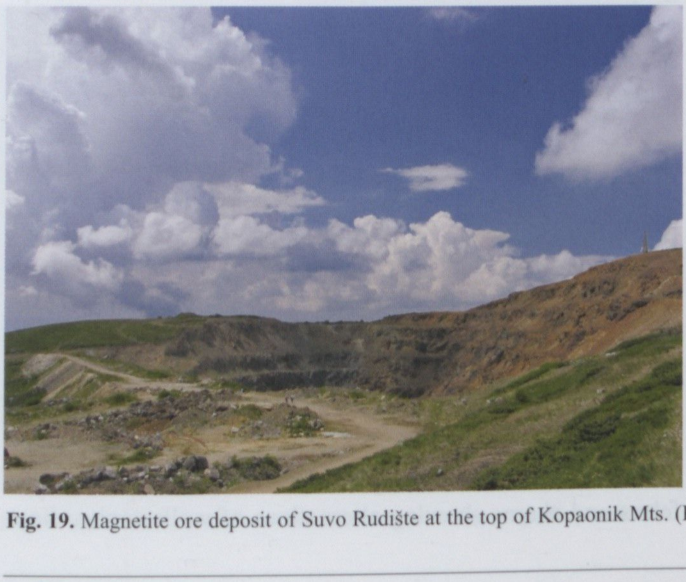


Fig. 19. Magnetite ore deposit of Suvo Rudište at the top of Kopaonik Mts. (Photo by Nada Vasković).

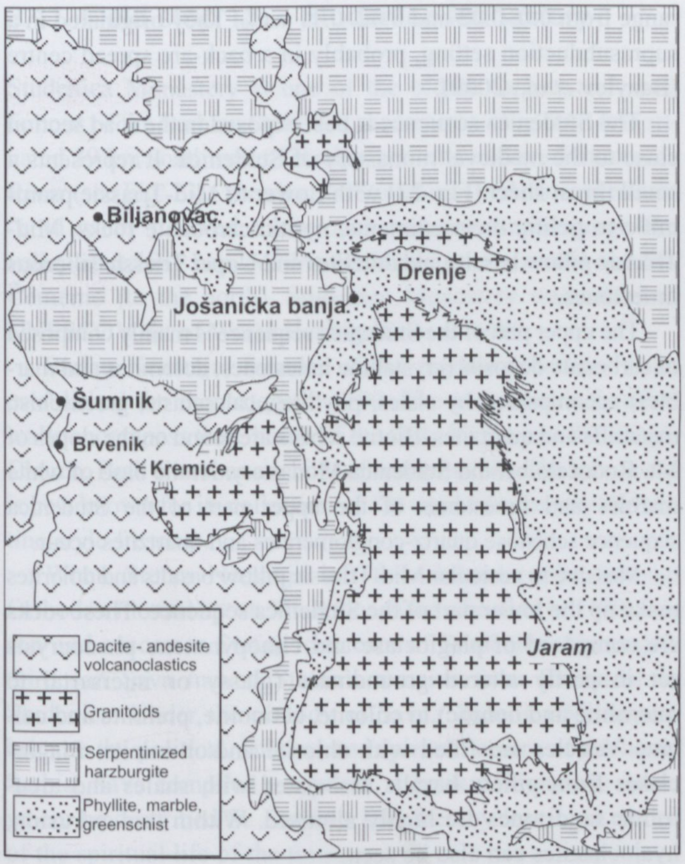

Fig. 20. Simplified geological sketch of the Kopaonik Mts. area showing the distribution of the main granitic bodies.

are believed to be Miocene in age (K/Ar ages range from 18-22 Ma). However, recent U-Pb data (Senecio Shefer, unpublished) suggest that the isolated masses of Drenje and Željin are also Oligocene in age and that they were probably formed at the same time as the main Kopaonik mass. Therefore, the peraluminous granite of Polumir, situated 15 km northern of the Mount Kopaonik, remains the only Miocene (<20 Ma) granitoid in the area.

The main granitoid mass of Kopaonik Mts. is a N–S elongated plutonic body intruded into a northward dipping anticline made up of Triassic metamorphic rocks (Fig. 20). The main intrusion displays a zonal distribution of rock types. The southernmost part of the pluton (the deepest part) is represented by porphyritic granodiorite and quartz monzonite, the middle part by mostly equigranular granodiorite and the northernmost part (the shallowest facies) by fine-grained granodiorite to quartz diorite. All field relations among the facies appear to be transitional except in the northernmost area where irregular bodies and dykes of diorite and quartz diorite composition occur.

In general, these granitoid rocks consist of quartz, andesine, K-feldspar (Or > 86%), biotite (Mg# ~55) and magnesio-hornblende as main, and titanite, epidote, allanite, apatite, zircon and magnetite as accessory minerals. A porphyritic texture developed through the appearance of large microperthitic K-feldspar grains, often as large as 3×5 cm. Transitions between more and less mafic facies are mostly gradual, but in places there is evi-

Fig. 21. A granitoid boulder rounded by weathering at the northern slopes of Kopaonik Mts. (Photo by Nada Vasković).

dence of the coexistence of two different magmas (crystal mushes?) – *e.g.* sharp but irregular contacts between compositionally different facies, large K-feldspar grains enclosed in a more mafic domains, etc. These granites are often weathered and along the northern slopes of Kopaonik Mts. numerous boulders rounded by weathering processes are found (Fig. 21).

3.9. Field stop 9. KU – Mid- to Late Triassic low-grade metamorphic rocks (Jošanička Banja)

About 4 km west of Jošanička Banja, in the sections cut by the road, the KU is exposed. The Mid-Late Triassic *i.e.*, Carnian to Norian (Sudar, 1986) rock sequence is composed of sericite-chlorite schists, subordinate chlorite-epidote-actinolite schists, metabasalts and thin-bedded crystalline limestones. Limestones make up the middle and uppermost parts of the sequence and contain intercalated pelite/psammite sediments. This sequence probably represents distal continental shelf deposits with rifting-related basalts. The whole metasedimentary sequence is also slightly contact metamorphosed because of the influence of the Kopaonik granitoid body.

The section in the road-cut comprises slates, phyllites, metasandstones and limestones (Fig. 22). Intercalation of pillow basalts and limestone occurs on the slope above this point. Northwest from the village of Županj, these limestones are composed of Carnian (Middle Cordevolian, Julian and Tuvalian) conodonts.

3.10 Field stop 10. KU – The Studenica sequence

At Biljanovac we will enter the Western Vardar Ophiolitic Zone (WVZ) and pass through serpentinised spinel harzburgites, which build up the southwestern flanks of the large ophiolite complex of Stolovi (Bazylev *et al.*, 2009). Serpentinised

Fig. 22. Slightly metamorphosed limestones and fine-grained metaclastites about 4 km west from Jošanička Banja (Photo courtesy of Kristina Šarić and Vladica Cvetković).

spinel harzburgites crop out along the road from Biljanovac to Ušće and further to the north along both sides of the Ibar River valley as far as Kraljevo. These rocks show the limited compositional variation of primary minerals (Bazylev *et al.*, 2009): the range of Cr# in the spinels is 0.45–0.50; the Mg# of the olivines is ~91.1; the alumina range of the orthopyroxenes is 2.7–2.8 wt%; and Na_2O and TiO_2 in the clinopyroxenes range from 0.0–0.02 and 0.02–0.11 wt%. They originated in a suprasubduction setting, probably in a back-arc spread centre (Bazylev *et al.*, 2009).

The Studenica sequence is best exposed in the road section close to the medieval monastery of Studenica. It represents a small thrust sheet (Fig. 23) with Lower to Mid-Triassic psammitic to pelitic metasediments, neritic carbonate rocks, Mid-Triassic pillow basalts and dolerites and Upper Triassic siliceous limestones.

The upper part of the Studenica sequence is mainly composed of carbonate deposits (crystalline limestones, dolomites and marbles) accompanied by slates, phyllites, calcschists, greenschist, metatuffs and quartzites. Biotite schists are found on the slopes of Mt. Rodočelo behind Studenica Monastery. At the base of white marbles and limestones of the upper part of the Studenica sequence schistose quartz-conglomerates and quartzites occur.

Massive to vesicular Mid-Triassic pillow basalts and dolerites make up the lower part of the Studenica sequence. These rocks are composed of plagioclase and clinopyroxene phenocrysts set in partly altered groundmass (glassy or intersertal to microlitic and ophitic) to chlorite, actinolite, prehnite and calcite. Vesicles are filled with chlorite and/or calcite. Plagioclases from pillow basalts associated with shales and aleurolitic sandstones are highly albitised. Within this extrusion, hyaloclastites can also be seen.

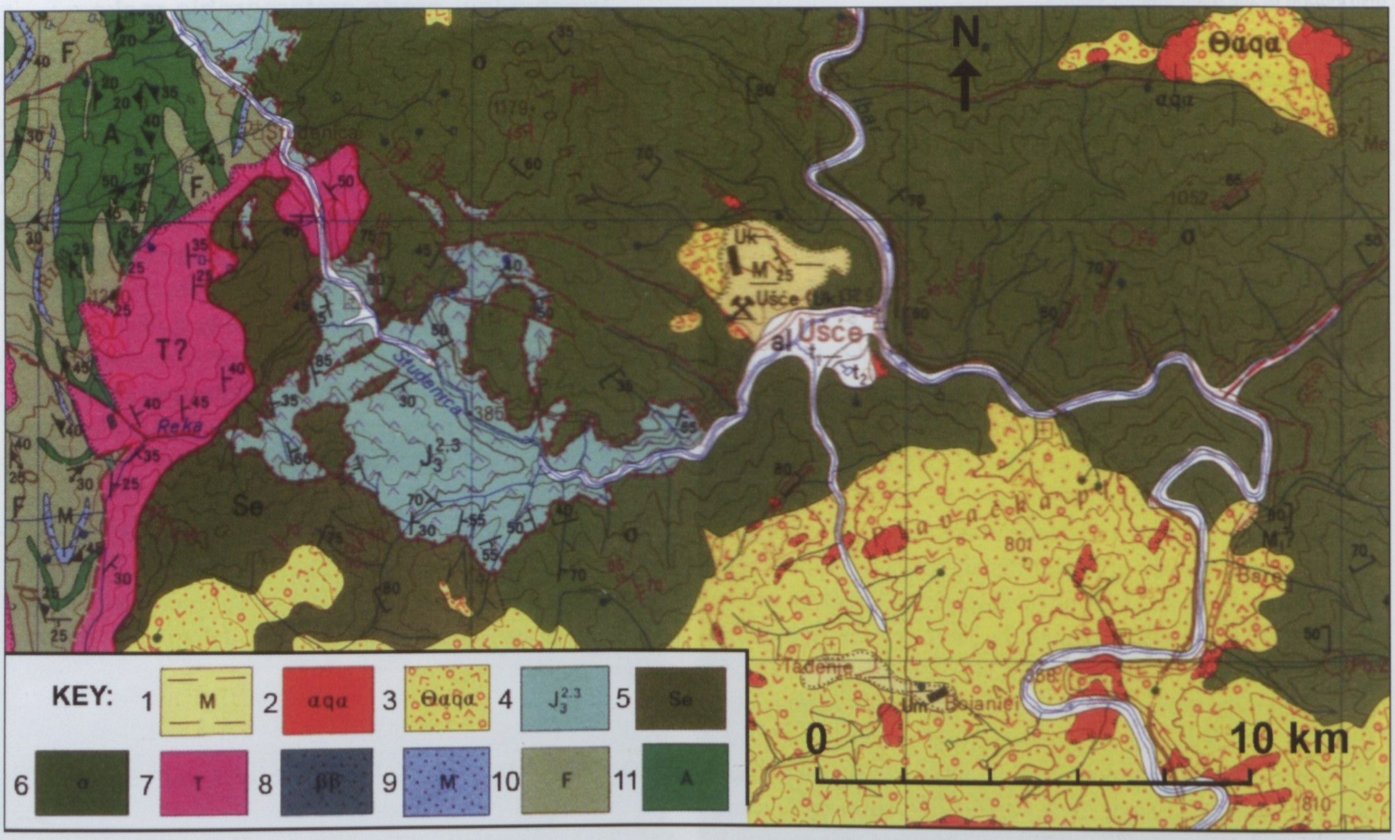

Fig. 23. Geology of the Studenica series (Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Vrnjci, Urošević *et al.*, 1973a).

Key: 1 – Conglomerates, sandstones, shales, marls; 2 – Dacite-andesites; 3 – Pyroclastites; 4 – Mélange: shales, marls, sandstones, cherts, limestones and diabases; 5 – Serpentinites; 6 – Serpentinised harzburgites; 7 – Limestones, dolomites and marbles; 8 – Metabasalts; 9 – Marbles and calcschists; 10 – Sericite-chlorite schists, phyllites, slates; 11 – Amphibolites and amphibole schists.

3.11 Field stop 11. – Studenica Monastery

Studenica Monastery is one of the oldest, largest and most famous of the Serbian Orthodox monasteries (Fig. 24). It is situated 39 km southwest of Kraljevo, in the valley of Studenica River (see Fig. 23). The river of Studenica (in Serbian it means "cold water") carved a long and deep arc-shaped gorge-like valley stretching between Mt. Radočelo (to the south) and Mt. Čemerno (to the north). Studenica Monastery was added to UNESCO's list of World Heritage Sites in 1986.

Stefan Nemanja, founder of the medieval Serbian state, established the monastery in 1190. The monastery's fortified walls encompass the Church of the Holy Virgin and the King's Church. Both churches are built of white marble. The monastery is best known for its collection of 13^{th}- and 14^{th}-century Byzantine-style frescoes.

When Stefan Nemanja left for Chilandar (the Serbian Orthodox monastery on Mt. Athos, where he died in 1199), his son and successor Stefan took care of Studenica. Nemanja's third son Sava moved Stefan's remains from Chilandar to Studenica. Under the custody of Sava, Studenica Monastery became the political, cultural and spiritual centre of medieval Serbia. Sava compiled a typikon, a book of monastic rules, where he described St. Simon's life, thereby leaving a record of the spiritual life of the time.

King Radoslav added to the church a splendid narthex in 1235 and King Milutin built a small but gorgeous church dedicated to St. Joachim and St. Anna.

During the long period of Turkish domination (1459), the monastery was often attacked and severely damaged. It was restored in 1569, when the frescoes in the Church of the Holy Virgin were repainted. In the early 17^{th} century, an earthquake and fire damaged the monastery, destroying a number of historical documents and frescoes.

The Church of the Holy Virgin is a domed single-nave basilica. Its eastern end has a three-sided apse, while an extended narthex faces west. There are also vestibules on the north and south sides. In the 1230s, a large exonarthex was added. The facades were built of slabs of white marble; the interior walls were revetted with tuff blocks. The Church harmoniously combines two architectural styles: Romanesque and Byzantine. The blending of these two styles is known as the "Raška" style.

The church of St. Joachim and St. Anna was constructed in 1314, in the form of a compressed cross, with the exterior structure of an octagonal dome. It is built of stone and tuff, with plastered facades.

The monastery buildings also include the small single-nave Church of St. Nicholas with frescoes from the 12^{th} to early 13^{th} centuries. Between the Church of St. Nicholas and the King's Church remains of the Church of St. John the Baptist can be found. West of the Church of the Holy Virgin stands an old refectory made of rubble. Finally, on the west side there is a bell tower, built in the 13^{th} century. Remains of frescoes on the external part of the narthex show the genealogy of the

Fig. 24. Studenica Monastery. (Photo by Vesna Matović)

Fig. 25. Frescoes of King Stefan Milutin and Crucifixion in Studenica Monastery (west side).

Nemanjić dynasty (Fig. 25). To the north of the refectory is the monastic living quarters and lodge dating from the 18^{th} century – now a museum with a number of priceless exhibits from the Studenica treasury.

After visiting Studenica Monastery, we shall return to Jošanička Banja Spa and then to Kopaonik holiday resort where participants will be accommodated. Jošanička Banja Spa is situated on the western slope of Mount Kopaonik at an altitude of 555 m and has all the features of a health resort. It boasts natural hot mineral springs with water temperatures from 36 to 88 °C. The mineral waters of Jošanička Banja can be used on their own or for the prevention and treatment of various illnesses and diseases.

