EGU series - Émile Argand Conference

13th Workshop on Alpine Geological Studies

September 7th-18th 2017
Zlatibor Mts. (Serbia)

Vladica Cvetković, Kristina Šarić, Ana Mladenović

Three ophiolitic belts – one ocean?

FIELD TRIP GUIDE

University of Belgrade - Faculty of Mining and Geology

Serbian Geological Society

Serbian Academy of Sciences and Arts

European Geosciences Union

EGU series: Émile Argand Conference

13th Workshop on Alpine Geological Studies

September 7th - 18th 2017
Zlatibor Mts. (Serbia)

Vladica Cvetković, Kristina Šarić, Ana Mladenović

Three ophiolitic belts – one ocean?

FIELD TRIP GUIDE

University of Belgrade - Faculty of Mining and Geology

Serbian Geological Society

Serbian Academy of Sciences and Arts

European Geosciences Union

Financially supported by:
Republic of Serbia - Ministry of Education, Science and Technological Development

EGU series: Émile Argand Conference -
13th Workshop on Alpine Geological Studies –
September 7th – 18th 2017 Zlatibor Mts. (Serbia)

Vladica Cvetković, Kristina Šarić, Ana Mladenović

Three ophiolitic belts – one ocean?

Field Trip Guide

Organizers:
University of Belgrade – Faculty of Mining and Geology
Serbian Geological Society
Serbian Academy of Sciences and Arts

Published by:
University of Belgrade - Faculty of Mining and Geology, Đušina 7, 11000 Belgrade

For publisher:
Prof. Dr. Dušan Polomčić, Dean

Printed by:
Sapient Graphics, Belgrade

Number of copies: 80

CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

55(497.11-15)(036)

CVETKOVIĆ, Vladica, 1964-
Three Ophiolitic Belts - One Ocean? : field trip guide [at] Émile Argand Conference - 13th Workshop on Alpine Geological Studies, September 7th - 18th 2017 Zlatibor Mts. (Serbia) / Vladica Cvetković, Kristina Šarić, Ana Mladenović. - Belgrade : Faculty of Mining and Geology, 2017 (Belgrade : Sapient Graphic). - 36 str. : ilustr. ; 30 cm. - (EGU series)

Tiraž 80. - Bibliografija us svako poglavlje.

ISBN 978-86-7352-323-1

1. Šarić, Kristina, 1969- [аутор] 2. Mladenović, Ana, 1987- [аутор] 3. Émile Argand Conference - Workshop on Alpine Geological Studies (13 ; 2017 ; Zlatibor)
а) Србија, западна - Геологија - Водичи
COBISS.SR-ID 243322124

Financially supported by:
Republic of Serbia – Ministry of Education, Science and Technological Development

Content

A Brief Outline of the Geology of Serbia

Geographically, the Serbian territory belongs to the central Balkan Peninsula. There are several regional geographical-geological entities that run through its present-day territory. Along the western and central parts of Serbia a NNW-SSE striking mountainous range is called the Dinaride orogen. It is the Serbian territory where this orogen is directly juxtaposed to another mountain range – the Carpathians. Albeit having different roots, these two orogenic belts both came here from the Alps. The Dinarides follow a rather linear path, first running NW-SE in Slovenia and Croatia and, after an inflection point in northwest Serbia, they continue in a N-S direction. On the other hand, the Carpathians have a longer and curvilinear 'road'. Encircling the flat Pannonian area, they pass through many countries and finally manage to enter Serbia near the Danube Gorge, where, in fact, they start to be Carpatho-Balkanides.

A simplified geotectonic regionalization of present day Serbia and adjacent areas follows the same reasoning of a junction of two differently vergent orogen branches – Dinarides and Carpatho-Balkanides. It, however, differs with respect of the chosen geodynamic interpretation (shortly addressed below). In general, the following units are distinguished (from east to west): 1) East Serbian Carpatho-Balkanides, and Serbo-Macedonian Unit, 2) Complex Ophiolite Suture (including: Vardar Zone mélange, Jadar, Kopaonik and Drina-Ivanjica basement units, and Dinaride mélange), and 3) the units of the External Dinarides. With the exception of the collage composing the External Dinarides with major outcrops occurring westwards from the border between Serbia and Bosnia and Herzegovina, the excursion will get through all the other above mentioned geotectonic units.

To speak roughly about geomorphology and mountain ranges is one thing, but trying to explain or at least illuminate the geodynamic history of this region is far more difficult. In order to do that, we start from the simplest geological facts and link them to adequate geotectonic interpretations. We believe that the main impression of everyone who takes a brief sight of any tectonic map of Serbia is captured by a complex NNW-SSE stretching zone of ophiolites in a broadest possible sense. These sometimes very chaotic rock assemblages consist of tectonically emplaced relicts of ancient oceanic lithosphere, which are spatially associated with various sediments and exotic tectonic blocks (olistoliths, olistoplaques). Although their original state is severely damaged by later events, the ophiolites are crucial for understanding the geological development of this region. Accordingly, the geological framework of Serbia and its neighborhood can be plainly defined as consisting of two collages of continental units separated by this complex belt of dismembered ophiolites. These amalgamated continental units have once belonged to the southern/southwestern margin of Europe (Eurasia) and northern/northeastern margin of Africa (Gondwana) – margins that before the end of Mesozoic era were separated by a wide ocean called Tethys. From the moment when the last parts of the Tethyan ocean closed (which happened most probably in the latest Mesozoic), once widely separated continental margins started to share a common geological history.

The description given above is a huge oversimplification but there is hardly a shorter yet still accurate illustration of the Serbian geology. There is much complexity related to the real nature of the present ophiolites, and disagreements about the true number of the formerly existing Mesozoic oceans still exist. The one-ocean story (e.g. Schmid et al., 2008, and references therein) argues that there was only one Tethys ocean between the ancient Eurasia and Gondwana continents and that the present day geotectonic pattern merely resulted from subsequent tectonic events. These authors argue that the basement units occurring within the ophiolite-bearing suture zones represent tectonic windows rather than microcontinent blocks or so-called terranes and emphasize, and that there are no important compositional differences between the ophiolite rocks of the Vardar Zone and Dinarides and therewith conclude that there was only one ocean. On the other hand, the multi-ocean stories suggest that the history of the ancient Tethys was not that simple and that it comprised more than one oceanic domain (e.g. Karamata, 2006; Robertson et al., 2009). These authors generally suggest that the Balkan ophiolites represent more than one suture (at least the Vardar Zone and the Dinarides) and that the basement rocks found inside the ophiolite mélanges represent microcontinents, i.e. terranes.

There are on-going projects that are partly or completely aimed at a solution to this debate. Some of them keep trying to challenge the problem of peridotite compositions, while others are aimed at studying igneous ophiolite members. Some, in turn, want to deal with sediments from the accompanying accretionary wedge sediments, and others focus on tectonics and deformation. This excursion will provide the participants with a closer look to these ophiolites and associated rock units. They will be able to see various parts of the Tethyan lithosphere from large, km-sized masses of obducted ophiolites and their basement rocks (including metamorphic sole) through gabbro-diabase complexes and associated granitoid rocks to relatively small gabbro basaltic olistolith blocks in mélange.

* * *

This more than simplified outline was aimed at articulating the most important facts of the Serbian geology, leaving behind unnecessary details and strongly debatable questions. Our intention was to put all the information in a single story which should be intelligible for someone who encounters this area for the first time. Eventually, this is a journey guidebook which demonstrates to the participants that they travel through once very much alive ocean(s) and continents.

Further reading:

Cvetković, V., Prelević, D., Schmid, S. (2016): Geology of South-Eastern Europe. In: P. Papić (Ed): Mineral and Thermal Waters of Southeastern Europe, *Environmental Earth Sciences*, 1-30, DOI 10.1007/978-3-319-25379-4_1.

Karamata, S. (2006): The geological development of the Balkan Peninsula related to the approach, collision and compresion of Gondwanan and Euroasian units. – in: Eds. Robertson, A.H.F. & Mountrakis, D.: Tectonic Development of the Eastern Mediterranean Region. *Geological Society, London, Special Publication*, 260, 155-178.

Robertson, A.H.F., Karamata, S., Šarić, K. (2009): Overview of ophiolites and related units in the Late Palaeozoic–Early Cenozoic magmatic and tectonic development of Tethys in the northern part of the Balkan region. *Lithos,* 108, 1-36.

