# Vardar Zone: new insights into the tectono-depositional subdivision

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# VARDAR ZONE: NEW INSIGHTS INTO THE TECTONO-DEPOSITIONAL SUBDIVISION

**dr MarinkoToljić[1,*], dr Uroš Stojadinović[1], Nemanja Krstekanić[1,2]**

[1]University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia, [2] Utrecht University, Faculty of Geosciences, Department of Earth Sciences, Utrecht, the Netherlands

*corresponding author: dr Marinko Toljić, full professor, University of Belgrade, Faculty of Mining and Geology, marinko.toljic@rgf.bg.ac.rs

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## Apstrakt

Vardarska mega jedinica je složena tektonska jedinica nastala tokom mezozojske tektonsko-depozicione evolucije Neotetisa i margina njemu susednih kontinenata. Vardarska mega jedinica se može podeliti na tri tektonske celine kontrastnih litostratigrafskih svojstava i interne tektonske arhitekture. Od zapadu ka istoka to su: Zapadna Vardarska Zona, Centralna Vardarska Zona i Istočna Vardarska Zona. Litostratigrafski sadržaji ovih zona su su deponovani u tri različita domena, a to su, od zapada ka istoku, basen pasivne Adrijske margine, dubokomorski rov i ispredlučni basen na aktivnoj Evropskoj margini.

## Abstract

Vardar mega-unit represents complex tectonic unit, which was structured during Mesozoic tectono-depositional evolution of Neotethys and the adjoining continental margins. Vardar mega-unit can be subdivided into the three tectonic entities characterized by contrasting lithostratigraphic and structural features. Going from west towards east these are: Western Vardar Zone, Central Vardar Zone, and Eastern Vardar Zone. Lithostratigraphic contents of these zones were, again, deposited in three different domains. From west to east, these domains are: basin of the Adriatic passive margin, subduction trench, and forearc basin of the European active margin.

## 1. Introduction

Present-day complex architecture of the Adria-Europe suture area represents the result of Mesozoic evolution of the northern branch of the Neotethys Ocean and subsequent formation of the Pannonian Basin. The northern branch of the Neotethys Ocean (i.e., Meliata-Maliac-Vardar Ocean of Schmid et al., 2008; Handy et al., 2010; or Vardar Ocean of Dimitrijević, 1997; Pamić, 2002; Karamata, 2006) was opened during Late Triassic to Middle Jurassic period (Pamić et al., 2002) between Adria and units of the European affinity. Post Middle Jurassic intraoceanic subduction (Pamić et al., 2002), Late Jurassic obduction, and subsequent Cretaceous-Paleogene convergence, resulted in closure of the Vardar Ocean and formation of complex tectono-stratigraphic contents of the Vardar mega-unit, which separates Adria-derived and Europe-derived units (Kossmat, 1924). Existing regional tectonic divisions share similar opinions concerning architecture of regional thrusts in the Dinarides and Carpatho-Balkanides, including the Serbomacedonian unit (Dimitrijević, 1997; Marović et al., 2002; Schmid et al., 2008). Main differences appear when it comes to tectonic affinity of the actual suture area between Adria and Europe. Various authors (Dimitrijević, 1997; Pamić, 2002; Karamata, 2006; Marović et al., 2007a; Schmid et al., 2008) made their own subdivisions, which often included tectonic units with similar names yet dissimilar lithostratigraphic and tectonic features, as well as their positions.

Different approaches in interpretation of regional tectonic relations, and sometimes even interpretations of local geological cross sections, do not contribute to better understanding of basinal arrangement and tectonic setting of the suture area. This was the main motive to develop study in which existing data will be presented in the new context, thus providing tenable model for Mesozoic basinal and tectonic evolution of the Dinaridic segment of the Neotethys.