Day 3

Western Vardar Ophiolitic Zone (WVZ, Kopaonik area)

The Western Vardar Ophiolitic Zone (WVZ) *sensu lato* represents a large region of ophiolites and mélange (Karamata, 2006; Fig. 3). It is generally supposed to be the remnant of a single oceanic back-arc basin (Karamata, 2006; Bazylev *et al.*, 2009).

The WZV is relatively narrow in the Kopaonik area, where it is located between the Drina–Ivanjica Unit and the Kopaonik Unit (Fig. 3). The ultramafic massifs it contains (Banjska, Troglav–Stolovi and Trnava, Fig. 4) range in composition from spinel lherzolites (Banjska) to spinel harzburgites (Troglav–Stolovi, Trnava). All of them originated in the same geodynamic setting, probably in a back-arc spread centre (Bazylev *et al.*, 2009).

The mélange between Raška and Novi Pazar is mainly composed of blocks and olistoliths of sandstone, chert, gabbro and basalts set in a clayey-silty to very low-grade clayey-argillaceous matrix.

Aside from their granitoid formation, the areas south and west of Kopaonik Mts. experienced extensive Oligocene ($\geq$ 30 Ma) to Oligocene/Miocene ($\leq$ 25 Ma) volcanism of an intermediate-acid and calc-alkaline character (andesite-dacite, quartz latite) and later Oligocene/Neogene volcanism of basic composition (basalts and andesitic basalts). The andesitic rocks of the early volcanic phase occurring to the west of the Kopaonik granitoid mass are in places contact-metamorphosed and hydrothermally altered under its the influence (Figs. 20, 26).

In the area between Biljanovac and Raška, Oligocene andesites can be found interrupted by the Upper Oligocene–Miocene Jarandol Basin (coal, sedimentary magnesite and borate deposits) – Fig. 26. The Jarandol basin (200 km^2) extends from Ušće in the north to Raška in the south and ~10 km to the west and 3 km to the east of Baljevac. It probably developed in the Oligocene period due to the collapse of the Dinaridic orogen and stabilised in the Miocene. A large part of the basin is filled with mainly contemporary calc-alkaline dacite-andesite rocks and volcano-sedimentary (lacustrine) rocks and host borates (Piskanja deposit).

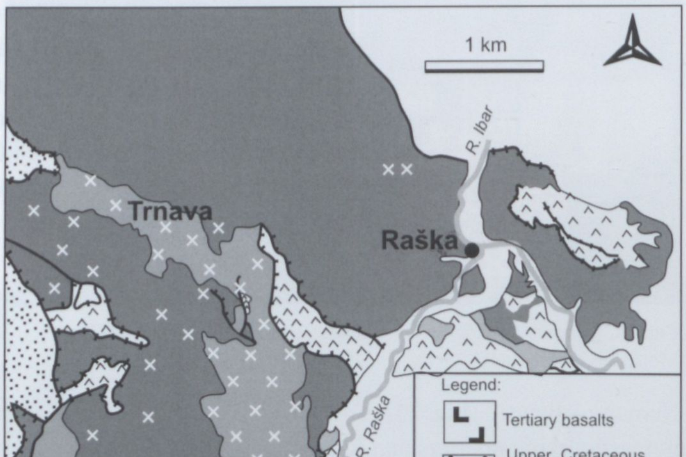

Fig. 26. Simplified geological map of the area Raška–Novi Pazar–Sopoćani (according to the Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Novi Pazar, Urošević *et al.*, 1973b).

3.12 Field stop 12. WVZ – Oligocene andesites (Brvenik, Šumnik quarry; adopted from Cvetković et al., 2009)

A few kilometers after Boljevac, at the crossroads and confluence of the Brvenica and Ibar rivers, there is a large andesite outcrop (Šumnik quarry, Fig. 27).

Fig. 27. Andesites of Šumnik.
(Photo courtesy of Kristina Šarić and Vladica Cvetković)

The andesites of Šumnik are products of the Early Oligocene volcanic phase ($\geq$ 30 Ma) and most probably represent relicts of thick lava flows. Deeper masses of such extrusions usually produce columnar jointing whereas their roof and lateral portions are autobrecciated. These autoclastic deposits are commonly misinterpreted as pyroclastic rocks.

The andesites are mostly fresh. The holocrystalline groundmass comprises phenocrysts of plagioclase (45–52% An), hornblende, and subordinate clinopyroxene (augite) with magnetite and apatite as accessories. Very slight argillitisation and chloritisation are noted. Detailed data on its geochemistry and age are needed and its very origin is still an open question.

WVZ – Trnava ultramafic massif and mélange (Raška–Novi Pazar)

Along the Raška-Novi Pazar road we will see units of the WVZ: the Trnava ultramafic massif and mélange (or so-called Diabase-Chert Formation) comprising blocks and olistoliths of various sediments, dolerite, gabbro-dolerite, gabbro and serpentinised harzburgite (Fig. 26). Cumulate peridotites are found only as fragments at the southern margin of the massif.

The Trnava massif (15×8 km) is mainly composed of serpentinised spinel harzburgites with subordinate spinel lherzolites and rare dunites sometimes with chromitite segregations (Popević, 1971). According to Bazylev *et al.* (2009) the spinels have a Cr# of 0.31–0.43; the olivines Mg# range from 90.2–91.0; the orthopyroxenes contain 2.5–3.3 wt% of Al_2O_3, and the clinopyroxenes are low-Ti (0.07–0.10 wt% TiO_2) and low-Na (0.08–0.11 wt% Na_2O). The fragments of cumulate peridotite are plagioclase lherzolite and the olivine has an Mg# of 78.7.

3.13 Field stop 13. WVZ – Trnava ultramafic massif and mélange: Mélange and fine-grained gabbro block (~3.5 km from Raška)

In the area of Raška, the mélange is composed of sheared turbidites interbedded with sheared red mudstones. The phacoidal fabric of sandstones is a consequence of layer-parallel extension. These sandstones are intercalated with green and red sheared chert up to two metres thick.

At this field stop we will observe the contact between the mélange and the gabbro. The contact is sharp due to sliding of the gabbro block into the mélange. The gabbro is medium- to fine- grained and is composed of altered An-rich plagioclase and mostly uralitised clinopyroxene. The mélange is represented here by mudstone with mainly elongated ellipsoidal blocks of sandstones and subordinated fragments of other rocks. A two-metre-thick horizon of sheered and deformed green and red cherts can be seen within the mélange.

About 6 km further along the road, a second block of medium-grained gabbro dissected by diabase dykes on its west side appears in the mélange. Going further to the southwest, along both sides of River Raška, an alternation of serpentinised harzburgite with gabbros, as well as gabbros and dolerite dykes, can be observed. This large gabbro-dolerite mass extends in a NW–SE direction and probably represents the upper part of the oceanic crust.

3.14 Field stop 14. WVZ – Trnava ultramafic massif and mélange: Gabbros, serpentinites and mélange (9 km from Raška)

Along a 200-metre section of road, multiple alternations of serpentinites and gabbros can be seen. Serpentinised harzburgite overlays gabbro. Sub-automorphic to ophitic gabbro is fine- to medium-grained, rarely coarse-grained and comprises altered pyroxene (hypersthene, augite) and An-rich plagioclase. Within the serpentinites, smaller blocks and lenses (up to 50 cm) of rodingite are found.

The sedimentary rocks are well stratified and comprise mostly grey to greenish or dark brown sandy siltstones and siliceous shales with subordinate sandstones. The other parts of the section are represented by a mélange containing abundant sandstone, occasional dolerite, and blocks settled in a very low-grade clayey-argillaceous matrix. Within the mélange, on the left side of the road, you can see a chert olistolith (5×5 m).

3.15 Field stop 15. WVZ – Trnava ultramafic massif and mélange: Pillow basalts and mélange (13 km from Raška)

There is quite a thick zone of dolerite and not very well developed pillow basalt. At this point the pillow lavas are exposed to the east and the olistostrome-mélange to the west. The olistostrome-mélange is represented by blocks of sedimentary rocks, mainly sandstones, and in places by dolerite in clayey-silty matrix.

After the mélange we will enter the Maastrichtian (–Palaeocene?) flysch (known as Kosovska Mitrovica Flysch), which is a transgressive formation over the WVZ in the east and over the Drina–Ivanjica Unit in the west. The contact is tectonically disrupted. It is mostly made up of sequences of sandstone at the base graduating to shale at the top. The flysch is only slightly folded, but intensive folding is visible locally in the upthrusting zones.

3.16 Field stop 16. Church of St. Peter and Đurđevi Stupovi Monastery

At the entrance to the town of Novi Pazar stands one of the oldest Serbian churches (9th or 10th century), Church of St. Peter (*Petrova crkva* in Serbian, Fig. 28a), closely associated with Stefan Nemanja. Its walls are covered with frescoes from the 10th to 12th centuries. In architectural style, it is similar to the churches built in Georgia and Armenia between the 7th and 9th centuries, but due to later reconstructions and extensions it acquired a unique shape and therefore was included in the UNESCO world heritage list in 1979.

On a hilltop overlooking Novi Pazar is the 13th-century Monastery of Đurđevi Stupovi (Fig. 28b), which was founded by Stefan Nemanja. The architecture of the monastery combines the Byzantine and Romanesque and has recently been restored.

After visiting Đurđevi Stupovi we will travel through the Maastrichtian flysch for about four kilometers toward the town Novi Pazar.

Novi Pazar is located in the region of Sandžak (Fig. 29). Its name means "new bazaar". The town probably began its own life as an informal trading enclave, affiliated to the nearby

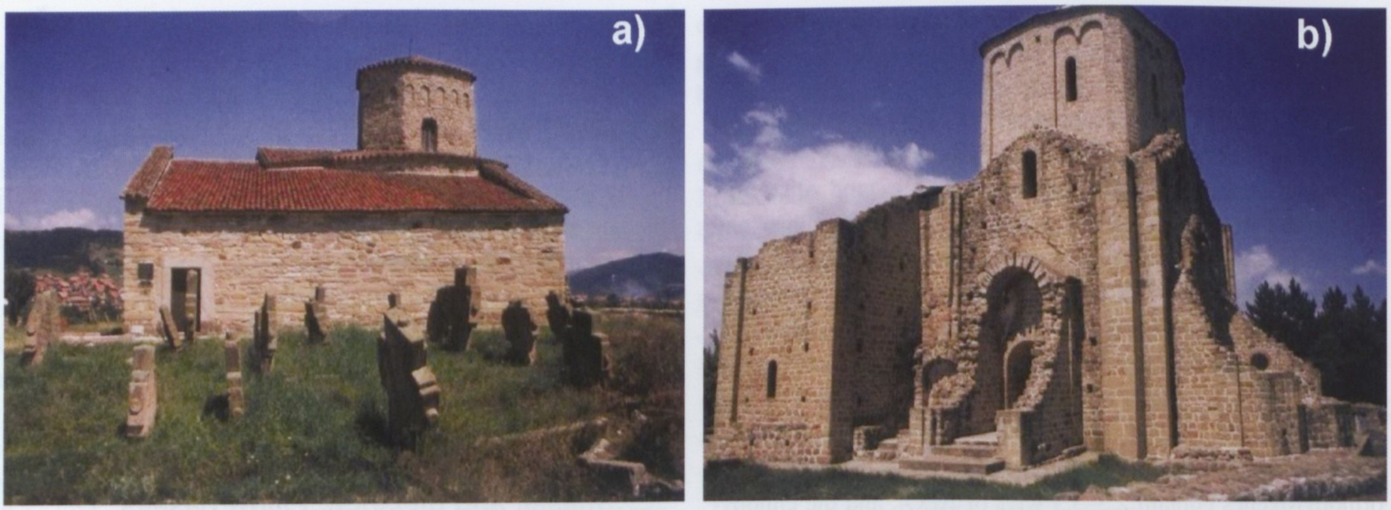

Fig. 28. The 9th century St. Peter Church with graveyard and frescoes (left) and the 12th century Monastery of Đurđevi Stupovi (right).

Fig. 29. The town Novi Pazar – a part of the downtown with a hotel on River Raška.

medieval capital of the Serbian Kingdom, Ras (now called Stari Ras). Novi Pazar was formally founded as a city in its own right in 1459–1461 by Isa-beg Ishaković, who was also the founder of the city of Sarajevo (Bosnia). The city was the capital of the Ottoman Sanjak of Novibazar that existed between the 15th and 20th centuries. The Sandžak of Novibazar was occupied by the Austro-Hungarian Monarchy in 1878 and had been administered by the Monarchy until 1908, when it was returned to the Ottoman Empire, which dominated this territory till the First Balkan War (1912).

The fine Altun-Alem mosque is the largest in this part of the Balkan Peninsula and dates back to the 16th century. There are also numerous historic Ottoman buildings, such as the fine Amir-Aga Han (lodge) from the 17th century, a hammam (Turkish bath) from the 15th century, and the Turkish fortress built in 15th century (destroyed except the walls, where now a pleasant walled park can be found in the city centre).

After crossing through Novi Pazar, we will visit the Sopoćani Monastery, which is located about 17 km to the southwest.

3.17 Field stop 17. Sopoćani Monastery

The Sopoćani Monastery (Fig. 30), a foundation of King Uroš I of Serbia, was built in the second half of the 13th century, near the source of the Raška River in the region of Ras – the centre of the medieval Serbian state. King Uroš I strengthened the state by fixing its boundaries and promoting its economy, especially by silver and lead mining. The church is dedicated to the Holy Trinity and was completed around 1265, the interior being decorated shortly thereafter. Archbishop Sava II, who became the head of the Serbian Orthodox Church in 1263, is represented in a procession of archbishops near the altar. The frescoes of Sopoćani are considered to be the most beautiful and famous examples of European painting of the age. What the painters of Sopoćani attained in linearity and colouring was surpassed only by the Italian Renaissance.

On the western wall of the nave is a famous fresco called the Dormition of the Virgin (this fresco is under UNESCO protection). In the 16th century the monks left the monastery several times due to the Ottoman threat. During one raid in 1689 the Ottoman Turks set fire to the monastery and carried away the lead from the roof the church. The monks escaped with some important relics to Kosovo. The monastery remained deserted for more than two hundred years, until the 20th century. The church slowly decayed. Finally, during the 20th century the monastery was restored and today it is inhabited by a thriving fellowship of dedicated monks. Because of the fact that most of the Sopoćani frescoes still shine with radiant beauty – surviving more than two centuries of extreme exposure to the elements, many consider this nothing less than a divine miracle. Among them the most impressive are the Crucifixion, the Founder's Composition, the Resurrection, the Apostles, and Christ appearing to the Women after the Resurrection, the Death of the King's mother Anna Dandolo in the narthex and the frescoes portraying King Dušan and his family in the outer narthex

The design of the Church of Holy Trinity conforms to the building style of 13th-century Serbian churches, an advanced

Fig. 30. Sopoćani Monastery, a) Apostle Philip, a fresco formerly known as "Lepi Jovan" (Handsome Jovan).

form of the Raška style with a clear Romanesque influence. The church is built of travertine. Since 1979 the monastery has been under UNESCO protection.

Drina–Ivanjica Unit (DIU)

From Sopoćani we will return to the Novi Pazar – Sjenica road and at Dojeviće Spa we will enter the Drina–Ivanjica Unit, which extends as far as Duga Poljana (Figs. 31, 32).

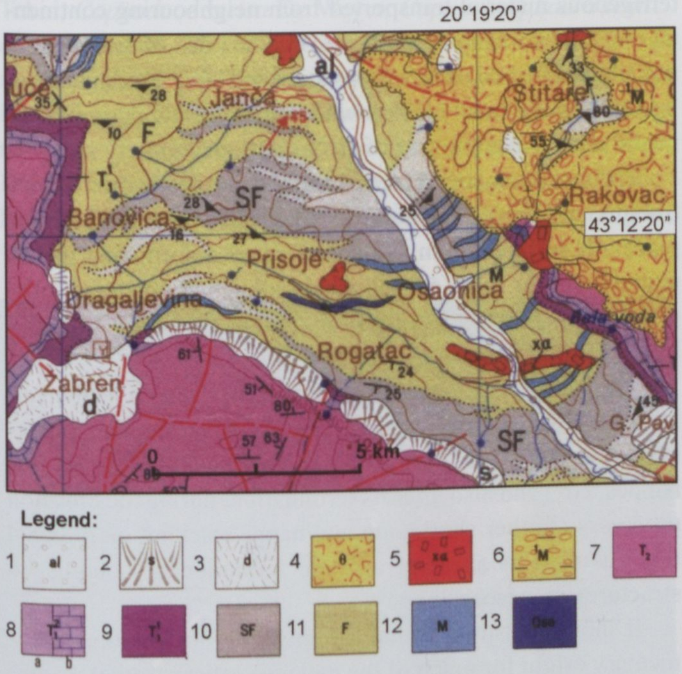

Fig. 31. Geological map of the Osaonica area (Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Sjenica – Mojsilović *et al.*, 1965).

