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Review paper
Прегледни рад

Field excursion guide to the Geology of Fruška Gora (Southern Pannonian Basin,Serbia)

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Abstract. Fruška Gora, a prominent inselberg within the southern margin of the Pannonian Basin, preserves a complex geological record of both orogenic and post-orogenic processes in the central Balkans. This one-day field excursion highlights key outcrops of the Vardar Zone ophiolitic belt, including Serbia's only documented blueschist-facies rocks, as well as serpentinites, diabases, and pillow lavas, which collectively record subduction-related metamorphism and the emplacement of oceanic lithosphere during the closure of the Neotethys ocean. Additional stops include Upper Cretaceous flysch successions intruded by Oligocene latites (≈35 Ma), whose tectonic evolution has been constrained by paleomagnetic studies documenting post-collisional rotations and extensional tectonics. Together, these localities provide valuable insights into the interplay of subduction, magmatism, and basin evolution, establishing Fruška Gora as a key site for understanding the geodynamic history of the southern Pannonian Basin.

Key words:
blueschists, Pannonian Basin, Vardar Zone ophiolites, Cenozoic latites

Апстракт. Фрушка гора, изоловано узвишење на јужном ободу Панонског басена, чува сложен геолошки запис који обухвата орогене и посторогене процесе централног Балкана. Ова једнодневна теренска екскурзија истиче кључне профиле офиолитског појаса Вардарске зоне, укључујући једини до сада документовани локалитет стена фасције плавих шкриљаца у Србији, као и серпентините и дијабазе, који заједно приказују субдукциони метаморфизам и финално постављање океанске литосфере током затварања Неотетиса. Додатне тачке екскурзије обухватају горњокредне флишне сукцесије интрудоване олигоценским латитима (~35 Ma), чија је старост додатно утврђена палеомагнетским студијама које указују на постколизионе ротације и екстензиону тектонску активност. Заједно, ови локалитети пружају јединствен увид у међусобно деловање субдукције, магматизма и развоја басена, позиционирајући Фрушку гору као један од кључних локалитета за разумевање геодинамичке историје јужног Панонског басена.

Кључне речи:
плави шкриљци, Панонски басен, офиолити Вардарске зоне, кенозојски латити

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Introduction

Fruška Gora is a prominent inselberg within the southern margin of the Pannonian Basin. Rising above the surrounding lowlands and partially covered by Miocene sediments, it is structurally expressed as an east–west-trending horst bounded by two major regional normal faults to the north and south. These faults accommodated differential uplift and subsidence during the evolution of the basin (Toljić et al., 2013). This tectonic configuration has preserved a diverse geological record that documents multiple stages of orogenic and post-orogenic processes in the central Balkan region.

The one-day field excursion will depart from the conference venue and visit several key outcrops that exemplify the complex geological history of Fruška Gora (Fig. 1). Participants will examine sequences belonging to the Vardar Zone ophiolitic belt, including Serbia's only documented occurrence of blueschist-facies rocks. These glaucophane-bearing schists provide rare evidence of high-pressure metamorphism associated with Late Jurassic–Early Cretaceous subduction, recording the emplacement of oceanic lithosphere fragments during the closure of the Neotethyan domain. Additional exposures of serpentinites, diabases and pillow lavas will illustrate the internal architecture of the ophiolitic complex and its significance for the regional geodynamic evolution.

Beyond the ophiolitic assemblages, the itinerary includes Upper Cretaceous flysch successions deposited in foreland-basin settings, and subsequently