Schmid, S., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski. K. (2008): The Alpine – Carpathian – Dinaride orogenic system: correlation and evolution of tectonic units. Swiss J. Geosci, 101, 139 – 183. doi: 10.1007/s00015-008-1247-3

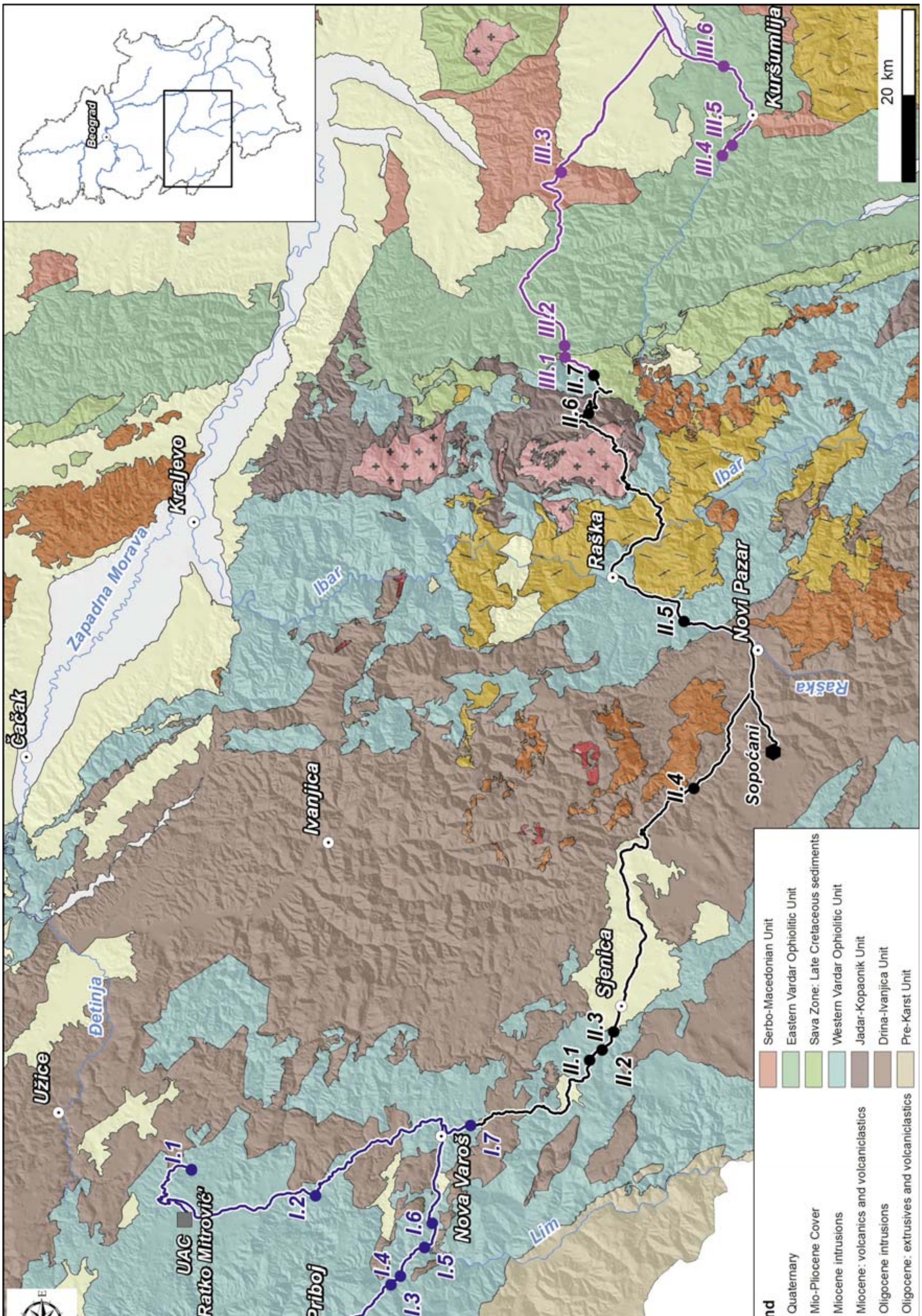

Figure 1. Tectonic map and map of tours. Tectonic units are compiled after General geological map of SFRY based on tectonic zonation of Schmid et al. (2008)

Day 1: 16. 09. 2017. Saturday

Zlatibor, UAC ‘Ratko Mitrović’ – Zlatar, Hotel ’Zlatarski zlatnik’

Field stop I.1: Amphibolites of the metamorphic sole beneath the Zlatibor Mts. massif
Field stop I.2: Ultramafic rocks of the Zlatibor Mts.
Field stop I.3: Amphibolites of Bistrica
Field stop I.4: Olistoliths inside the ophiolitic mélange of Bistrica
Field stop I.5: Pillow lavas of Bistrica
Field stop I.6: Carbonate olistolith overlying the Diabase-Chert Formation
Field stop I.7: Radiolarites of the Diabase-Chert Formation

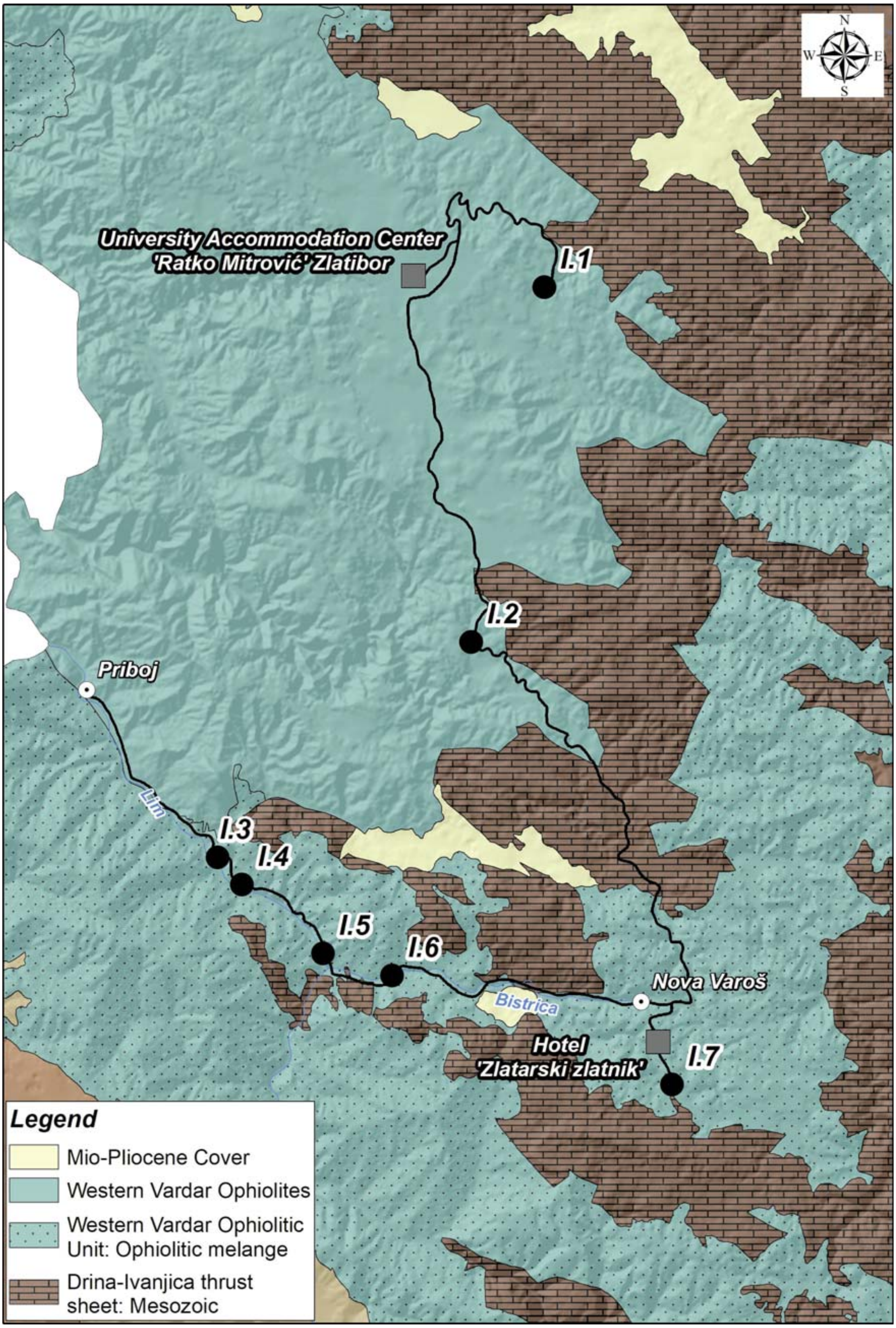

Figure 2. Day 2: Map of the tour

Metamorphic sole – a record of ophiolite emplacement

Williams and Smyth (1973) are often cited as having been among the first who recognized that large ultramafic masses of obducted ophiolites are usually hot enough to cause contact-metamorphism of underlying rocks. They first interpreted metamorphic rocks associated with alpine peridotites of Newfoundland as contact aureoles related to tectonic transport of hot slabs of oceanic crust and mantle. However, yet 1968 it was our late professor Stevan Karamata who first described similar inverted metamorphic aureoles associated with the peridotite massive of Brezovica. During the second half of the 20th century many studies of such rocks associated with the Dinaride ophiolites in Bosnia and Serbia were done providing important insights into the age of the ophiolite emplacement and thereby into the Tethys ocean history.

Further reading:

Karamata, S. (1968): Zonality in contact metamorphic rocks around the ultramafic mass of Brezovica (Serbia, Yugoslavia). In: *Proceedings of the 27th International Geological Congress*, Prague 1, 197–207.

Lanphere, M.A., Coleman, R.G., Karamata, S., Pamić, J. (1975): Age of Amphibolites Associated with Alpine Peridotites in the Dinaride ophiolite zone. Yugoslavia. *Earth Planet. Sci. Lett.*, 26, 271-276.

