GEOLOŠKI ANALI BALKANSKOGA POLUOSTRVA
Volume 83 (1), July 2022, 23–37
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https://doi.org/10.2298/GABP220404004S
Review paper
Прегледни рад

The birth of the Sava Suture Zone: The early geological observations and the context of bimodal magmatism (southern Belgrade outskirts; Anđelković, 1973)

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Abstract. This paper presents one of the significant results of the research of Prof. Dr. Milodrag Anđelković. The study underlines the first field record providing the evidence of the Upper Cretaceous bimodal magmatism that evetually led towards the definition of the Late Cretaceous "Sava–Vardar Zone" in 2002 (Pamić, 2002). Currently, the 20-years old "Sava–Vardar Zone" i.e., the Sava Suture Zone regarded as a crustal assembly formerly intervening the amalgamated Adria and south Eurasian affinities. The pioneering field mapping-based observations contributing the debuted Sava Suture Zone, are in the underestimated report of Prof. Dr. Milodrag Anđelković, presenting his observations of the typifying Late Cretaceous bimodal magmatism (published in 1973 in the regional XIX-century established journal *„Annales geologiques de la peninsule Balkanique"*; Title: "*Геологија мезозоика околине Београда",* translated: The geology of Mesozoic assembly: vicinity of the Belgrade area). In that time, during early 1970's, the entire geoscience community of former Yugoslavia for a long time denying any Late Cretaceous magmatism within the Vardar Zone, offering a counterargument grounded onto the geosyncline tectonic framework.
The 1973 paper was published much prior the constraints on the Late Cretaceous bimodal magmatic intrusions, discussed as the "Peri Adriatic Sava magmatic arc" or Peri Adriatic Lineament, but only three decades later. The Anđelković's 1973 report represents the first published record, interpreting a number of the Late Cretaceous bimodal magmatic mini-occurrences distributed in the modern-day Sava Suture Zone belt. Despite using the previous tectonic model, the often-neglected descriptions of the Jurassic–Late Cretaceous biostratigraphy and their spatial relationship with the confined magmatic entities, allow the important correlation of a number of Late Cretaceous small-scale basins, positioned to the northwest (Bosnia & Herzegovina, Croatia), and to the south of Belgrade (Central Serbia, North Macedonia). The understanding of this suture zone, bending in the vicinity of Belgrade, is of primary importance, providing the characterization of the terminal Alpine collisional mechanism in the area.

Key words:
"Sava Zone", Sava Suture Zone, "Lower Sava Suture Zone, "Upper Sava Suture Zone", Anđelković (1973).

Апстракт. У овом прегледном раду, посебна пажња је посвећена једној од најважнијих, али често занемарених регионално-геолошких достигнућа проф. др. Милодрага Анђелковића. У својој публикацији *„Геологија мезозоика околине Београда"* објављеној у Геолошким аналима Балкан-

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скога полустрва, Anđelković (1973) истиче по први пут, на просторима бивше СФРЈ постојање горњокредног магматизма који је присутан у веома геолошки комлексној околини Београда. Аутор издваја два типа до тада неутврђених горњокредних догађаја, и дели их на базични и андезитски магматизам. Тек двадесетак година касније, гоњокредну "Сававардар зону" издваја Pamić (2002), а преузима Schmid et al., (2008, 2020), стварајући нову концепцију геологије и тектонике Балканског полуострва, засновану на обједињеним кредним мега-теранима (геолошким ентитетима уобличеним током горњокредног сажимања ових простора). Узимајући у обзир да је давне 1973. године, целокупна геолошка заједница одбацивала било какво постојање горњокредних догађаја, у овом раду се наглашавају ранија достигнућа о тзв. „бимодалном" горњокредном магматизму околине Београда. На жалост, рад Anđelković (1973) се није узимао у разматрање, током настанка нове идеје о постојању овог комплексног горњокредно-палеогеног сутурног асемблажа. Уз детаљан преглед рада Anđelković (1973), у овој публикацији се истиче и развој различитих хипотеза и њихових интерпретација Сава Сутурне Зоне у последњих двадесет година.

Кључне речи.
Сава Зона, Сава Сутурна Зона, доња Сава Сутурна Зона, горња Сава Сутурна Зона, Анђелковић (1973).

Introduction: Vardar Zone & its Sava Suture Zone

The Vardar Zone *s.s.*represents a prominent yet much debated collisional paleosuture disconnecting Adria from Eurasian affinities (Dimitrijević, 1997; Karamata, 2006; Pamić, 2002; Schmid et al., 2008; Tolji ć et al., 2018; Fig. 1). The Vardar Zone is a fossil composite Neotethyan accretionary agglomeration, comprising the Jurassic ophiolites and the Cretaceous flysch-bearing sequences (Dimitrijević, 1997; Karamata, 2006; see Robertson et al., 2009, Spahić &

