Tectonic evolution of the European margin and Neotethys suture zone in the region of Belgrade (Northern Šumadija-Serbia)

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Abstract: - Cretaceous-Paleogene convergence between Adriatic and European tectonic units was followed by formation of basins that was governed by mechanisms associated with long-lived subduction. In the trench developed directly above the subduction zone syn-contractional flysch turbidites were deposited. In addition, facially heterogeneous sediments were deposited in the fore-arc type of basin, which was developed further to the east from the subduction zone. Convergent tectonic regime triggered formation of a sequence of congruent fold and thrust structures. The entire tectonic setting was established in the long-lived compressional strain field, whereby the maximum stress axis was perpendicular to the orientation of convergent system. The subduction had features of orthogonal type subduction. The results of structural and facial studies in the Šumadija region indicated the Bela Reka Fault as the most prominent structure in this tectonic setting. This fault system separated trench turbidites in the footwall and Cretaceous-age fore-arc deposits in the hanging-wall.

Key-Words: - Neotethys, suture, convergence, trench, forearc, thrust-fold belt, Šumadija

1 Introduction

Following the Triassic rifting and Jurassic-Cretaceous processes of obduction and oceanic consumption, the SE European branch of the Neotethys Ocean in the Dinarides region was finally closed during the Cretaceous-Paleogene collision of units with European and Adriatic affinities [1].

Starting from Early Cretaceous initiation of intraoceanic subduction, the convergent tectonic regime lasted through entire Cretaceous and continued during the Latest Cretaceous-Early Paleogene phase of continental collision. The present-day tectonic setting of the Europe-Adria boundary was further complicated by the phase of Oligocene-Miocene extension. The extension was associated with formation of the Pannonian Basin and exhumation of magmatites along its margins [2], [3]. Pliocene-Quaternary phase of compression has led to inversion of existing basins and current positioning of the suture zone between Adria and Europe continental entities. The suture zone can be traced from Zagreb along the Sava River, across the Fruška Gora Mts to Belgrade. South from Belgrade it goes across the Kosmaj Mts and east from Kopaonik Mts and Priština towards FYR Macedonia where along the Vardar River it passes further in Greece (Fig. 1). The long lasting phase of compression, as well as spatially and temporally localized phases of extension governed the development of a series of basins characterized by facially variable deposition [4], [5]. Pronounced contrast exists between sedimentary formations of the Dinarides and metamorphics of the Carpatho-balkanides, which are separated by zone of flysch-turbidites. This feature was the reason for uniform positioning of the suture in a number of studies. The zone of collision was defined as Vardar Zone [6], [7], Sava-Vardar zone [5] or Sava zone [1].

Long lasting and complex tectonic and depositional evolution of the suture so far has been sectionally reconstructed. Studies in its northwestern segment point to complex relations between units of the passive continental margin, the obducted ophiolites, and the Mesozoic sedimentary cover [8]. Kinematic study in the Fruška Gora Mts enabled the reconstruction of phases of folding and thrusting, as well as the Tertiary extensional exhumation of the mountains metamorphic core [9], [10]. In addition, the Kopaonik Mts represent an area with complex relations between Paleozoic to Mesozoic sediments and metamorphics with continental affinity and the units which correspond with the oceanic lithosphere. The entire setting was further complicated by the phases of Tertiary extension and exhumation of Oligocene-Miocene magmatites [11], [12]. On the other hand, tectonic evolution of segments of the suture between Belgrade and Kopaonik Mts and south from Kopaonik were not studied thoroughly.

The Belgrade surroundings were partly investigated from stratigraphic point [13], [14]. However, complex tectogenesis along with partial display of litho-stratigraphic features define the Northern Šumadija as insufficiently studied region [4].
Recent investigations of geological setting in the Northern Šumadija were oriented towards the reconstruction of tectonic and depositional histories of Belgrade wider surroundings [15]. In this area the Mesozoic age ophiolites, sediments, and magmatites crop-out beneath Neogene sedimentary cover of the Pannonian Basin.