Srećković-Batoćanin, D., Vasković, N., Matović, V., Gajić, V. (2012): Correlation of metabasic rocks from metamorphic soles of the Dinaridic and the Western Vardar zone ophiolites (Serbia): three contrasting pressure-temperature-time paths. *Ann. Géol. Pén. Balkan.*, 73, 61 – 85.

Williams, H., Smyth, W.R. (1973): Metamorphic aureoles beneath ophiolite suites and alpine peridotites: tectonic implications with West Newfoundland examples. *Am. J. Sci*, 273, 594-621.

Field stop I.1: Amphibolites of the metamorphic sole beneath the Zlatibor Mts. massif

GPS coordinates: *399986, 4841495*

These outcrops show part of a very well preserved sequence of the metamorphic sole rocks occurring below the Zlatibor Mts. ultramafic massif. The metamorphic grade ranges from amphibolite to greenschist facies conditions. At some places the rocks transition into unmetamorphosed and only slightly sheared protoliths, mostly derived from the underlying olistostrome mélange. Amphibolites predominate on this outcrop, because the other parts of this succession are detached or covered (figure I.1-1). Kinematic indicators observed in the wider area of this outcrop systematically show top-WSW tectonic transport.

The amphibolite is composed of green hornblende, plagioclase (up to 50% An), epidote and rare clinopyroxene (with 3-7 % of jadeitic component). Temperature and pressure estimates suggest that these rocks originated on temperatures of around 620-650°C and pressures of about 3-4 kbar. According to their chemistry and assuming a predominantly isochemical metamorphism, their protolith was akin to MORB-type basalts. Metamorphic processes, i.e. the formation of metamorphic hornblende, are dated by K/Ar method to 160±8 Ma. This indicates that the hot ultramafic body was emplaced (obducted) over the olistostrome mélange in the late Middle Jurassic.

Figure I.1-1 Outcrops of the metamorphic sole amphibolites underlying the Zlatibor Mts. ultramafic massif (left) with a detail showing foliation in the amphibolites (right).

Field stop I.2: Ultramafic rocks of the Zlatibor Mts.

GPS coordinates: *397022, 4827106*

The Zlatibor Mts. ultramafic massif geotectonically belongs to the Western Vardar Ophiolitic Unit, i.e. to the westernmost part of the Balkan Peninsula composite ophiolite belt. Ultramafic massifs further westwards in Bosnia (e.g. Krivaja – Konjuh) correspond to the same zone. The ultramafic massif of Zlatibor Mts. is up to 3 km thick, but it mostly represents a much thinner ophiolite slice. The predominant ultramafic rock is lherzolite, while harzburgite is subordinate, whereas dunites and pyroxenites occur only rarely. Serpentinization is generally weak, but it is substantially more pronounced along the marginal parts. At some places listvaenite occurrences can be found.

The lherzolites are generally composed of olivine (Fo<90), orthopyroxene (En<88, Al_2O_3>2 wt%), clinopyroxene (Al_2O_3~2 wt%) and brown to brown-yellowish aluminium-rich spinel (Al_2O_3 mostly above 40 wt%). Serpentine, rare talc and chlorite are the most abundant secondary minerals. At some places, the peridotites are underlain by metamorphic sole rocks, mostly amphibolites.

Figure I.2-1 Outcrops of the peridotites of the Zlatibor Mt. ophiolite massif.

During the late Early Cretaceous and the beginning of the Late Cretaceous, the ultramafic rocks were weathered, i.e. lateritized, and a weathering crust developed above many occurrences. This crust is composed of limonite in its highest levels, deeper it becomes smectitic grading into serpentinite and normal lherzolite with magnesite. At some places economically important deposits of Fe-rich bauxite formed above these peridotites.

Further reading:

Faul, U.H., Garapić, G., Lugović, B. (2014): Subcontinental rift initiation and ocean-continent transitional setting of the Dinarides and Vardar zone: Evidence from the Krivaja-Konjuh Massif, Bosnia and Herzegovina. *Lithos* 202–203, 283–299.

Lugović, B., Altherr, R., Raczek, I., Hofmann, A.W., Majer, V. (1991): Geochemistry of peridotites and mafic igneous rocks from the Central Dinaric Ophiolite Belt, Yugoslavia. *Contrib. Mineral. Petrol.* 106, 201-216.

Maksimović, Z., Kolomejceva-Jovanović, L. (1987): Composition of coexisting minerals of Yugoslav peridotites and the problems of geothemometry and geobarometry of two ultramafic zones. Extrait du GLAS de l'Académie serbe des sciences naturelles et mathématique, 51, 21-52.

Diabase-Chert Formation – a close relative to ophiolites

The Balkan ophiolite complexes do not constitute only the remnants of the ancient oceanic bottom – basalts, gabbros and peridotites, which are comparable to rocks dredged from the recent oceans. Namely, there are also other lithologies which form this chaotic association that bewildered geologists in the first half of the 20th Century. Basically, the association is composed of all the lithologies that could have approached the area of subduction throughout the whole history of its existence. The matrix is a silty-sandy material directly deposited in deep marine troughs and therefore has sometimes flysch-like features. It was subjected to synsedimentary deformation usually via slumping of more consolidated sedimentary material (olistostrome mélange) and exotic blocks which are usually gravitationally introduced into the trench (chert, limestone, diabase-basalt, and other olistoliths). Even though complex and chaotic, this synsedimentary deformed association was further tectonically reworked, first contemporaneously connected 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 a large scale as well as shearing and formation of boudinaged structures on a mesoscale).

If one has difficulties to imagine what would be the final product of these roughly simultaneous sedimentary and tectonic processes, he/she should visit south-west Serbia where many outcrops of such exotic rock associations are exposed. During the fifties the unit as a whole was misinterpreted as Triassic in age because the investigators did not know that in such deposits the superposition method was useless. However, the name that they coined at that time has remained forever. Namely, the silty matrix is readily eroded and commonly covered by vegetation and what sticks out are olistolith blocks variable in size and composition. Among them, diabase and chert are most resistant to erosion and, therefore, very abundant, thus the name – Diabase-Chert (Hornstein) Formation was derived. This is akin to "wildflysch with ophiolitic detritus" (Laubscher & Bernoulli 1977).

Further reading:

Kossmat, F. (1924): Geologie der zentralen Balkanhalbinsel—Kriegsschauplaetze 1914–1918, geologisch dargestellt, 12, 1–198.

Karamata,S., 1988: "The Diabase-chert formation" – some genetic aspects. - *Bulletin XCV de l'Acad. Serbe des Sciences et des Arts, Classe des Sciences mathem. et naturelles,* 28, 1-11, Beograd.
Laubscher, H.. Bernoulli, D. (1977): Mediterranean and Tethys. In: Nairn, A.E.M., Kanes, W.H. Stehli, F.G. (Eds.): The Ocean Basins and Margins V. 4A, Plenum Publ. Comp., New York, 1–28.
Obradović, J., Milovanović, D., Vasić, N. (1987/88): Siliceous rocks in Mesozoic from Serbia in association with Diabase-chert and Porphyrite-chert Formation. *Bull. Nat. Hist. Museum,* 42/43 (A), 23-49 (in Serbian, with English abstract).

Field stop I.3: Amphibolites of Bistrica

GPS coordinates: 386854, 4819848

Along the road Priboj – Bistrica, outcrops of amphibolite-grade metamorphic rocks occur several times. The true nature of these rocks still remains to be resolved. They most likely represent metamorhopsed olistoliths, hundreds of meters thick, whose relationships with other mélange lithologies, especially with the matrix material, are very difficult to observe.

Garnet amphibolites (I.3-1) are composed of saussuritized plagioclase, hornblende and garnet. These medium-grained rocks are metamorphosed under upper amphibolite facies conditions. They show nematoblastic and granoblastic as well as subordinate porphyroblastic textures. Garnet crystals are typically reddish and sometimes reach up to 1 cm in diameter. At some places garnet is very abundant constituting up to 20% of the rock volume. The polyphase crystallization of amphiboles and zoning of garnet with different types of inclusions are visible.

Figure I.3-1 Garnet amphibolites along the road Priboj – Bistrica.

Further reading:

Balen, D., Operta, M., Pamić, J. (2003): The geothermobarometry of Alpine amphibolites from the metamorphic sole of the Krivaja-Konjuh ultramafic massif (Dinaride Ophiolite Zone, Bosnia). VI Alpine Workshop, Sopron, Hungary, 14-16 September 2003. *Annales Universitatis Scientiarum Budapestiensis, Sectio Geologica*, 35, 131-132.
Popević, A., Korikovsky, S.P., Karamata, S. (1993): Garnet clinopyroxenite from Bistrica, Southern Zlatibor, Serbia, *Bulletin of the Geological Society of Greece* 28/2, 93–103.
Popević, A., Memović, E., Zakariadze, G., Milovanović, D., Karamata, S. (2004): The basalts of Podpeć (near Priboj, SW Serbia), the youngest (?) basaltic rocks of the Dinaridic ophiolitic basin, *Geologica Balcanica,* 34/3–4, 21–28.