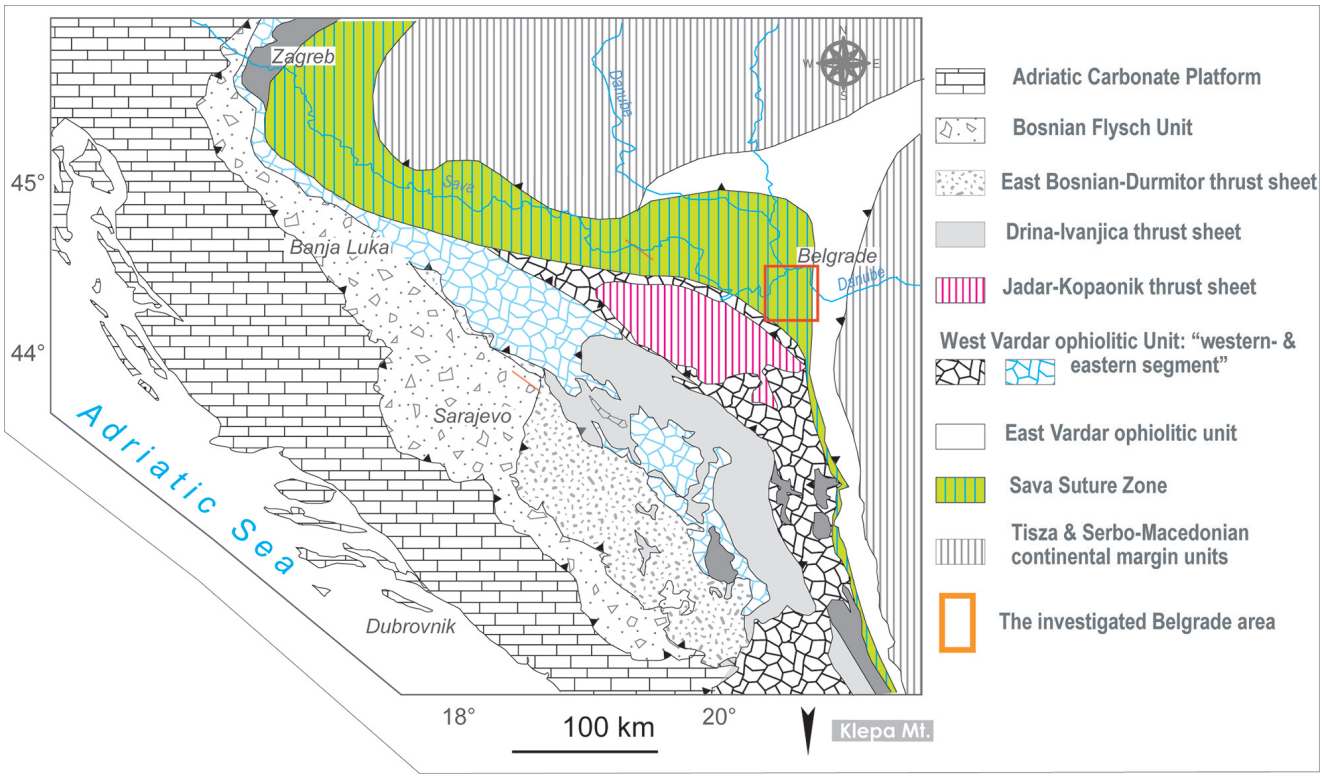


Fig. 1. *The position of the Sava Suture Zone, intervening the Adria and Euroasian tectonic units (inset from Schmid et al., 2008, modified).*

Gaudenyi, 2020, for a discussion; Fig. 1). The Vardar Zone *s.s.* incorporates the West Vardar Zone (the ophiolite-bearing system representing the principal Jurassic-aged oceanic segment), and it's another composite ophiolite-decorated foreland sequence, referred to as the East Vardar Zone (Gallhofer et al., 2017; Fig. 1). The West Vardar Zone is separated from the latter foreland by the "Sava-Vardar Zone", "Sava Zone", "North Bosnian Zone" (Grubić, 1980), "Central Vardar Zone" (Dimitrijević, 1997; Toljić et al., 2019; Márto et al., 2022) or Sava Suture Zone (Spahić & Gaudenyi, 2022). The Sava Suture Zone is best exposed in Bosnia and Herzegovina, Croatia, striking across northern Serbia, Belgrade, Central Serbia, North Macedonia and Greece (Fig. 1).

The 1000 km long Late Cretaceous Sava Suture Zone of the composite Vardar Zone represents one of the highly attractive Tethyan topics, often discussed in the last 10–15 years. Thus, the composite Vardar Zone *s.s.* intervening the Dinarides/Hellenides and south Eurasia, established itself as a polygon for the Plate Tectonic theory, allowing the interpretations of a number of subducting plates. The upper plate during this collision was the European derived units of Tisza "Dacia" super imposed onto the Adria derived units of the Dinarides. The most debuted issue is the bimodal igneous Upper Cretaceous succession that is unconformably overlain by Maastrichtian to Paleocene siliciclastics, abundant with ophiolite and acidic rocks detritus. Such configuration suggests reworking of the dominantly Campanian magmatics. Another topic of the ongoing debates is the tectonic setting itself.

The Sava Suture Zone disconnects the Dinarides of the Apulia/Adria from the South European foreland, marked by the prominent syn-collisional tubidite *i.e.* 'Gosau-type' flysch-bearing sequence. The Upper Cretaceous–Paleogene syn-collisional turbidites are characterized by the underlying, rather localized extension-driven mini-magma Late Cretaceous system.

Another tectonic concept is that the "Sava Zone", "Central Vardar Zone" is a "relic ocean" of the Neotethys (Karamata et al., 2000; Ustaszewski et al., 2009, 2010; Grubić et al., 2010; Toljić et al., 2018, 2021). Because the latter has no documented oceanic crust of Cretaceous age, just recently a renewed oblique pull-apart tectonic model has been proposed (Spahić & Gaudenyi, 2022).

The interpretation of the investigated "ocean-related" Late Cretaceous convergent system, evolved into the pull-apart system in the fore-arc position (connecting the Sava River, Central Serbia with North Macedonia; see Spahić & Gaudenyi, 2022, and references therein), passing a long way from the Kossmat's (1924) "transitional zone". There are a number of open issues related to the Vardar Zone, often either neglected or much debated across international studies:

There is an obvious ambiguity revolving around the exact historical moment when the bimodal magmatics of the Upper Cretaceous age were mapped and outlined for the international inferences. Despite Pamić (2002) coined the "Sava–Vardar Zone", this study provides evidence that the bimodal magmatism as key indicator for the Sava Suture Zone, was introduced much earlier (Anđelković, 1973);

The issue of the paleogeographic inheritance of the Jadar block: according to Dimitrijević (1997) this unit belongs to the Vardar Zone, whereas Schmid et al. (2008) attributed to"distal Adria plate";

• Number of Jurassic Peri Tethyan oceans and their closure times (Dimitrijević, 2001; Robertson et al., 2009; see Spahić & Gaudenyi, 2020, 2022 for a discussion);

• The Alpine vergence of the western Serbo-Macedonian realm, some authors indicate west-vergent thrusting of the latter onto the East Vardar Zone (Rakić et al., 1976), whereas others are of the opinion that the East Vardar Zone is upthrusted onto the Serbo-Macedonian Unit during the Early Cretaceous (Schmid et al., 2008; Matenco et al., 2011);

• The debated tectonic origin of the herein investigated near-Belgrade bimodal Late Cretaceous (Santonian) magmatism (e.g., Anđelković, 1973; Toljić et al., 2021);

• The constraints on the Sava Suture Zone, i.e., its subdivision into the "Lower Sava Suture Zone", and the "Upper Sava Suture Zone" (which will be also highlighted in this study).

A historical overview of the Sava Suture Zone concept

Kossmat's (1924) "transitional zone" represents a tectonic feature situated between the "*Šumadija*"

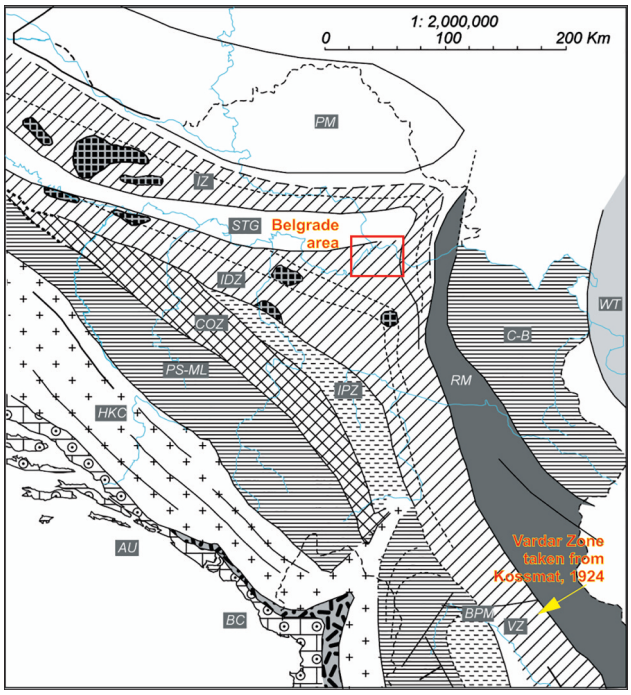


Fig. 2. *The geotectonic sketch map of former Yugoslavia, by applying geosyncline model, produced by Petković (1958). The Vardar Zone referring to the small area in the vicinity of Vardar River in North Macedonia. Other units are: "Budva Cover" (BC), "Outer ophiolites rocks", "Autochton" or near-Adriatic Sea belt (AU), "High-karst cover (HKC)", "Zone of Paleozoic schsits and Mesozoic Limestones (PS-ML)", "Central Zone of ophiolitic rocks (COZ)", "Internal Paleozoic Zone" (IPZ),"Internal Dinaridic Zone of Dinaric horst (IDZ)", "Pannonian Mass" (PM), "Vardar Zone" (VZ), "Bitolj-Prilep Mass" (BPM). IZ – "Inner Zone", STG – "Sava Tectonic Graben", RM – "Rhodopean Mass", C-B – "Carpathian-Balkan Arch", WT – "Walachian Table".*

