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Reconsidering Paleozoic differences between the Jadar block and the Drina–Ivanjica unit

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Abstract. The peculiar Jadar block has an intervening position separating the main Neotethyan West Vardar Zone (including ophiolites of Late Jurassic age) and a passive margin lithospheric segment of the Apulia/Adria microplate referred to as the Drina-Ivanjica block. The review aimed to reassess the peri-Neotethyan paleogeography affecting the evolution of the Neotethyan oceanic crust ('single' *vs.* 'multiple oceans' or single- *vs.* two ophiolite belts) by juxtaposing the key differences of the late Variscan temporal evolution (controlling early Alpine paleogeography) between the Jadar block and Drina–Ivanjica crystalline segment. The study goal is the questionable paleogeographic affinity of the Jadar block. Contrary to the recent inferences attributing the Jadar block as a segment of the Apulia/Adria microplate, the study examine whether and how the Jadar Late Paleozoic succession may allow for an alternative paleogeographic solution of the Neotethyan relevance. According to this comparison survey of these late Paleozoic successions, it appears that the Jadar block may carry a (tentative) evidence of the proximity of the western Paleotethys. The comparison yields a putative paleogeographic position associating the Jadar block with the post-Variscan European margin (not Apulia/Adria microplate). The proposed shift of the Permian-Triassic paleogeographic position of the Jadar block inevitably affects the obduction length *i.e.* questions a favourable protracted along strike-width of the overriding Neotethyan West Vardar ophiolites ('single ocean model').

Key words:
Jadar terrane, Drina–Ivanjica block, Permian-Triassic paleogeography, Eocimmerian basement, Paleotethys, Neotethys.

Апстракт. Јадарски блок се налази између главног дела некадашњег Неотетиса или Западне вардарске зоне и Дринско-ивањичке пасивне маргине која припада Апуљско-јадранској микроплочи. Циљ овог рада је кратка реевалуација ране фазе ободних делова неотетиске палеогеографске ситуације кроз упоредну анализу каснопалеозојске тј. варисцијске еволуције поменута два блока. Каснопалеозојска фаза је имала кључни утицај на рано алпску еволуцију некадашњег Неотетиса. У новијим радовима Јадарски блок је често представљен као део Апуљско-јадранске микроплоче, док се у овој студији указује на могућност да овај блок на

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Кључне речи:
Јадарски блок,
Дринско-ивањички блок,
Пермо-тријаска палеогеографија,
Палеотетис, Неотетис.

основу својих каркатеристика може бити (ре)интерпретиран као сегмент промторијума пост-Варисцијске јужноевропске маргине, која је била под утицајем затварања Палеотетиса. Предложена позиција Јадарског блока утиче на горњојурско-доњокредну тектонску интерпретацију Западновардарских офиолита као и предложену дужину самог обдуковања преко анализираних доминантно палеозојских блокова.

Introduction and problem statement

The late Alpine underthrusting and accretion of the Apulia/Adria microplate with south European foreland allowed the formation of a West Balkan Dinaric-Hellenic orogen, a branch of the Alpine-Himalayan belt. This accretionary orogen largely reconfigured and obscured the predating early Alpine configuration (*e.g.*, Dornsiepen et al., 2001; Haas et al., 2019; Spahić et al., 2020), a successor of the late Variscan – Eocimmerian setting (*sensu* Zulauf et al., 2018; Spahić et al., 2019; see Fig. 1 for the tectonic units). The ongoing closure, shortening, convergence and late Alpine nappe stacking of this rather peculiar western branch of Tethyan Ocean ejected distal margin of this short-lived ocean – highly-deformed thick-skinned Drina–Ivanjica crystalline slice (*sensu* Đoković, 1985), a segment of Apulia/Adria microplate. The initial ocean–microplate convergence was replaced by a microplate-microplate collision allowing a rearrangement of the original Neotethyan configuration by juxtaposing the aforementioned thick-skinned fragment along the mildly deformed Jadar block of intriguing paleogeographical affinity (European or African?). This highly complex pre-Alpine to Neotethyan agglomeration is positioned to the southwest of Belgrade, in western Serbia, and eastern Bosnia and Herzegovina (*sensu* Filipović, 1974; Filipović et al., 2003; Fig. 1). Despite a considerable effort of the local (*e.g.*, Dimitrijević, 1997, 2001; Filipović et al., 2003; Hrvatović, 2005; Karamata, 2006; Kolar-Jurkovšek et al., 2019) and the international community, a very significant but poorly correlated issue is the role of the Jadar block (or 'Jadar–Medvednica–Bükk'; *cf.* Schmid et al., 2020) during the Late Jurassic – Early Cretaceous Neotethyan closure.