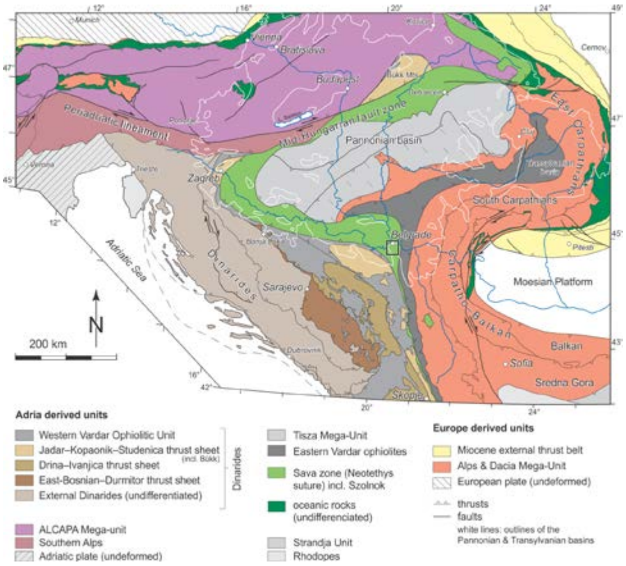

Fig. 1. Tectonic map of the SE Europe with labeled position of the Northern Šumadija region [1].

The main target of this study is to unravel important features of tectonic setting in the northernmost Šumadija. For that purpose we conducted structural and lithostratigraphic investigations of Mesozoic units in Belgrade surroundings. This includes analysis of fold structures and positions and kinematic features of major faults. Furthermore, geological columns of Mesozoic units were reconstructed in order to understand their genesis. The analysed data were integrated into coherent frame of tectonic evolution of this specific segment of Adria-Europe collision zone.

2. Geological Background

2.1 Lithostratigraphic units

The existing publications about Mesozoic ophiolites and sediments in the Belgrade surroundings represent fundaments for discussing lithostratigraphic features of Northern Šumadija rock formations [13], [14], [16]. In vertical succession larger rock units separated by regional transgressions can be distinguished. These are Jurassic ophiolites, ophiolitic mélanges, and deep water sediments; Lower Cretaceous deposits; and Upper Cretaceous deposits (Appendix 1). Neogene and Quaternary sediments of the Pannonian Basin periphery, which have large spatial distribution, were not in focus of this study and as such will not be presented in details.

2.1.1 Ophiolites, ophiolitic mélanges, and Jurassic deep water sediments

Jurassic products are exposed as dip water deposits, ophiolitic mélanges and the associated obducted ophiolites. In the Belgrade surroundings major segment of the typical fully developed ophiolitic sequence is missing. Only its deepest parts comprised of the serpentinized peridotites are present. Segments of the former oceanic crust can be recognized as small size bodies of the spilites and diabases, and also as segments of the mélange, as claystones and radiolarites with intrabedded basaltoid rocks, all together perceived as parts of the pelagic and semipelagic segments of the oceanic crust terminal sequence. The immediate footwall of the mélange has not been discovered exposed at the surface. The ophiolites unconformable lie below the Cretaceous rudites and pelites of the “paraflysch sequence” [15]. With the other, younger formations of Lower Cretaceous age the contacts are tectonic, while the calcrudites that represent the base of Upper Cretaceous flysch transgresivelly cover the ophiolitic mélange [13]. The ophiolitic mélange is characterized by the typical matrix comprised of clays and radiolarites, which includes meter-sized blocks of sandstones, sandy marls, limestones, and rare blocks of spilites. Within the matrix there are also numerous smaller pieces of cherts and few larger blocks that can reach the size up to 10 meters.
The age of ophiolitic mélange has been determined as the Kimmeridgian-Tithonian [16]. Radiolarites from the well near Grocka have Late Barthonian-Early Callovian and Middle Oxfordian-Early Tithonian age [17]. The cherts from Bela Reka locality contain radiolarites association of the Callovian-Kimmeridgian age and tectonized matrix of the mélange from village Ripanj (Appendix 1) shows early Ladinian and middle Barthonian – lower Tithonian times [18].
Sedimentary layer covering the parts of oceanic crust is represented by claystone, sandy claystone and radiolarites, often associated with the syn-depositional spilites and their pyroclastites. Pelites contain Upper Jurassic aptychi [13], and the chert layers in alternation with claystones contain radiolarians that correspond with the middle