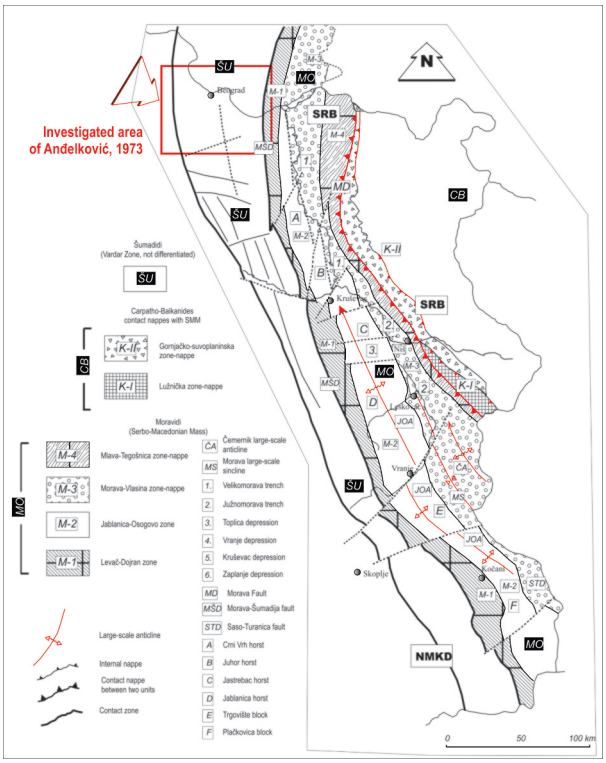


Fig. 3. *Obsolete tectonic map of the Central-East Serbia (slightly modified after Anđelković 1982). The Belgrade area is composed of "Šumadides", dominantly Cretaceous, turbidite-bearing system. The author spent the entire career working on the latest Jurassic to several Cretaceous turbidites-bearing system of the "Šumadides".*

(modern-day the East Vardar Zone; segment in Serbia) and the Eastern Alps (Kossmat, 1924, in Petković, 1958). The term "Vardar Zone" itself is coined by Kossmat (1924), working near Vardar River (North Macedonia; Fig. 2). The term "*Šumadidi*" (Central Serbia) is referring to a precursor of the modern-day second intraoceanic East Vardar Zone of the Late Jurassic–Early Cretaceous age (Fig. 1), and was coined by Anđelković (1975a; Fig. 3). This "*Šumadidi*" zone belongs to the northern segment of the north Alpine segment (inclusive the "Neokomian flysch"; Anđelković, 1975a) and comprises the "Gledići zone" and the "Rudnik zone" (Anđelković, 1984), where near-Belgrade Lower Cretaceous facies are mapped as the "paraflysch" (Dimitrijević & Dimitrijević, 2009). The two Cretaceous turbidite belts are separated by the west-vergent thrust emplacing the lowermost Cretaceous 'paraflysch' sediments in the eastern hanging-wall over the typical uppermost Cretaceous turbidites of the Sava Zone (Toljić et al., 2018).

The ongoing rise of the Plate Tectonics theory in 1970's (see Kearey et al., 2009, for a discussion) induced a global debate among geologists, in particular, for followers of the geosyncline framework. The intriguing Vardar Zone *s.l.* (for a definition, see Spahić & Gaudenyi, 2020), and the Sava River valley itself (Fig. 1), represented a vertically mobile system of a number of the "geosynclines" (e.g, Petković, 1958; Fig. 2). The geosyncline framework accepted no existence of any "tectonic suture", because the Earth crust or tectonic movements are interpreted exclusively by applying vertical crustal motions and associated processes. In former Yugoslavia, the discussion grew into a "verbal battle" among different groups of geologists, in particular these preferring the "geosyncline", or vertical crustal movements *vs.* those few favoring the new Global Tectonics model or Plate Tectonics. The latter model has been largely developed since

1967, however, with many of those rejecting it up to late 1970's, and in the case of former Yugoslavia, denying it even throughout 1980's. A new group of, so-called, "nappests", or geologists favoring huge horizontal displacements of the Earth crust or thrusts, nappes (lead by Prof. Dr. Milodrag Anđelković) was a kind of "transitional solution" (*e.g.*, large east-vergent thrusting of the eastern Serbian crustal slices; Fig. 4). Nevertheless, some of the geologists working in the given frameworks provided an important insight into the modern-day tectonic solutions, in particular Prof. Dr. Milodrag Anđelković (Fig. 4).

MILODRAG Ž. ANĐELKOVIĆ
МИЛОДРАГ Ж. АНЂЕЛКОВИЋ
1927 – 1998

Fig. 4. *The photo of Prof. Dr. Milodrag Anđelković (photo taken from Pavlović et al., 1998).*

From the "Sava-Vardar Zone" towards the Sava Suture Zone: Newest cycle of research

The new cycle of the Vardar Zone research started with the Dimitrijević (1997), i.e., the Pamić's report

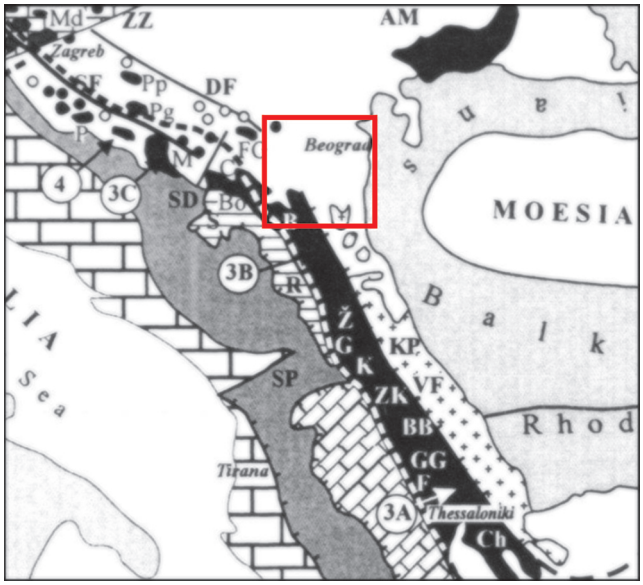


Fig. 5. *Simplified paleogeographic and structural map of the Dinarides and Hellénides (after Pamić, 2002, slightly modified).*

from 2002 (Fig. 5). The latter author isolated several composite sequences of the "Sava–Vardar Zone": 1) Cretaceous to Lower Paleogene flysch at the base interlayered with subduction-related bimodal basalts and rhyolites; 2) Upper Paleogene metamorphic sequences, which originated from adjacent Mesozoic units; 3) Paleogene tectonized ophiolite mélange; 4) Eocene syn-collisional granites; 5) Oligocene post-syn-collisional granitoids and shoshonites with subordinate andesite-dacites, and 6) post-collisional Neogene volcanic associations. In his milestone paper, Pamić (2002) despite indicating the important geological features of the Belgrade area, does not use or mention any of the previously reported (bimodal) magmatic occurrences underlined much earlier by Anđelković (1973).With a few exceptions (Toljić et al., 2018, 2021), almost the same situation is with other more recent publications dealing with the complex Belgrade area, and the "Sava Zone" as a whole.