## 2. Methodology

Tectonic subdivision of the Vardar mega-unit presented in this study is based on field investigations of regional structures and sedimentary facies along several orogen-perpendicular cross-sections. Field investigations were followed by reconstruction of depositional environments and tectonic regimes, and by correlation of tectono-stratigraphic units along the strike of orogen. Formations properties were analysed, which included analyses of age and features of the ophiolites overstep sequences, as well as the geometric and kinematic features of the main tectonic structures in Serbia. Basic Geological Maps of Yugoslavia 1:100,000 and other published studies were used to correlate regional tectono-stratigraphic units (e.g., Ustaszewski et al., 2009; Schefer et al. 2012, Matenco and Radivojević, 2012; Toljić et al., 2013; Stojadinović et al., 2013; Božović et al., 2013; Gallhofer et al., 2017; Stojadinović et al., 2017; Erak et al., 2017.; Prelević et al., 2017; Toljić et al., 2018). Tectonic zones were separated using the criteria developed by Pamić (2002), Karamata (2006), Dimitrijević (1997), as well as the criteria that consistently rely on concept of „composite units“ (Schmid et al., 2008). Such approach favours the Mesozoic evolution of the Vardar Ocean as part of the Neotethys and specific paleogeographic domain in which tectonic zones of the Vardar mega-unit were developed during Jurassic and Cretaceous convergence processes.

## 3. Mesozoic basinal arrangement of the Vardar Ocean and tectonic subdivision of the Vardar mega-unit

Vardar mega-unit (Dimitrijević, 1997; Pamić, 2002; Karamata, 2006) represents complex tectonic unit, which was structured during Mesozoic tectono-depositional evolution of the Vardar Ocean and the adjoining continental margins. It represents assemblage of various former paleogeographic, basinal, and tectonic domains, which can be presently recognized based on the features of basement of the Mesozoic basins, lithostratigraphic features of sediments, features of tectonic structures, position of ophiolite sequences, and structural superposition of tectonic units. Hence, based on the aforementioned criteria Vardar mega-unit can be divided into the tectonic units or zones, which can be distinguished using features of their continental basement, directions of tectonic transport of the obducted ophiolites, age and facial features of sediments. In addition, regional fault structures mark the internal boundaries between these zones, as well as their external boundaries toward the other tectonic units. Following „single ocean“concept (Schmid et al., 2008), classical arrangement of basin with oceanic crust includes passive oceanic/continental margins and active zone of spreading, and subsequently also intraoceanic or continental subduction zone, i.e. active continental margin (see Pamić et al., 2002). In accordance with such basinal architecture, within external boundaries of the Vardar mega-unit (Dimitrijević, 1997; Pamić, 2002; Karamata, 2006), three zones characterized by contrasting lithostratigraphic and structural features can be distinguished. Going from west towards east these are: Western Vardar Zone, Central Vardar Zone, and Eastern Vardar Zone (Figure 1). Lithostratigraphic contents of these zones were derived from three different domains, basin of the Adriatic passive margin, subduction trench, and forearc basin of the European active margin, respectively.

### 3.1 Basin of the passive continental margin – Western Vardar Zone (WVZ)

In present-day coordinates, southwestern margin of the Vardar Ocean is juxtaposed to the passive continental margin of Adria, which is made-up of metamorphic basement and/or otherwise not metamorphosed Paleozoic sediments. Paleozoic formations are overlain by Lower Triassic clastics and carbonates, Middle Triassic shallow water carbonates associated with basic and acidic volcanics, Upper Triassic carbonates and, locally, Lower Jurassic limestones with chert (Pamić, 1984; Dimitrijević, 1997) that have Adriatic affinity (Schmid et al., 2008). Over such continental margin, segment of oceanic lithosphere was obducted during Late Jurassic. These ophiolites are today located in two separate belts (Figure 1): Dinaride Ophiolite Zone (DOZ) and Ophiolites of Western Vardar Zone (OWVZ). They are composed of serpentinized peridotites, gabbros, dolerites, basalts and locally granites (Dimitrijević, 1997; Pamić et al., 2002). Identical ophiolitic mélange made up of tectonized shale-alevrolitic matrix with fragments of carbonates, cherts, radiolarites, schists, serpentinites, gabbros, dolerites and spilites is located at the base of the ophiolites of both belts. Age of radiolarite and ophiolite fragments in mélange spans from Ladinian to Tithonian (Vishnevskaya et al., 2009; Šegvić et al., 2018). As ophiolitic mélange is the product of obduction (e.g., Schmid et al., 2008), age of fragments in the mélange demonstrate that obduction is the Late Jurassic, most probably late Tithonian event. Ophiolites of Vardar mega-unit obducted on top of Adriatic continental margin in post-obductional times became part of that passive continental margin adjoining the remaining segment of the Neotethys. Unconformably overlying DOZ are Upper Tithonian-Lower Cretaceous continental slope deposits (Karamata et al., 2004; Vishnevskaya et al., 2009) and/or clastic-carbonate Lower Cretaceous sequences (Mikes et al., 2008). On the other hand, overstep sequence of OWVZ is Albian-Cenomanian and Cenomanian-Turonian in age (Djerić et al., 2009; Gajić, 2014). Albian-Cenomanian and Cenomanian-Turonian shallow water limestones demonstrate gradual transition both upwards and lateral into Santonian-Campanian deep water marls and limestones with chert which, later change to clastic flysch of