Oxfordian-early Tithonian, and the late Barthonian-early Tithonian age [18].

2.1.2 Lower Cretaceous deposits

During the lowermost Cretaceous post-obductional period rapid subsidence in the European margin was associates with the deposition of coarse grained sediments over the ophiolites and ophiolitic mélanges, representing the transgressive base of the paraflysch sediments of the Central Vardar subzone [4], [19]. Even though in Belgrade surroundings the direct contact with the older rocks is not clearly exposed, the basal levels of the paraflysch can be recognized in the calcrudites that make level of carbonate breccia up to 4 meters of thickness. These breccias are very heterogeneous, and besides big pieces of carbonates also contain pieces of cherts. These sediments overlay the assemblage composed of sediments and volcanites as part of the mélange, as well as the Upper Jurassic marls with aptychi, and pre- Lower Cretaceous deep water sedimentary facies.

At the southern periphery of the urban Belgrade area, as well as in a few scattered zones located further south, there are numerous outcrops of limestones containing shallow-marine fauna with the corrals, briozoe, brachiopods, most frequently stratigraphically defined as Tithonian [13], [14]. Our research indicates that Tithonian carbonates were redeposited into the basal layers of Lower Cretaceous coarse clastics. In the matrix these contain microfossils that define their age as Beriassian [15]. They can be found as large carbonate olistolitic bodies, as in the areas of Rušanj and Bela reka or as numerous redeposited carbonate intraclasts present in the calciturbidites sequences such as the carbonates of Straževica area.

The carbonatic turbidites are laterally towards west passing into the paraflysch sediments. Paraflysch sequences are comprised of laminated claystones, siltstones, marls, marly limestones, calcrudites and calcarenites, which expose weak turbidites features. Paraturbidites composed of marls and claystones are with horizontal lamination, sometimes with intervals exposing the convolution, beds made of calcrudites and calcarenites are graded, and the lower bedding surfaces show sparse sedimentary textures. The available data is indicating longitudinal paleotransport in the direction NNW-SSE [15].

Paraflysch is upwards changing into the conformable Valengian-Barremian beds with cephalopods [20]. These were studied in the Straževica area where marls, claystones, and marly limestones contain numerous macro fauna of middle and upper Neocomian, among which the Barremian forms are predominant, while the entire association points to a stratigraphic range between Valengian and Lower Barremian [14].

Near village of Rušanj marls contain Valengian age phylloceras, tiny ammonites with pyrite and inoceramuses. Younger, discordant spilite dykes are intruded into the sediments with cephalopods, which is frequent phenomenon in the area. Here, the beds with cephalopods also include calcarenites with horizontal lamination (mostly of Barremian age) with the lenses of shallow water limestones. All together, these are considered as the Barremian-Aptian flysch [13], [14].

Lateral facial changes from the deep to shallow water Barremian sediments can be traced in the Košutnjak area where marly sediments with scarce cephalopods are found alternating with the shallow water clastites and carbonates of the Urgonian facies [21]. Furthermore, in this area Urgonian carbonates pass laterally and upwards into the very shallow, organic carbonates of Aptian age, found associated with ferruginous, poorly consolidated clastites, both sharing the common ophiolitic detritus [14].