Field stop I.4: Olistoliths inside the ophiolitic mélange of Bistrica

GPS coordinates: *387795, 4818295*

Further on, towards Bistrica, two outcrops show two olistolith blocks of different composition, one basaltic and another made of limestone, both set in a silty-clayey matrix. In addition to these two larger blocks, the olistostrome matrix contains cm- to m-sized elongated and sometimes rounded sandstone fragments, which is typical for the diabase-chert formation in Serbia.

The basaltic olistolith consists of unsorted subangular to subrounded fragments of basaltic lava, ranging in size from a few cm to around one meter (I.4-1). The basaltic rock is porphyritic, amygdoidal with abundant voids filled with calcite. The fragments lay in a fine-grained hyaloclastic matrix which gives the rock an open framework fabric. Although the matrix is highly altered, mostly chloritized and calcitized, the relicts of glass shards originated from the chilled margins of the larger fragments can be seen. This basaltic rock differs in geochemistry from other basalts (pillow lavas) of the Dinaride ophiolites in having a more OIB-like composition.

On the right side of the road outcrops a 30 m long, around 10 m high and 3-4 m thick olistolith of Triassic "Bódvalenke-type" red bedded cherty limestone (I.4-2). Such olistoliths are found as blocks in the lower sedimentary complex of both the Darno and Szarvasko Ophiolite Complexes in Hungary. It is interesting that this formation has a much wider distribution at the surface in the Othrys and North Pindos ophiolite complexes of Greece. As such this represents another characteristic feature that was previously believed to represent important difference between the Dinaridic Ophiolitic Belt and the mélange of the Vardar zone.

Figure I.4-1 Olistolith of basaltic hyaloclastites.

Figure I.4-2 Olistolith of Triassic cherty limestone.

Further reading:

Kovács, S. (2010): Type section of the Triassic Bódvalenke Limestone Formation (Rudabánya Hills, NE Hungary) – the northwesternmost occurrence of a Neotethyan deep water facies. *Central European Geology*, 53/2–3, 121–133.

Popević, A., Memović, E., Zakariadze, G., Milovanović, D., Karamata, S. (2004): The basalts of Podpeć (near Priboj, SW Serbia), the youngest (?) basaltic rocks of the Dinaridic ophiolitic basin, *Geologica Balcanica,* 34/3–4, 21–28.

Photo stop I.4a: Ultramafic and metamorphic series of Bistrica

GPS coordinates: 390603, 4815433

Further on, along the road to Bistrica, long exposures of ultramafic and metamorphic rocks, ranging from several hundred meters up to a few kilometers, alternate with each other. Contacts between these rocks are tectonic in character. This stop exposes one such tectonic contact where kinematic indicators show top-WNW tectonic transport.

Peridotites are represented by tectonized lherzolites that ocasionally contain lenses of dunites ranging in thickness from a few meters to up to hundred meters. Very subordinately, these ultramafic rocks contain cm/dm-thick veins of garnet-pyroxenites. The foliation in peridotites, developed as elongated orthopyroxene and olivine porphyroclasts, has a NNW-SSE direction and dips towards SE.

Corundum- and pargasite-bearing amphibolite occurs as blocks with tectonic contacts with the adjacent ultramafic rocks. In addition, they are found alternating with garnet amphibolites. The texture of the corundum-pargasite amphibolite is nematoblastic but elements of granoblastic, seldom porphyroblastic textures are also evident. Microscopically, it is possible to distinguish synkinematic and postkinematic growth of pargasite in these amphibolites. Corundum occurs as small pinkish to violet fine-grained accumulations.

Figure I.4a-1 Outcrops of the peridotites and metamorphics of Bistrica.

Further reading:

Bazylev, B., Zakariadze, G., Popević, A., Kononkova, N., Karpenko, S. & Simakin, S. 2006: Spinel peridotites from Bistrica Massif (Dinaridic ophiolite belt): The possible fragment of a sub-continental mantle. In: Mesozoic ophiolite belts of the northern part of the Balkan Penninsula; *Proceedings of a Conference organized by the Serbian Academy of Sciences & Arts*, Belgrade-Banja Luka, 12–14.

Milovanović, D. (1989): Garnet-pyroxene amphibolites near Bistrica, Souther part of Zlatibor ultramafic Massif (Yugoslavia). *Rendiconti della Societa Italiana di Mineralogia e Petrologia*, 43-3, 765-772.

Field stop I.5: Pillow lavas of Bistrica

GPS coordinates: 391040, 4814486

In the vicinity of the crossroad Nova Varoš – Prijepolje – Priboj and close to the Bistrica Lake some of the best exposed outcrops of Jurassic pillow lavas in Serbia can be observed (figure I.5-1, left). Here occurs a more than 20 m thick pile of pillows that range in size from very small, fist-like pillows to those more than 1 m in diameter. The pillows show typical glassy margins and tiny normal joints and are surrounded by fine-grained and almost schistose hyaloclastic matrix (figure I.5-1, right). The lower parts of the pillows show effects of plastic deformations, which suggests that this is a normal sequence of pillow-lavas.


Figure I.5-1 Outcrops of pillow lavas of the Bistrica sequence.

The rocks in general show spilitic mineral associations characterized by the presence of albite, relicts of clinopyroxene, chlorite, epidote and opaque minerals. Scarce geochemical data indicate that these rocks originated from MORB-type magmas.

Field stop I.6: Carbonate olistolith overlying the Diabase-Chert Formation

GPS coordinates: *393822, 4813592*

The outcrop is situated in the vicinity of Bistrica on the right side of the road towards Nova Varoš. An olistolith of Upper Triassic red and gray Hallstatt limestone (most probably Lower and Middle Norian in age) is overlying reddish silty-sandy matrix material of the Diabase-Chert Formation (figure I.6-1). The contact is obviously tectonic and is characterized by deformation of the underlying matrix, as well as the carbonate rock itself, with very well developed and pervasive cleavage (figure I.6-2).

Figure I.6-1 A huge limestone olistolith overlying the matrix material of the Diabase-Chert Formation.

Figure I.6-2 Deformation structures of the limestone olistolith and the underlying matrix.

Radiolarites: Important story-tellers in ophiolite terrains

Radiolarians occurring predominantly in siliceous sedimentary rocks are very important story-tellers about geological evolution of ophiolite terrains and are sometimes unique for constraining the timing of ophiolite emplacement. However, the accurate understanding of the sediments that contain the as siliceous ooze is crucial for using this information in reconstructing the origin of particular ophiolite segments. The Balkan ophiolites contain various types of radiolarians-bearing rocks which, among other cases, may represent pelagic sediments directly associated to ocean floor basalts, sediments of carbonate platform that sunk below the CCD, or pelagic intervals within flysch sequences.

Field stop I.7: Radiolarites of the Diabase-Chert Formation

GPS coordinates: 405148, 4809168

On the left side of the road Nova Varoš – Sjenica, in an old quarry, cherts to radiolarites of characteristic red colour, which are alternating with limonite-rich pelites, are exposing. Chert layers are 3 – 5 cm thick, while the thickness of the pelites does not exceed 2 cm. In the limonite-rich parts, the rock tranists into siliceous limonite. Within the dark red, poorly clayey radiolarite, radiolarians of Upper Bajocian to Oxfordian age were determined.

Figure I.7-1 Outcrop of radiolarites of the Diabase-Chert Formation.

Day 2: 17. 09. 2017. Sunday

Zlatar, Hotel 'Zlatarski zlatnik' – Kopaonik, Vila 'Ranković'

Field stop II.1: Conglomerates inside the Diabase-Chert Formation
Field stop II.2: Diabase-Chert Formation and underlying radiolarites
Field stop II.3: Chert and albite granite olistoliths near Sjenica
Field stop II.4: Metamorphic rocks of the Drina – Ivanjica Unit
Field stop II.5: Contact between ultramafic rocks and ophiolitic mélange
Field stop II.6: Kopaonik Metamorphic Series
Field stop II.7: Metamorphosed ophiolitic mélange