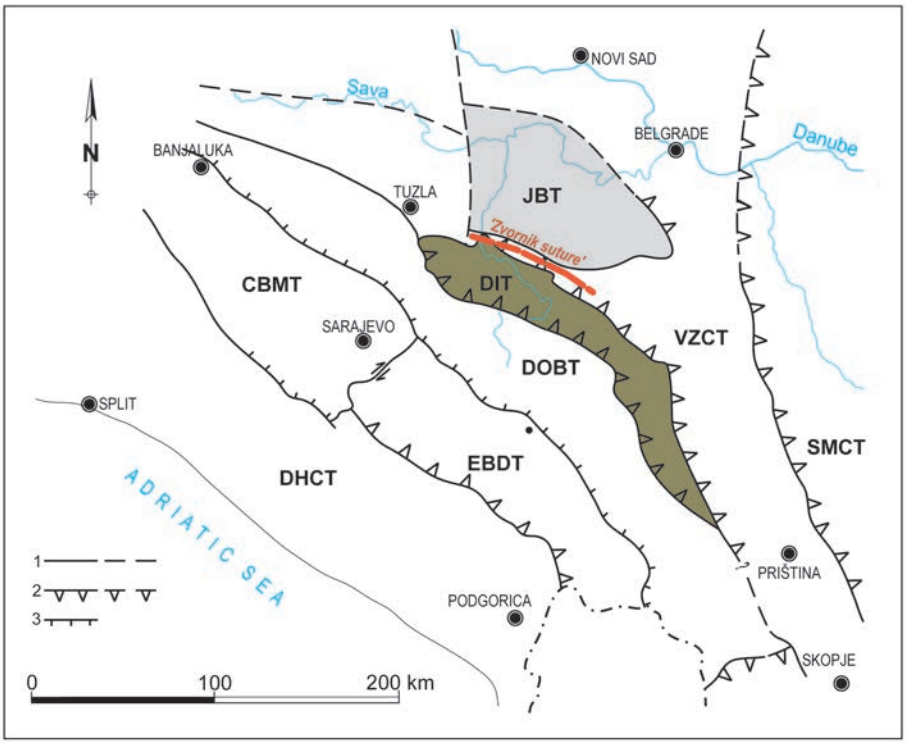

Fig. 1. *Main tectonic units of central-western Serbia, Bosnia and Herzegovina:* ***SMCT****- The Serbian-Macedonian composite terrane;* ***VZCT****- The Vardar Zone composite terrane;* ***JBT****- The Jadar Block terrane;* ***DIT****- The Drina-Ivanjica terrane;* ***DOBT****-The Dinaric Ophiolite Belt terrane;* ***EBDT****- The East Bos-nian-Durmitor terrane;* ***CBMT****- The Central Bosnian Mts. terrane;* ***DHCT****- The Dalmatian-Herzegovinian composite terrane. Thick line denotes the position of the 'Zvornik suture'.* ***1.*** *Fault,* ***2.*** *Thrust (nappe),* ***3.*** *Tectonic boundary, unspecified (modified after Karamata, 2006).*