Stratigraphically higher are Albian sediments belonging to the various facies, changing from relatively deep water cephalopods to the very shallow water beds with corals, crinoids, and gastropods. Near the locality Koviona the nappe oriented in the direction N-S is exposing the change from Aptian shallow water carbonates to Albian shallow water facies, while in the surroundings, along several scattered tectonically exposed outcrops carbonate facies with ammonites fauna of Albian age were identified [16], [13].

Albian age deep water facies in the area of Rušanj lithologically represent marls, claystones, and sandstones, while their shallow water stratigraphic equivalents are made of conglomerates, glauconitic sandstones, ferruginous sandstones, oolitic iron ore, and sandy limestones (found at the periphery of Makiš, see Appendix 1).

In the thrust sequence comprised of the Lower Cretaceous sediments in the Rušanj area and going further south biostratigraphic evidences confirm presence of Albian-Cenomanian sediments [13].

2.1.3 Upper Cretaceous deposits and volcanites

Upper Cretaceous rocks are separated from older rocks by a regional unconformity and by a major fault structure. They are transgressive over serpentinites and the associated ophiolitic mélange and sediments of the Lower Cretaceous, including the Albian-Cenomanian deposits. Coarse grained clastites of different lithology are part of the pre-flysch Upper Cretaceous unit, which is spatially distinguished east from the Bela Reka Fault (BRF, Appendix 1). In Belgrade surroundings polimict Gosau type conglomerates and coarse grained sandstones contain pieces made by quartzite, limestones, sericite schists, cherts, and sandstones. Going upwards the sequences are made of graded and laminated clastites exposing different granulometry, and containing fragments of globotruncanas. Besides the monomict conglomerated with pieces of serpentinite, the base of Upper Cretaceous series is frequently comprised of banks of calcrudites and calcarenites. These pass upwards into the calcarenites in alternation with marls.

The magmatism in the northern Šumadija area is most certainly characterized by a polyphase evolution. Besides the Upper Jurassic spilites, the presence of younger basic and acid magmatites along with their tuffs associated with the Lower and Upper Cretaceous sediments has been confirmed [13], [15]. In the central part of investigated area, the Lower Cretaceous rocks are also cut by numerous spilites dykes (Appendix 1).

In addition, syn-depositionally emplaced spilites are also found in association with Upper Cretaceous limestones. Furthermore, the olistostrome sediments from the base of Upper Cretaceous sediments near Kijevo contain big fragments of andesitic volcanites [15]. All these features point to bimodal type of volcanism.

Thick series of flysch sediments as carbonatic and sandy lithofacies make several spatially distinctive zones, separated by large faults, older sediments and Neogene deposits. These are primarily distributed in the area west of Bela Reka Fault (see Appendix 1). Near Belgrade flysch sediments expose clastics character. In the surrounding of Sopot and Ralja flysch build of alternation of calcarenites, sandy marls and marls. Going towards to west fine grained clastites are passing into marls in alternation with siltstones, with the share of marls increasing gradually. Southwestern segment of the Upper Cretaceous flysches is made up by grey and dark blue marls, marly limestones and locally sandy limestones. In the surroundings of Barajevo, the fine grained sandstones and siltstones are upwards passing into the thick sandstone sequences, and these again pass into the siltstones, claystones, and marls.

The classical outcrop of higher levels of the flysch sediments was observed between Barajevo and Rušanj. The sequence is comprises of marls, sandy marls, and carbonate sandstones. Marls make the dominant sequence member, and show well developed properties of flysch deposits [15]. Around Sremčica the turbiditic sequences are made up by marls and sandy marls, coarse grained calcarenites, medium grained sandstones, and siltstones.

Besides the described fauna, Upper Cretaceous age has been also documented earlier. Micropaleontological investigations of carbonates near Sopot confirmed presence of the upper Senonian-Mastrichtian fauna [16]. In the area of Barajevo the age of flysch is defined as generally Senonian [20]. The age of flysches between Rušanj and Sremčica is upper Senonian [14]. Recent lithostratigraphic investigations defined the age of shallow water calcarenites as Coniacian-Maastrichtian, and the age of flysch sediments as Campanian-Maastrichtian to Paleogene [15].