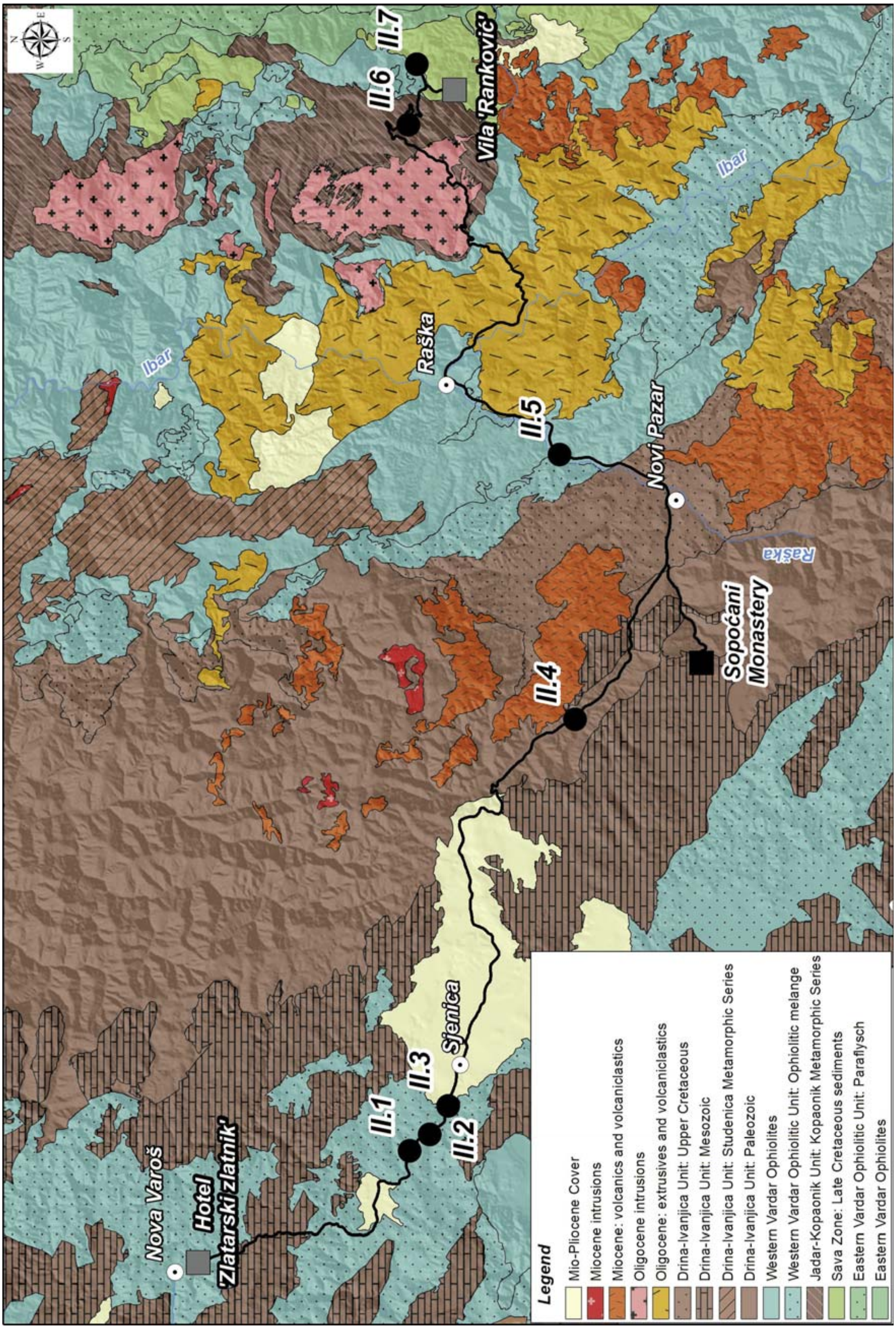

Figure 3. Day 2: Map of tour

Field stop II.1: Conglomerates inside the Diabase-Chert Formation

GPS coordinates: 412707, 4795417

A 6 – 7 m long outcrop (figure II.1-1) of a composite conglomerate olistolith set in a silty-sandy matrix occurs on the Zlatar Mts. The conglomerate is interlayered with reddish coarse-grained sandstone. The rock consists of unsorted pebbles of variable dimensions, sometimes up to 20 cm in diameter. Among the pebbles, there are rounded fragments of light gray Permian and dark gray Carboniferous limestones (both with fusulinids) together with quartz sandstone and arkose, brown friable sandstone, lydite, quartz, cherts, limestone of unknown age, and mafic igneous rocks. The largest part of the olistolith shows a crude gradation in mesoscale. This conglomerate block may represent the relict of the filling of a submarine channel.

Figure II.1-1 An outcrop of a conglomerate olistolith.

Field stop II.2: Diabase-Chert Formation and underlying radiolarites

GPS coordinates: 413907, 4793933

On this locality, a contact between the radiolarite olistolith and the overlying (±underlying) rocks of the Diabase-Chert Formation is outcropping.

Figure II.2-1 An outcrop of Diabase-Chert Formation and underlying Middle to Upper Jurassic radiolarites.

The section of the underlying olistolith is represented (from bottom to top) by fine-grained compact grey limestone Liassic micro-association, compact pink limestone with gastropods and poorly conserved cephalopods, Rosso Ammonitico rich in cephalopods of Lower Toarcian age, red radiolarian schists and radiolarites with a thick bed of graded calcrudite. According to determined radiolarians, this section is dated to Middle to Upper Jurassic.

The Diabase-Chert Formation, overlying the olistolith, is mostly represented by sandstone blocks. According to determined radiolarians, these are dated to Upper Triassic.

Field stop II.3: Chert and albite granite olistoliths near Sjenica

GPS coordinates: 415991, 4792600

A decameter-sized olistolith entirely composed of cherts can be seen on the right side of the road Nova Varoš – Sjenica. The chert is bedded with up to several cm thick individual beds (figure II.3-1, left). The rock is reddish-to-green in color, locally with thin interlayers of siliceous shale. It is also slightly sheared on the margin and locally contains some olistostrome matrix material. The chert contains Triassic (the latest Carnian – late Middle Norian) radiolarians. This is an important indication about the existence of an oceanic realm at that time.

Figure II.3-1. Olistoliths inside the Jurassic Diabase-Chert Formation: reddish radiolarite (left) and albite granite (right).

On the opposite side of the road an olistolith (about 100 m in size) of albite granite, that belongs to the ophiolite association, is exposed in an old quarry. The granite is incorporated into the ophiolite mélange with obscured contacts with the adjacent rocks. It is mainly composed of albite, quartz and chloritized amphibole (?). The granite is extremely sodic (up to 6-7% of Na_2O and K_20 below 1%) and has high Y and Zr contents which are usually found in oceanic plagiogranite.

Further reading:

Goričan, S., Karamata, S., Batoćanin-Srećković, D., 1999. Upper Triassic (Carnian-Norian) Radiolarians in Cherts of Sjenica (SW Serbia) and the Time Span of the Oceanic Realm Ancestor of the Dinaridic Ophiolite Belt. *Bulletin T.CXIX de l'Academie Serbe des Sciences et des Arts .Science Naturelles* 39, 141-149.

Milovanović, D., Srećković-Batoćanin, D., Savić, M., Popović, D. (2012): Petrology of plagiogranite from Sjenica, Dinaridic Ophiolite Belt (southwestern Serbia). *Geologica Carpathica,* 63, 97-106.

Vishnevskaya, V.S., Djeric, N., Zakariadze, G.S., (2009): New data on Mesozoic Radiolaria of Serbia and Bosnia, and implications for the age and evolution of oceanic volcanic rocks in the Central and Northern Balkanides. *Lithos,* 108, 72-105.

Field stop II.4: Metamorphic rocks of the Drina-Ivanjica Unit

GPS coordinates: 444280, 4783310

Along the roadcut between Sjenica and Novi Pazar low-grade metamorphic rocks of the Drina-Ivanjica Unit crop out. These rocks are predominantly represented by phyllites, Paleozoic in age, which form the basement of the Drina-Ivanjica Mesozoic successions.

This low-grade metamorphic formation is metamorphosed up to greenschist facies conditions, which was associated to polyphase deformation. The time span for this metamorphic event is not unequivocally constrained, however both K/Ar ages and deformation characteristics of the wider area suggest that the tectonic event leading to such metamorphism in this area should be older than Late Cretaceous.

According to the 'one ocean scenario' (e.g. Schmid et al., 2008) the Drina-Ivanjica metamorphic rocks (along with those of the Jadar and Kopaonik blocks) represent tectonic windows below a single ophiolitic thrust sheet in which the most distal paleogeographic domains of Adria are exposed.

Further reading:

Đoković, I. (1985): The use of structural analysis in determining the fabric of Paleozoic formation in the Drina-Ivanjica Region. *Ann. Géol. Pén. Balkan*., 49, 11-160.
Milovanović, D. (1984): Petrology of low metamorphosed rocks of the central part of the Drina-Ivanjica Paleozoic. *Bull. Mus. Hist. Nat. Belgrade*, A, 39, 13-139.
Schmid, S., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski. K. (2008): The Alpine – Carpathian – Dinaride orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci*, 101, 139 – 183. doi: 10.1007/s00015-008-1247-3

Figure II.4-1 Phyllites of the Drina-Ivanjica Unit.

The Sopoćani Monastery

The old Serb Orthodox monastery of Sopoćani is the foundation of St. King Uroš I. It was built in the second half of the 13^{th} century and is located west of Novi Pazar, near the source of the Raška River. This monastery is a World Heritage Site since 1979 accompanying with Stari Ras (Old Ras), a medieval capital of the Serbian great župan Stefan Nemanja.

The frescoes in the monastery are a true masterpiece of art that have brought international fame to the Sopoćani monastery. The Sopoćani monastery represents an exceptional example of the Raška school. It was named after the Old Slavic word "sopot" which means "spring". The church has a form of the Romanesque three-nave basilica with a massive semicircular apse in the central part of the nave. The church also has a tall bell tower. The facade was covered with fresco-plaster, and then decorated with ornaments in white, ocher and rouge color. The facade got destroyed during centuries. The interior of the church is decorated with colored stucco ornaments. Frescoes in the Sopoćani are substantially preserved thanks to their quality and they represent some of the greatest achievements of the monumental wall painting in Serbia. The most significant frescoes are located in the central part of the church.