Almost at the same time, Grubić (2002) underlines the importance of the oblique motions associated with the Peri-Adriatic Lineament. Author's focal point is dextral transcurrent motions, emphasized across the entire suture corridor. The compressional behavior affected the Lower Cretaceous shortening in the Carpathian-Balkan arc.

A few years later, the milestone paper by Schmid et al. (2008), accepted the "Sava–Vardar Zone" concept of Pamić (2002). The regional-scale report covering almost the entire former Yugoslavia, speculated that in Santonian times (84 Ma) the two branches of the "Alpine Tethys" (or Valais and Piemont-Liguria Oceans) connected to the Carpathian embayment by the development of a Cretaceous-age limb of the Neotethyan future back-arc ocean. The authors emphasize that some segments of Neotethys were consumed in the context of obduction during Late Jurassic times, followed by the late opening occurring during the Cretaceous ("Sava Back-Arc Ophiolites"). These authors presented a kind of argumentation, proposing that the Cretaceous-age oceanic "branches of Neotethys likewise the Sava Back-Arc Ocean", were directly in the contact with the Alpine Tethys along the present-day Sava-Zone.

Ustaszewski et al., (2009, 2010) reported the extensive field-based study of the "Sava Zone" segment striking along northern Bosnia and Herzegovina. The reported concept is supporting the Cretaceous subduction of the remnant of Meliata Vardar oceanic lithosphere, which further led to the formation of a suture. The authors suggested that the "Sava Zone", or "Sava Ocean" or "Alpine Tethys" was a deep basin, having oceanic lithosphere until the Campanian. The closure of this corridor occurred before the Maastrichtian to earliest Paleogene. This Late Cretaceous oceanic domain probably represented a remnant of the Vardar Ocean.

Gerzina (2010) in her PhD thesis, provided the geological map of the wider "Zvornik suture" area, outlining the highly deformed area separating Adria or the Drina–Ivanjica block in western Serbia from the "Sava Zone" (for further details, see also Dimitrijević, 2001; Spahić & Gaudenyi, 2020).

Grubić et al. (2009, 2010) investigated several outcrops of inter-lava calcareous pelagic sediments on Kozara Mt., northern Bosnia. It is important to underline that this prominent geologist of Serbia and former Yugoslavia (Grubić, 1980) defined this zone much earlier as the "North Bosnian Zone", whereas the "Sava Zone" is outlined as another tectonic unit associated with the Slovenian Alps. According to 2009–2010 study, the exposed crustal fragment contains *in situ* planktonic foraminifera of late Santonian–earliest Campanian age. Assuming that these lavas form part of the extrusive sequence of an ophiolite, authors are of opinion that such configuration establishes that Mesozoic oceanic crust still existed within the Vardar zone (its western belt in northern Bosnia), prior to the final closure of Tethys (in this region by the end of latest Cretaceous time). These studies also indicate the age of the turbidite matrix (by using palinomoph) which goes from Late Jurassic to Late Cretaceous.

Dunčić et al. (2014) provided the deep subsurface biostratigraphic inferences beneath the Pannonian basin. The study focal points are Late Cretaceous deep-water complexes that represent an oceanic island arc and foredeep systems. The drilled ophiolites intercalated with hemipelagic and pelagic limestones are interpreted to belong to the "Sava Zone".

Milošević et al. (2017) describes a peculiar metamorphic succession of the Prosara Mt. (northern Bosnia & Herzegovina), having the mineral composition that is mostly comprised of sericite, with smaller amounts of quartz and feldspar. The author is of opinion that the Upper Cretaceous and/or pre-Upper Cretaceous Mesozoic clastic and carbonate sediments comprise the protolith of these metamorphic rocks, further interpreting that the Prosara Mt. represents an integral part of the Cretaceous subduction complex.

Prelević et al. (2017), Sokol et al. (2019), boosted the excellent idea of the oblique convergent margin, indicating that the sigmoid-shaped Upper Cretaceous Klepa Mt. basalt is a product of the crustal extension, developed on the nearby continental margin. Köpping et al. (2019) documented a transtensional pull-apart system developed to accommodate the Klepa basalts in North Macedonia.

Toljić et al. (2018, 2021), accepted the "Sava relic ocean" of Karamata et al. (2000), Schmid et al. (2008), further suggesting that the "Sava Zone" represents a fossil fore-arc basins. The authors introduced the Topola bimodal magmatics (Central Serbia), and based on planktonic foraminiferal assemblages, the age constraints are Coniacian to Santonian.

Bragin et al. (2019) emphasize that the former continental margin was rather at the proximity of the Avala Mt., thus shifting the contact line (proposed slightly earlier by Toljić et al., 2018) to the east of the Bela Reka fault/nappe.

Balen et al. (2020) provide constraints on the Požeška Gora granite (Croatia) that is mainly composed of alkali feldspar (perthite) and quartz. The emplacement constraints derived from $^{206}Pb/^{238}U$ versus $^{207}Pb/^{235}U$ concordia age determined on zircon, fits this event for 83.6±1.5 Ma (Santonian–Campanian).

Toljić et al. (2019), and Márto et al. (2022) reintroduced the "Central Vardar Zone" of Dimitrijević (1997) explaining the geotectonic subunit of the Vardar Zone *s.l.*, striking from the west towards the central part of Serbia. According to the sketch map (Toljić et al., 2019), the geotectonic units are: Western Vardar Zone, Central Vardar Zone, and Eastern Vardar Zone. Lithostratigraphy of these zones is a function of the tectonic domain: the subduction trench belongs to the basin of the Adriatic passive margin, and the forearc basin is a segment of the European active margin.

Spahić & Gaudenyi (2022), Spahić et al. (2022), are reintroducing the oblique Neotethyan Vardar boundary proposed earlier by Dimitrijević & Dimitrijević (1975) and Grubić (2002). The authors furthermore provided the explanation of the magma-source for the debuted Kozara Mt. Upper Cretaceous ophiolite-like crustal segment in Bosnia and Herzegovina (for details see Grubić et al., 2009, 2010, Cvetković et al., 2014). The Sava Suture Zone is actually a narrowing corridor formed after the Jurassic closure of Neotethys, subdivided into the "Lower Sava Suture Zone", and the "Upper Sava Suture Zone". The "Lower Sava Suture Zone" represents the relics of the Santonian-Campanian bimodal volcanism, occurring rather locally along the entire exhumed subduction trench, whereas the "Upper Sava Suture Zone" is composed of the top-sealing turbidites. The "Lower Sava Suture Zone" may often occur as a debris flow system, or as pyroclastic entities (Anđelković, 1973; Karamata et al., 1997).