Neogene sediments of the Pannonian basin or the paragenetically various Quaternary deposits make unconformable cover of the Mesozoic sediments of Belgrade surroundings.

2.2 Tectonic Setting

In Belgrade surroundings Tertiary sediments of the Pannonian Basin that cover Mesozoic age magmatites and sediments, complicate understanding of relations between tectonic units. In addition Neogene sediments totally cover units with Adriatic affinity [22], which are present further south in the Aranđelovac area [4].

In the tectonic context Mesozoic sediments and magmatites of Belgrade surroundings are frequently interpreted as contents of the Vardar Zone, i.e. Internal and Central Vardar subzone [4]. This is segment of the suture that can be followed from Zagreb, across Belgrade to Skoplje. Defined as the Sava-Vardar Zone [5] or the Sava Zone [1] it is comprised of Upper Cretaceous flysch-turbidites and interpreted as the suture that separates continental domains of Adria and Europe (Fig. 1).

3. Fold deformations and fault kinematics

Field investigations of fold and fault structures in Belgrade surroundings resulted in new inferences about tectonic evolution of Northern Šumadija.

3.1 Features of fold structures

Features of fold structures are significant for interpretation of strain field in which these structures were formed. Data about folds were collected in all Mesozoic sediments, but analyzed only for Cretaceous sediments. The measurements were statistically processed and presented in diagrams representing models of folds developed in Cretaceous deposits. The area comprised of Lower Cretaceous sediments is characterized by tight, slightly WSW vergent folds with the axis oriented in the NNW-SSE direction (Fig. 2).

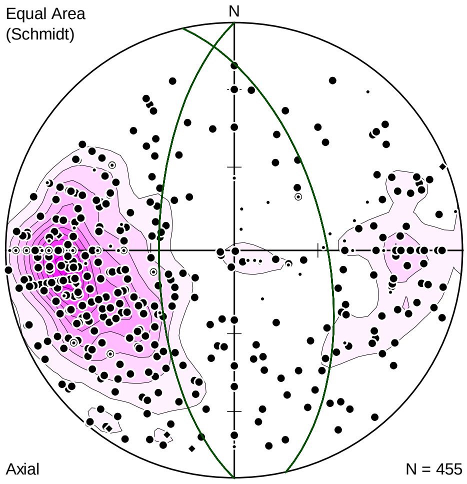

Fig. 2. Statistical diagram showing bedding measured in Lower Cretaceous sediments.

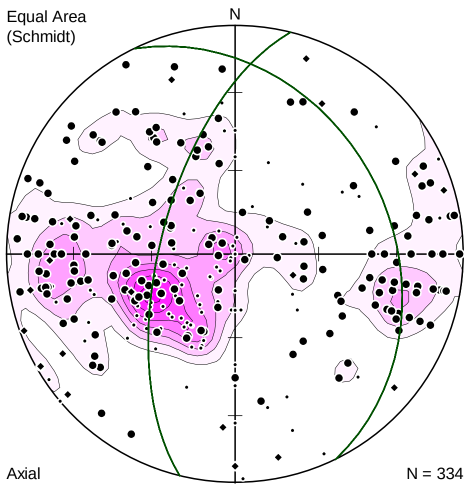

Fig. 3. Statistical diagram showing bedding measured in Upper Cretaceous sediments situated east from the BRF.

Upper Cretaceous sediments have double genesis. East from the Bela reka fault (BRF) shallow water sedimentary facies are dominant, while west from the BRF flysch sediments prevail. In the sediments east from the BRF asymmetric, markedly west-vergent folds with the axis oriented in the N-S direction are developed (Fig. 3). Flysch sediments west from BRF are folded in folds with axes oriented in N-S direction, with almost vertical axial planes and slight vergences towards west (Fig. 4).