Legend: 1. Alluvium; 2. Alluvial fan; 3. Deluvium; 4. Volcanic breccia and tuff; 5. Quartz latite; 6. Conglomerate and sandstone; 7. Limestone; 8. Limestone: a) oolitic; b) clayey; 9. Quartz conglomerate and sandstone; 10. Phyllites, metaaleurolite, metasandstones; 11. Phyllite; 12. Marble; 13. Sericitic quartzite

As mentioned in the introduction, the DIU is situated between the DOB and the WVZ. It is composed of low-grade metamorphosed Early Paleozoic to Middle Carboniferous terrigenous sediments (arenite, siltstone, shale, rarely quartz conglomerate), with subordinate basaltic rocks and limestones. These Paleozoic units were covered by Triassic, mainly carbonate, sediments. The DIU was probably the northeastern part of Adria block from the Carboniferous until the Ladinian. During the Late Ladinian period, it was separated and the Dinaridic ophiolite basin (as a marginal sea) originated between the main part of Adria block and the DIU. Mainly Triassic shallow-water carbonate sediments were deposited on the DIU. After closure of the Dinaridic ophiolite basin, the DIU rejoined the Adria block in the Upper Jurassic.

3.18 Field stop 18. DIU – Paleozoic low grade metamorphic rocks (Osaonica)

Folding of the Drina–Ivanjica Paleozoic rocks during the Variscan and Alpine orogenesis created at least three generations of folds (Đoković, 1996). The first generation (Variscan) is relatively poorly preserved in the area between Novi Pazar and Duga Poljana. Their re-folding during Alpine tectonic movement caused the formation of gentle m-dm sized folds (second generation) and accordion folds (third generation).

The area between Novi Pazar–Osaonica–Duga Poljana is composed of low-grade metamorphosed pelitic, arenitic, aleurolitic and carbonate rocks, with thin lenses of metamorphosed coarse-grained quartz conglomerate also visible (Figs. 31, 32). The only recognisable sedimentary structure is bedding. The 10 to 50 cm thick layers of fine- to coarse-grained clastites metamorphosed into phyllites, sericite-chlorite schist and quartzites. The carbonate rocks transformed into calcschists and marbles. The Lower to Middle Carboniferous age of the carbonate rocks

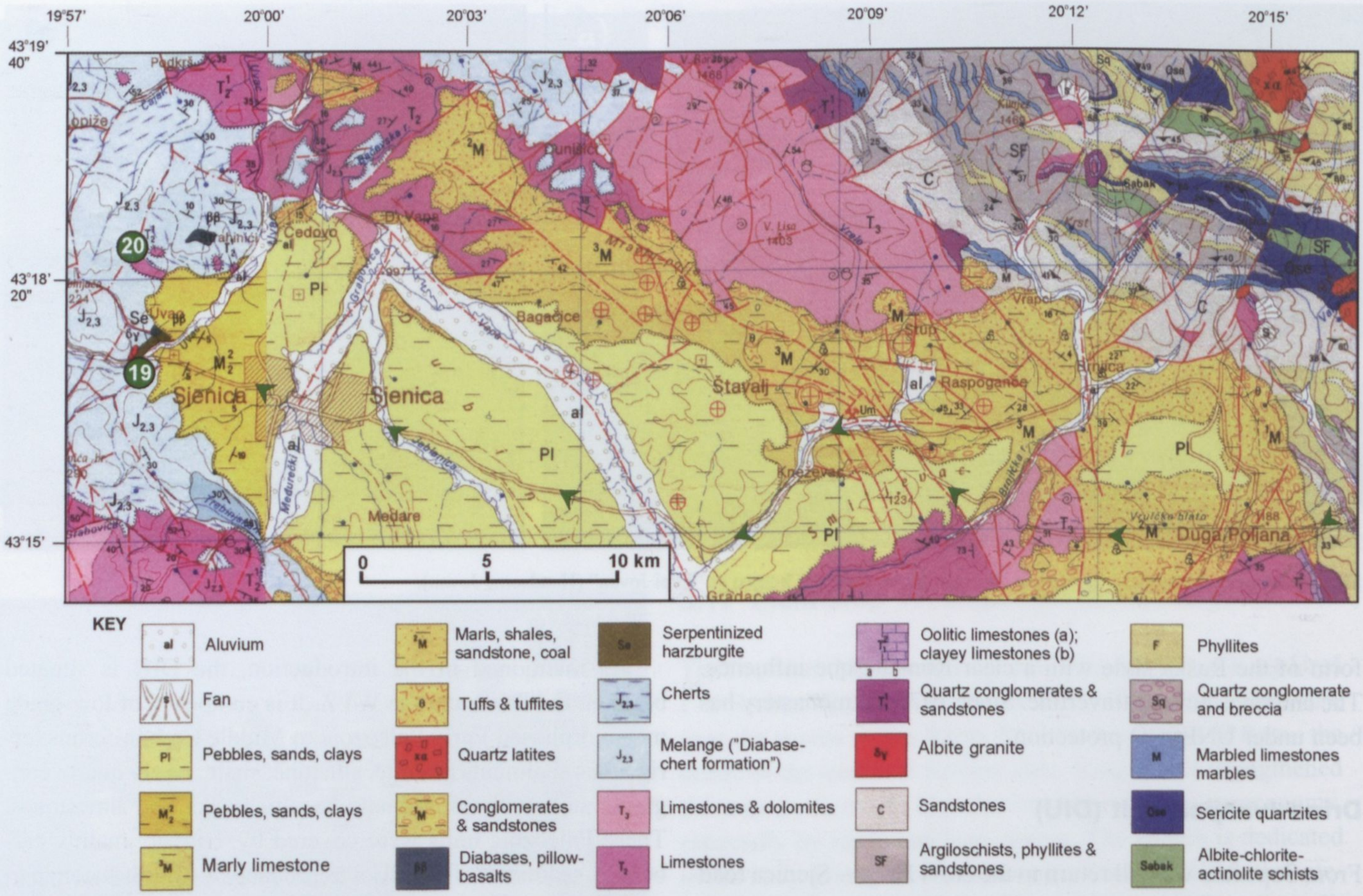

Fig. 32. Geological map of the area between Duga Poljana and Sjenica with field stop locations. (Basic Geological Map of Yugoslavia, scale 1: 100 000, sheet Sjenica, Mojsilović *et al.*, 1965 and Bijelo Polje – Živaljević *et al.*, 1984).

was determined by comparing them to the Golija carbonate (to the north) with its conodont fauna.

Along the road cut southeast from Osaonica, folded phyllites, sericite-chlorite schists and metaarenite have been preserved (Fig. 31). At this stop apical parts of m-sized compressed first-generation folds of with northeastern vergences at an angle higher than 90° can be seen. These folds re-folded to form gentle m-dm folds or were destroyed during the Alpine orogenic movements. Transpositional movement along the cleavage of the axial plane resulted in the formation of accordion folds.

Dinaridic Ophiolite Belt (DOB)

Close to the village of Duga Poljana we will enter the DOB. Towards the south it broadens after the Metohija Depression to continue as the Mirdita–Pindos Ophiolite Belt in Albania and Greece.

In Serbia, the DOB is presented as an assemblage formed in a trench over the subducting crust of the Dinaridic marginal sea. The DOB, originating in the Ladinian period, began to subduct during the Dogger and closed during the Upper Malm. The trench assemblage consists of an olistostrome mélange or mélange (see Karamata 2006; Robertson *et al.*, 2009) which basically comprises all the lithologies that could have entered an area of subduction during its existence. It is composed of terrigenous material transported from neighbouring continental units, rock fragments from the oceanic crust of the marginal sea, ultramafic bodies of various sizes and platy limestone bodies that gravitationally slid down from the neighbouring continental units becoming part of an olistostrome (gravity slice).

The sandy-silty matrix was directly deposited in deep marine troughs and therefore it shows flysch-like features in some places. It suffered from syn-sedimentary deformation due to slumping of the more consolidated sedimentary material (olistostrome mélange) and olistoliths (chert, limestone, diabase-basalt, etc.) gravitationally entered the trench.

This very complex and chaotic assemblage was tectonically reworked, first contemporaneously with subduction (accretionary wedge, obduction of large ophiolite and other exotic nappes, etc.) and also after its termination, during the collision processes (further shortening and nappe stacking on regional scale as well as shearing and the formation of boudinaged structures in mesoscale).

It should be stressed that Karamata (2006) favours a sedimentary origin for much of the mélange (olistostrome) in contrast to Robertson, who advocates its tectonic origin in the northern Balkan Peninsula (see Robertson *et al.*, 2009).

We should emphasise the undoubted existence of sedimentary mélange (*i.e.* olistostrome). It includes examples of graded, matrix-supported conglomerates (polymict debris flows), interbedded with sandstone turbidites and shales as we shall see at the Krš Gradac location, where polymict debris flows were formed most probably as channelised units that were shed with an emplacing ophiolite, together with other lithologies (*e.g.* Permian limestone, basalt, radiolarite).

The area between Duga Poljana and Sjenica belongs to the northern part of the Pešter plateau. It is built up of gravitationally slid Triassic limestone plates (probably from the south) and flat lenses in and over the olistostrome mélange.

The geology of the area between Duga Poljana and Sjenica is shown in Fig. 32.

3.19 Field stop 19. DOB – Chert and albite granite olistoliths (~3 km to the west of Sjenica)

A ten-metre-high chert olistolith can be seen on the left side of the Sjenica–Nova Varoš road (Fig. 33a). The outcrop is located 3 km west of Sjenica. This road section was described by Goričan *et al.* (1999) as a block or olistolith in the mélange. The block on the left bank of the river (just opposite the quarry, about 20 m from a bridge) is composed of an approximately 11-m thick sequence of thin-bedded, reddish to dark green chert with interlayers of siliceous shale up to a few millimetres thick. The contact of this chert-block with the olistostrome comprising rounded subgraywacke fragments in a shaly matrix is sharp and mainly sheared and schistose. Within this chert-block Triassic radiolarians (*e.g. Kahlerosphaera kemerensis* Tekin, *Capnodoce serisa* De Wever, *Capnuchosphaera lenticulata* Pessagno, *Xiphotecaella rugosa* Bragin) of Norian age and conodonts (*Grodella sp. cf. G. deliculata* Mostler) of Rhaetian age were found (Vishnevskaya *et al.*, 2009). These new data imply the existence of an oceanic realm at that time. It must be stressed that a similar Triassic association of radiolarians can be found in Albania (Kellici & De Wever, 1994; Chiari *et al.*, 1996; Marcucci & Prela, 1996, Vishnevskaya, 2001; Bortolotti *et al.*, 2006).

On the opposite side of the road, an olistolith of albite granite (about 100 m in size) with an ophiolitic association is exposed in an old quarry (Fig. 33b). This granite was incorporated into the ophiolite mélange. Contact with the adjacent rocks is obscured. It is mostly composed of albite, quartz and chloritised amphibole (?). The granite is extremely sodic (up to 6–7% of Na_2O and <1% K_2O). The contents of Y and Zr imply its similarity with oceanic plagiogranites (Cvetković *et al.*, 2009).

3.20 Field stop 20. DOB – Olistostrome mélange, Krš Gradac locality (8 km west of Sjenica)

The Krš Gradac section is located on the west side of the road Sjenica–Nova Varoš *i.e.* on the southwest slope of Gradac Hill (Fig. 32). On the road about 8 km from Sjenica and below the road, where a local dirt road branches towards Rainovići, two olistoliths are exposed.

The first olistolith located on the road-cut is of massive Dachstein Limestones (Norian and Rhaetian) with brachiopod and megalodont fauna.

The second olistolith occurs in the creek, below the road. This section from bottom to top is built up as follows: 5-m thick, fine-grained, grey (oolitic in places) and 5–8-m thick, light reddish Liassic limestone (in places similar to intraformational breccia) with gastropods and cephalopods; 0.5–1-m thick Lower Toarcian "ammonitico rosso", rich in cephalopods; hard ground (just above the hard ground, the limestone contains large ammonites); 0.5–1-m thick red radiolarian schists and 2.5-m thick red, green to black radiolarites with a thick bed of graded calcrudite and fragments with Liassic and Upper Kimmeridgian–Portlandian limestones. In the last part of the section, Middle and Upper Jurassic radiolarians dominate (Vishnevskaya *et al.*, 2009). The upper part of the section

Fig. 33. Olistoliths of chert, (a) reddish radiolarite and (b) albite granite, locality Sjenica. (Photo courtesy of Kristina Šarić and Vladica Cvetković).

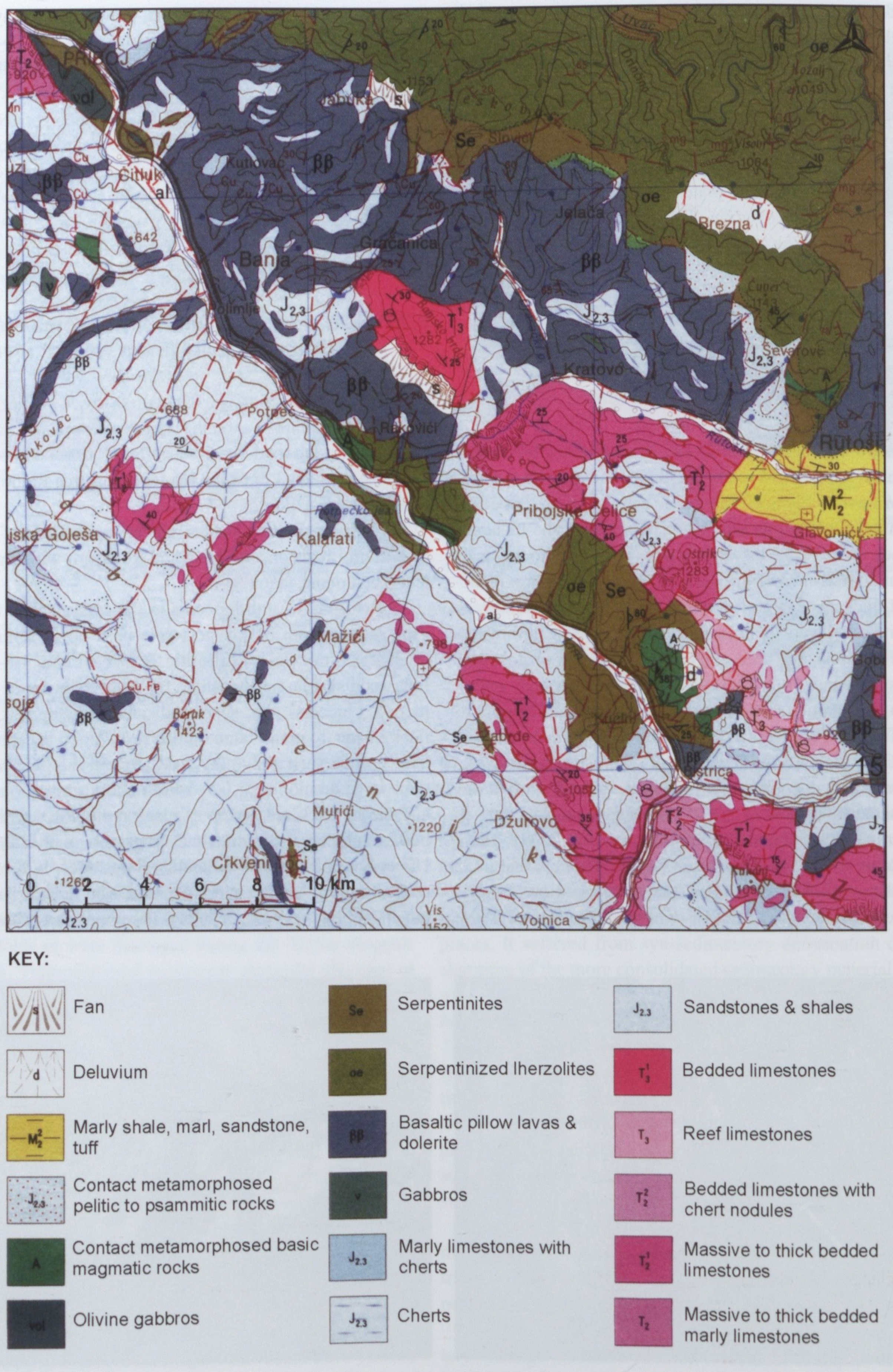

Fig. 34. Geology of the area between Priboj, Bistrica and Prijepolje (Basic Geological Map of Yugoslavia, scale 1: 100 000, sheet Prijepolje, Ćirić *et al.*, 1980).