The current controversial paleogeographic models of the investigated NE segment Apulia/Adria indenter revolve around the emplacement of the cross-lithospheric hanging wall mainly comprised of the West Vardar ophiolites (main NW Neotethyan ocean; *e.g*., van Unen et al., 2019; Schmid et al., 2020; van Hinsbergen et al., 2020), positioned above the two distinctive assemblages referred to as the Drina–Ivanjica block and Jadar terrane. Mainstream explorers impose the model of extended across strike-width of the Jurassic oceanic crust (West Vardar ultramafic massifs), fingerprinting a single Neotethyan ocean ('single ocean' model; *e.g.*, Schmid et al., 2008; Maffione & van Hinsbergen, 2019). However, earlier, dominantly local authors favour several Peri-Neotethyan oceans or 'multiple oceans' model (*e.g*, Channel & Kozur, 1997; Dimitrijević, 2001; Karamata, 2006; Faith et al., 2017). Those favouring 'single ocean' concept often neglect or disregard essential Late Paleozoic contrarieties separating the two footwall crustal slices, Drina-Ivanjica- and Jadar block (*sensu* Đoković & Pešić, 1985). Jadar block or "Jadar–Kopaonik unit" is attributed either as a segment of the main Vardar Zone (*sensu* Dimitrijević, 1997, 2001) or as a Mesozoic distal-most Adriatic margin emplaced on top of Drina–Ivanjica block, respectively (*cf.* Csontos & Vörös, 2004; Schmid et al., 2008, 2020; van Hinsbergen et al., 2020; Fig. 2).

The following juxtaposition of these two basement systems emphasizes the differences in the Late Paleozoic – Early Mesozoic (including overlapping Eocimmerian-) developments. The results suggest a possibility that the Jadar block may have had a different (pre)Neotethyan paleogeographic position relative to the approaching Apulia/Adria leading edge. The following late Variscan – early Alpine comparison offers an Alpine paleogeographical solution for the Jadar block that, we believe, better accounts for the Neotethyan relationships.

Paleogeographic constraints: Jadar- *vs.* Drina–Ivanjica block

The Dinarides are a principal substructure of the Apulia/Adria microplate (*sensu* Dimitrijević, 1997; Fig. 1). Deciphering the extremely complex Late Paleozoic–Mesozoic surface and subsurface constraints of this former Apulia/Adria accretionary wedge has increasingly becoming a topic of interest for both, geological and geophysical communities (*e.g*., Schmid et al., 2008; Majstorović et al., 2017; Subašić et al., 2017; van Unen et al., 2019; Schmid et al., 2020; van Hinsbergen et al., 2020). Its (former) distal passive margin block (thick-skinned slice) is referred to as the Drina–Ivanjica block. The adjoining crustal slice, referred to as the Jadar block is accommodated across the narrow fault zone referred as the 'Zvornik suture' – a segment of the Vardar Zone (Dimitrijević, 1997; Karamata, 2006; Gerzina, 2010; Fig. 1). The 'Zvornik suture' separates the two major fragments: (i) Jadar block (characterized by the preserved Devonian–Triassic sequence; *sensu* Filipović et al., 2003) and (ii) folded greenschist-facies Drina–Ivanjica block (Neoproterozoic – Lower Paleozoic and Carboniferous; Spahić et al., 2018 and references therein).

As mentioned earlier, 'single ocean' model places the "Jadar–Kopaonik unit" as a segment of the Apulia/Adria microcontinent bordering to the Drina–Ivanjica block. Accordingly, the Jadar block is sandwiched between the main Vardar Zone (Fig. 1) and Drina-Ivanjica block (footwall position) representing the farthermost cross-lithospheric footwall segment beneath the formerly overlaying West Vardar ophiolites. According to the 'single ocean' model, these West Vardar ophiolites produced a geologic segmentation reaching hypothetically over 100 km of across strike-width. A deep-seated basement thrust transported thick ultramafic crust over the (former) continental margin or Drina–Ivanjica block into what is now denominated as the Inner Dinaridic Ophiolite Belt (Fig. 1).