Anđelković's contribution to the geology of the Sava Suture Zone, essential achievements

As described, a number of interpretations during the last 20 years, discussing the regional geology, petrology, geophysics, tectonics, paleontology, paleogeography, yielded several different interpretations of the Belgrade area that seems to be an important segment of the elongated Sava Suture Zone (Fig. 1). These papers are dealing with its tectonics, kinematics, paleogeography and Late Cretaceous regional geological context. However, in many pioneering papers, the description of the Late Cretaceous magmatism (Anđelković, 1973) reported for the Belgrade area was very often rejected or neglected (e.g., Dimitrijević, 1997; Pamić, 2002; Grubić, 2002).

Prof. Dr. Milodrag Anđelković is a well-known scientist of former Yugoslavia, with a lot of achievements in biostratigraphy and tectonical importance in geology of highly complex Western Balkan Peninsula, in particular the complex Belgrade area: (i) the Mesozoic stratigraphic (Fig. 6), magmatism and tectonic problems, including bimodal magmatism (e.g., the position and the age of near-Belgrade spilites and

Fig. 6. *Sketch representing the outcrops of Lower Cretaceous age (Anđelković, 1975b)*

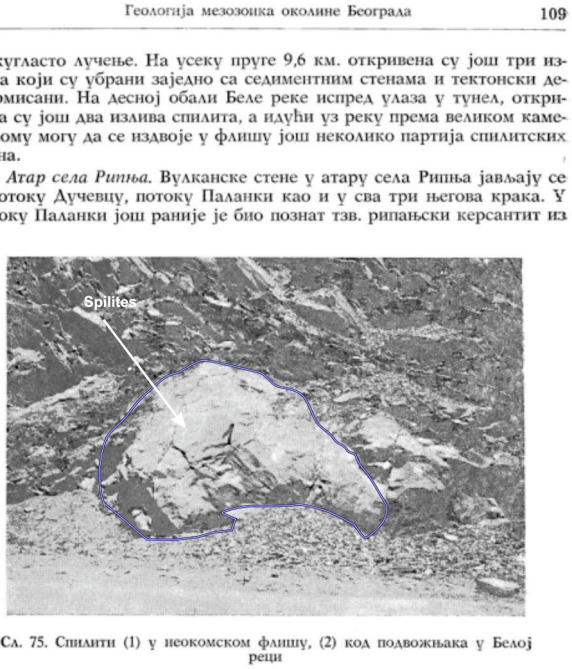


Fig. 7. *Bela Reka location of spillites (Anđelković, 1973)*

andesites; Fig. 7) as a summary that was firstly reported in 1973 (Anđelković, 1973), (ii) the Lower Cretaceous stratigraphic problems with a number of species (Anđelković, 1975b), (iii) the Upper Cretaceous stratigraphy with a number of localities with species giving the age (Anđelković, 1975b). In his main career achievements, dating from the second half of the 20th century, referred to as the "*Геологија Србије, Стратиграфија*" (translated: *Geology of Serbia, Stratigraphy*) was published in the ten books, that are subdivided according to geological age, e.g. "Precambrian and Paleozoic Stratigraphy", "Mesozoic Stratigraphy", etc. (1975–1977). The work also includes the here underlined and discussed report „*Геологија мезозоика околине Београда*" (translated: "*Mesozoic Geology of the vicinity of Belgrade area"*), another book related to Dinarides "*Tectonics of Dinarides*", and over 300 scientific papers, 20 monographies, and 10 university books (see the entire publication list in Pavlović et al., 1998).

During early career, already in the 1950's, Dr Milodrag Anđelković attempted to decipher the individual flysch-bearing systems in the Belgrade area. Anđelković recognized the two different turbidite system (Anđelković, 1954), that are in the field rather similar, almost indecipherable. These sediments are many years documented as belonging the three different Late Cretaceous paleogeographic provinces, the European or hanging wall (presumably East Vardar Zone; Spahić & Gaudenyi, 2022), Adriatic (presumable its margin) and subduction-collisional trench, which represent the same basin or were separated in individual subbasins during their evolution (see Toljić et al., 2018, for a discussion). In these extremely complicated terrains of the Belgrade area, Anđelković managed to separate several previously undifferentiated stratigraphic horizons, yielding the Upper Jurassic ophiolite mélange up to the Upper Cretaceous turbidite sequences. In the associated Kosmaj – Babe area (southern Belgrade outskirts; Fig. 6), he emphasized the presence of the "Golt" of modern-day Albian sequence (Fig. 8).

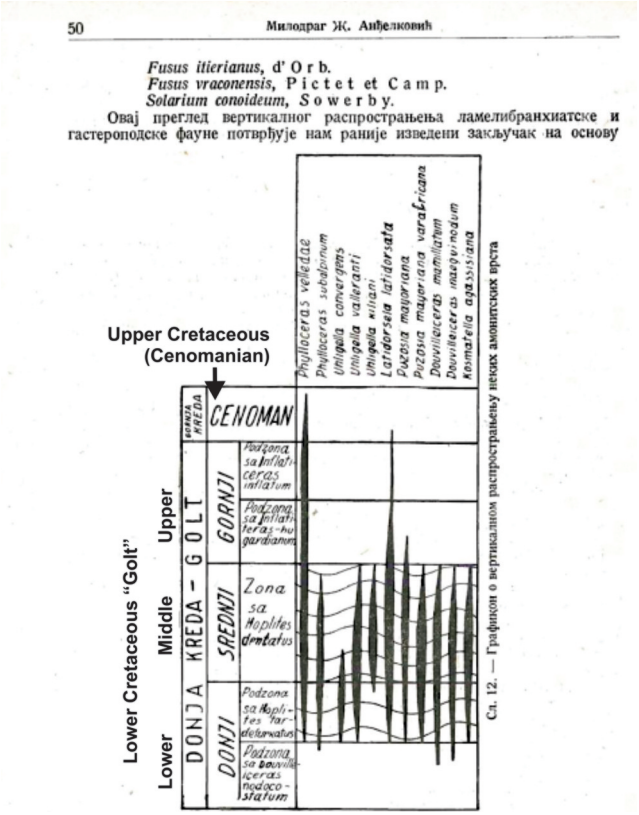


Fig. 8. *The graphical distribution of some of ammonoidea species indicating "Golt" or modern-day Albian in the vicinity of Babe - Guberevac area (inset partially translated from the original paper Anđelković, 1954).*

Dr Milodrag Anđelković did a huge work starting in early career, up to his late professorship stage. Among extremely difficult stratigraphic tasks, his ac-