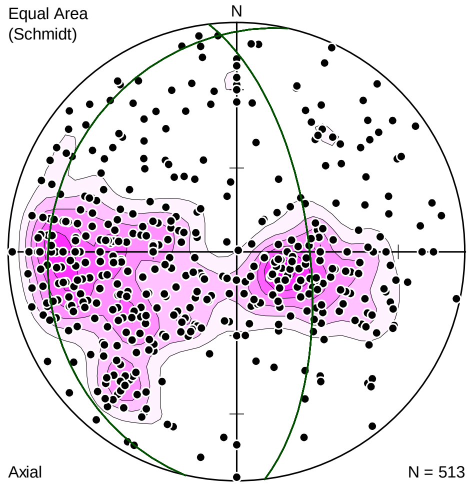

Fig. 4. Statistical diagram showing bedding measured in Upper Cretaceous sediments situated west from the BRF.

3. 2 Kinematics of main fault structures

In the region governed by the long lasting convergence regime (from Jurassic to Paleogene) complex system of fold and thrust structures was formed. During conducted investigations kinematics of various fault structures were reconstructed. Among these, dominant faults are reverse dislocations with NNW-SSE orientation. These separate the research area into three different lithofacial domains (Appendix 1).

Association of faults separates Upper Cretaceous flysch sediments in west, from mélanges, various Lower Cretaceous deposits, and Upper Cretaceous pre-flysch deposits in the east. It represents complex fault zone oriented in direction NNW-SSE, which deeps steeply towards east (Fig. 5). The fault zone is defined as the Bela Reka Fault (BRF). Kinematic indicators infer top-to-west reverse movements.

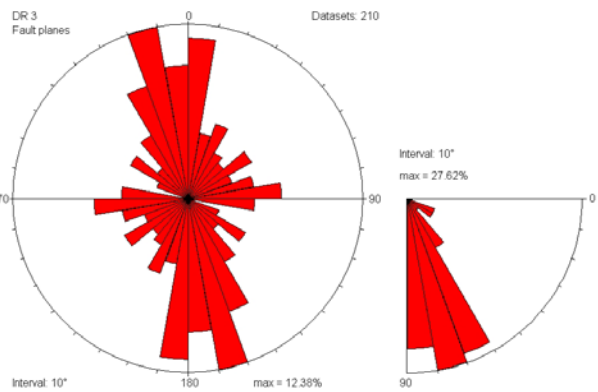

Fig. 5. Diagram showing dip direction/dip of field investigated faults.

Another important structure is situated further east. Along this fault the serpentinized peridotites were thrusted mostly over the Upper Cretaceous pre-flysch sediments. As the previous one, this structure is also oriented in direction NNW-SSE and it deeps relatively steep towards east-northeast.

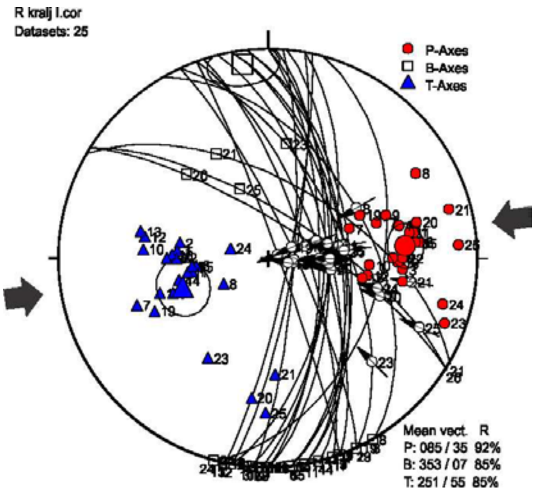

Fig. 6. Reconstructed compressional strain field for the Bela Reka fault.

Kinematic investigations of faults show complex setting that was generated during long time interval and poly-phase kinematic activation in compressional and later on in extensional strain field. For the association of faults defined as the Bela Reka Fault compressional strain field oriented in direction ENE-WSW was reconstructed in the present-day coordinates (Fig. 6). Compressional strain field in which fault association defined as the Avala Fault was activated is oriented in direction NE-SW (Fig. 7).