(18 m thick) is mostly composed of very thin-bedded (5–10 cm, rarely up to 15 cm) red to green–grey clayey chert. This olistolith is overlain by an olistostrome mélange with mostly sandstone blocks. Chert fragments contain Upper Triassic (Carnian–Norian) radiolarians. Northeast of the fault, the olistostrome mélange is tectonised and has a schistose silty-clayey matrix (abounding in rock fragments in the part rich in cherts) with manganese nodules and small fragments of cherts, diabases and sandstones-greywackes.

From this point we will continue to Nova Varoš where participants will be accommodates in the "Vila Jelena".

After Sjenica, on our way to Nova Varoš, along the road, terrigenous members of the olistostrome or mélange (see Robertson *et al.*, 2009) and the matrix are mostly covered by younger sediments. The olistoliths of more resistant rocks (*e.g.* Norian and Rhaetian massive Dachstein Limestones with brachiopod and megalodont fauna; fine-grained to oolitic Liassic limestones, Jurassic to Triassic radiolarian cherts, rarely basalts and conglomerate) can be seen in some places.

A Callovian to early Kimmeridgian radiolarian association was determined in the olistostrome mélange located on the Nova Varoš–Bistrica road (Obradović *et al.*, 1986; Obradović & Goričan, 1988).

Day 4

At present, due to the existence of limited data, the emplacement of ultramafic rocks in relation to the mélange of the Dinaride Ophiolite Belt still remains unsolved. Several ophiolitic massifs of the DOB (*e.g.* Bistrica, in Serbia) are assumed to be part of the extensionally exhumed sub-continental mantle lithosphere that was emplaced during the Late Jurassic–Early Cretaceous period within the mélange together with other ophiolite massifs of the supra-subduction zone type. This idea is mostly based on mineral chemistry data and sparse geochemical data (*e.g.* Bazylev *et al.*, 2006, 2009).

3.21 Field stop 21. DOB – Subcontinental ophiolite and metamorphic sequence (Bistrica)

From Priboj we will travel southeast along the southwestern slope of Zlatibor Mts., mostly composed of olistostrome mélange and peridotite with a metamorphic sole (Fig. 34).

At the left side of the Priboj–Bistrica road, large outcrops of peridotites and metamorphic rocks occur. The true nature of these rocks still remains to be solved. It seems that they are part of an hundreds of metres thick olistolith, whose relationship with other mélanges lithologies, particularly with the matrix material, is hard to examine. However, some of these rocks have been pervasively metamorphosed and could, in turn, be parts of the ancient lower crust exhumed during Triassic rifting and then incorporated during the convergent-collision processes.

The Bistrica tectonic block of about 2×2 km² in size is located on the southwestern slope of the large Zlatibor peridotite massif. It is mainly composed of fertile spinel lherzolites and is highly tectonised in its southern part. Dunite lenses ranging in thickness from a few to more than 100 metres are also found (Fig. 35), as well as occasional layers of pyroxene-poor harzburgite (see Bazylev *et al.*, 2006, 2009). These ultramafics also contain garnet-pyroxenite veins (1 to 10 cm thick) accompanied in some places by spinel hornblendite veins (Milovanović, 1988; Popević *et al.*, 1993). In the northern part these veins show a massive cumulate texture; in the southern part they are tectonised together with the peridotites. Elongated orthopyroxene and olivine porphyroclasts in the peridotites are oriented in a NNW–SSE direction with a SE dip.

The Bistrica spinel lherzolite (Bazylev *et al.*, 2009) are composed of low-Mg olivine (Mg# 89.4–90.3) with a high content of NiO (0.32–0.40 wt%), high-Al orthopyroxene (Al_2O_3: 4.4–5.6 wt%), clinopyroxene (TiO_2: 0.33–0.50 wt%; Na_2O: 0.85–1.7 wt%) and yellowish-brown low-Cr spinel (Cr# 0.10–0.16). The spinel lherzolites in contact with the pyroxenite veins contain fine grains of hornblende intergrown with orthopyroxene. It has been found that the Bistrica spinel lherzolites show similarity with spinel lherzolites from Sjenički Ozren (Bazylev *et al.*, 2009). The values of preliminary two-pyroxene and olivine-spinel geothermometry for the Bistrica peridotites average 886 and 834 °C, respectively. According to the data obtained, Bazylev *et al.* (2009) supposed its formation to have resulted from a continental rift (or extensional) setting.

Apart from the ultramafic rocks, along the road section close to the tunnel there are various exposures of high- to medium-grade metamorphic rocks. Medium-grained granulites composed of basic plagioclase, pyroxenes and garnet appears as blocks measuring tens of metres in thickness. The internal foliation exhibits a NNW–SSE strike and ESE dip and generally runs parallel to the layering in the peridotites, although with differences in some places. On the basis of the garnet– pyroxene–plagioclase compositions, it was calculated that these rocks had meta-

Fig. 35. Outcrop of chromite-bearing dunites, Bistrica. (Photo courtesy of Kristina Šarić)

morphosed at 900 °C maximum temperature and up to 10 kbar pressure (Milovanović, 1988; Karamata *et al.*, 1996b).

Corundum-pargasite-bearing amphibolites occur as blocks about 100 m further from the tunnel and have tectonic contact with the adjacent ultramafic rocks. In addition, they are interbedded with garnet amphibolites. Microscopically, it is possible to distinguish synkinematic and postkinematic growth of pargasite in these amphibolites. Corundum occurs as small pink to violet fine-grained accumulations. The garnet amphibolites are composed of saussuritised plagioclase, hornblende and garnet. These medium-grained rocks metamorphosed under upper amphibolite facies conditions. The garnet is red, measures up to 1 cm in diameter and in some places makes up to 20% of the rock volume. Polyphase crystallisation of the amphiboles and zonality of the garnet with different type of inclusions are visible.

3.22 Field stop 22. DOB – Olistostrome mélange, basaltic breccia olistolith and Triassic "Bódvalenke-type" red, bedded, cherty limestone olistolith (Bistrica; adopted from Cvetković et al., 2009)

About 5 km from Bistrica on the road Priboj–Bistrica road, one specific complex section of olistostrome mélange appears. At this large exposure participants will be able to observe in one place two olistoliths set in a silty-clayey matrix. The matrix contains cm-m-sized elongated and sometimes rounded sandstone fragments, which are typical features of the olistostrome mélange.

The basaltic olistolith is made up of unsorted sub-angular to sub-rounded fragments of basalt ranging in size from a few cm to around one meter (Fig. 36). The basaltic rock is porphyritic, amygdaloidal with abundant voids filled with calcite. The fragments are set in a fine-grained hyaloclastic matrix, which gives the rock an open framework fabric (honeycomb effect?). Although the matrix is much altered (mostly chloritised and calcitised), relicts of glass shards originating from the chilled margins of larger fragments can be seen. This basaltic rock differs in geochemistry from other pillow basalts of the Dinaridic ophiolites in having a more OIB-like composition (see Vishnevskya *et al.*, 2009).

Fig. 36. Olistoliths of basaltic hyaloclastites.
(Photo courtesy of Kristina Šarić and Vladica Cvetković).

On the right side of the road an olistolith of Triassic "Bódvalenke-type" red, bedded, cherty limestone occurs. The outcrop is 30 m long, around 10 m high and 3-4 m thick. Such olistoliths are also found as blocks in the lower sedimentary complex of both the Darnó and Szarvaskő Complexes in Hungary (Grill & Kozur, 1986). It should be stressed that these Triassic "Bódvalenke-type" red, bedded, cherty limestones are more widespread on the surface in the Othrys and North Pindos Ophiolite complexes (Greece, De Wever *et al.*, 1979; Jones *et al.*, 1992). As such they represent another characteristic feature according to which the Dinaridic Ophiolite Belt differs from the mélange of the Vardar Zone.

Further along the road up to the Bistrica–Prijepolje intersection, there are km-long ultramafic slices of serpentinised lherzolites as well as lenses or platy-like bodies of light green dunite rocks composed of partially serpentinised olivine and subordinately ortho- and clinopyroxene and chromite (Fig. 35). The chromite makes bands, elongated accumulations or lenses up to several cm thick.

3.23 Field stop 23. Mileševa Monastery and the Mileševa mélange

From the Bistrica–Prijepolje intersection, we will turn south towards Prijepolje and further east to visit Mileševa Monastery and the chert olistolith in its vicinity.

Along both sides of the Bistrica–Prijepolje road, exposures of two olistoliths of Triassic limestones can be seen. Both are massive or bedded and considerably re-crystallised. Outcrops on the right side of road are Anisian and on the left Ladinian. The second often contains chert nodules, and in some places intercalates with thin (5–10 cm thick) beds of marl. Jurassic mélange dominates in this area. It is composed of olistoliths, blocks and fragments of sandstones, limestones, cherts and igneous rocks (gabbro, pillow basalts) set in a silty (clayey)-sandy matrix. The geology of this area is shown on Fig. 34.

3.23.1 Mileševa Monastery

Mileševa Monastery (Fig. 37) is dedicated to the Ascension of Our Lord and can be found on the River Mileševka, near the city of Prijepolje. It was founded by the Serbian king Stefan Vladislav I in 1235. Here King Vladislav buried the relics of his uncle St. Sava (moved from Trnovo, Bulgaria) in 1236. The king's body is also buried here. In 1594, the Turks removed the holy relics of Serbia's greatest saint, St. Sava, from the monastery and publicly burned them on Vračar Hill in Belgrade, thus making him a posthumous martyr.

Fig. 37. The Mileševa Monastery and its most famous fresco, the "White Angel".

Mileševa Monastery is one of the most important Serbian sanctuaries and spiritual centres. Some historians believe that the coronation of King Tvrtko I of Bosnia took place in Mileševa in 1377. The Monastery was also a famous printing centre at the time of the Turkish occupation. In the first half of the 16th century, the first church service books were illustrated here. In the 15th century, the monastery was the seat of the Metropolitan Bishopric of Dabar and Bosnia. In 1459 the Turks set the monastery on fire, but it was soon restored. One of the oldest schools also existed in the monastery. In the middle of the 16th century, during the time of Patriarch Makarije (the Serbian Patriarchy was restored in 1557), the monastery was thoroughly renovated. Its external narthex was built and painted and probably cut through the wall between the narthex and the nave. In later times, after several Turkish demolitions, a new restoration was undertaken in 1863, when the church considerably changed in appearance. The Church of the Holy Ascension was built in the style of the Raška School.

The first group of frescoes was painted in the 1230s. The other groups, including works from the Turkish period, can be found in the exonarthex. These 13th-century frescoes are considered to rank among the highest achievements of European art of that time.

In addition, in order to attain a realistic effect, the frescoes offer psychological characterisations of their subjects. As in most frescoes, the founder (in this case King Vladislav) is depicted holding a small model of the church. The eyes of many of the figures were gouged out or obliterated by the Turks. Frescoes depicting the Last Judgment were heavily damaged during the Second World War. Scenes from the Passion Week cover large portions of the walls. The church's most famous fresco is the "White Angel", now regarded as a symbol of Serbia (Fig. 37). Around the angel other parts of the Easter story and the Resurrection are depicted. Remnants of a fresco that once covered the scene leads one to speculate that the angel with its enigmatic smile might not have been with us today if it had not been for this preservation.

At a road section about 3 km east of Prijepolje, planktonic foraminifers of the genus *Hedbergella* and poorly preserved Late Tithonian–Berriasian radiolarians were found in blocks of red limestone associated with basalt (see Vishnevskaya et al, 2009).

3.23.2 DOB – Mileševa mélange

Within the mélange close to the monastery along a section of a local road leading to the Mileševka River, olistoliths and blocks of red to grey cherts and red limestones set in a sheared silty-clayey to sandy matrix can also be seen (Fig. 38). The cherts are thin-bedded and highly folded (Fig. 38a).

After visiting the monastery and having a brief look at the Mileševa mélange we will return via Prijepolje to Bistrica on the main Bistrica-Nova Varoš road. This area between Bistrica and Nova Varoš is built up of olistostrome mélange mainly represented by olistoliths of basaltic pillow lavas, gabbros and Upper Triassic limestones.

3.24 Field stop 24. DOB – Pillow lavas and olistolith overlying the mélange (Bistrica)

Close to the Bistrica–Prijepolje–Nova Varoš crossroads and Bistrica Lake dam, some of the best exposed outcrops of Jurassic pillow lavas can be found (Fig. 39). There is a thick

Fig. 38. Mileševa Mélange with limestone olistolith and a block of folded thin-bedded grey chert (a).

(more than 20 m) pile of pillows ranging in diameter from 10 cm to about 1 m. The pillows show a typical glassy margin with tiny normal joints and surrounded by an almost schistose hyaloclastic matrix. The rocks mainly comprise albite, relicts of clinopyroxene, chlorite, epidote and opaque minerals. Meagre geochemical data indicate that these rocks originated from N to EMOR-type magmas (Zakariadze *et al.*, 2006; Vishnevskaya *et al.*, 2009).

The Upper Triassic olistolith situated about 2 km from Bistrica on the right side of the road towards Nova Varoš is composed of red and grey Hallstatt-type limestone (most probably Lower and Middle Norian in age). It overlays the red silty-sandy matrix material of the mélange (Fig. 40). The contact is obviously tectonic and is characterised by plastic deformations of the underlying matrix. This suggests that the olistolith was emplaced as a completely solid body whereas the matrix was most likely still semi-consolidated.