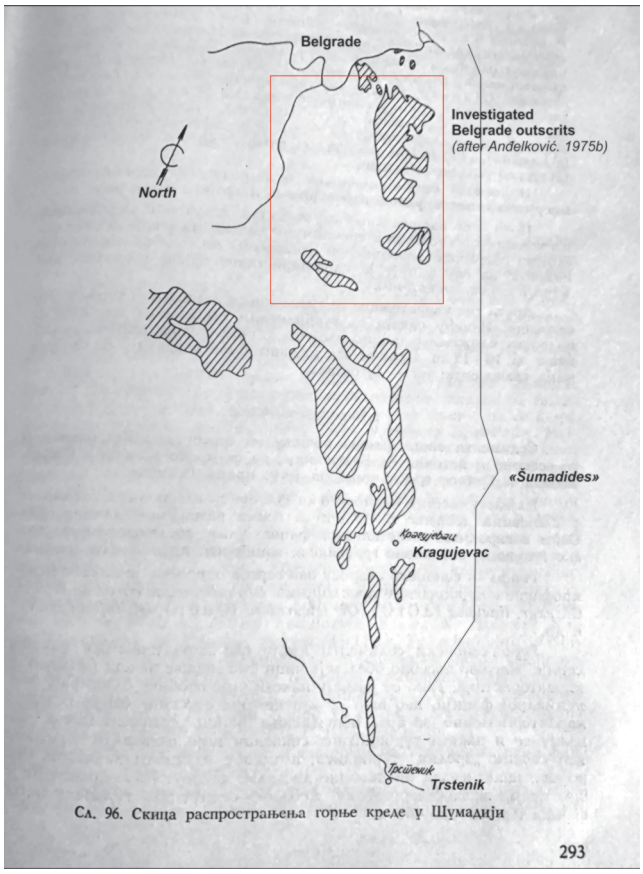


Fig. 9. *Sketch representing the outcrops of Upper Cretaceous age (Anđelković, 1975b)*

tivity was mainly directed onto often sterile clastic sequences southern of Belgrade (Fig. 9) where he separated several turbidite sequences: "Avala flysch", "Barajevo flysch", and "Ostružnica flysch" (Fig. 10). Among his activity to decipher complex Upper Cretaceous turbidites was the separation of the (i) "Avala flysch" (which is subdivided into purely clastic and marly sequences, with a larger presence of carbonate minerals). Importantly, Anđelković highlighted that three turbidite sequences were developed in different Late Cretaceous times, and in different paleogeographic domains (Anđelković, 1975b). According to Anđelković, the highly deformed "Avala flysch" is composed mainly of dominant sandstone, marl, claystone and limestone lenses. This turbidite belt strikes towards the south near the Kosmaj Mt. The author classified the following fauna (globotruncana, foraminiphera), largely facilitating the age constraints of the turbidites, further facilitating the incoming tectonic investigations (Anđelković, 1975b, page 286-287): *Globotruncana lapparenti* Boll., *G. lapparenti tricarinata* Quer., *G. lapparenti lapparenti* Boll., *G. reicheli* Morn., *Globotruncana rosetta* Gras., *G. arca* Cuch., *Marsonella oxigona* Reuss., *Stensioina cf. excultagradata* Keller, *Texturella turris* d'Orb., *T. piramidalis* Ras., *Cristelaria orbiculis* d'Orb., *Globigerina bulloides* d'Orb. The vertically next subsequence is marlstone-abundant system, with inoceramus and foraminiphera, gradually transforming into the sandstone-bearing flysch sequence.

(ii) "Barajevo flysch" has a different clastic-to-carbonate content (Anđelković, 1975b). This sequence is comprised of dominant marlstones, sandy marlstones, breccia and brecciated limestones, calcarenites. The occasionally discovered limestones are

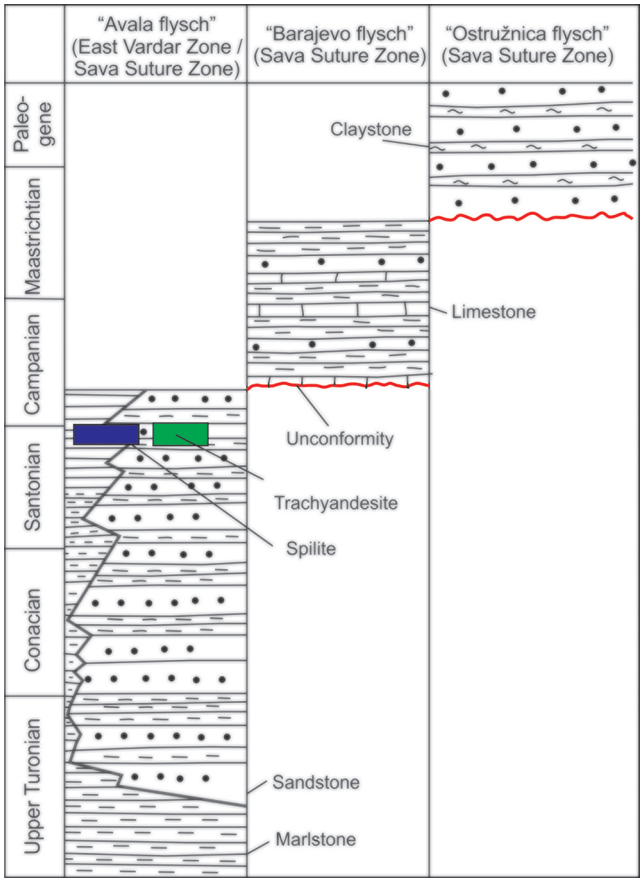


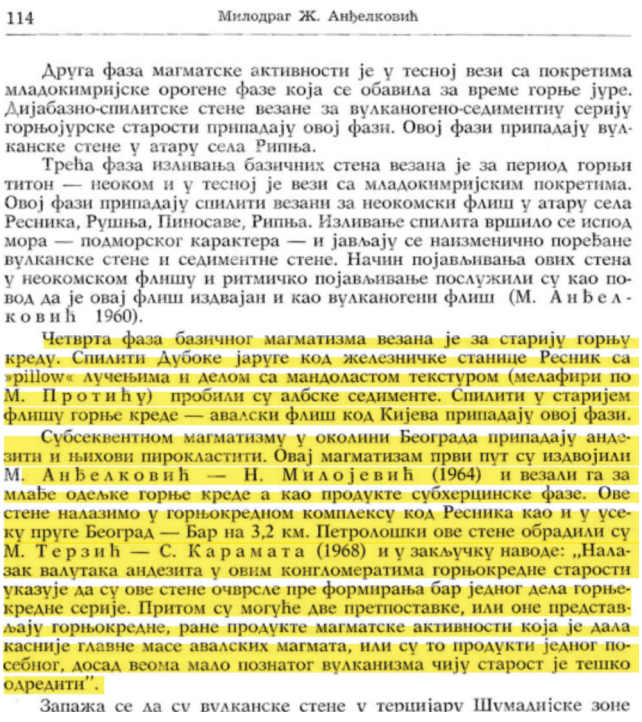
Fig. 10. *The stratigraphic columns of the near-Belgrade turbidite belts. The inset from Anđelković (1975b), modified. The "Avala flysch", Ostružnica" and "Barajevo flysch" are now segments of the Sava Suture Zone and East Vardar foreland. The blue and green rectangles represent the basic and acidic magmatic imprints, respectively.*

abundant with "siderolites" (Anđelković (1975b, 288), e.g., *Siderolites vidali* Douv., *S. calcitrapoides* Lam., Orbidoides: *Orbitoides media* Schlumb., *O. apiculata* Schlumb., *Simblobitoides gensacicus* Leym., *Lepidorbitoides sp.* The sequence with marls and claystone is abundant with Globotruncana's: *Globotruncana lapparenti lapparenti* Boll., *G. arca* Cush., *G. stuarti* Lapp., *G. rosetta* Gar., *G. linnei* d'Orb., *Gyrdina globose* Hag., *Textularia turris* d'Orb., *T. flabeliformis* Gomb., *Pseudotextularia elegans* Rzch., *Globigerina cretacea* d'Orb., *Gümbelina globulosa* Ehrcemb.