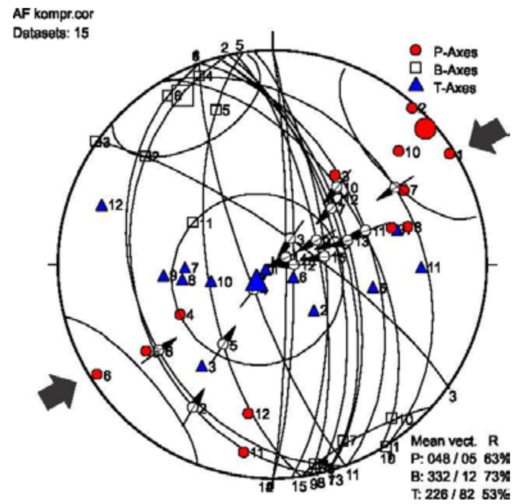

Fig. 7. Reconstructed compressional strain field for the Avala fault.

3 Discussion

The depositional evolution of Jurassic-Cretaceous sediments in Šumadija region is associated with the convergent tectonic environment, which was developed during the subduction of the oceanic crust of the Sava-Vardar ocean under the European margin. Early Cretaceous beginning of intraoceanic subduction [1] was subsequently followed by consumption of oceanic lithosphere and formation of basins in the active continental margin domain [15], [23]. The turbiditic flysch trench sediments were significantly consumed within the subduction zone. The fore-arc type of basin was developed between the accretionary wedge and the main continental hinterland, at the periphery of European active continental margin [23]. The infill of this basin is represented by facially various deposits. During the subsequent phases of Cretaceous subduction and Cretaceous-Paleogene continental collision these sediments became part of the fold and thrust belt.

Regression in the Early Cretaceous recorded in the basin located at the European margin was most probably governed by the subsidence as a result of isostatic response of the lithosphere that followed Upper Jurassic bi-vergent obduction of ophiolites [1], [2]. Short-lived basin exhumation at the boundary between Early and Late Cretaceous can be result of tectonic accretion in the subduction zone. Subduction was ongoing through Cretaceous and in Late Cretaceous it resulted in subduction of significant segment of oceanic lithosphere. These processes resulted in the regressive slab retreat and associated extension in the fore-arc and its hinterland. This can be, again, recognized by renewed phase of subsidence in the basin at the European margin, and by development of rift basin in the European continental crust domain at the positions of back-arc extensional areas [24].

In the Northern Šumadija region the effects of Late Cretaceous extension can be recognized in existence of the short-lived bimodal syn-depositional magmatism that was coeval with deposition of Santonian - early Campanian shallow water carbonate facies [15]. During the Late Cretaceous the ongoing convergence was associated with subsidence of the fore-arc basin and deposition of predominant shallow water sediments. The basin developed above the subduction zone still recorded flysch sedimentation. During the processes of long lived Cretaceous convergence, the subduction passed in continental collision and the orogenic fold and thrust belt with complex setting was formed. The compressional strain field was generally perpendicular to the orientation of convergent system. Long lived subduction showed features of orthogonal type subduction.

The data presented in this study concerning lithostratigraphic and tectonic features of units in the southern surroundings of Belgrade allow for proper defining of their distribution and most important properties.

The most important structure in tectonic setting of Šumadija is represented by a complex fault zone that separates trench turbidities from sediments of accretionary wedge and the ones deposited at the European margin. This structure is here defined as the Bela Reka Fault [15]. This first order tectonic boundary separates in Belgrade surroundings the turbidites of Sava Zone, which are contents of suture between Adria and Europe, from contents of the Eastern Vardar ophiolites Zone [1].