Maastrichtian and possibly Paleogene age, as the most distal products of the passive margin (Gajić, 2014; Toljić et al., 2018).

Although they originate from the same ophiolitic sequence, during Late Cretaceous-Paleogene collision, DOZ and OWVZ were separated in two belts, hence DOZ is here interpreted as a part of the composite Drina-Ivanjica unit (Figure 1) and OWVZ as a part of Western Vardar Zone (Figure 1) which base is represented by Paleozoic-Triassic sequences of Adriatic affinity (i.e., Jadar-Kopaonik unit of Schmid et al., 2008).

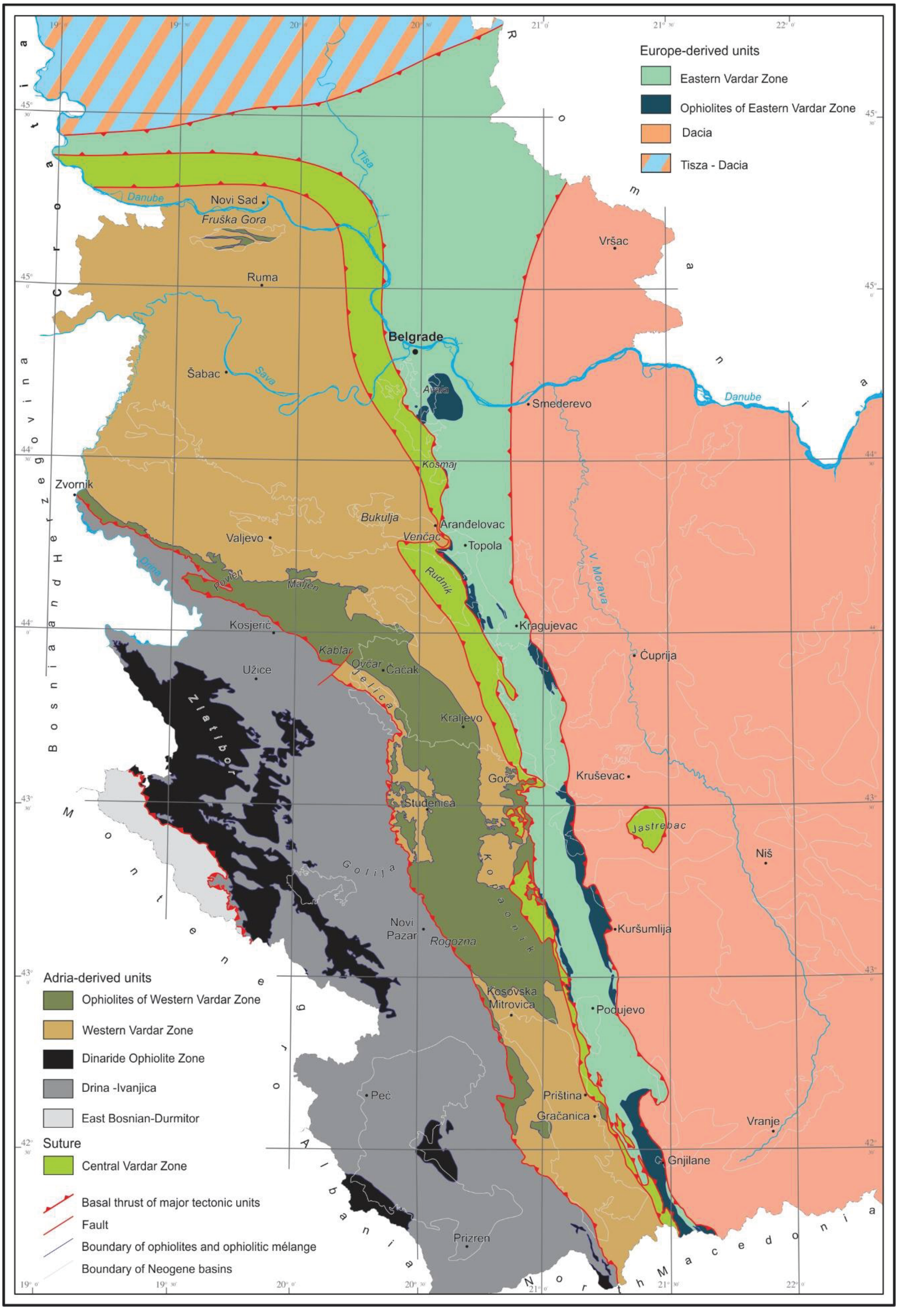


*Figure 1 – Tectonic map of the Vardar mega-unit in Serbia. Note that, in the map, the complicated eastern boundary of the Eastern Vardar Zone is interpreted as the initial obduction thrust (see text for further explanation on the geometry of this contact).*

The basal thrust of the Western Vardar Zone can be separated in two segments, northwestern that is oriented in NW-SE direction from Zvornik to Jelica mts., and central and southeastern segment that has NNW-SSE orientation from Jelica mts. to the border between Serbia and North Macedonia (Figure 1). The basal WVZ thrust, earlier described as the Zvornik suture (Dimitrijević, 1997 and references therein), in its northwestern segment has footwall composed of Paleozoic metamorphics and Triassic carbonates of Drina-Ivanjica unit, and in Kosjerić area (Figure 1) shallow water Upper Cretaceous limestones (Dimitrijević, 1997). Hanging wall of the northern segment of the basal WVZ thrust is built up of Jurassic ophiolitic mélange and ophiolites that are, locally, unconformably overlain by Upper Cretaceous sediments. In the central and southern