From this point going in the direction of Nova Varoš and further north up to Lake Zlatar (*Zlatarsko Jezero* in Serbian) we will drive through the Mid-Upper Jurassic mélange comprising olistoliths of various size represented by Triassic limestones and Jurassic basaltic pillow lavas of the MOR-type similar to those observed close to Bistrica (Vishnevskaya *et al.*, 2009) – Fig. 41. Huge exposures of these pillow lava olistoliths are best exposed in the area of Crkvina and near Nova Varoš. The relationships between the mélange and the Triassic carbonate units in this area are very complex. The Triassic limestones are preserved as olistoliths in the mélange or as huge

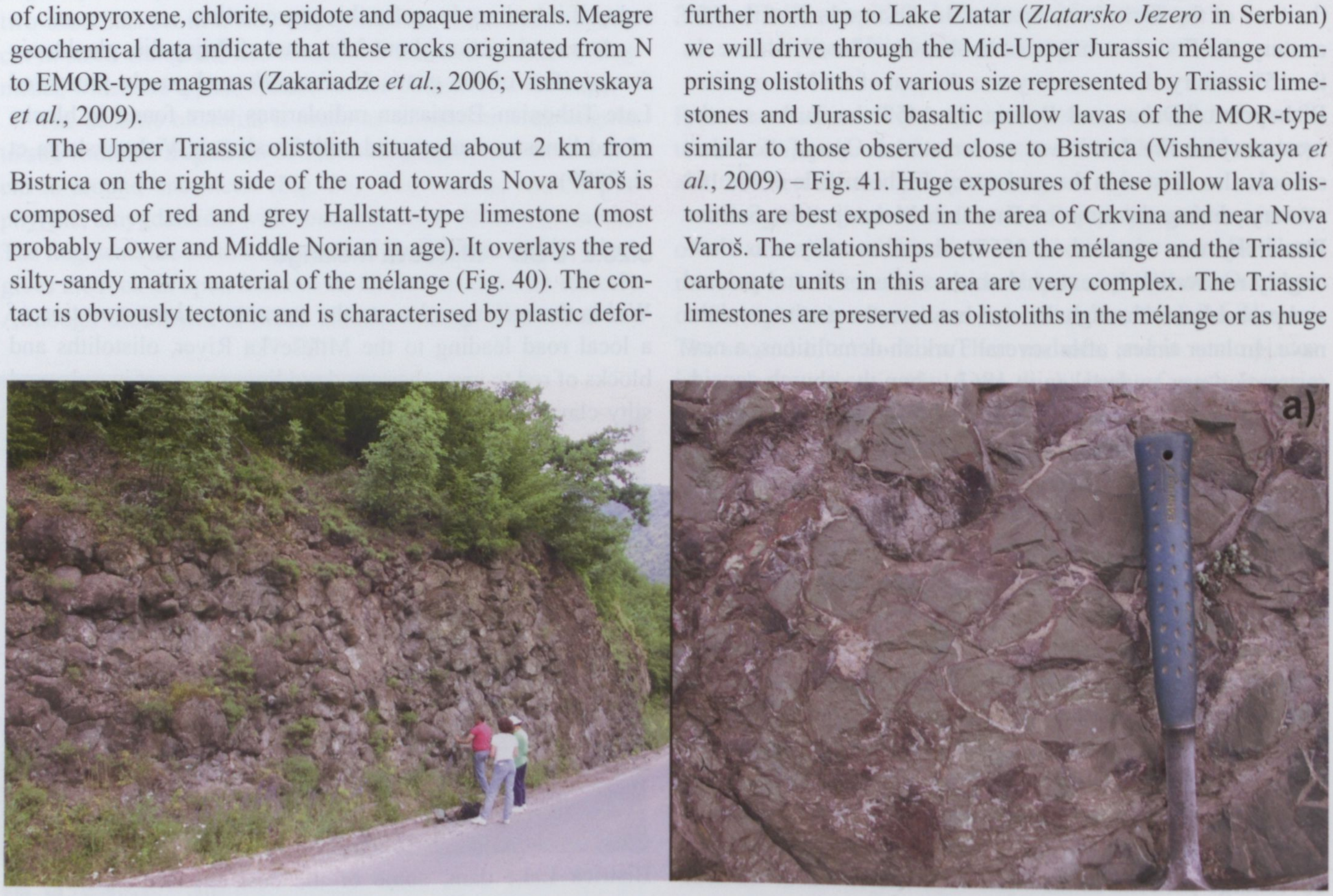

Fig. 39. Pillow lavas near Bistrica and a detail showing the cross section of some pillows (a). (Photo courtesy of Dragan Milovanović)

Fig. 40. A huge limestone olistolith overlying the mélange. (Photo courtesy of Kristina Šarić)

megablocks that were gravitationally transported from the continental Paleozoic base of the DIU into the trough of the ophiolitic mélange during the Late Jurassic period (Dimitrijević *et al.*, 2000). These limestones also appear as huge piles of gravity nappes above the mélange. Beautiful olistoliths of red chert, red silicified siltstone, dark grey siltstones and pillow basalts can be seen in the area of Mt. Zlatar (called the "Zlatar cherts") *i.e.* north of Nova Varoš. The chert olistoliths are mostly about 1 m in size, while red siltstone occurs in 100-m size bodies.

Zlatibor Mts.

Zlatibor Mts. is a pearl among Serbian mountains due to its historical, ethnographical and cultural heritage. This still untouched part of western Serbia can boast exceptional natural beauty. And, indeed, Nature has been generous in this area, providing everything it could – clear water, clean air, golden forests (in

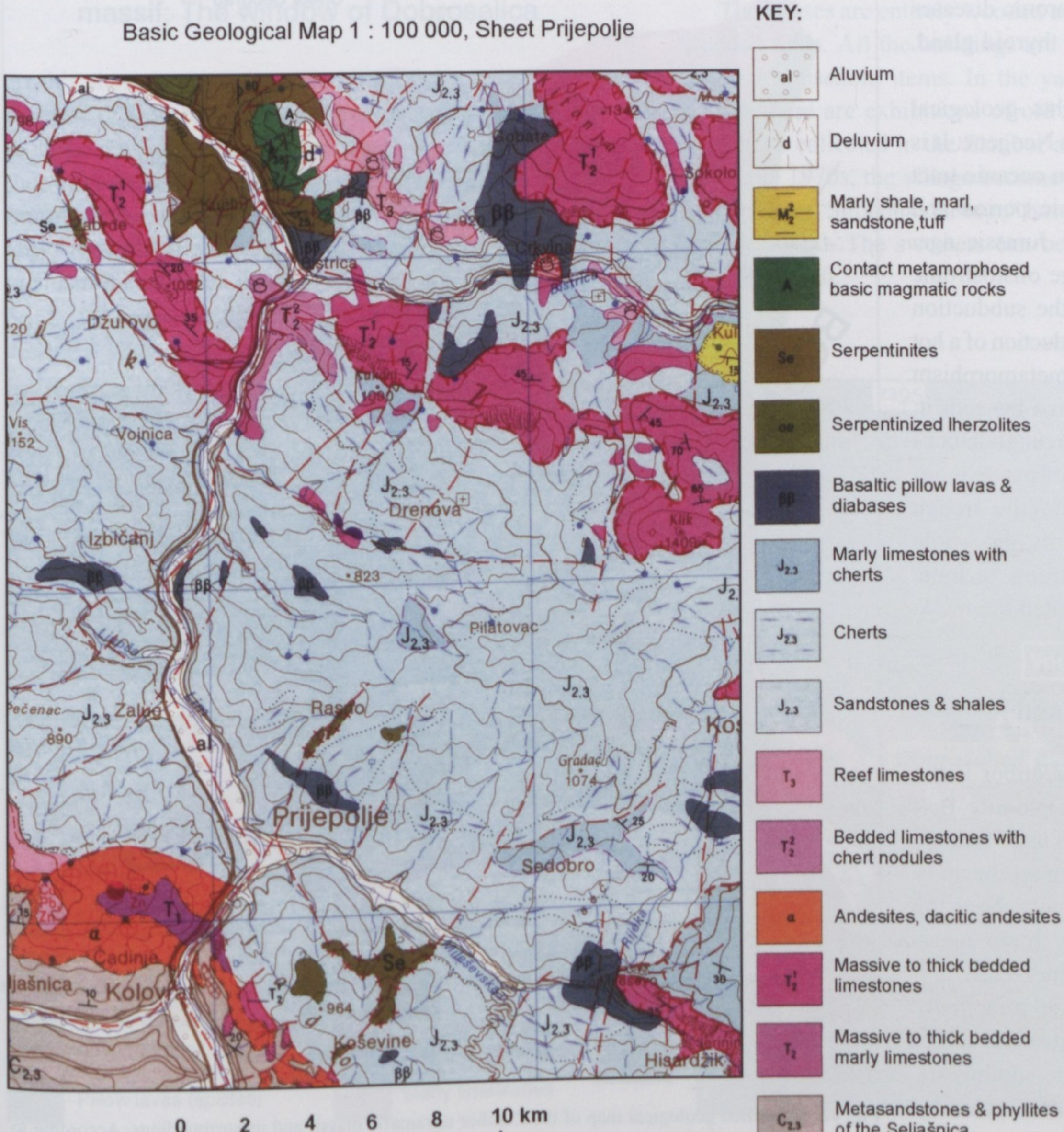

Fig. 41. Geology of the area between Bistrica–Nova Varoš–southeastern flank of Zlatibor Mts. (According to the Basic Geological Map of Yugoslavia, scale 1: 100 000, sheet Prijepolje, Ćirić *et al.*, 1980.)

Serbian "Zlatibor" means Golden Pine – a unique variety of pine: *Pinus silvestris* var. *zlatiborica*) and pastures stretching as far as the eye can see. The mountain spreads over an area of 300 km, is 43 km in length, southeast to northwest, and up to 37 km in width. This is a place where life is still lived in true unity with nature, a place where one can feel the past. The highest peaks are Tornik (1496 m), Brijač (1480 m) and Čigota (1422 m). The average height of Zlatibor Mts. is about 1000 m above sea level. The southern and the eastern borders of Zlatibor are natural – the Unac and Veliki Rzav rivers. To the west Zlatibor borders Bosnia – its villages of Mokra Gora, Semegnjevo and Jablanica mark the border. This mountain has been proclaimed a climatic spa for all acute and chronic diseases of the respiratory organs, thyroid gland, all types of anaemia, etc.

Zlatibor Mts. highlights geological history from Cambrium to Neogene. It is situated at the suture of an oceanic tract opened in the Mid-Trassic period and closed at the end of the Jurassic age. During this closing a huge olistostrome mélange was formed in the subduction trough. Besides this, the obduction of a hot ultramafic body caused metamorphism of the olistostrome mélange beneath it. Moreover, gravitationally huge blocks composed of Triassic platform carbonates were transported into the trough from the DIU. Subsequently the whole area was affected by strong tectonic compression, which disrupted the metamorphic base.

Zlatibor ophiolite massif

The ophiolitic massif of Zlatibor is the largest in the Dinaridic Ophiolite Belt (Figs. 5, 42). It represents a large tectonic slice (20×30 km), overlying sedimentary rocks with high-angle contact. Near the contact point, the country rocks metamorphosed into amphibolite facies.

The Zlatibor Massif is principally made up of spinel lherzolites and spinel harzburgites (mostly in the southwest). Small lenses of dunites accompanied by non-economic chromite ores occur in the southern (Brezna), central (Gornja Jablanica) and northern (Semegnjevo) parts of the massif. The shape of the ore bodies is platy, columnar, lenticular or irregular. The mineralisation is massive, nodular, layered or impregnated. The ore mineral is aluminian chromite (Popević & Karamata, 1996). It is associated with olivine and minor orthopyroxene. Generally, the extension of the ore bodies coincides with the axis of the massif (NNW–SSE).

The ultramafics are intensively fractured and serpentinised at the base of the thrust slice. Grabens are formed along the fault systems stretching E–W and the base is exposed at the surface. Their upper parts are weathered and cut by magnesite veins (Popević & Karamata, 1996). Peridotites from the central part of the massif are slightly to moderately serpentinised and contain relics of primary minerals.

According to data from Bazylev *et al.* (2009) the Cr# in the spinels ranges

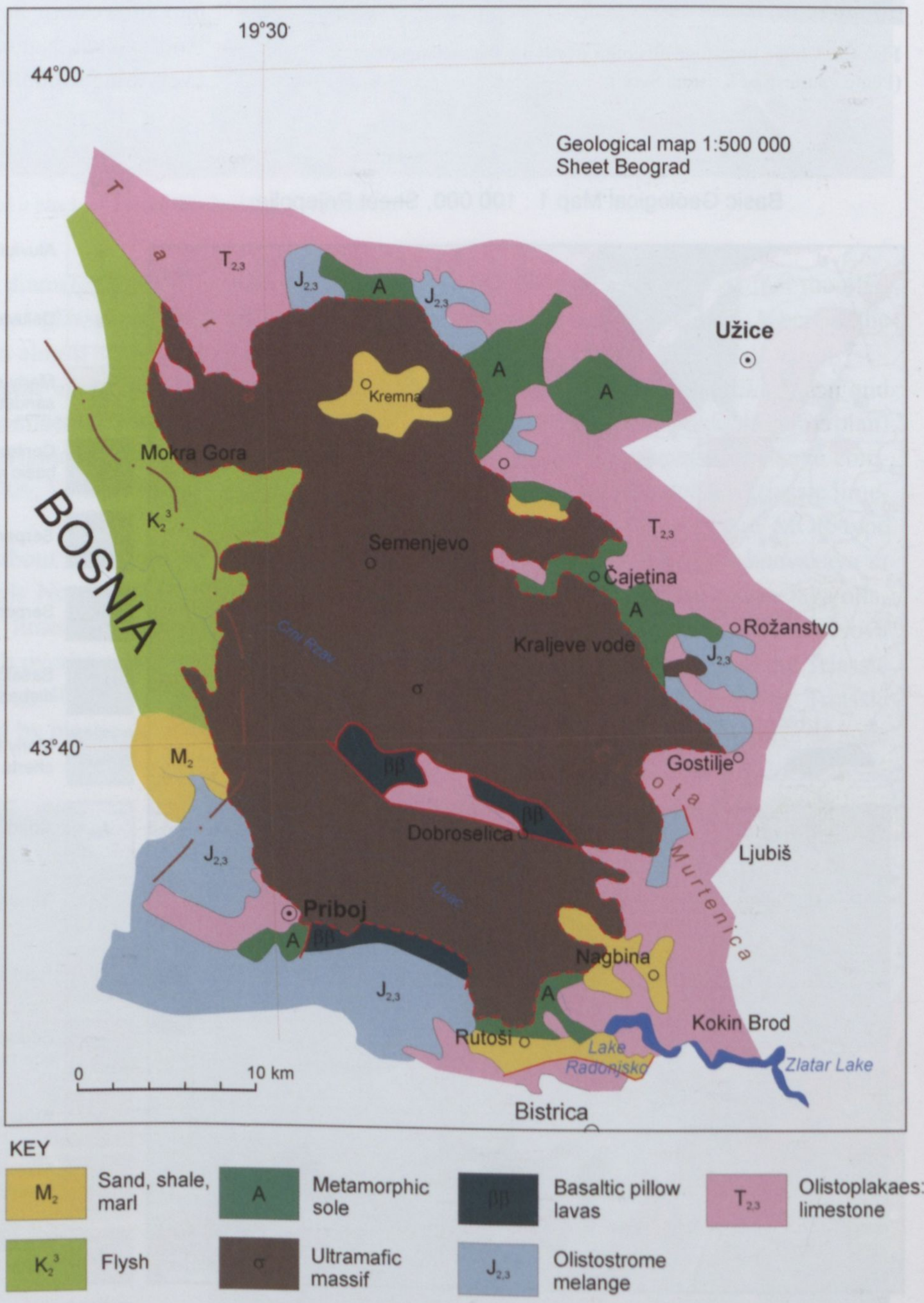

Fig. 42. Simplified geological map of the Zlatibor ultramafic massif and its surroundings. According to Geological map 1:500 000, sheet Beograd (edited by the Federal Geological Institute of S.F.R. Yugoslavia)

from 0.13–0.50; the Mg# range in the olivine from lherzolites is 90.0–90.9 and from harzburgites 90.5–90.8; all the olivines have high Ni contents (0.34–0.43 wt% NiO); alumina in the orthopyroxenes from lherzolites ranges from 5.5 to 3.2 wt% and drops to 2.3 wt% in the harzburgites.

It is supposed that the suprasubduction setting of this massif probably originated in a back-arc spreading centre (Bazylev *et al.*, 2009).

In the area between Kokin Brod and Vodice a weathering crust developed on the ultramafics and can be seen along the road. It formed during the late Lower Cretaceous and beginning of the Upper Cretaceous period. The weathering processes were characterised by the efficient leaching of magnesia and the formation of a smectite zone enriched by Ni-rich nontronite in the lower levels, which gradually passes into to serpentine. The upper levels are predominately limonitic.

3.25 Field stop 25. DOB – Zlatibor ophiolite massif: The window of Dobroselica

At this short stop a panoramic view of the deep valley – the window of Dobroselica – can be seen west of this part of the road. Looking downwards there are ultramafics on both sides of the valley (but extending to different depths), followed by metamorphics (but due to tectonic displacements, their succession is not complete) and finally there are rocks representing an olistostrome complex down to the floor of the valley (Fig. 43).

3.26 Field stop 26. The lherzolites of Zlatibor (around Vodice)

At this short road stop, a large outcrop of serpentinised lherzolite can be seen. It is composed of olivine with wavy extinction, slightly bent orthopyroxene and clinopyroxene, and occasionally amphibole and spinel. Besides serpentine minerals, the lherzolite rock also contains talc and chlorite.

From Vodice we will turn to the east toward Sirogojno (ethno-village) via Ljubiš and Gostilje.

3.27 Field stop 27. The ethno-village of Sirogojno

The ethno-village of Sirogojno, set up in 1979, is an open-air museum of folk buildings – old rural buildings from Zlatibor were gathered together and put on show (Fig. 44). The museum is situated at an altitude of 890 m and is 24 km from Mt. Zlatibor.