The following in-depth comparison emphasizes the often-neglected Paleozoic-late Variscan paleogeographical/depositional/tectonic constraints that might affect the choice of the Alpine model. The following key differences identified: (1) absence of early Paleozoic sequence within the Jadar Block (no analogue of the Drina formation), (2) significant difference in the magnitude of deformations between the Jadar block *vs*. greenschist-facies folded Drina-Ivanjica basement, and (3) the presence of the Permian-Triassic succession within the Jadar system lacking within the Drina–Ivanjica block.

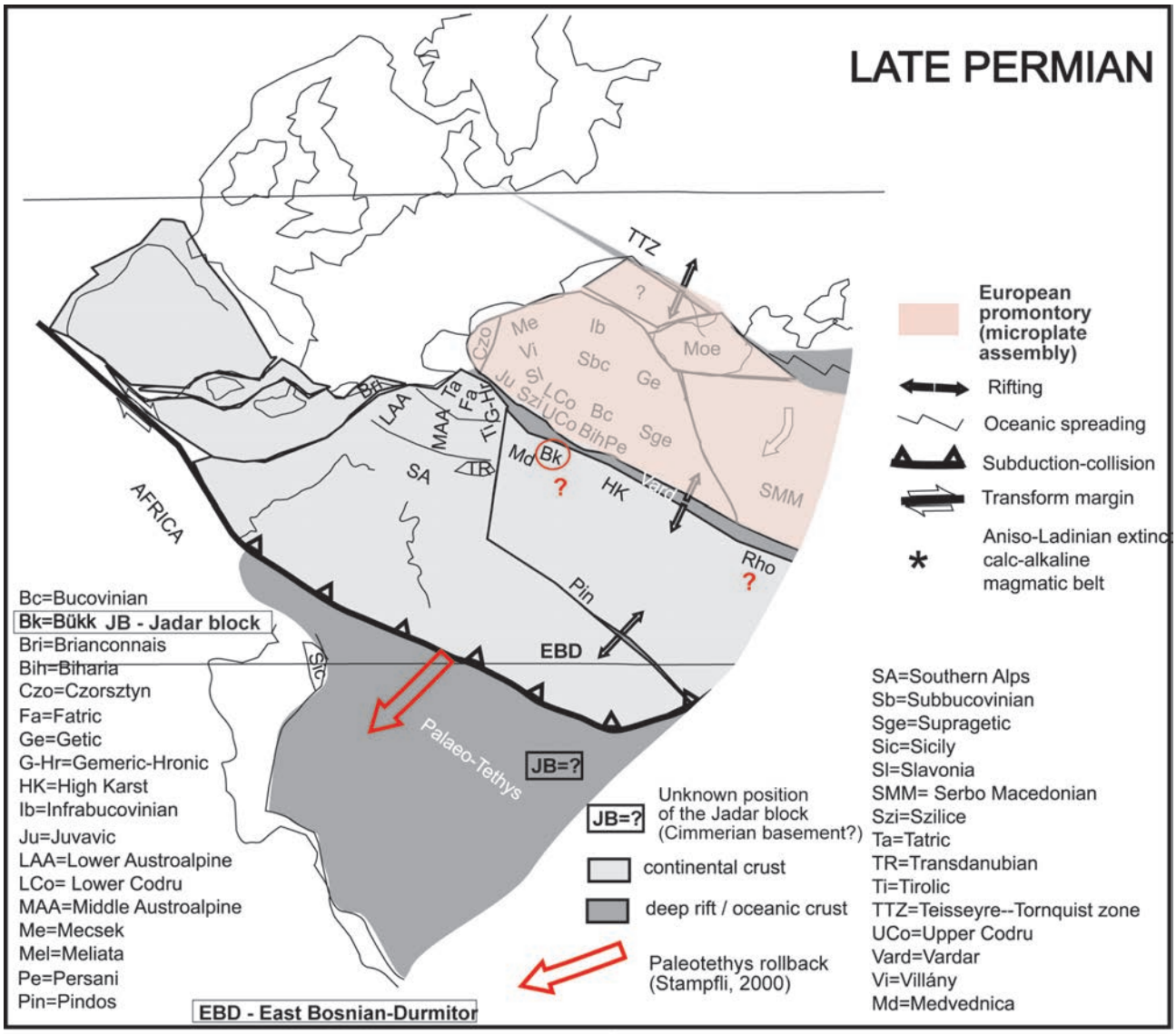

Fig. 2. *Neotethyan-related units in the Late Permian time (modified from Csontos & Vörös, 2004 and references therein). Thin curves indicate present geographic contours in stable Europe and Africa, eventually the contours of the Adriatic Sea are marked. Arrow at the Tunis promontory indicates a southward-directed movement of the Paleotethyan oceanic lithosphere (rollback).*

Absence of early Paleozoic succession within Jadar block (confirmed in Drina–Ivanjica block)

The Drina–Ivanjica block is composed of the Neoproterozoic-Lower Paleozoic Drina Formation (*cf.* Đoković, 1985; Spahić et al., 2018), the Jadar block has no documented record of any pre-Devonian rocks (*cf.* Filipović et al., 2003). Towards the west of the investigated area (western segment of the Jadar block in Croatia; Fig. 1), this allochonous segment is comprised of the Paleozoic complex represented by fossiliferous Silurian to Carboniferous greenschist-facies metaclastics, marbles, and orthogreenschists (*sensu* Pamić & Jurković, 2002). In addition, the Jadar block in Bosnia & Hercegovina (Teočak) exposes a Permian–Triassic shallow marine succession (Kolar-Jurkovšek et al., 2019). Consequently, the missing Neoproterozoic–Lower Paleozoic sequence within the Jadar system may suggest a different paleo-basin

position (in Paleozoic reference) relative to "Drina early Paleozoic succession.