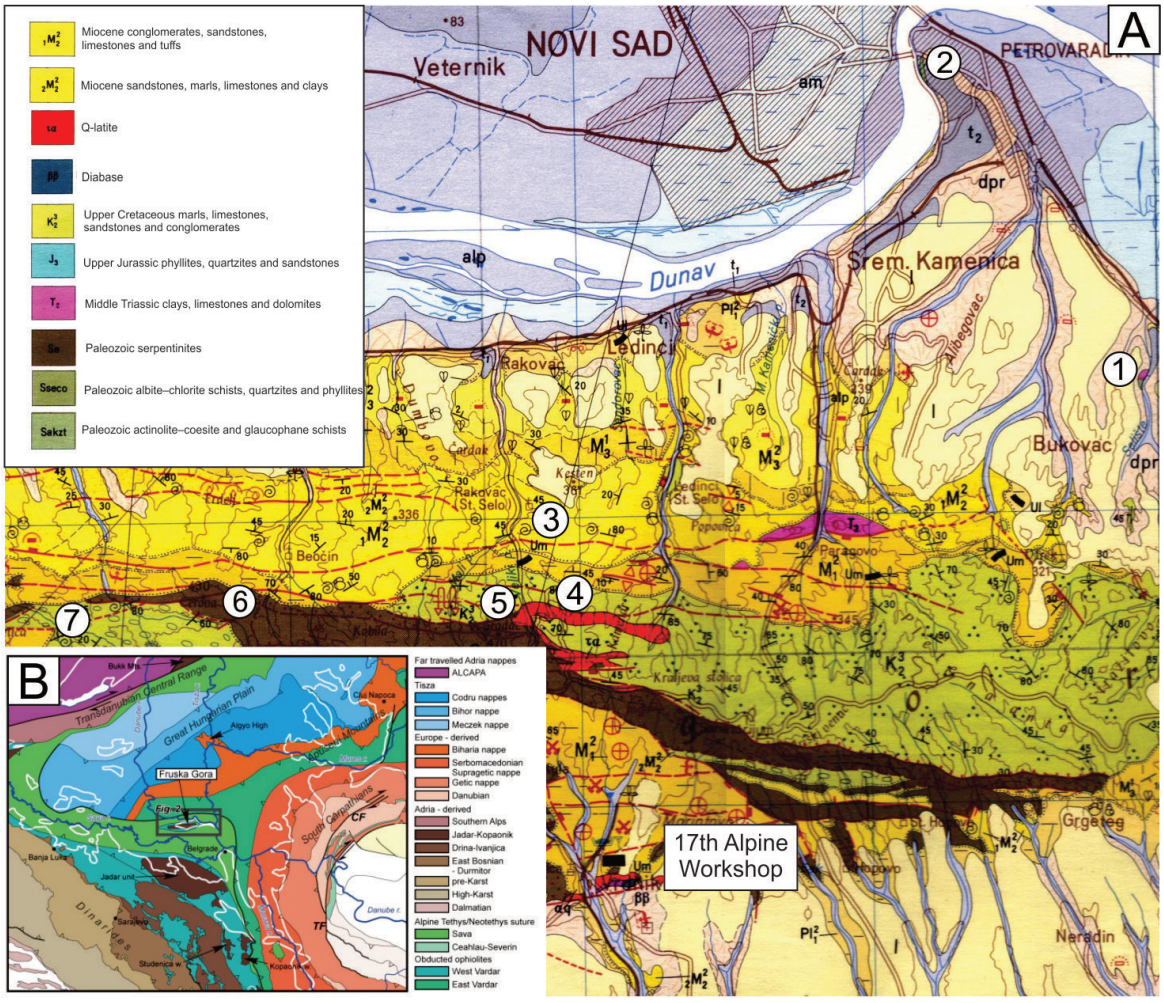

***Fig. 1**. **A)** Geological map of FT5 on Fruška Gora showing the field stops:1. Blueschist from Sremski Karlovci; 2. Diabase near Petrovaradin Fortress; 3. Volcaniclastics exposed in the abandoned Beli Majdan Quarry; 4. Cenozoic volcanics – Rakovac quarry; 5. Quartz latites and Upper Cretaceous flysch sediments; 6. Serpentinized peridotites; 7. Campanian–Maastrichtian red beds of Srednje Brdo (Čičulić-Trifunović & Rakić, 1976; Toljić et al., 2013). **B)** Detailed tectonic map of the zone between the Dinarides and the Carpathians (from Toljić et al., 2013, modified after Schmid et al., 2008).*

intruded by Oligocene magmatic bodies. These intrusions, exposed in the central part of Fruška Gora, can be correlated with contemporaneous volcanic rocks observed elsewhere in the western Pannonian Basin (Pamić & Balen, 2001; Pamić et al., 2002). Paleomagnetic studies of these intrusions, predominantly latites dated at 35±5 Ma by the K–Ar method, reveal post-collisional rotations and exten-sional tectonic deformation within the southern Pannonian Basin. These findings provide evidence for significant crustal stretching and underscore the close relation-ship between magmatic reactivation, lithospheric extension, and basin development during the Tertiary.