(iii) "Ostružnica flysch" is the third type of the Upper Cretaceous turbidites, characterized exclusively by clastic rocks (Anđelković, 1975b). This sequence contains sandstone and claystone with scarce fauna. There are though some inoceramus species listed in the Anđelković's (1975b, page 289) study: *Inoceramus balticus* Bohm., *Siderolites vidali* Douv., *Orbitoides cf. apiculata* Schlumb., *Orbitoides sp.* The most important observation of Anđelković (1975b), is that the "Ostružnica flysch" is barely disturbed in tectonic sense.

With regards the debuted Upper Cretaceous magmatic event that has often been debuted during the last 20 years, Anđelković (1973) separated a number of smaller-scale basic and acidic rocks (Fig. 7). The author separated several magmatic episodes, occurred during the Mesozoic time (Anđelković, 1973): (i) magmatic stage occurred prior to the Upper Jurassic, (ii) Upper Jurassic stage, (iii) Tithonian–Berriasian stage, and (iv) Upper Cretaceous. The Upper Cretaceous magmatic imprints are near Pinosava (andesite-type pyroclastics), the „Bela Reka–Rušanj–Resnik belt" is the location characterized by the outcropping basic rocks, mainly spillites, including pillow occurrences. This location is described as „syn-depositional" basalts of Toljić et al. (2021). The „Bela Reka–Rušanj–Resnikbelt" crosscut the Albian marls and marly limestones. However its concordant position with the „Neocomian flysch" or „paraflysch" indicates Lower Cretaceous age or Berriasian, Valanginian, and Hauterivian ages. The exception is a „Ripanj kersantite", the exposure which is described as a member of the „spilite group" by Anđelković (1973), and is recently dated on Ar-Ar ages by 86.80±0.5 Ma and 86.90±0.5 Ma (Sokol et al., 2020). This further implies that there

NOTE: Translation of the yellow marked text, see in the figure caption



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Друга фаза магматске активности је у тесној вези са покретима младокимријске орогене фазе која се обавила за време горње јуре. Дијабазно-спилитске стене везане за вулканогено-седиментну серију горњојурске старости припадају овој фази. Овој фази припадају вулканске стене у атару села Рипња.

Трећа фаза изливања базичних стена везана је за период горњи титон — неоком и у тесној је вези са младокимријским покретима. Овој фази припадају спилити везани за неокомски флиш у атару села Ресника, Рушња, Пиносаве, Рипња. Изливање спилита вршило се испод мора — подморског карактера — и јављају се наизменично пореёане вулканске стене и седиментне стене. Начин појављивања ових стена у неокомском флишу и ритмичко појављивање послужили су као повод да је овај флиш издвајан и као вулканогени флиш (М. Анђелковић 1960).

Четврта фаза базичног магматизма везана је за старију горњу креду. Спилити Дубоке јаруге код железничке станице Ресник са »pillow« лучевима и делом са мандоластом текстуром (мелафири по М. Протићу) пробили су албске седименте. Спилити у старијем флишу горње креде — авалски флиш код Кијева припадају овој фази.

Субсеквентном магматизму у околини Београда припадају андезити и њихови пирокластити. Овај магматизам први пут су издвојили М. Анђелковић — Н. Милојевић (1964) и везали га за млађе одељке горње креде а као продукте субхерцинске фазе. Ове стене налазимо у горњокредном комплексу код Ресника као и у усеку пруге Београд — Бар на 3,2 км. Петролошки ове стене обрадили су М. Терзић — С. Карамата (1968) и у закључку наводе: „Налазак валутака андезита у овим конгломератима горњокредне старости указује да су ове стене очврсле пре формирања бар једног дела горњекредне серије. Притом су могуће две претпоставке, или оне представљају горњокредне, ране продукте магматске активности која је дала касније главне масе авалских магмата, или су то продукти једног посебног, досад веома мало познатог вулканизма чију старост је тешко одредити".

Запажа се да су вулканске стене у терцијару Шумадијске зоне

Fig. 11. *The first interpretation of the Late Cretaceous bimodal magmatism by Anđelković (1973). Translation from Serbian of the essential page of the paper Anđelković (1973):*
"The fourth phase of basic magmatism is related to the older Upper Cretaceous. Spilites of Duboke jaruge (location translated to Deep ravines) anear the Resnik Train Station with »pillow lava« with "mandollar texture" (melaphyres per M. Protić) penetrated the Albian sediments. Spilites in older Upper Cretaceous - the Avala flysch (the Avala flysch is precursory analogue of the East Vardar Zone turbidites, see Spahić et al., submitted) near Kijevo - belongs this stage.
Subsect magmatism around Belgrade belongs to andesites and their pyroclastic equivalents. This magmatism was first singled out by Anđelković & Milojevic (1964). The authors attributed the age to Upper Cretaceous as products of the subhercine stage. We find these rocks in the upper part of the complex near Resnik, as well as along the Belgrade-Bar railroad at 3.2 km. Petrologically these rocks were processed M. Terzić – S. Karamata (1968) and in the conclusion stated: "Finding andesite debris in these Upper Cretaceous conglomerates, indicates that these rocks hardened before the formation of at least one part of the Upper Cretaceous series. There are two assumptions possible, or they represent the upper, early products of magmatic activity later, the main masses of Avala Mt. magmas, or it is the product of a special, until now very little-known volcanism whose age is difficult to determine". Nevertheless, the age of andesitic volcanism in the debris flow is constrained later, to be of the Turonian age (Karamata et al., 1997), recently dated as of the Santonian age (Toljić et al., 2021).

is a high probability that the entire „spilite group" could be of the Upper Cretaceous age. This issues needs further study as Anđelković (1973) describes a spilite occurring in Hajdučki potok as „intercalated" into the Lower Cretaceous Neocomian turbidite system.

With regards the acidic andesite-type volcanism (Fig. 11), Anđelković & Milojević (1964) describe for the first time this Upper Cretaceous event. This event is confined between turbidite claystones and layered limestone with the presence of Globotruncans (section of the Belgrade–Bar railway). The andesites are with mica biotite, biotite-augite, having a higher presence of Na, which is actually more trachyte-type andesite (Anđelković, 1973).