Mild deformations of Jadar block *vs.* greenschist-facies folded Drina–Ivanjica basement

The three sedimentary-magmatic subcomplexes are separated within the Jadar block (Đoković & Pešić, 1985): (i) The Middle Devonian–Middle Carboniferous clastic-to-carbonate sequence overlain by a continental Baskhirian and Moscovian sequence. The Devonian record is not identified in the Drina-Ivanjica block. Nevertheless, the Carboniferous of both crustal slices, Jadar- and Drina–Ivanjica segments are characterized by the presence of turbiditic successions: (i.1) Jadar block: Lower Carboniferous Visean – Serpukhovian Kulm or "Variscan" flysch; (*sensu* Filipović et al., 1993, 2003) whereas the Lower- to Middle Carboniferous "Golija/Konglomerati & Kovilja/Birač formations" are separated within the (i.2) Drina–Ivanjica block. Peculiarly enough, the presence of Middle Carboniferous within the Jadar block is not documented (*cf.* Filipović et al., 2003).

The principal difference between the two Paleozoic systems is the weakly deformed Paleozoic succession of Jadar block (anchizonal overprint with a preserved original layering; *e.g.* Filipović et al., 2003). Such low-grade imprint is in contrary to dominant greenschist-facies of the Drina–Ivanjica block (*c.f.* Milovanović, 1984). In addition, the Drina–Ivanjica Paleozoic successions underwent severe shortening accompanied by the isocline folding and transposition which obliterated the initial layering (Đoković, 1985). (ii) The upper Middle Devonian – a gradually deepening up to the Upper Carboniferous–Lower Permian succession recorded within the Jadar block is not documented within the Drina–Ivanjica block. The essential difference is (iii) the Upper Permian–Upper Triassic terminal sequence (*sensu* Filipović et al., 1993; Kolar-Jurkovšek et al., 2019). In the Drina–Ivanjica block, the uppermost stratigraphic segments of the succession are missing (Upper Carboniferous–Lower Permian) (ii), as well as the entire Upper Permian sequence (iii) The new deposition cycle starts with the Upper Triassic (Dimitrijević, 1997);