Interestingly, in Belgrade area and also further in the south Eastern Vardar ophiolites Zone does not show dominantly ophiolitic character. Predominant are Lower and Upper Cretaceous deposits, with subordinate Jurassic deep water sediments and ophiolites. It is plausible that the basin at the European margin was formed above the oceanic type of crust, and partly also on the metamorphics of the European continental crust. Since the eastern segments of the contact zone have Tertiary sedimentary cover in the Velika Morava trench, it is also possible that in this segment Jurassic ophiolites were obducted over the European margin towards east. However, in the Northern Šumadija there are still no direct evidences to support this claim.

The existing interpretations that define this region as a part of Internal and Central Vardar Subzone [4] do not correspond with its actual geological setting. Our observations indicate that the area south of Belgrade contains partial equivalents of the Central Vardar Subzone, which were previously recognized in Jurassic deep water sediments, ophiolites, Lower Cretaceous “paraflysch” deposits, and Lower Cretaceous shallow water deposits [19]. However, Upper Cretaceous sediments in the Belgrade surroundings were interpreted as a part of Internal Vardar Subzone [4]. According to our interpretation Upper Cretaceous sediments of Šumadija were deposited in two basins that were separated by a prominent reverse fault zone. The eastern basinal domain in the Upper Cretaceous also remains in positions of the Central Vardar Subzone, or the Eastern Vardar ophiolites Zone [1]. The western basinal domain is missing older fundament, which was consumed in the long lived subduction zone. Furthermore, the contents of the Adriatic passive margin further in the west are covered by Tertiary sediments. South from Belgrade the Jadar Block is defined as part of External Vardar Subzone [4]. Objectively, this is domain characterized by complex tectonic setting, which includes ophiolitic mélanges and ophiolites obducted towards west, facially and stratigraphically variable contents of passive Adriatic margin, as well as the Upper Cretaceous turbidites. Defined in such manner Jadar Block actually represents complex amalgam of several tectonic units. This property disables its direct correlation with tectonic units in Belgrade surroundings. The exception is the flysch sediments of so-called “Jermenovac” type [25] that most probably represent genetic equivalent of Upper Cretaceous flysch sediments in Belgrade surroundings. Together, these can be interpreted as part of the Sava Zone [1].

Structural association includes congruent faults and folds that were generated in long lived compressional strain field oriented perpendicular to the convergence zone. Main reverse faults were primary formed in the Early Cretaceous; they became prominent structures during Cretaceous convergence; and were reactivated by the Paleogene collision.

In Neogene times the orogen was exposed to the extension, which was genetically associated with complex processes of Pannonian Basin formation, followed by the exhumation of magmatites along its margins [3], [10]. These processes additionally complicated the setting in the Adria-Europe suture domain. The suture and adjacent basinal domain were finally shaped during the Pliocene-Quaternary inversion of the Pannonian Basin [9]. The effects of recent compression are recognized in steepening of existing reverse dislocations and reactivation of Avala Fault, together with slight re-orientation of the maximum compression axis reconstructed for this fault (Fig. 8).

4 Conclusions

The Belgrade surroundings represents an area situated in subduction-collision domain of the European and Adriatic continental blocks. The zone of convergence existed through entire Cretaceous and Early Paleogene. The long lasting contractional processes resulted in very complex tectonic and depositional relations between different Mesozoic formations. Cretaceous deposits are genetically related to the two distinctive regional basinal domains. One is the trench, situated in the western parts, and the other forearc basin situated more to the east at the European margin. Basins and their associated sediments are separated by the Bela Reka Fault, regional scale fault system that is the most prominent in tectonic setting of Šumadija region. The Bela Reka Fault in its footwall has contents of the trench and Sava Zone, while its hanging-wall carries the contents of the forearc basin and Central Vardar Subzone or the Eastern Vardar ophiolites zone.

5. Acknowledgements

This study was partly supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project No. 176015. The author is grateful to professors Grubić, Djoković, and Marović for all knowledge shared during the collaboration.

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Appendix 1. Geological map of Belgrade area [15].