The houses are entirely wooden and were constructed using wooden nails. All the buildings are furnished with authentic, original household items. In the yard and basements of the houses there are exhibitions of old tools and equipment that have been collected in the Zlatibor area (Fig. 43).

In the 1970s, the village became famous for its hand-knitted sweaters. "Sirogojno Fashion" has gained popularity throughout the world. The sweaters can be bought in the sales and exhibition hall.

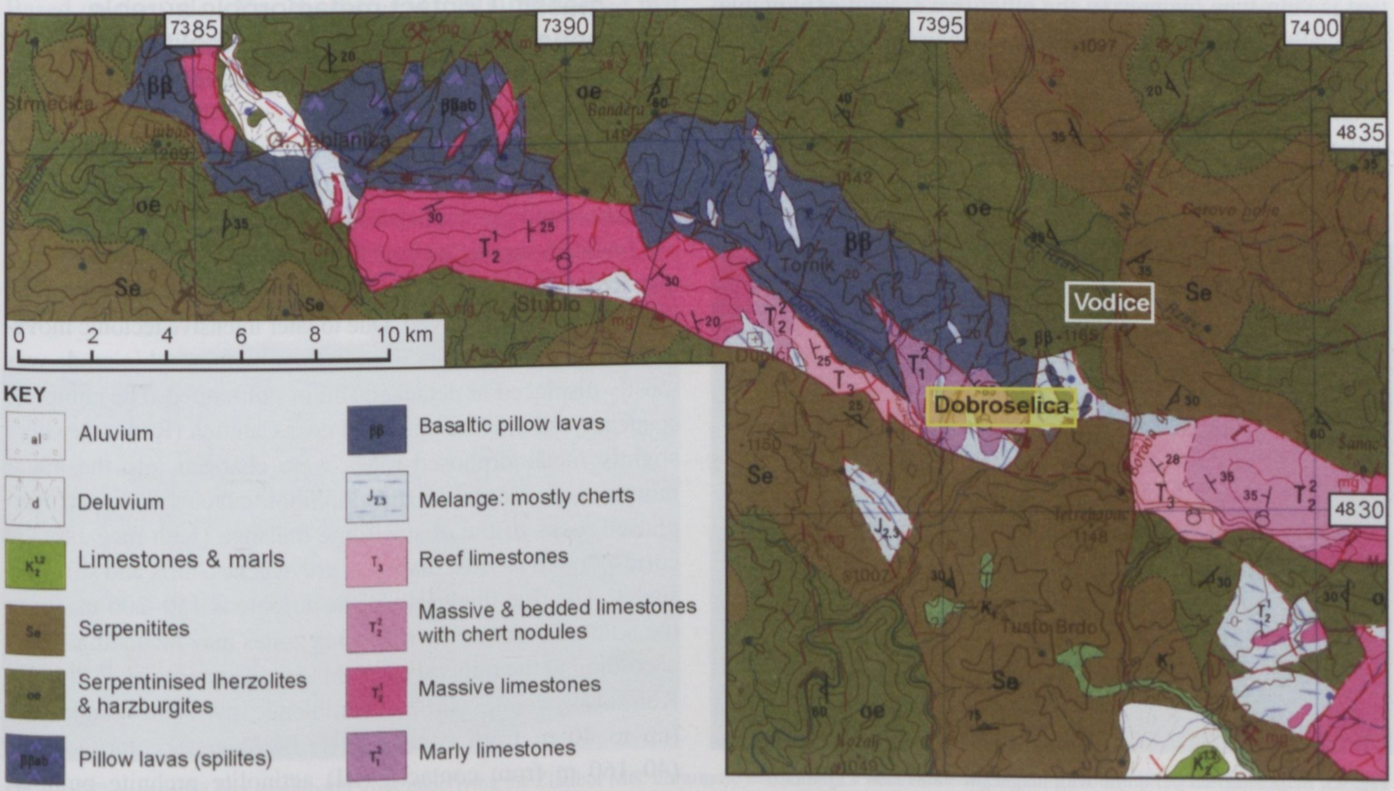

Fig. 43. The window of Dobroselica (According to the Basic Geological Map of Yugoslavia, scale 1:100 000, sheet Prijepolje, Ćirić *et al.*, 1980.)

Fig. 44. Ethno-village Sirogojno.

Several restaurants and cafés offering traditional food and drinks are located in the middle of the village. Near Sirogojno is the village of Gostilje (12 km) with its famous waterfall on the Katušnica River. On the road to the village of Rožanstvo (6 km) is the well-known cave of Stopića Pećina.

3.28 Field stop 28. DOB – Zlatibor ophiolite massif: Magnesite veins (near Èajetina)

In the Zlatibor ultramafic massif and related Neogene lacustrine basins three types of magnesite ore deposits can be found – of the vein, stockwork and sedimentary type. The most important is vein-type magnesite; the other two are not exploitable, especially the sedimentary type, due to their low quality. Stockwork magnesite is usually associated with the vein-type one.

Economic deposits can be found along the major faults or graben-like structures associated with zones of intensive weathering of ultramafics (weathering crust) or below them. Economic

Fig. 45. Serpenitinised peridotite with magnesite veins near Čajetina. (Photo courtesy of Kristina Šarić)

magnesite deposits occur in the areas of Kremna, Čajetin Semegnjevo and in the area exposed in the northwestern part o the Dobroselica window (Fig. 42). Vein-type magnesite accoun for a total amount of 3,000,000 tons of good quality ore.

The outcrop at this field stop shows a section, tens of metre long, of ultramafic rocks cut by numerous veins of white micro crystalline to cryptocrystalline magnesite (Fig. 45). The genera chemical composition of this magnesite is characterised by Si contents of up to 1.7 wt%, CaO contents ranging from 1.1- wt% and MgO contents ranging from 45-46 wt%.

3.29 Field stop 29. DOB – Zlatibor ophiolite massif: Contact metamorphic aureole beneath the massif – amphibolites (about 6 km after turning towards Rudine)

Beneath the Zlatibor Ultramafic (plate-shaped) Massif a co tact metamorphic aureole was formed under conditions amphibolite to greenschist facies. Contact metamorphic rock are found in the vicinity of Braneško Polje, Čajetina-Rudir and Rožanstvo (Fig. 42). Only the high-grade metamorph rocks have been preserved. Due to later intensive tectonic mov ments, the zone characterised by low metamorphic grade wa mostly displaced or detached and/or obliterated. The comple sequence can only be observed near Čajetina (Rudine), whe slightly metamorphosed rocks were changed into the meta morphics of greenschist and amphibolite facies. The metamo phosed rocks of the olistostrome mélange (with megablock correspond to basalts, diabases, greywackes, tuffs and siliceou shales. The true thickness of the aureole is 150–200 m. Fro the point of contact, the following zones may be distinguishe according to the mineral assemblages (Karamata *et al.*, 1996 Korikovsky *et al.*, 2000): (I) hornblende–pyroxene–plagiocla (up to 40 m from contact); (II) hornblende–chlorite–albi (40–160 m from contact); (III) actinolite–prehnite–pumpe lyite (up to 250 m from contact).

Metadolerites and metabasalts from the third zone contain well-preserved ophitic and porphyritic textures and augite phenocrysts; the groundmass of greywackes and tuffs is re-crystallised into fine-grained aggregates of chlorite, pumpellyite, epidote, actinolite, prehnite, albite, calcite, quartz and leucoxene. Plagioclase has mostly been replaced by prehnite, pumpellyite and calcite. This mineral assemblage recorded a temperature of 300–350 °C and pressure conditions of about 3–3.5 kbar (Korikovsky *et al.*, 2000). The transition zone (II) comprises epidote, ± actinolite, hornblende, plagioclase (albite, oligoclase), calcite, quartz and magnetite (metabasites) or muscovite, epidote, albite and quartz (metapelites) or garnet, muscovite, ±biotite, ±epidote, albite and quartz (metasandstones). The temperature range estimated for this zone is about 400–500 °C (Korikovsky *et al.*, 2000). The first zone (I) is marked by the disappearance of chlorite and appearance of hornblende, enrichment of plagioclase by An-component (40–50%) and crystallisation of clinopyroxene in the metabasites and the appearance of garnet with noticeable prograde zoning in gneisses close to the point of contact. Korikovsky *et al.* (2000) reported a temperature of 550–650 °C for metabasites according to the garnet-plagioclase thermometer of Blundy & Holland (1990). Based on the stability of epidote in matabasites (amphibolites) and muscovite in gneisses as well as the preservation of prograde zoning in garnets from gneisses these authors estimated a temperature of 650 °C in the contact zone. Due to the absence of the required mineral assemblage in the metabasites studied, Korikovsky *et al.* (2000) roughly estimated a pressure of 3 to 3.5 kbar according to the jadeite concentration (2–3%) in clinopyroxene (Holland, 1980) at a temperature of 650 °C. Based on these data Korikovsky *et al.* (2000) presumed that the Zlatibor Massif was tectonically stabilised and started to cool isobarically at depths of 12–13 km suggesting that these depths are much shallower compared to the cooling depths of other massifs (*e.g.* Brezovica, Banjska, Ozren).

At our stop (Fig. 46), only the amphibolites can be observed. The other parts of the aureole are detached or obliterated. The amphibolites have the composition of MOR-type basalts. The metamorphism, *i.e.* the formation of hornblendes happened 160±8 m.y. ago according to K/Ar age calculation, which indicates that the hot ultramafic body was emplaced over or into the olistostrome in the late Mid-Jurassic period.

From this stop we will travel about 10 km to Kraljeve Vode ('King's Waters' in English), the main tourist resort of Zlatibor Mts. where participants will be accommodated.

Day 5

Early in the morning we will drive from Zlatibor to Mokra Gora to visit the ethno-village of Drvengrad ('Wooden Town' in English) and then continue to Užice, passing through the northern part of the Zlatibor Ultramafic Massif and Upper Triassic limestones (gravity slices from the Drina–Ivanjica Unit). From Užice to Požega and further to Divčibare we will cross the Drina–Ivanjica Unit and enter the WVZ at Pijesak village a few km after the village of Kalenići.

3.30 Field stop 30. The ethno-village of Drvengrad

Mokra Gora ('Wet Mountain' in English) is a village on the northern slopes of Zlatibor Mts. that is turning into a very popular tourist centre due to its unique attractions. It became popular after the reconstruction of an old narrow-gauge railway famous for the so-called Šargan Eight. The name comes from the unique shape of the "Šargan loop" that was built to climb over the steep Mt. Šargan; the line of the track resembles number 8 in projection. Famous Serbian film director Emir Kusturica could not resist the beauties of Mokra Gora, after shooting his film "Life is a Miracle" at this location, so decided to stay and live there. He built his own town Drvengrad ('Wooden Town') on the top of Mećavnik Hill. He received the Philippe Rotthier European Architecture Award by the Brussels Foundation for this project.

Fig. 46. Outcrops of the first amphibolite zone underlying the Zlatibor Mts. ultramafic massif with a detail showing banding (bottom). (Photo courtesy of Kristina Šarić and Vladica Cvetković)

Fig. 47. Ethno-village Drvengrad with St. Sava Church in the middle.

The area of Drvengrad represents a 19th-century settlement (Fig. 47). Places worth visiting there include the gallery shop, art gallery, one of the most modern sound and picture cinemas in Europe, the ethnographic museum, national cuisine restaurant with a daily seasonal menu of healthy home-made food, and a cake shop, in which you can taste tarts made according to almost forgotten recipes and homemade sweet pies.

The village of Kremna, northeast of Mokra Gora, is famous for two prophets from the 19th century, Miloš Tarabić (1809–1854) and his nephew Mitar Tarabić (1829–1899). Almost all of their prophecies are claimed to be true up to now. One of them, called *Drilling in the Earth*, may be interesting for geologists, says "*People will drill wells in the ground and pump some kind of gold, which will produce light, speed and power. The Earth will weep because of that. Men will not know that more energy and light exists on the surface of the Earth. Only after many years will people realise that they were fools to have drilled holes in the ground.*"

Drina–Ivanjica Unit (DIU)

3.31 Field stop 31. DIU – Late Paleozoic terrigenous metasedimentary rocks (Kalenić)

At this locality participants will be able to observe low-grade metamorphosed terrigenous sediments (mostly metasandstones, metasiltstones and phyllites) with intercalations of marble. The foliated metasandstones comprise clasts of quartz, muscovite and rock fragments set in a quartz-sericite matrix. The highly foliated and folded phyllites are composed of sericite and quartz. Marble appears in the form of intercalations or lenses within the low-grade metamorphosed terrigenous sediments. The large quarry of "Mandina Stena", in which the marble is extracted, is located several kilometres away from here towards Požega.

After the DIU, going from Kalenići towards Divčibare, we will enter the Western Vardar Ophiolitic Zone (WVZ) *i.e.* the Maljen Ultramafic Massif.

Western Vardar Ophiolitic Zone (WVZ) – Maljen ultramafic massif

Bukovi, Maljen and Suvobor Mts. are low mountain ranges. The highest peaks are Kraljev sto (1104 m), Osečinska Strž (976 m), Veliki Maljen (970 m) and Drenovački Kik (948 m). The boundary of the region is the River Dičina to the east and the road towards Divčibare holiday resort to the west. Mt. Maljen boasts huge complexes of conifer forests - black and white pine, fir and sporadically spruce. Mt. Suvobor on the other hand has extensive broadleaf woodlands, meadows and pastures.

The Maljen Ultramafic Massif forms the ridge of Maljen and Suvobor Mts. (Fig. 48). The peridotite massif of Maljen (50×15 km) is mainly composed of spinel harzburgites. Cumulate peridotite bodies appear near the spinel harzburgite on the western and northern slopes of the massif. Contacts between the cumulate and residual peridotites are mostly obscured. The cumulate sequence is represented by various types of gabbro-peridotite rocks. Their relationships with tectonite (harzburgite) and dolerites can be observed only at a few places south of the village of Brežđe. The gabbros, south and southeast from there, are thrust onto Cenomanian conglomeratic limestone and sandstone. In the southwestern part, peridotites are in tectonic contact with the mélange mostly composed of blocks and olistoliths of sandstone, chert, conglomerate and limestone.

On the northern margin of Mt. Maljen there is a small block of various cumulate ultramafic and gabbroic rocks. The gabbroic sequence begins with olivine gabbro and olivine gabbro-norite and continues with gabbro-norite. Within it small bodies (up to 20 m^2) of cumulate peridotite occur. The upper parts of this sequence comprise veins of gabbro-pegmatite and microgabbro as well as thin veins of dolerite which gradually enlarge.

The association of gabbro-peridotite rocks in the area of Mt. Bukovi (on its western slope) is in tectonic contact with the tectonite-harzburgites (to the east) and the basalt-dolerite complex (to the west). The cumulate sequence begins with feldspar dunites and plagioclase lherzolites, which gradually passes into coarse-grained poikilitic lherzolites after 10 m. The ultramafic rocks are thrust onto the gabbroic sequence – plagioclase poikilitic lherzolites directly overlay the massive plagioclase-clinopyroxene gabbros. Xenoliths of the latter can also be seen within the sequence. Ožanj Hill (east of Kaona) is built up of gabbro (troctolite), pyroxenite, as well as large amounts of plagioclase-clinopyroxene dunite, plagioclase poikilitic lherzolite and plagioclase lherzolite.