Photos of the Sopoćani Monastery exterior and interior

Field stop II.5: Contact between ultramafic rocks and ophiolitic mélange

GPS coordinates: 463668, 4784465

Along the main road from Novi Pazar to Raška ocurs an about 30 m long outcrop where the contact between ultramafic rocks and the matrix of ophiolitic mélange can be observed. On this outcrop, ultramafic rocks are represented by highly tectonized serpentinized peridotites. The ophiolitic mélange contains cm – dm blocks of amphibolite, peridotite and gabbro, that are set in silty – sandy matrix. The contact between the ultramafics and the ophiolitic mélange is rather complex and is most probably a result of Cretaceous/Paleogene deformations.

Figure II.5-1 An outcrop of ultramafic rocks and ophiolitic mélange.

National Park Kopaonik

The National Park Kopaonik represents the region protected by the law and restricted area which keeps its natural condition, and protect its own animal and plant species, its relief and other natural rarities. It was founded and proclaimed in 1981. It covers an area of 11.800 ha. A total of 689 ha of the wildlife refuge is under special protection in 13 natural reservates (areas). Besides, the Park encompasses 26 natural monuments, 17 geomorphologic, 6 geologic, 8 hydrologic and 15 objects classified as natural and cultural goods.

The park is placed on the highest part of the mountain. Its main part is represented by a mountainous, relatively leveled region of medium height about 1700 m above sea-level. The lowest altitude is about 640 m above sea-level and the highest altitude is Pančićev vrh (2017 m), named after one of the first natural scientist in Serbia.

The Kopaonik Mts. landscapes

Field stop II.6: Kopaonik Metamorphic Series

GPS coordinates: 487823, 4795497

On the road from the Kopaonik touristic centre down to Brzeće, a several-km long outcrop is exposing low-grade metamorphic rocks of the Kopaonik Metamorphic Series. The Kopaonik Metamorphic Series is part of the Jadar – Kopaonik thrust sheet, which represents the most distal part of the Adriatic margin, covered by the obducted Late Jurassic ophiolite nappe. The Jadar – Kopaonik thrust sheet, along with its ophiolitic cover, was included into the Late Cretaceous out-of-sequence top-W thrusting.

The Kopaonik Metamorphic Series include Paleozoic metasedimentary basement which is overlain by metamorphosed Triassic to Middle/?Upper Jurassic sediments. These Mesozoic metasediments show a polyphase penetrative tectonic overprint, related to three phases of Cretaceous and Paleogene compressional tectonics, as well as Miocene extension that exhumed the Kopaonik core-complex. Cretaceous – Paleogene compressional phases were associated with polyphase greenschist-facies metamorphism, which locally reaches lower-amphibolite grade conditions.

Figure II.6-1 Strongly deformed rocks of the Kopaonik Metamorphic Series, displaying effects of Paleogene greenschist metamorphism and related ductile deformations.

Further reading:

Egli, D. (2008): Das Kopaonik-Gebirge in Südserbien – Stratigraphie, Strukturen und Metamorphose. MSc Thesis, University of Basel, Basel.

Schefer, S. (2010): Tectono-metamorphic and magmatic evolution of the Internal Dinarides (Kopaonik area, southern Serbia) and its significance for the geodynamic evolution of the Balkan Peninsula. *PhD thesis. University of Basel*, Switzerland.

Schefer, S., Egli, D., Missoni, S., Bernoulli, D., Fügenschuh, B., Gawlick, H-J., Jovanović, D., Krystyn, L., Lein, R., Schmid, S., Sudar, M. (2010): Triassic metasediments in the internal Dinarides (Kopaonik area, southern Serbia): stratigraphy, paleogeographic and tectonic significance. *Geologica Carpathica* 61 (2), 89 – 109. doi: 10.2478/v10096-010-0003-6.

Zelić, M., D'Orazio, M., Malasoma, A., Marroni, M., Pandofli, L. (2005): The metabasites from the Kopaonik metamorphic complex, Vardar zone, southern Serbia: remnants of the rifting-related magmatism of the Mesotethyan domain or evidence for Paleotethys closure in the Dinaric-Hellenic belt? *Ofioliti*, 30 (2), 91-101.

Zelić M., Levi N., Malasoma A., Marroni M., Pandolfi L., Trivić, B. (2009): Alpine tectono-metamorphic history of the continental units from Vardar zone: the Kopaonik Metamorphic complex (Dinaric-Hellenic belt, Serbia). *Geological Journal* 45, doi: 10.1002/gj.1169.

Field stop II.7: Metamorphosed ophiolitic mélange

GPS coordinates: 492253, 4794884

On the road from Brzeće to Brus, an outcrop of the ophiolitic mélange of the Western Vardar Ophiolitic Unit is exposed. The mélange contains mainly cm – dm blocks of serpentinite, but rare fragments of basalts, turbiditic sandstones and carbonates are also found. These blocks are embedded in silty, brownish to reddish muddy matrix material. The ophiolitic mélange of the eastern flanks of the Kopaonik Mts. is of considerable thickness and tectonically overlies the Kopaonik Metamorphic Series.

On this outcrop, the rocks exhibit very well developed foliation that represent Paleogene deformation structures of the Kopaonik Mts. area.

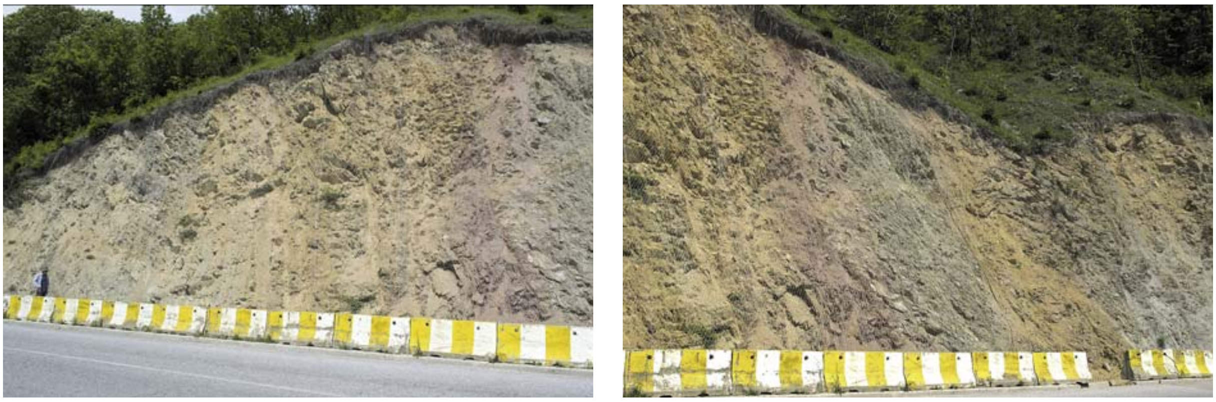

Figure II.7-1 An outcrop of the ophiolitic mélange, metamorphosed during Paleogene.

Further reading:

Egli, D. (2008): Das Kopaonik-Gebirge in Südserbien – Stratigraphie, Strukturen und Metamorphose. *MSc Thesis, University of Basel*, Basel.

Schefer, S. (2010): Tectono-metamorphic and magmatic evolution of the Internal Dinarides (Kopaonik area, southern Serbia) and its significance for the geodynamic evolution of the Balkan Peninsula. *PhD thesis. University of Basel*, Switzerland.

Zelić, M. (2004): Tectonic history of the Vardar zone: constraints from the Kopaonik area (Serbia). *PhD Thesis, Universita di Pisa*, Italy.

Day 3: 18. 09. 2017. Monday

Kopaonik, Vila 'Ranković' – Belgrade

Field stop III.1: Late Cretaceous sediments of the Sava Zone
Field stop III.2: Peridotites of the Eastern Vardar Ophiolitic Unit
Field stop III.3: Metamorphic rocks of the Serbo-Macedonian Unit
Field stop III.4: Intraophiolitic granites of the Eastern Vardar Ophiolitic Unit
Field stop III.5: Pillow lavas of the Eastern Vardar Ophiolitic Unit
Field stop III.6: Late Cretaceous flysch of the Eastern Vardar Ophiolitic Unit