segment, footwall of the basal thrust is made up of Drina-Ivanjica metamorphic basement with Triassic sedimentary cover and Senonian "Kosovska Mitrovica flysch" (Dimitrijević, 1997) along the entire strike of the thrust, while the hanging wall is represented by slivers of metamorphics, Triassic carbonates, ophiolitic mélange and ophiolites, as well as shallow water limestones. In the area of Studenica (Figure 1), hanging wall is composed of Paleozoic metamorphics and metamorphosed Triassic-Jurassic sediments (Schefer et al., 2010), including metamorphosed ophiolitic mélange and ophiolites. From Golija mts. to Rogozna mts. (Figure 1) hanging wall consists of ophiolitic mélange and ophiolites, while in Kosovska Mitrovica area this structure is complicated with out of sequence thrusting of Senonian flysch over ophiolites, so the basal WVZ thrust is interpreted at the base of the westernmost serpentinite occurrence. Towards SSE hanging wall is built up of Paleozoic metamorphics, Triassic carbonates, ophiolitic mélange and ophiolites, Albian-Cenomanian sediments, Upper Cretaceous shallow water sediments and turbidites, that are all together thrusted over "Kosovska Mitrovica flysch" as a typical overstep sequence of Drina-Ivanjica Paleozoic (Dimitrijević, 1997).
In the Fruška Gora mts. (Figure 1) flysches are found associated with Adria-derived Triassic sediments and Jurassic ophiolites (see Toljić et al., 2013). Flysches of the Fruška Gora mts. are sedimentologically similar to the "Ljig flysch", unit that represents part of the distal Adriatic margin deposits (Gajić, 2014). Therefore, flysches of the Fruška Gora mts. are here interpreted as a part of the Western Vardar Zone (Figure 1).