Field Stop 1. Blueschists near Sremski Karlovci

The blueschists of Fruška Gora represent one of the most remarkable metamorphic occurrences in Serbia and have been dated at 123 Ma (Milovanović et al., 1995; Korikovsky & Karamata, 2011). These metabasites and interlayered phengite–chlorite–quartz metasandstones record high-pressure/low-temperature (HP/LT) conditions definitive of subduction-related metamorphism. Petrographically, the peak mineral assemblage comprises glaucophane, epidote, chlorite, actinolite, and minor albite, defining a pronounced foliation (Milovanović et al., 1995). Microstructural analyses indicate a prograde evolutionary pathway, typically evidenced by Na-amphiboles with crossite/riebeckite cores and glaucophane rims. Geothermobarometric constraints utilizing Si-rich phengite place the metamorphic peak at T ~350^{0}C and P ~4–8 kbar (Milovanović et al., 1995). The characteristic blue coloration of these rocks reflects the abundance of sodic amphiboles formed during the burial and metamorphism of oceanic crustal fragments within a subduction zone associated with the closure of the Neotethys Ocean. Stratigraphically, this HP/LT metamorphic overprint is assigned to the Late Jurassic–Early Cretaceous (Korikovsky & Karamata, 2011), correlating with the regional phase of closure of the Neotethys and the tectonic imbrication of its oceanic lithosphere. From a geodynamic perspective, this locality is of exceptional regional significance. Together with comparable isolated basement occurrences in the Medvednica and Motajica mountains (Sokol et al., 2020), the Fruška Gora blueschists delineate a remnant subduction system that records the complex convergence history culminating in the Cretaceous–Paleogene collision between the Adria microplate and Europe. This locality is significant not only because it represents the only documented occurrence of blueschist-facies rocks in Serbia, but also because it provides direct evidence of the geodynamic processes that shaped the Vardar Zone during the closure of the Neotethys Ocean (Fig. 2).

Fig. 2. *Blueschist outcrop, the only occurence identified in Serbia to date.*

Field Stop 2. Diabase at Petrovaradin

Beneath the Petrovaradin Fortress, the bedrock exposes diabase and pillow lavas belonging to the ophiolitic complex of Fruška Gora (Fig. 3). These rocks provide an accessible record of oceanic crust

Fig. 3. *Diabase and pillow lavas from the ophiolitic complex beneath Petrovaradin Fortress.*

formation and submarine magmatism within the Neotethyan domain. Petrographically, they are composed predominantly of plagioclase and clinopyroxene, with widespread secondary alteration to chlorite and epidote. Stratigraphically, they are assigned to the Late Jurassic and are associated with the main phase of ophiolite emplacement in the Vardar Zone (Dimitrijević, 1997). This locality is of particular significance as it offers a direct insight into the formation of oceanic crust and its subsequent tectonic emplacement, preserved beneath Petrovaradin Fortress, one of the most prominent landmarks in the region.

Field Stop 3. Beli Majdan Quarry

Beli Majdan Quarry (Fig. 4) is an important geological and historical site near Stari Rakovac. The rocks exposed in the quarry comprise limestones, sandstones, and tuffs deposited in the Pannonian Sea (Tomić et al., 2020). Archaeological evidence indicates that the site was already being exploited in the

Fig. 4. *Entrance to the historical and geological site of Beli Majdan Quarry on Fruška Gora.*

12th century, when stone blocks from the quarry were used in architectural elements of the Benedictine abbey at Gradina–Dombo (Stojkovski, 2013). The quarry remained active in later centuries, particularly in the 18th century, when it supplied material for the chapel at the Stari Rakovac cemetery (1751) as well as for numerous carved tombstones that are still preserved today. The extensive rock gallery, formed through centuries of extraction, represents an impressive monument to the region's stone-working tradition and cultural heritage.