Summary and conclusions

The report underlines that the birth of the Late Cretaceous "Sava Zone" or the Sava Suture i.e., the first record of the Late Cretaceous bimodal magmatism was actually in 1973. A review of published scientific papers (especially in the last 15–20 years), shows that the results of a number of previous researchers from the former Yugoslavia, are not adequately evaluated. The pioneering observations contributing the debuted Sava Suture Zone, are in the underestimated report of Prof. Dr. Milodrag Anđelković, presenting his observations of the typifying Late Cretaceous bimodal magmatism. However, the paper from Anđelković (1973) was used just in a few occasions, mainly for stratigraphic inferences, e.g., Toljić et al (2018, 2021). Other pioneers, (e.g., Pamić, 2002; Schmid et al., 2008) neglected the important observations near Belgrade summarized in the paper of Anđelković (1973).

The study shows that the near-Belgrade Cretaceous volcanic activity is clearly overlapping in the modern-day configuration. The study also provides inferences for the "Lower and Upper Sava Suture Zone" (Fig. 12). The "Lower Sava Suture Zone" rep-

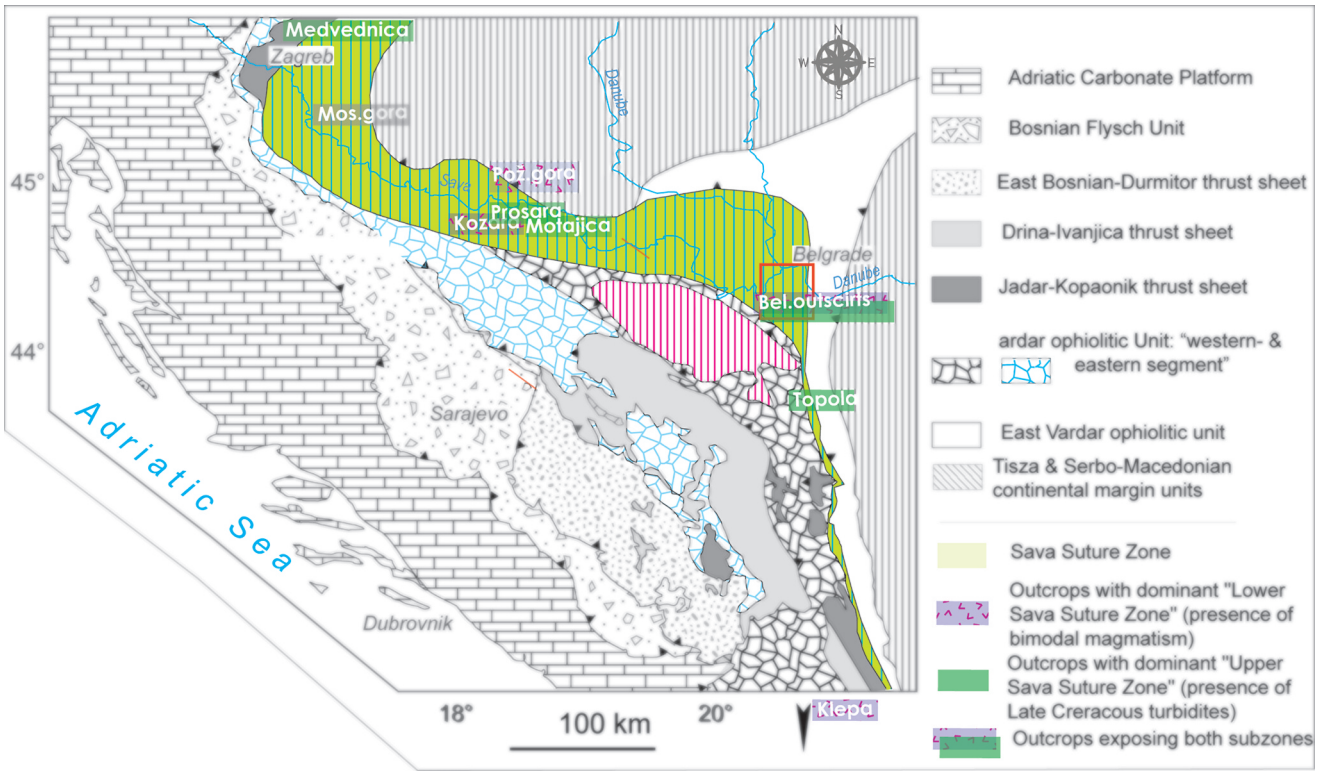

Fig. 12. *The Sava Suture Zone, subdivided into the "Lower Sava Suture Zone" and "Upper Sava Suture Zone". The locations with "Lower Sava Suture Zone" are in blue rectangle, whereas the Upper Cretaceous "Upper Sava Suture Zone" turbidites are in green color (inset from Schmid et al., 2008, modified).*

resents area with the exposed Santonian-Campanian magmatism, whereas the turbidite-bearing "Upper Sava Suture Zone" overlays either magmatic bodies or debris flow with magmatic rocks. There is a number of locations exposing both zones, yet, these subzones need a clear, field-based separation one from another. This is of particular importance for the ongoing mapping campaigns of Serbia (e.g., Blagojević, 2019).

The two main problems remain for future inferences: (i) The absolute age constraints on the "spillite group", as according to Anđelković (1973) is of the post-Early Cretaceous or the post-"Neocomian age". This is partially in line with the recent findings of Sokol et al., (2020), and the Santonian Rušanj peperites described in Toljić et al. (2021). Importantly, the age of andesite-type volcanism has the proven Late Cretaceous age (Karamata et al., 1997) or the Santonian age of Resnik trachyandesites (Toljić et al., 2021).

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

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Резиме

Рађање Сава сутуре зоне: рана геолошка разматрања и контекст бимодалног магматизма (јужна периферија Београда; Анђелковић, 1973)

Прве идеје о кредној "Сава зони", као и равоју кредног бимодалног магматизма познате су још од 1973. године. Преглед објављених научних радова (нарочито у последњих 15–20 година) указује да резултати претходних истраживача (из бивше Југославије) нису адекватно оцењени. Пионирска запажања која су допринела издвајању Сава Сутурне Зоне, се могу наћи у једном, благо речено потцењеном извештају проф. др Милодрага Анђелковића. У овом раду дат је преглед његових запажања о горњокредном бимодалном магматизму околине Београда. Треба истаћи да је рад Анђелковић (1973) цитиран само у неколико наврата, углавном за стратиграфске закључке, нпр. Toljić et al. (2018, 2021).

Ова студија показује да се вулканска активност у близини Београда јасно преклапа са данашњом конфигурацијом Сава Сутурне Зоне. Студија такође даје закључке за две подзоне: „Доња Сава Сутурна Зона" и „Горња Сава Сутурна Зона" (Слика 12). „Доња Сава Сутурна Зона" представља област са изложеним сантонско-

кампанским магматизмом, док турбидитска „Горња Сава Сутурна Зона“ покрива наведена магматска тела. Постоји низ локација за обе зоне, али, овим подзонама је потребно јасно одвајање једне од друге. Тачно дефинисање наведене зоне и подзона је од посебног значаја за текућу кампању геолошког картирања Реублике Србије, 1: 50,000 (нпр., Blagojević, 2019).

Manuscript received April 04, 2022
Revised manuscript accepted June 10, 2022