### 3.2 Subduction trench – Central Vardar Zone (CVZ)

Sava-Vardar Zone was first defined by Pamić (2002 and references therein) as „active continental margin formations". Schmid et al. (2008) interpreted the Sava Zone a suture between Tisza-Dacia Mega Units and the Dinarides, extending from Zagreb to Belgrade as the unit made-up of Upper Cretaceous ophiolites, metamorphics and magmatites. Further to the south from Belgrade the same unit can be followed as a stripe of Senonian flysches, squeezed in tectonic contact with West Vardar Ophiolites in their footwall and East Vardar Ophiolites in their hanging-wall. The facial analysis of Cretaceous sediments showed that Upper Cretaceous shallow-water sediments, flysches and/or turbidites can be found also westward and eastward from the Sava Zone flysches. By taking in consideration this fact and determining exact positions of regional thrusts which separate tectonic units, Central Vardar Zone (CVZ, Figure 1) was distinguished. Neogene sediments of the Pannonian Basin currently cover north-western segment of the CVZ, and thus separate it from its southern segment. The southern segment of the CVZ is predominantly made-up of synkinematic turbidites, deposited in the subduction trench during Cretaceous (Toljić et al., 2018). During the late Mesozoic, trench was positioned in the axial part of the Vardar Ocean, while in the present-day tectonic setting the synkinematic turbidites mark position of the suture. The suture is here recognized as the Central Vardar Zone, which spatially, structurally, and stratigraphically differs from Central Vardar Zone of Dimitrijević (1997 and references therein). Furthermore, different from the Sava Zone of Schmid et al. (2008) Central Vardar Zone beside Senonian, also contains Lower Cretaceous flysches, as well as Paleogene molasses (Toljić et al., 2018). In addition, it does not contain Upper Cretaceous ophiolites and magmatites that can be found in its equivalents further to the northwest (Ustaszewski et al., 2009).

In the northwestern segment of the Central Vardar Zone Upper Cretaceous flysches are covered by Neogene sediments of the Pannonian Basin (Čanović and Kemenci, 1988; Dunčić et al., 2017). From Belgrade towards south Central Vardar Zone represents narrow NNW-SSE oriented stripe, which can be traced from eastern flanks of the Venčac mts., east from Rudnik mts., west from Gledićke mts., and east from Kopaonik mts., in the tectonic window of the Jastrebac mts., towards Priština and further to the south in North Macedonia (Figure 1).

Sedimentary formations of the CVZ do not contain basement made-up of units which represent part of continental margins of the Vardar Ocean. Lithostratigraphically they are neither part of Adriatic nor European units. During Cretaceous subduction of remnants of the Neotethys oceanic crust, flysches of the CVZ were incorporated in the subduction zone, partly metamorphosed, and structurally significantly deformed and reduced (Stojadinović et al., 2013; Erak et al., 2017). Coniacian to Maastrichtian flysches represent contents of the CVZ in the area between Belgrade and Aranđelovac (Figure 1). At the eastern flanks of the Venčac mts., they are metamorphosed in subduction zone, and subsequently exhumed during Neogene extension (Stojadinović et al., 2013; Stojadinović et al., 2017; Marović et al., 2007b). South from Venčac mts., contents of the CVZ are represented by Albian-Cenomanian, Turonian, and Coniacian-Maastrichtian deep water and flysch sediments of ”Jermenovac facies” (Brković et al., 1980; Toljić et al., 2018). West from Kragujevac towards eastern flanks of the Goč mts. (Figure 1) contents of the CVZ are, again, covered by Neogene deposits. At the eastern flanks of the Goč mts., formations of the Central Vardar Zone can be recognized in the metamorphics situated in the hanging-wall of the ophiolites of the Western Vardar Zone, and in the footwall of Lower Cretaceous "paraflysch" sediments of the Eastern Vardar Zone (see Schefer, 2012). In the Jastrebac mts. extensional core-complex is made-up of Eocene granodioritic intrusion surrounded by metamorphosed Cretaceous-Paleogene sediments, which are interpreted as part of the Vardar Zone (Marović et al., 2007a) or the Sava Zone (Schmid et al., 2008; Erak et al., 2017). Between the Kopaonik mts. and Priština (Figure 1) Senonian flysch sediments of the Central Vardar Zone are deformed into isoclinal folds and significantly faulted. From Priština to Uroševac (Figure 1) Upper Cretaceous sediments of the CVZ also contain mélange which includes blocks of Senonian carbonates (Dimitrijević, 1997), and are structurally incorporated into the same thrust structure with Albian-Cenomanian sediments of the Eastern Vardar Zone.