We will enter the Maljen ultramafic massif on our way to Valjevo about 2 km after the confluence of the Mionica and Kladoroba rivers. Prior to that, we will pass through Upper Cretaceous (Upper Turonian) bedded limestones. The southern and western slopes of Mt. Maljen are made up of feldspar peridotite, gabbro, and basaltic pillow lava of the MOR type (Vishnevskaya *et al.*, 2009). To the west, along the ridge west of Kaona (Mt. Bukovi) after the ultramafic rocks of tectonite, cumulate feldspar peridotites occur, and later weathered gab-

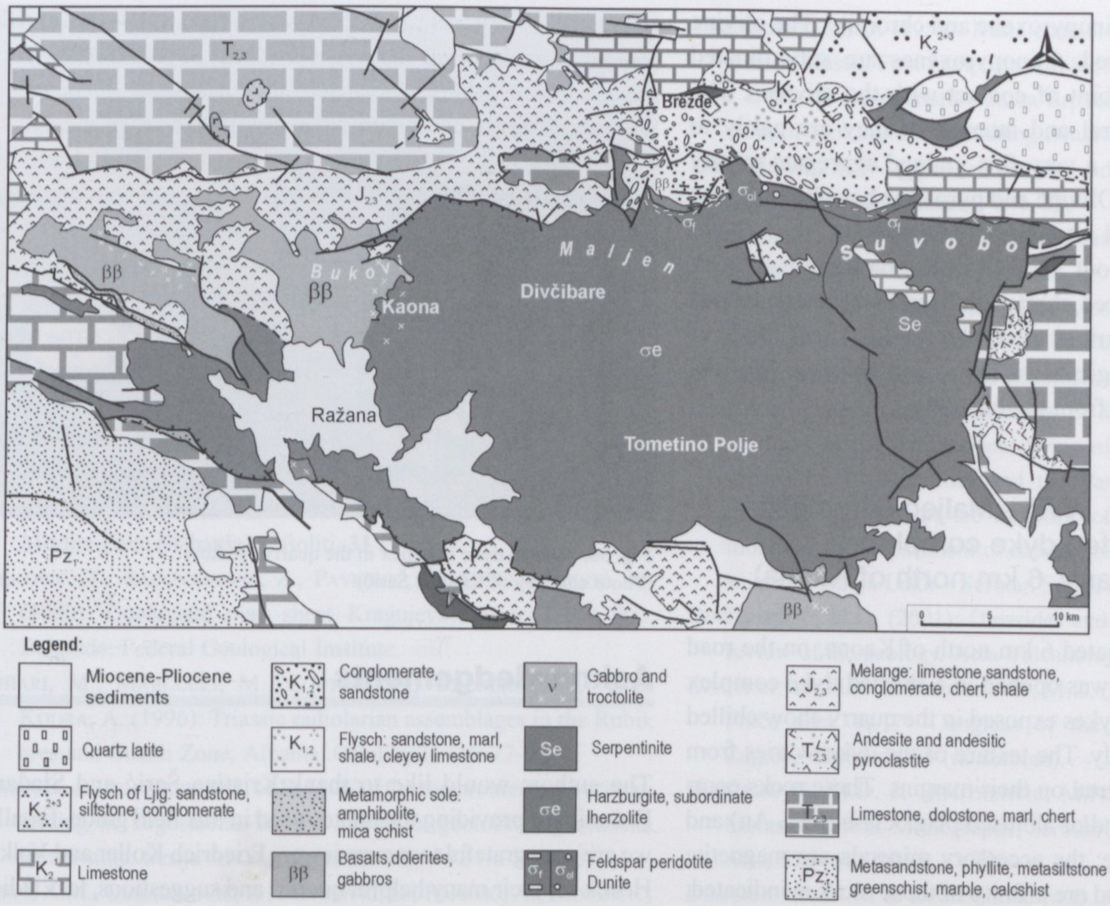

Fig. 48. Simplified geological map of the ultramafic massifs of Maljen and its surrounding. According to the Basic Geological Map of Yugoslavia, scale 1: 100 000, sheets Valjevo (Mojsilović *et al.*, 1965) and Gornji Milanovac (Filipović *et al.*, 1978).

bro and a sheeted dyke complex can be seen, and finally highly disrupted basaltic pillow lavas set in the mélange and comprising olistoliths, blocks and fragments of cherts, diabases, gabbros, sandstones and limestones (sometimes schistose and sandy) can be observed. The matrix is mostly silty-clayey and in some places schistose.

3.32 Field stop 32. WVZ – Maljen ultramafic massif: Layered harzburgite (Divčibare)

About 600–700 m further to the south from the Divčibare–Tometino Polje intersection, an outcrop of layered cumulate harzburgite can be seen with alternate thin layers (< 30 cm) of olivine and enstatite (Fig. 49).

3.33 Field stop 33. WVZ – Maljen ultramafic massif: Ultramafic cumulates – feldspar peridotites (1 km north of Kaona)

Feldspar peridotites with a typical cumulate texture occur mostly in the northern part of the Maljen Ophiolite Massif (south of Brežđe, Fig. 47). These rocks can be seen in an old quarry on the road to Divčibare. They are massive dark green-to-black and comprise feldspar grains up to 2 mm in size (~5 vol% of

Fig. 49. Layered harzburgite to the south of Divčibare holiday resort. (Photo courtesy of Slađana Dušanić)

plagioclase), olivine, clinopyroxene and chromite. The olivine has been slightly altered. Clinopyroxenes are subordinated and subhedral at the point of contact with the olivines. The plagioclases are anhedral and interstitial, they are partly to completely replaced by a very fine-grained aggregate mostly composed of prehnite. Olivine and pyroxene have been almost completely transformed into serpentine minerals.

At a road curve, about 3 km from Kaona there is a block (olistolith) of Carnian red chert with basalt and intercalations of violet red shales. Further along the road, a small block of grey limestone of pelagic basin facies can be seen. We will observe these outcrops from the bus only.

3.34 Field stop 34. WVZ – Maljen ultramafic massif: Sheeted dyke complex ("Bukovi" quarry, 6 km north of Kaona)

"Bukovi" quarry is situated 6 km north of Kaona, on the road to Valjevo. The quarry was opened in a sheeted dyke complex (Fig. 50). Most of the dykes exposed in the quarry show chilled margins on one side only. The texture of the dykes varies from coarse ophitic to intersertal on their margins. These rocks comprise partly calcitised and/or albitised plagioclase (65% An) and uralitised clinopyroxene; the accessory minerals are magnetite and leucoxene. An island arc affinity of these rocks is indicated.

After visiting the "Bukovi" complex we will drive back to Belgrade via Valjevo and Lazarevac.

Fig. 50. Sheeted dyke complex in the quarry "Bukovi". (Photo courtesy of Kristina Šarić)

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Appendix 1 – Itinerary for IMA2010 RS1 Field trip

Saturday, August 14, 2010 (Day 0)

Arrival to Belgrade and accommodation in hotels in downtown

Sunday, August 15, 2010 (Day 1)

07.30–08.00	Leaders will pick up participants in front of their hotels in downtown.
08.00	Travel through town, from north to southeast, towards Bubanj Potok – road E75
08.30	Field stop 1. EVZ – Western part of the northern branch of the EVZ (south of Belgrade): Serpentinised harzburgite (Bubanj Potok, Mt. Avala); observation from bus
08.30–11.30	Travel to Prevešt via Paraćin along highway E75, and then turn to west towards Ćićevac – Varvarin and Oparić.
11.30–12.15	Field stop 2. EVZ – Ophiolitic massif of Ždraljica: sheeted dyke complex of Prevešt
12.15–15.15	Travel to Kuršumlija and Žuč via Trstenik, Kruševac and Blace. Short lunch and coffee break in Kruševac or Blace
15.15–15.45	Field stop 3. EVZ – Granites
15.45–16.25	Field stop 4. EVZ – Kuršumlija ophiolitic massif: pillow basalts (Žuč)
16.25–17.45	Return to Kuršumlija and travel to Brus via Blace and Razbojna with short observation of Cretaceous paraflysch close to Brus (village Žiljci) from bus
17.30–18.30	Field stop 5. KU – Serpentinised harzburgites on the eastern slopes of Mt. Kopaonik (Brus) and coffee break
18.30–19.15	Travel to Kopaonik holiday resort via Brzeće, accommodation

Monday, August 16, 2010 (Day 2)

08.00	Travel to Jaram
08.15–09.00	Field stop 6. KU: Contact metamorphosed rocks (Jaram)
09.00–10.00	Return to Kopaonik holiday resort and drive by ski-lift to Suvo Rudište (the top of Mt. Kopaonik: Pančićev vrh)
10.00–11.00	Field stop 7. KU: Skarn-related magnetite ore deposit (Suvo Rudište)
11.00–13.00	Short walk to Kopaonik holiday resort, coffe break, travel towards Jošanička Banja
13.00–13.30	Field stop 8. KU: Granodiorite rocks of the Mount Kopaonik
13.30–14.00	Field stop 9. KU: Mid- to Late Triassic low metamorphic rocks (Jošanička Banja)
14.00–15.00	Travel to Studenica via Biljanovac and Ušće
15.00–16.45	Field stop 10. KU: Studenica sequence
16.00–17.00	Field stop 11. Monastery Studenica
17.00–18.30	Return to Ušće and travel to Kopaonik holiday resort via Biljanovac and Jošanička Banja, accomodation

Tuesday, August 17, 2010 (Day 3)

08.00–09.00	Travel to Brvenik via Jošanička Banja and Biljanovac
09.00–09.50	Field stop 12. WVZ: Oligocene andesites (Brvenik, Šumnik Quarry)
09.00–09.40	Field stop 13. WVZ: Trnava ultramafic massif and mélange: mélange and fine-grained gabbro block (~3.5 km from Raška)
09.40–09.55	Travel along the road Raška-Novi Pazar
09.50–10.25	Field stop 14. WVZ: Trnava ultramafic massif and mélange: Gabbros, serpentinites and mélange (9 km from Raška)
10.25–10.35	Travel along the road Raška–Novi Pazar
10.35–11.15	Field stop 15. WVZ: Trnava ultramafic massif and mélange: Pillow basalts and mélange (13 km from Raška)
11.15–11.30	Travel along the road Raška–Novi Pazar

11.30–12.45	Field stop 16. Church of St. Peter and Đurđevi Stupovi Monastery
12.45–13.30	Travel to Sopoćani via Novi Pazar (coffee break) and Dojeviće
13.30–14.40	Field stop 17. Sopoćani Monastery
14.40–15.10	Return to Dojeviće and travel to Osaonica
15.10–15.50	Field stop 18. DIU: Paleozoic low grade metamorphic rocks (Osaonica)
15.50–16.50	Travel to Sjenica via Duga Poljana
16.50–17.30	Field stop 19. DOB: Chert and albite granite olistoliths (~3 km west of Sjenica)
17.40–18.15	Field stop 20. DOB: Olistostrome mélange, Krš Gradac locality (8 km west of Sjenica)
18.15–19.15	Travel to Nova Varoš, accommodation

Wednesday, August 18, 2010 (Day 4)

08.00	Travel towards Priboj (Banja)
08.20–09.00	Field stop 21. DOB: Subcontinental ophiolite and metamorphic sequence (Bistrica)
09.00–09.20	Travel towards Bistrica of about 10 km
09.20–10.00	Field stop 22. DOB: Olistostrome mélange, basaltic breccia olistolith and Triassic "Bódvalenke-type" red, bedded, cherty limestone olistolith (Bistrica)
10.00–10.40	Travel to Prijepolje and Mileševa via Bistrica
10.40–11.30	Field stop 23. Mileševa Monastery and the Mileševa mélange
11.30–12.30	Return to Bistrica via Prijepolje and coffee break
12.40–13.10	Field stop 24. DOB: Pillow lavas of Bistrica and olistolith overlying mélange (Zlatibor Mts.)
13.10–14.50	Travel to Dobroselica via Nova Varoš and Kokin Brod
14.50–15.20	Field stop 25. DOB – Zlatibor ophiolite massif: The window of Dobroselica
15.20–15.30	Travel towards Vodice
14.55–15.20	Field stop 26. DOB – Zlatibor ophiolite massif: Lherzolites (around Vodice)
15.20–16.25	Travel to Sirogojno via Ljubiš
16.25–17.40	Field stop 27. Ethno-village Sirogojno with coffee break
17.40–18.10	Travel to Čajetina via Rožanstvo
18.10–18.40	Field stop 28. DOB – Zlatibor ophiolite massif: Magnesite veins (near Čajetina)
18.45–19.15	Field stop 29. DOB – Zlatibor ophiolite massif: Contact metamorphic aureole beneath the massif – amphibolites (about 6 km after turning towards Rudine)
19.15–19.35	Travel to Zlatibor holiday resort, accommodation

Thursday, August 19, 2010 (Day 5)

08.00–09.30	Travel to Mokra Gora via Čajetina and Kremna
09.30–11.30	Field stop 30. Ethno-village Drvengrad with coffee break
11.30–13.30	Return to Kremna and travel to Kalenić via Užice Požega and Čestobrodica
13.30–14.00	Field stop 31. DIU: Late Paleozoic terrigenous metasedimentary rocks (Kalenić)
14.00–14.45	Travel to Divčibare holiday resort via Ržana
14.45–15.15	Field stop 32. WVZ – Maljen ultramafic massif: Layered harzburgite (Divčibare, 0.8 km from turn to Tometino Polje)
15.15–16.30	Return to Divčibare and travel to Kaona
16.30–17.00	Field stop 33. WVZ – Maljen ultramafic massif: Ultramafic cumulates – feldspar peridotites (1 km north of Kaona)
17.00–17.15	Travel to Bukovi
17.15–17.50	Field stop 34. WVZ – Maljen ultramafic massif: Sheeted dyke complex ("Bukovi" quarry, 6 km north of Kaona)
17.50–20.00	Travel to Belgrade via Valjevo (coffee break), Lajkovac and Lazarevac. Accommodation or departure to Budapest (late evening or early morning train or plane)

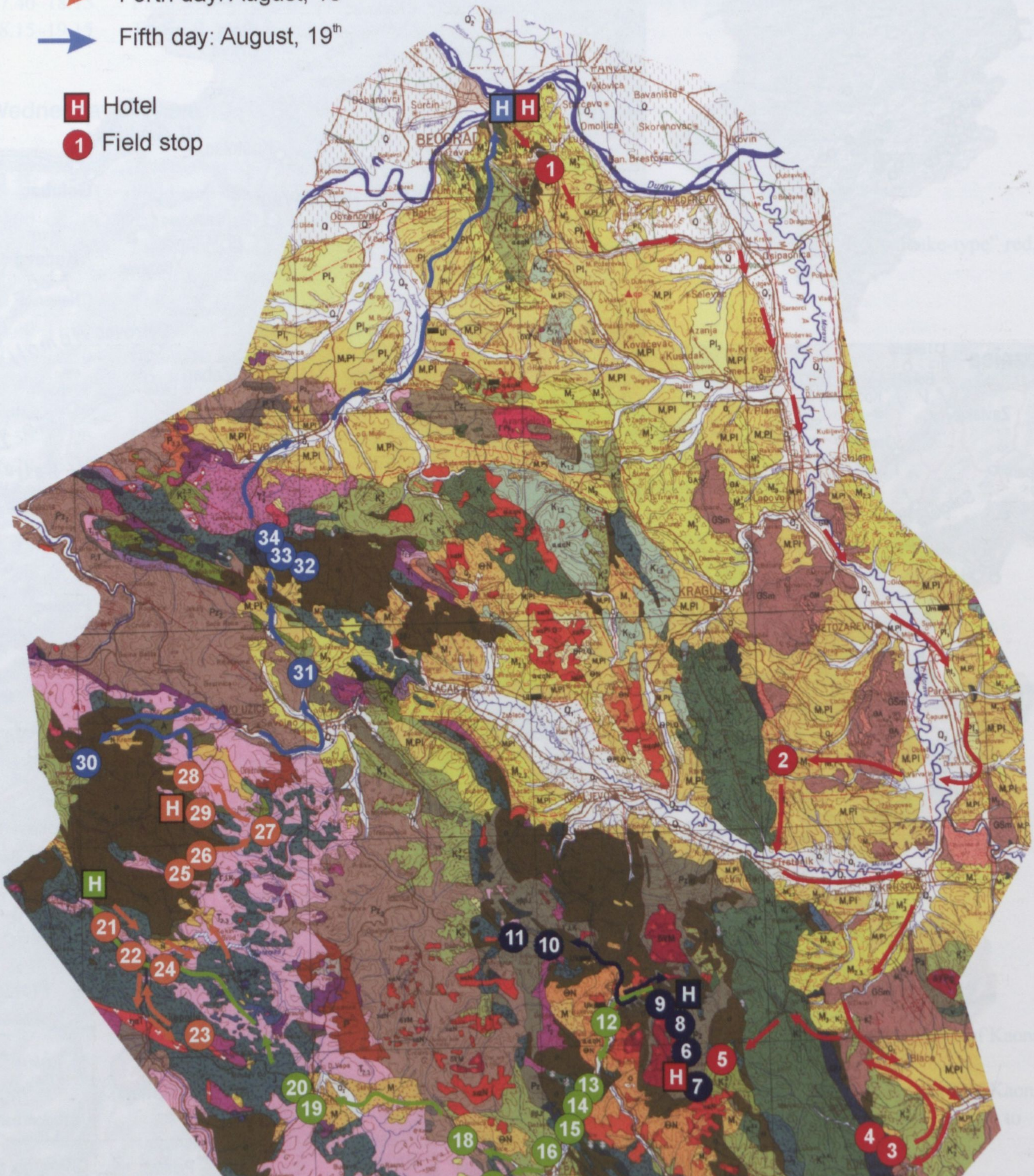
Road map of the visited area with field stop numbers.