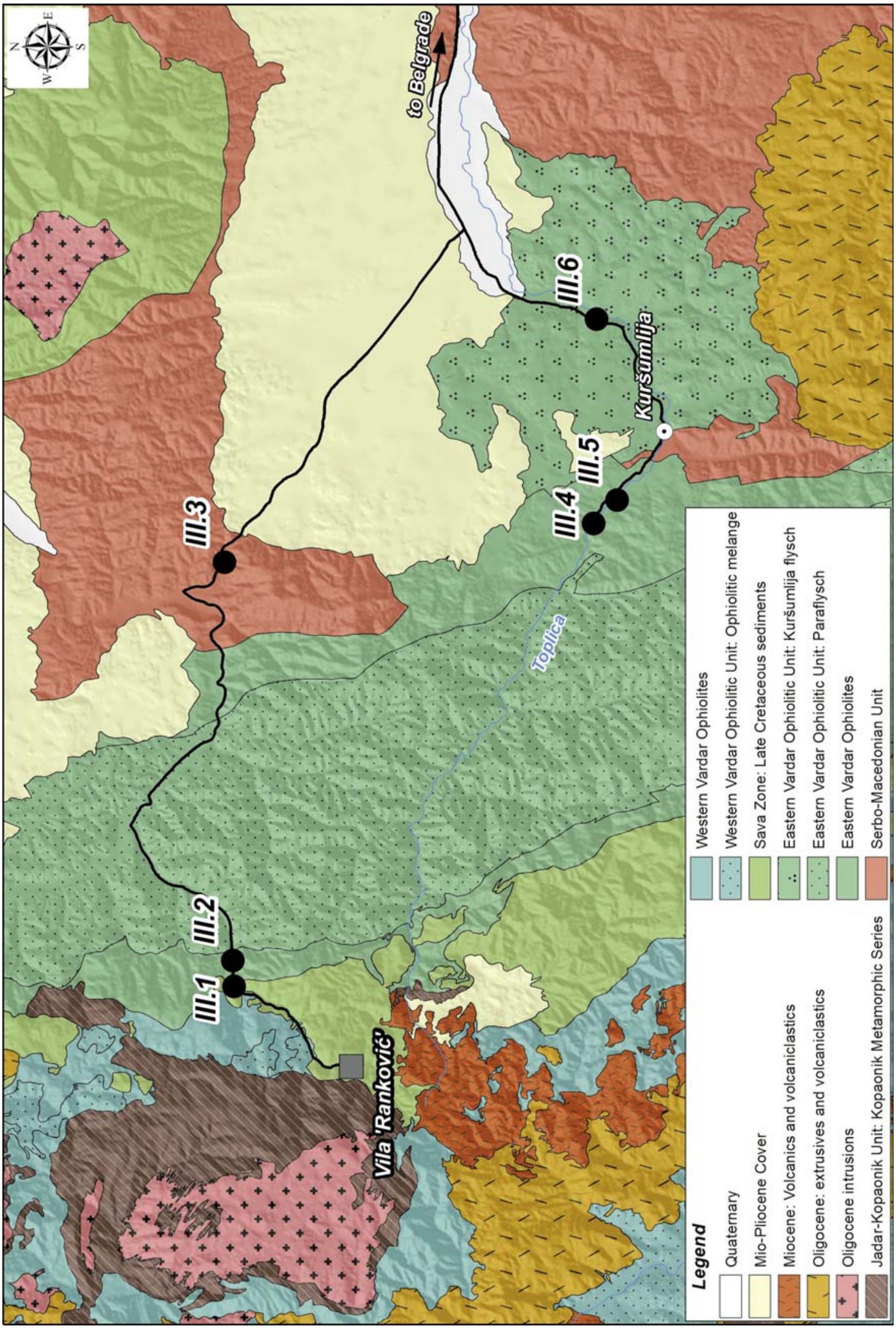

Figure 4. Day 3: Map of tour

Sava – Vardar Zone: A remaining conundrum of Balkan geology

Sava– or Sava–Vardar zone (Pamić 2002) occurs as a narrow belt that begins south of Zagreb, stretches WNW-ESE towards Belgrade, and then makes an inflection and continues southward to FYR of Macedonia. The Sava zone is younger and locally more metamorphosed than other Cretaceous flysch belts overlying the Jurassic mélanges. Because it contains blocks of Late Cretaceous ophiolite like basalt–diabase(±gabbro) complexes some authors believe that the Sava zone is the last suture that records the former presence of a Tethyan oceanic realm throughout Late Cretaceous times (Karamata 2006; Schmid et al. 2008; Robertson et al. 2009). Many authors (see Gallhofer et al. 2015) invoke that Late Cretaceous subduction of Sava zone oceanic lithosphere was responsible for the formation of well-known Late Cretaceous Banatite–Timok–Srednjegorje magmatic and metallogenetic belt. However, the interpretation that the Sava Zone represent the youngest ophiolites in this area is recently challenged by Prelević et al. (2017).

Further reading:

Karamata, S. (2006): The geological development of the Balkan Peninsula related to the approach, collision and compresion of Gondwanan and Euroasian units. – in: Eds. Robertson, A.H.F. & Mountrakis, D.:Tectonic Development of the Eastern Mediterranean Region. *Geological Society, London, Special Publication*, 260, 155-178.

Prelević, D., Wehrheim, S., Reutter, M., Romer, R.L., Boev, B., Božović, B., van den Bogaard, P., Cvetković, V., Schmid, S.M. (2017): The Late Cretaceous Klepa basalts in Macedonia (FYROM)—Constraints on the final stage of Tethys closure in the Balkans. *Terra Nova*, 29:145–153.

Robertson, A.H.F., Karamata, S., Šarić, K. (2009): Overview of ophiolites and related units in the Late Palaeozoic–Early Cenozoic magmatic and tectonic development of Tethys in the northern part of the Balkan region. *Lithos,* 108, 1-36.

Schmid, S., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski. K. (2008): The Alpine – Carpathian – Dinaride orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci*, 101, 139 – 183. doi: 10.1007/s00015-008-1247-3

Field stop III.1: Late Cretaceous sediments of the Sava Zone

GPS coordinates: 494335, 4798232

From the last point, the road to Brus is passing by the outcrops of turbidite sediments, and the outcrop on the field stop III.1 is the last in this succession of outcrops exposing Late Cretaceous sediments that unconformably overlie the Kopaonik Metamorphic Series and the Western Vardar Ophiolitic Unit.

These sediments contain large olistoliths, mainly composed of ophiolites and metamorphic rocks. This sedimentary succession is underlain by calcitic sedimentary breccia that contain ophiolitic detritus and previously metamorphosed fragments. This unit is mostly composed of red pelagic limestones, while olistoliths of calc-arenites, conglomerates and metamorphosed grainstones, are incorporated into the succession.

Like the previous units of the eastern flanks of the Kopaonik Mts., this rocks also exhibit penetrative ESE-dipping foliation, with frequent kinematic indicators showing top-WNW shear senses.

This Late Cretaceous unit is interpreted as the southern prolongation of the Sava Zone, which is believed to represent the main suture zone between the Dinarides and the Carpatho-Balkan orogen. Hence, parts of this turbiditic sequence are interpreted to have been formed during the Late Cretaceous to Early Paleogene closure of the Vardar branch of the Neotethys Ocean.

Figure III.1-1 An outcrop of the Late Cretaceous turbidites of the Sava Zone.

Further reading:

Schefer, S. (2010): Tectono-metamorphic and magmatic evolution of the Internal Dinarides (Kopaonik area, southern Serbia) and its significance for the geodynamic evolution of the Balkan Peninsula. *PhD thesis. University of Basel*, Switzerland.

Schmid, S., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski. K. (2008): The Alpine – Carpathian – Dinaride orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci*, 101, 139 – 183. doi: 10.1007/s00015-008-1247-3.

Ustaszewski, K., Kounov, A., Schmid, S., Schaltegger, U., Krenn, E., Frank, W., Fügenschuh, B. (2010): Evolution of the Adria – Europe plate boundary in the northern Dinarides: From continent-continent collision to back-arc extension. *Tectonics* 29, TC6017. doi: 10.1029/2010TC002668.

East Vardar and Serbo-Macedonian Unit: The European side story

Most researchers agree that a narrow ophiolitic slice that is attached to the westernmost margin of the Serbo-Macedonian Unit and is universally named East Vardar Zone is different from other Balkan ophiolites. The EVZ ophiolites display the most pronounced supra-subduction geochemical signatures and are believed to have formed in a short-lived intra-oceanic back-arc basin during subduction initiation within a back-arc setting. The most recent geotectonic interpretations consider the East Vardar ophiolites, along with the Serbo-Macedonian Unit, as integral part of the Carpatho-Balkan orogen.

Field stop III.2: Peridotites of the Eastern Vardar Ophiolitic Unit

GPS coordinates: 495663, 4798280

The serpentinized peridotites outcropping on this field stop is part of the east-vergent East Vardar Ophiolitic Unit, which is tectonically situated on top of the European deformed margin (i.e. the Carpatho-Balkan orogen). This ultramafic slice is not associated with known metamorphic sole rocks and that might suggest that the present-day contacts with adjacent units have been controlled by later tectonic events.

The serpentinite is strongly brecciated. Originally, it was primarily composed of olivine (22-55 vol %), enstatite (10-20 vol %) as well as rare diopsidic clinopyroxene and chromite, which are almost completely altered to serpentine. The generally accepted view is that these ultramafics are serpentinized tectonite harzburgite.

Basaltic rocks associated with these peridotites were found as relicts of shallow intrusions. There is evidence of the presence of boninite-like rocks within this ophiolitic sequence. Given that boninite lavas are regared as derived from melting of a strongly depleted source (e.g. harzburgite), is taken as another evidence that the East Vardar Zone ophiolites originated in an arc-related setting.