Boundaries between formations of the Central Vardar Zone with the ones of the WVZ and the EVZ are exclusively represented by tectonic contacts (Figure 1). Sediments are highly deformed, frequently into the isoclinal folds with strong west-southwest vergences, and tectonic transport towards west-southwest. The basal thrust of the Central Vardar Zone is between Belgrade and Aranđelovac covered by Neogene sediments. During the Oligocene-Miocene extension the thrust is at the eastern flank of the Venčac mts. (Figure 1) reactivated as extensional detachment, with metamorphosed Triassic carbonates in the footwall, and metamorphosed Cretaceous flysches in the hanging-wall (Marović et al., 2007b; Stojadinović et al., 2013). Further to the south, Rudnik fault is interpreted as tectonic boundary between distal flysches of the WVZ and Albian-Cenomanian and Upper Cretaceous flysches of the CVZ (see Toljić et al., 2018). In the area between Rudnik and Goč mts. the thrust is covered by Neogene formations. At the eastern flanks of Goč mts., flysches of the CVZ are metamorphosed and tectonically reduced (Schefer, 2012), and the basal thrust of the CVZ can be traced at the contact between ophiolites of the WVZ in the footwall, and phyllites and calcshists in the hanging-wall. Hence, east from Goč and Kopaonik mts. continuity of the Upper Cretaceous turbidites of the CVZ is locally interrupted, however the suture can still be traced since there is immediate contact between lower and upper plates of the former subduction system. Upper Cretaceous turbidites are here tectonically reduced during Oligocene and Miocene exhumation of Kopaonik and Željin intrusions along with the surrounding metamorphics (Schefer, 2012). Contrarily, metamorphosed Upper Cretaceous turbidites in the Jastrebac mts. did not undergo that much of reduction (see Erak et al., 2018). The basal thrust of the CVZ can be clearly traced until the border with North Macedonia (Figure 1). Upper Cretaceous flysches and clastites are thrusted towards WSW over serpentinites and metamorphics of the WVZ. Relations become complex in the vicinity of Gračanica, where Upper Cretaceous sediments that include fragments of recycled ophiolitic mélange (Dimitrijević, 1997) are thrusted over ophiolites of the WVZ.

### 3.3 Forearc basin of the active continental margin – Eastern Vardar Zone (EVZ)

Continuous zone comprised of ophiolites, ophiolitic mélange, and Cretaceous sediments, situated between gneisses of the Serbomacedonian unit in the east and Cretaceous flysches of the suture in the west, was defined as Central Vardar Subzone (Dimitrijević, 1997) or as Eastern Vardar Ophiolitic Unit (Schmid et al., 2008). After obduction in the Late Jurassic, ophiolites became integral part of the active European margin. Cretaceous sediments were subsequently deposited over such fundament in a basin developed above the subduction zone, which had position of a forearc basin at the active European margin (Toljić et al., 2018). Since the ophiolites in this zone have scarce distribution when compared to Mesozoic sediments, term „ophiolites“ in the name of this unit can be confusing. Therefore, this zone, previously defined as Central Vardar Subzone (Dimitrijević, 1997) or as Eastern Vardar Ophiolitic Unit (Schmid et al., 2008) was renamed into the Eastern Vardar Zone (Figure 1).

The Eastern Vardar Zone (EVZ) represents tectonic unit with European affiliation. In tectonic architecture of Serbia it can be traced as a NNW-SSE oriented belt, which extends from Belgrade towards border with North Macedonia and further to the south (Figure 1). Ophiolites and Cretaceous sediments of the EVZ are also found beneath Neogene sediments of the Pannonian Basin (Čanović and Kemenci, 1988; Dunčić et al., 2017). According to Schmid et al. (2008) Eastern Vardar Ophiolites Zone in the Pannonian Basin domain divides into the two branches. The first branch north from the Fruška Gora mts. bends towards west, while the second branch extends toward the northeast, thus connecting with correlative formations in