Key:

- First day: August, 15th
- Second day: August, 16th
- Thrd day: August, 17th
- Forth day: August, 18th
- Fifth day: August, 19th

H Hotel

1 Field stop



Geological map of the visited area with the route of the trip and field stop numbers.

Appendix 2 – Road log for IMA2010 RS1 Field trip

km	
0	Belgrade
0–15	Road E75 Belgrade–Bubanj Potok: travel through Miocene sediments. About five kilometres before Bubanj Potok the first outcrops of serpentinised harzburgites of Mount Avala appear.
15	Field stop 1: EVZ – Western part of the northern branch of the EVZ (south of Belgrade): Serpentinised harzburgite (Bubanj Potok, Mt. Avala); observation from bus.
15–20	Drive along highway E75. On the right side is Mount Avala, indicating the entry to the Eastern Vardar Zone (EVZ). The EVZ is only visible in erosion windows suggesting obscure mosaic structure. It comprises Upper Jurassic ophiolitic mélange and ultramafics, Cretaceous flysch, calc-alkaline intermediate to acid Oligocene–Miocene volcanic rocks and ore deposits (Pb-Zn, Hg), and Miocene–Pliocene sediments (sandstone, limestone, shale).
20–159	The area along the valley of River South Morava, between Bubanj Potok – Paraćin (E75), belongs to the Serbo-Macedonian Massif (SMM). It can be seen in erosional windows in the areas between Lapovo–Kraljevo and Kruševac–Blace. The other parts are covered by Miocene–Pliocene sediments.
159–201	After Paraćin, at Pojate we turn on regional road M5 up to Ćićevac, and then to west on local road R220 (Varvarin–Oparić–Prevešt). The western part of this area represents the trough (>160 km long) with Lower Cretaceous Paraflysch (LCP), extending from northwest (Lazarevac) to southeast (Kuršumlija) and further to south (Kosovo). Its base is built of crystalline schists (SMM), Upper Jurassic ophiolites and mélange. The first outcrops of the SMM can be seen in the area between Ćićevac and Prevešt. The hills on both side of the road are built of crystalline schists (mostly gneisses and micaschists) and covered by Miocene–Pliocene sediments.
201	Field stop 2. EVZ: Ophiolitic massif of Ždraljica: sheeted dyke complex (Prevešt).
201–229	Return to Oparić and travel to the south towards Trstenik along the local road R218 through Miocene–Pliocene sediments.
229–259	At Trstenik we turn to the east towards Kruševac along regional road E761
259–328	At Kruševac, turn to local road R102 (Razbojna–Blace), and then to south (road R222) towards Kuršumlija. This area is mostly composed of medium-grade gneisses and micaschists and Miocene–Pliocene sediments. The ophiolitic massif of Kuršumlija (EVZ) is thrusted over the SMM.
328–340	Local road R218 Kuršumlija – Žuč: The ophiolitic massif of Kuršumlija
340	Field stop 3. EVZ – Kuršumlija ophiolitic massif: Granites
349–352	Field stop 4. EVZ – Kuršumlija ophiolitic massif: Pillow basalts
352–411	Return to Blace (R222) and travel to the northwest (R102) to Razbojna and Brus (R222) through the Lower Cretaceous Paraflysh.
411–420	Before entering the Kopaonik Unit (KU), we cross the western flank of EVZ. There, the Mid–Upper Jurassic ophiolites are obducted onto the Kopaonik continental basement unit. The present-day contact with neighbouring units is probably related to later tectonic events or to presumption that the Kopaonik cold ultramafic slice has been passively transported from the east. Field stop 5. WVZ: Sserpentinised harzburgite (Brus).
420–446	At Brus we turn to the west towards Brzeće (R218a) and Kopaonik holiday resort, accommodation.
446–425	The Kopaonik Unit is composed of Triassic metamorphic rocks (the KU – microcontinent or erosion window?). It is overlain by mélange (Brzeće area) and intruded by large Oligocene granitoid body which caused contact metamorphism of the Kopaonik Unit.
425–427	Field stop 6. KU: Contact metamorphosed rocks of the Kopaonik Unit (Jaram)
427–429	Return to holiday resort and drive with chair lift to the top of Kopaonik Mt. (Pančićev vrh, 2017 m). Field stop 7: Skarn-related magnetite ore deposit (Suvo Rudište).
433	After return to Kopaonik holiday resort we drive to north towards Jošanička Banja (R118a). Along the road section small outcrops and boulders of granitic rocks can be seen.
438	Field stop 8. KU: Granodiorite rocks of the Kopaonik Mts.
488	Turn to the west on the road R119 towards Jošanička Banja (spa). This section of the KU is built up of the low-grade metamorphics and serpentinised harzburgites to the west. Contact between them is tectonic and mostly obscured.
492	Field stop 9: Jošanička Banja – Mid to late Triassic low metamorphic rocks of the Kopaonik unit
492–512	Along the same road after 6 km (Biljanovac) we turn to the north (road M22) towards Ušće. At Biljanovac we enter the area of Miocene volcanic formations (dacite-andesite) and the volcano-sedimentary basin of Jarandol originated during the Oligocene due to the Dinaride orogen collapse. This basin extends from Ušće to Raška and hosts coal, sedimentary magnesite and borate deposits. About ten kilometres before Ušće (locality Bare) we enter the Western Vardar Ophiolitic Zone (WVZ) and pass through the southwestern flanks of the large ophiolitic massif of Stolovi (serpentinised spinel harzburgites). These ophiolites can be observed from bus along the road section up to Ušće and further to the west.
512–530	At Ušće we turn to the west (R116) towards Studenica. We continue to follow serpentinised harzburgite of about 2 km along Studenica River. From there the Miocene volcano-sedimentary basin with coal can be followed for 3 km, and then serpentinised harzburgites for 2.5 km. There, we enter Upper Jurassic melange, which can be observed for 12 km. At this point the tectonic contact with the thrust sheet composed of Triassic low-grade metamorphics and marbles (Studenica sequence) can be seen
530	Field stop 10: Studenica sequence.

km	
532	Field stop 11. Studenica Monastery.
532–577	Return to Kopaonik holiday resort via Ušće (road M22) and Jočanička Banja (spa).
577–585	From Kopaonik holiday resort to Biljanovac and turn to the southwest to Brvenik (road M22). This area is composed of Oligocene andesites interrupted by the Upper Oligocene–Miocene Jarandol Basin.
585	Field stop 12. Oligocene andesites – Brvenik (Šumnik Quarry)
585–597	From Šumnik we continue to travel through Jarandol basin of about 5 km and then we enter the WVZ ophiolites (serpentinised harzburgite), which can be followed for 8 km. Approximately after 3.5 km from Raška a typical rock assemblage of olistostrome-melange is exposed.
597	Field stop 13. WVZ – Trnava ultramafic massif and mélange: Mélange and fine-grained gabbro block. At this stop we observe the contact between the mélange and the gabbro.
597–603	About 6 km further along the road-cut a second block of medium-grained gabbro cut by diabase dikes in its western side appears in the mélange. Along both sides of River Raška the alternation of serpentinised harzburgite, gabbros and basaltic rocks can be observed. This large NW–SE oriented gabbro-basaltic unit represents the upper part of the oceanic crust.
607	Field stop 14. WVZ – Trnava ultramafic massif and mélange: Gabbros, serpentinites and mélange (9 km from Raška).
613	Field stop 15. WVZ – Trnava ultramafic massif and mélange: Pillow basalts and mélange (13 km from Raška).
618–623	About 5 km before Novi Pazar we enter the Upper Cretaceous Flysch (sandstones, siltstones, marls).
624	Field stop 16. St. Peter church and Đurđevi Stupovi Monastery. Travel towards Novi Pazar.
625–638	At Novi Pazar we turn west to road M8 and drive up to Dojeviće; then turn to the southwest on local road to Sopoćani. After Dojeviće in the direction of Sopoćani we enter southeastern part of the Drina–Ivanjica Unit (DIU).
638	Field stop 17. Sopoćani Monastery.
638–678	Return to Dojeviće (road M8) and travel to Osaonica through the DIU.
678	Field stop 18. DIU: Paleozoic low-grade metamorphic rocks (Osaonica).
684	The DIU can be followed up to Duga Poljana. Their southern and northern parts are covered by Miocene volcano-sedimentary and sedimentary rocks. There are also small quartz latite to dacite extrusions. Close to village Duga Poljana we enter the Dinaride Ophiolite Belt (DOB). Towards the south the DOB broadens after the Metohija depression and continues as the Mirdita–Pindos ophiolite belt in Albania and Greece.
684–707	In the area between Duga Poljana and Sjenica the DOB is represented by a rock assemblage formed in the trench over the subducting crust of the Dinaridic marginal sea. The area between Duga Poljana and Sjenica (the northern part of Pešter plateau) is composed of gravitationally slid Triassic limestone plates (probably from the south) and flat lenses in and over the olistostrome-mélange. A large part of this area is covered by Miocene–Pliocene sediments.
710	Field stop 19. DOB: Chert and albite granite olistoliths (~3 km to the west of Sjenica).
718	Field stop 20. DOB: Olistostrome mélange, Krš Gradac locality (8 km west of Sjenica).
726	Travel towards Aljinovići (about 8 km) and turn to the north on local road R231.
726–783	From this point we continue to Nova Varoš – accommodation in 4* Hotel "Vila Jelena".
783–790	Travel towards Priboj (Banja).
790	Field stop 21. DOB: Subcontinental ophiolite and metamorphic sequence (Bistrica).
790–800	Travel towards Bistrica.
800	Field stop 22. DOB: Olistostrome mélange, basaltic breccia olistolith and Triassic "Bódvalenke-type" red, bedded, cherty limestone olistolith (Bistrica).
800–834	At Bistrica turn to the south on road M21 towards Prijepolje through Upper Jurassic melange.
824–828	At Prijepolje turn to Mileševa (M8). Through Upper Jurassic melange.
828	Field stop 23. Mileševa Monastery and mélange (chert olistolith).
828–862	Return to Bistrica – turn to the east on road M21.
862	Field stop 24. DOB: Pillow lavas and olistolith overlying the mélange (Bistrica).
862–890	Travel to Nova Varoš along road M21; all the way through Upper Jurassic melange (olistoliths and blocks of pillow lavas, limestone, gabbros, terrigenous sediments in sandy-silty matrix).
890–938	At Nova Varoš we turn to the north towards Mount Zlatibor along road E763 to Dobroselica via Kokin Brod and Draglica. Mount Zlatibor is situated at the suture of an oceanic tract that have been opened in the Mid Triassic time and closed at the end of Jurassic time. During the closing subduction trough was filled with an ophiolitic melange (as a huge olistostrome) with obduction of hot ultramafic body that caused metamorphism of melange beneath it. Within this area melange can be observed along both road sides up to Kokin Brod and further to north up to Draglica – there we see a good exposure of Lower and Upper Triassic limestone megablocks, sometimes with cherts, which were gravitationally transported from the Paleozic base of the DIU into the trough during the late Upper Jurassic time. These mélange can be observed almost up to Draglica. Close to Draglica we enter Zlatibor Ultramafic massive. Subsequently, the whole area underwent a strong compression with tectonisation of the metamorphic sole beneath ultramafics.

km 938	Field stop 25. DOB – Zlatibor ophiolite massif: The window of Dobroselica. Excellent panorama view of ultramafics (on both sides of the valley) followed by metamorphics and the olistostrome complex represented by olistoliths of Triassic limestones and basaltic pillow lavas and diabases.
938–940	Travel towards intersection of road E763 and River Rzav – locality Vodice, through Zlatibor ultramafics with a small zone of weathering crust close to Vodice.
940	Field stop 26. DOB – Zlatibor ophiolite massif: Lherzolites (around Vodice).
942–969	Travel along local road to Sirogojno via Ljubiš and Gostilje compose of large Triassic megablocks (limestones).
972	Field stop 27. Ethno-village Sirogojno
972–990	Travel to Čajetina via Rudine. After Rožanstvo driving on the west we enter the highly tectonised and displaced Zlatibor metamorphic sole (gneisses, schists, amphibolites) and hardly serpentinised ultramafics with magnesite veins (Čajetina).
992	Field stop 28. DOB – Zlatibor ophiolite massif: Magnesite veins (Čajetina).
992–996	Field stop 29. DOB – Zlatibor ophiolite massif: Contact metamorphic aureole beneath the massif – amphibolites (about 6 km after turning towards Rudine).
996–1006	Travel to Zlatibor holiday resort and accommodation
1006–1044	Travel from Zlatibor via Čajetina along E761 to the intersection with road R112 (Kneževići). Turn to the west (R112) towards Kremna and Mokra Gora. All the way we drive through Zlatibor ultramafic massif. Near Mokra Gora we enter Upper Cretaceous sandy-clayey limestones.
1044	Field stop 30. Ethno-village Drvengrad.
1044–1132	Return to Kremna and travel to Kalenići via Užice Požega and Čestobrodica. In the area between Mokra Gora and Kremna we pass Upper Cretaceous limestones and enter northwestern part of the Zlatibor ultramafic massif and Miocene marls and dolomites at Kremna. After Kremna, we return to the Zlatibor ultramafic zone, which can be followed to Braneško Polje. From the intersection of the roads R112 and E763 (Kneževići) we drive to north through melange up to Užice. There we enter the DIU. Along the road E763 we travel along the margin of DIU (Đetinja River) and the Upper Jurassic olistostrome melange of the DOB (~1–3 km south). From Požega up to Kalenići we drive through the DIU.
1132	Field stop 31. DIU: Late Paleozoic terrigenous metasedimentary rocks (Kalenić) After 3km we enter Western Vardar Ophiolitic Zone, which is covered by Upper Cretaceous and Miocene sediments. About 7 km from Kosjerić starts the Ultramafic Massif of Maljen, consisting serpentinised spinel harzburgites and cumulate rocks (feldspar peridotites, gabbros) and large scheeted dyke complex of Bukovi. At Kaona we turn to the east on local road R205a towards Divčibare holiday resort (7 km). At Kaona (on the right side of road) Ožanj hill is composed of cumulate sequence (gabbros, troctolites, pyroxenite and plagioclase-clinopyroxene dunites and plagioclase lherzolites). Towards Divčibare the Maljen ophiolite complex is made up of serpentinised harzburgites. At intersection of roads R205a and R205 we turn to the south and drive of about 1 km.
1173	Field stop 32. WVZ – Maljen ultramafic massif: Layered harzburgite (Divčibare)
1173–1195	Return to road intersection R205 and R205a (Divčibare holiday resort) and back to Kaona.
1195–1100	Field stop 33. WVZ – Maljen ultramafic massif: Ultramafic cumulates – feldspar peridotites (1 km north of Kaona).
1195–1100	Travel to Bukovi (M21) along Bukovi gabbro-diabase complex.
1100	Field stop 34. WVZ – Maljen ultramafic massif: Sheeted dyke complex ("Bukovi" quarry, 6 km north of Kaona), before the intersection of roads R205a and M21, ~2km).
1100–1192	Travel to Belgrade via Valjevo, Lajkovac (M4) and Lazarevac (M22, *i.e.* E763). On this way we pass through Western Vardar Ophiolitic Zone with Upper Jurassic melange and then close to Valjevo we enter the Jadar unit (mostly covered). After Lajkovac we pass through Miocene–Pliocene sedimentary cover and after Lazarevac (close to Meljak) we enter Easter Vardar Zone, also covered by Miocene–Pliocene sediments. On the right side of road (6 km further) a panorama view of Mount Avala can be seen. Accommodation in Belgrade or departure to Budapest (late evening or early morning train or plane)