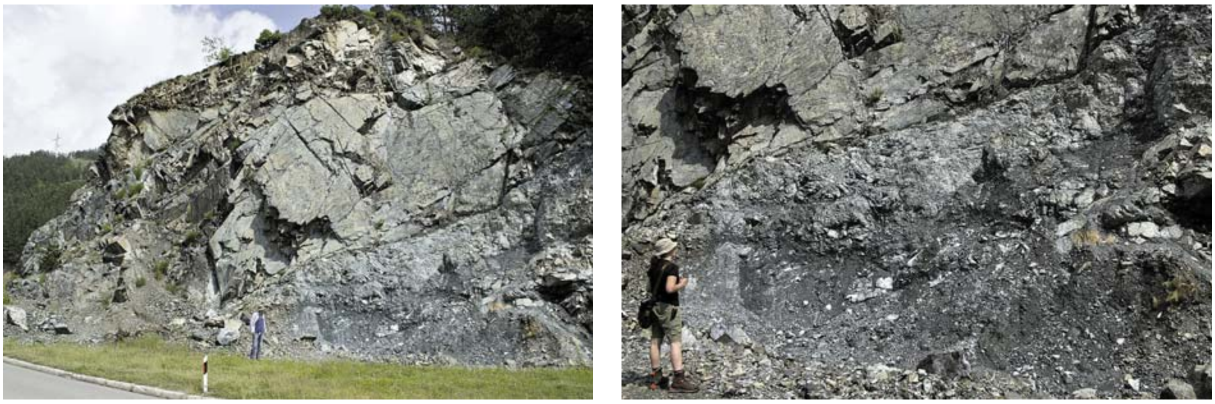

Figure III.2-1 An outcrop of the serpentinized peridotites of the Eastern Vardar Ophiolitic Unit.

Further reading:

Dimitrijević M.D. (2001): Dinarides and the Vardar zone: a short review of the geology. *Acta Vulcanologica,* 13 (1-2), 1-8.

Schmid, S., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski. K. (2008): The Alpine – Carpathian – Dinaride orogenic system: correlation and evolution of tectonic units. *Swiss J. Geosci*, 101, 139 – 183. doi: 10.1007/s00015-008-1247-3

Zelić, M. (2004): Tectonic history of the Vardar zone: constraints from the Kopaonik area (Serbia). *PhD Thesis, Universita` di Pisa*, Italy.

Zelić, M., D'Orazio, M., Malasoma, A., Marroni, M., Pandofli, L. (2005): The metabasites from the Kopaonik metamorphic complex, Vardar zone, southern Serbia: remnants of the rifting-related magmatism of the Mesotethyan domain or evidence for Paleotethys closure in the Dinaric-Hellenic belt? *Ofioliti*, 30 (2), 91-101.

Zelić M., Levi N., Malasoma A., Marroni M., Pandolfi L., Trivic, B. (2009): Alpine tectono-metamorphic history of the continental units from Vardar zone: the Kopaonik Metamorphic complex (Dinaric-Hellenic belt, Serbia). *Geological Journal* 45, doi: 10.1002/gj.1169.

Field stop III.3: Metamorphic rocks of the Serbo-Macedonian Unit

GPS coordinates: *515811, 4779900*

On the left side of the road Brus – Kuršumlija, an about 30 m long outcrop is exposing metamorphic rocks of the Serbo-Macedonian Unit. The polyphase deformed and metamorphosed Serbo-Macedonian Unit is part of the east-verging Carpatho-Balkan orogen, which represents the deformed European margin. The Serbo-Macedonian Unit is generally in a lower tectonic position with respect to the Eastern Vardar Ophiolitic Unit.

The area of this outcrop is composed of an association of amphibolite facies metamorphic rocks, which are locally affected by retrograde metamorphism in greenschist facies conditions. These rocks are represented by micaschist and rarely gneiss of various composition, and very subordinate of migmatites that contain intercalations of quartzites, amphibolites and marbles. The age of metamorphism in the neighboring area of this field stop is not constrained. According to the visible structures in the wider area of the outcrop, at least three main deformational phases related to the Late Cretaceous – Paleogene orogenic build-up are reported also in this area.


Figure III.3-1 An outcrop of micaschists of the Serbo-Macedonian Unit.

Further reading:

Antić, M.D., Kounov, A., Trivić, B., Wetzel, A., Peytcheva, I., Quadt, A. (2016): Alpine thermal events in the central Serbo-Macedonian Massif (southeastern Serbia). *International Journal of Earth Sciences,* 105, 1485. doi: 10.1007/s00531-015-1266-z.

Antić, M., Peytcheva, I., von Quadt, A., Kounov, A., Trivić, B., Serafimovski, T., Tasev, G., Gerdjikov, I., Wetzel, A. (2016): Pre-Alpine evolution of a segment of the North-Gondwanan margin: Geochronological and geochemical evidence from the central Serbo-Macedonian Massif. *Gondwana Research*, 36, 523–544.

Erak, D., Matenco, L., Toljić, M., Stojadinović, U., Andriessen, P.A.M., Willingshofer, E., Ducea, M.N. (2017): From nappe stacking to extensional detachments at the contact between the Carpathians and Dinarides – The Jastrebac Mountains of Central Serbia. *Tectonophysics,* 710 – 711, 162 – 183. doi: 10.1016/j.tecto.2016.12.022

Field stop III.4: Intraophiolitic granites of the Eastern Vardar Ophiolitic Unit

GPS coordinates: 517776, 4780056

The East Vardar ophiolites contain three genetically different groups of intraophiolitic granites: (1) low-Sri granites, (ii) high-Sri granites and (iii) tholeiitic plagiogranites. All these granites are similar in the field having a clear leucocratic character in comparison to the adjacent basic rocks.

This outcrop of granite belongs to the low-Sri group characterized by index of peraluminousity (ASI) from 1.00 to 1.80, K_2O = <2 wt.% to >6 wt.%, and $^{87}Sr/^{86}Sr$ = 0.7033 to 0.7062. The granites in general show geochemical characteristics of the rocks derived from arc-related magmas. Šarić et al. (2009) suggested that the low-Sri granites have been formed by obduction-induced melting of immature volcaniclastic sediments; these could represent mafic/intermediate volcaniclastic debris that was originally deposited in an island arc setting. In addition, some samples of the low-Sri granites show adakite-like features (Al_2O_3 >15 wt.%, Sr/Y>20, Y<15 ppm, Yb<1.5 ppm as well as a mantle-like Sr–Nd isotopic signature, similar to ophiolite-related adakite-like rocks that have later been distinguished in the Demir Kapija ophiolitic sequence (Božović et al., 2013).


Figure III.4-1 Intraophiolitic granite of the East Vardar Ophiolitic Unit.

Further reading:

Božović. M., Prelević, D., Romer R., Barth, M., Bogaard, P.V.D., Boev, B. (2013): The Demir Kapija Ophiolite, Macedonia (FYROM): a Snapshot of Subduction Initiation within a Back-arc. *Journal of Petrology*, 54 (7):1427–1453.

Resimić-Sarić, K., Cvetković, V., Balogh, K. (2005): Radiometric K/Ar data as evidence of the geodynamic evolution of the Zdraljica Ophiolitic Complex (central Serbia). *Ann. Géol. Pén. Balkan.*, 66, 73-79.

Šarić, K., Cvetković, V., Romer, R.L., Christofides, G., Koroneos, A. (2009): Granitoids associated with East Vardar ophiolites (Serbia, F.Y.R. of Macedonia and northern Greece): origin, evolution and geodynamic significance inferred from major and trace element data and Sr-Nd-Pb isotopes. *Lithos*, 108, 131-150.

Field stop III.5: Pillow lavas of the Eastern Vardar Ophiolitic Unit

GPS coordinates: 518953, 4778871

The section Žuč-Kuršumlija ends with outcrops of the volcanic section of the East Vardar Zone ophiolite slice. Basaltic pillow lavas occur here associated with diabase dykes. Pillow lava basalts are intersertal and microophitic in texture and are predominantly composed of albite, uralite and chlorite; however, some relics of primary clinopyroxenes can be observed, too. The piles of pillow lavas are at some places intersected by diabase dykes. The dykes show chilled margins and tiny normal joints, which are typical features of shallow emplacement of feeder dykes. The dyke interiors are intersertal and ophitic in texture and have similar composition to the adjacent basaltic lava.

Figure III.5-1 Pillow lavas of the Kuršumlija ophiolitic complex of the East Vardar Zone.

Field stop III.6: Late Cretaceous flysch of the Eastern Vardar Ophiolitic Unit

GPS coordinates: 528119, 4779900

On the road Kuršumlija – Prokuplje, an outcrop exposing Late Cretaceous flysch sediments is situated. These sediments are interpreted as a cover of the East Vardar Ophiolitic Unit and unconformably lie above the Serbo-Macedonian Unit.

Figure III.6-1 Late Cretaceous flysch sediments of the Eastern Vardar Ophiolitic Unit (Kuršumlija flysch).

The sequence is represented by conglomerates, shallow-water deposits and turbidites. Unlike the similar deposits on the eastern side of the Kopaonik Mts. (Late Cretaceous sediments of the Sava Vardar Zone, field stop III.1) these sediments are not deformed or are very poorly deformed, and have very well observed primary sedimentary structures.

Émile Argand Conference (EGU series) - 13th Workshop on Alpine Geological Studies - September 7th-18th 2017, Zlatibor Mts. (Serbia) was supported by

Republic of Serbia - Ministry of Education, Science and Technological Development

http://www.mpn.gov.rs/

International Association of Sedimentologists

IAS
INTERNATIONAL ASSOCIATION OF SEDIMENTOLOGISTS

http://www.sedimentologists.org

Hotel "Lav", Zemun

http://www.hotellav.co.rs

ISBN 978-86-7352-323-1