Transylvania. Further to the north EVZ is tectonically overlying the formations of the Tisza-Dacia mega-unit, in agreement to interpretations in seismic cross-sections (Matenco and Radivojević, 2012). In Belgrade surroundings (Figure 1) the oldest contents of the EVZ are represented by Upper Jurassic deep water claystones and radiolarites associated with syndepositional basalts, serpentinized peridotites and ophiolitic mélange. The ophiolitic mélange contains fragments of serpentinites, diabases, limestones, claystones, and cherts with Late Anisian to Early Tithonian radiolarian assemblages (Bragin et al., 2011; Bragin et al., 2019). Post-obductional cover is made up of Berriasian calcturbitites, followed by Valanginian cherty limestones, and Valanginian to Barremian marls with cephalopods, all together frequently described as the „paraflysch" (Dimitrijević and Dimitrijević, 2009). The Lower Cretaceous paraflysch, which represents the diagnostic facies of the EVZ, in northern Šumadija contains abundant fragments and large olistoliths of Tithonian shallow water limestones redeposited in the Berriasian basal clastites sequence (Toljić, et al., 2018). Basin infill continues with Barremian-Aptian and Albian-Cenomanian sediments of various facies, which are shallowing upwards. Upper Cretaceous transgressive basin infill in Belgrade surroundings is represented by Coniacian and Santonian shallow-water limestones, Campanian-Maastrichtian marls and sandstones, and Paleogene molasses. Coniacian-Santonian limestones are associated with syndepositional basalts and trachyandesite volcaniclastics (Toljić et al., 2018), while Lower Cretaceous paraflysch is intruded by lamprophyre dykes dated at around 85 Ma (Sokol et al., 2017). Syndepositional basalts are also found with Turonian carbonates in Topola area.

From Topola to Kragujevac (Figure 1) base of the EVZ is comprised of ophiolitic mélange and ophiolites, which are covered by the entire Berriasian to Albian-Cenomanian sedimentary sequence, including the paraflysch. Together with transgressive Turonian-Senonian sediments, the entire Cretaceous sequence is known as the Stragari and Šljivovac facies (Brković et al., 1980). Further towards the south, from Kragujevac until Gnjilane (Figure 1) Eastern Vardar Zone is around 15 kilometres wide and predominantly made-up of Berriasian to Albian-Cenomanian paraflysch (see Dimitrijević and Dimitrijević, 2009). The paraflysch is transgressively overlying heterogeneous ophiolitic mélange and ophiolites, locally intruded by Jurassic granites (Šarić et al., 2009). In the area between Jastrebac mts. and Kuršumlija (Figure 1) at the eastern periphery of the EVZ elongated diabase body is located, which is, again, thrusted NW from Kuršumlija by Middle Triassic semi-metamorphosed clastics and carbonates (Malešević et al., 1980). East of Priština, and going to southeast towards the border with North Macedonia (Figure 1) EVZ is predominantly comprised of gabbros, diabases with frequent intrusions of granites, ophiolitic mélange and subordinately of Berriasian to Albian-Cenomanian clastics, which are part of paraflysch sequences (Dimitrijević and Dimitrijević, 2009), as well as from recycled Senonian mélange (Dimitrijević, 1997).

The basal thrust of the Eastern Vardar Zone is markedly west-southwest vergent structure with tectonic transport towards the west-southwest. In Belgrade area (Figure 1) it is represented by a thrust named the Bela Reka Fault, which separates Upper Cretaceous flysches of the CVZ in the footwall from the ophiolites, ophiolitic mélange, paraflysch and Upper Cretaceous shallow water sediments in the hanging-wall (Toljić et al., 2018). In the Kosmaj mts. (Figure 1) footwall of the thrust is comprised of Upper Cretaceous flysches, and the hanging-wall contains serpentinites, Albian sediments, and Upper Cretaceous turbidites. In Aranđelovac area the thrust was reactivated as extensional detachment (Marović et al., 2007b; Stojadinović et al.,