Field Stop 4. Latites of Stari Rakovac

The Stari Rakovac locality represents an important outcrop in northern Serbia where Cenozoic volcanism can be studied (Fig. 5). The latites from the

Fig. 5. *Latites at Field Stop 4 near Stari Rakovac village (**5a** - outcrop; **5b** - quarry).*

quarry near Stari Rakovac intrude into Paleozoic metamorphic complexes, making them an important geotectonic marker. Intrusion is constrained to the Oligocene, based on a crystallization age of 35±1 Ma obtained by K–Ar geochronology (Čupković, 1997). Porphyritic latites are characterized by individual feldspar phenocrysts set in a fine-grained ground-

mass, while glomeroporphyritic latites display clusters or aggregates of feldspar crystals, commonly accompanied by biotite and amphibole (Čupković, 1997), reflecting variations in crystallization dynamics within the magma. These intrusive latites record magmatic differentiation and late-stage intrusion within a post-orogenic extensional regime (Early–Middle Miocene), related to the tectonic evolution of the Pannonian Basin (Toljić et al., 2013).

Field Stop 5. Intruded latite dyke

The exposed profile in the abandoned quarry near the village of Stari Rakovac (Fig. 6) reveals latites dated to the Eocene–Oligocene transition, approximately 35 Ma (K–Ar, Knežević et al., 1991). These rocks show a porphyritic texture with phenocrysts of hornblende, augite, andesine plagioclase (~An37%), and biotite, set in a holocrystalline groundmass of the same minerals. Based on their SiO_2/K_2O ratios, they belong to the shoshonitic series and have been interpreted as products of partial melting of a mixed mantle–crust source in response to crustal thinning along the southern margin of the Pannonian Basin (Horvath & Berckhemer, 1982). The profile is highly illustrative, showing latites intruded into Upper Cretaceous flysch sediments and Jurassic? serpentinites (Dimitrijević, 1997; Karamata 2006; Toljić et al., 2012), making it a significant locality for understanding the geotectonic evolution of Fruška Gora.

***Fig. 6**. Latites intruded into Upper Cretaceous flysch sediments.*

Field Stop 6. Ophiolitic fragments near Beočin

At this locality, intensively altered and tectonized Jurassic serpentinized peridotites are exposed (Fig. 7) (Dimitrijević, 1997; Karamata 2006; Robertson et al., 2009). They extend along the axis of Fruška gora in an east–west direction, and thrusting of serpentinized peridotites over Badenian formations has been documented in several exploratory water wells. These thrusts are associated with intense Neogene strike-slip tectonics (Toljić et al., 2013), making the locality important for understanding the structural evolution. The peridotites of Fruška Gora belong to the ophiolitic fragments of the Vardar Zone and are predominantly harzburgitic in composition (olivine

***Fig. 7.** Outcrop of exposed Jurassic peridotites.*

+ orthopyroxene, with minor clinopyroxene (Robertson et al., 2009 and references therein). Their presence documents depleted mantle residues, representing fragments of oceanic lithosphere incorporated into the regional tectonic framework.

Field Stop 7. Debeli Cer red beds

Campanian–Maastrichtian red beds of Debeli Cer quarry (Fig. 8), situated on the northwestern slopes of Fruška gora, represent the pelagic development of the Upper Cretaceous within the Inner Dinarides (Schmid et al., 2008; Toljić et al., 2013). The succession is composed of calcarenitic sandstones, subarkosic varieties, ferrous sandstones with inter-

bedded conglomerates, and biomicrites in red and light-gray tones, reflecting a depositional environment in which pelagic sedimentation was influenced by shallow-water detrital input. The fossil assemblage includes palynomorphs of the Normapolles group, planktonic and benthic foraminifers, traces of serpulids, and remains of rudists, molluscs, echinids, and calcareous algae (Čičulić-Trifunović & Rakić, 1977), altogether illustrating the interplay between pelagic sedimentation and biogenic input during the Late Cretaceous.

Fig. 8. *Abandoned Debeli Cer Quary exposing Campanian–Maastrichtian red beds.*

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