2013). The footwall is made-up of Upper Cretaceous metamorphics of the Venčac mts., while the hanging-wall contains Urgonian and Aptian carbonates, Albian-Cenomanian clastites, and Turonian-Senonian turbidites. Towards the south, the Stragari Fault (Dimitrijević, 1997) separates flysches of the CVZ from serpentinites, ophiolitic mélange, and Cretaceous sediments of the EVZ. From Kragujevac to the Kopaonik mts. (Figure 1) footwall of the basal thrust contains Upper Cretaceous flysches, while the hanging-wall contains Lower Cretaceous paraflysch, a locally ophiolitic mélange and ophiolites. In Kopaonik mts. paraflysch is situated east from the basal thrust of the EVZ, and ophiolites, metamorphics, and Upper Cretaceous flysches of the WVZ and CVZ in complex structural relation are located in the west (Schefer, 2010). In the area between Kopaonik mts. and Gnjilane (Figure 1) Lower Cretaceous paraflysch and Albian-Cenomanian clastics, with local appearances of ophiolites, are thrusted over the Upper Cretaceous flysches of the CVZ. In the southernmost segment between Gnjilane and border with North Macedonia (Figure 1) Upper Cretaceous flysches in the west are found in tectonic contact with diabases, gabbros, and ophiolitic mélange in the east.
Eastern boundary of the Eastern Vardar Zone is structurally complex and it shows strong lithostratigraphic contrast of units on its sides. The contact between metamorphics and Mesozoic ophiolites and sediments is always tectonic. Wherever the boundary is exposed at the surface, metamorphics of the Serbomacedonian unit are located in the east, and formations of the EVZ in the west. Primary tectonic contact between the ophiolites and metamorphics was structured in the Upper Tithonian (Bragin et al., 2011) when the ophiolites of the EVZ were obducted towards east over the metamorphics of the Serbomacedonian unit (Schmid et al., 2008; Erak et al., 2017). The ophiolites were subsequently, as a segment of a forearc basin, tectonically transported towards west-southwest. During the Cretaceous-Paleogene convergence the contact was additionally complicated by formation of bivergent thrusts in the hinterland of the subduction zone, followed by thrusting of metamorphics over the ophiolite and paraflysch from east to west. During Miocene times normal faults were formed along the contact, during the extensional opening of the Velika Morava graben (Matenco and Radivojević, 2012; Erak et al., 2017).

## 4. Regional tectonic model – basinal and tectonic evolution of the Vardar mega-unit

Geodynamic evolution of the Vardar mega-unit is characterized by a polyphase changeover between extensional and contractional tectonic regimes. Middle to Late Triassic opening of the northern branch of the Neotethys between Adriatic and European continental units can be recognized in widespread Anisian to Ladinian volcanism and gradual deepening of Triassic sedimentary facies (Dimitrijević, 1997). Middle Jurassic intraoceanic subduction (Pamić, 2002; Schmid et al., 2008), which was initiated at the northwestern margins of the ocean, had its equivalents at the ocean northeastern margins (Gallhofer et al., 2017). Concurrently, in the upper plate domain, in the east, short-lived suprasubduction magmatism was manifested in island arc and/or forearc basin domain (Šarić et al., 2009; Božović et al., 2013; Gallhofer et al., 2017). In Late Jurassic bivergent obduction of the oceanic crust was conducted on both Adriatic and European continental margins (Schmid et al., 2008). The Late Jurassic obduction was followed by subsequent re-initialisation of subduction in Beriassian times (e.g. Toljić et al., 2013, 2018). The Albian–Cenomanian contraction resulted in exhumation of the forearc basin at the European active margin, which can be a far-field effect of the onset of the orogenic collision and convergence recorded by the neighbouring Carpathian orogen. The Turonian–Santonian switch to subsidence, extension and magmatism in the forearc was associated with a period of slab retreat and steepening (Toljić et al., 2018). In Late Cretaceous–Paleogene times final stages of closure in the Neotethys led to the formation of suture between Adria- and Europe-derived continental units (Pamić et al., 2002; Karamata, 2006; Schmid et al., 2008). The younger phase of Oligocene–Miocene extension structurally overprinted the former continental collision deformation and led to formation of the Pannonian Basin (Matenco and Radivojević, 2012), which was, again, exposed to inversion starting from Late Miocene times (Horvath et al., 2015).

## 5. Conclusions

Vardar mega-unit represents complex tectonic unit, which was structured during Mesozoic tectono-depositional evolution of Neotethys and the adjoining continental margins. Vardar mega-unit can be subdivided into the three tectonic entities characterized by contrasting lithostratigraphic and structural features. Going from west towards east these are: Western Vardar Zone, Central Vardar Zone, and Eastern Vardar Zone. Lithostratigraphic contents of these zones were, again, deposited in three different domains. From west to east, these domains are: basin of the Adriatic passive margin, subduction trench, and forearc basin of the European active margin.

Western Vardar Zone is integral part of the Dinarides, while Eastern Vardar Zone was structurally incorporated into the tectonic setting of units with European affiliation. Central Vardar Zone is situated at the positions of suture between Europe-derived units in the east and Adria-derived units in the west.

Both zones of ophiolites in the Dinarides (i.e. Dinaride Ophiolite Zone and Ophiolites of Western Vardar Zone), along with the ophiolites of the Eastern Vardar Zone all contain ophiolitic mélanges with similar ages of fragments beneath the obducted ophiolites. This fact goes in favour of the „single ocean“ concept.

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