Jadar block: Upper Permian - Upper Triassic succession

As mentioned earlier, the Permian–Ladinian subsidence cycle (Filipović et al., 2003) is a depositional peculiarity not recorded within the northeastern passive segment of Apulia/Adria (Drina–Ivanjica block). Nevertheless, a record of the Upper Permian lagoon-type deposition and continental Triassic is documented within the formerly sunken Apulia/Adria margin or East Bosnian-Durmitor block (Chiari et al., 2011 and references therein; Fig. 1). The presence of the nearly complete Upper Permian–Upper Triassic environment within the Jadar block (including the Late Ladinian/pre-Carnian metaandesite and its pyroclastics) is described as the early Alpine crustal extension (Filipović et al., 2003). On the other hand, Eocimmerian successions of a similar age are well known across Eastern Mediterranean (*e.g.* Zulauf et al., 2018 and references therein). The presence of Permian – Late Triassic succession within the Jadar block may mark the opposite side of the Variscan Apulia/Adria- or the (former) European promontory – westernmost edge of the south European margin (*sensu* Stampfli, 2000; Fig. 2). Thus, the Jadar block with its Permian–Triassic succession could preferably pinpoint the proximity of the south European margin *i.e.* it may represent a fragment of the one-time Variscan–Cimmerian Paleotethyan basement. These inferences are in line with the earlier conclusions that the Palaeotethyan domain was not fully closed in SE Europe lasting during the early Triassic (Stampfli, 2000). Depending on each particular micro-basin of the early Alpine age (*e.g.*, Inner Dinaridic Ophiolite belt or 'Dinaric ocean'; *sensu* Dimitrijević, 2001; Karamata, 2006), it appears that the Middle- to Late Triassic sequences of the Dinarides realm (in particular those missing Lower Triassic) may mark the onset of the Alpine cycle across West Balkan (opening Neotethys/Vardar Ocean). In SE European scale or within a southern paleogeographic extension of the Drina–Ivanjica block in North Macedonia and Greece, these findings

are moreover aligned with the sporadic occurrence of the Permian-Triassic within the Pelagonian unit (*sensu* Mountrakis, 1986; Stampfli, 2000; Scherreiks et al., 2014). The vicinity of a large dextral strike-slip 'Zvornik suture' (*sensu* Gerzina, 2010; Gerzina & Csontos, 2003) may also mark a Paleotethyan involvement. Moreover, this principal disjunctive fault system could represent a segment of the principal Paleotethyan suture separating the formerly welded Permo-Triassic Europe from Africa (see Fig. 6 of Stampfli, 2000). In that case, the Jadar block could be a segment of Late Permian–Triassic south European promontory, its westernmost corner.

Conclusions

Regardless of the apparent Eocimmerian involvement of the Jadar block, Jadar- and Drina–Ivanjica crustal fragments have significant differences in the Lower Paleozoic- (*sensu* Spahić et al., 2018), as well as the Late Paleozoic (late Variscan) to early the Alpine tectonic and paleogeographic evolution. Despite these crustal slivers underwent the relevant Variscan (probably succeeded by the Eocimmerian in case of Jadar block) and Alpine interferences, the record of any significant thermal overprint coupled with the tectonic shortening of the Jadar block is absent. A mild anchimetamorphic overprint with the preserved sedimentary layering, including the documented presence of the Kulm flysch suggest that the Jadar block was probably at the opposite European side of the formerly accreted Apulia/Adria microplate similar as suggested by Korn et al., (2010). There is a high likelihood that the Jadar segment was attached to a SE European margin, thus having a separate evolution from the Drina–Ivanjica crystalline block (Apulia/Adria microplate). Moreover, the spectrum of Sepukhovian ammonoid genera suggests a South Variscan position of the Jadar Block, implying a narrow basin (western Paleotethys; Korn et al., 2010). In the Alpine plan, Drina–Ivanjica crystalline block in turn experienced the multiple metamorphic overprinting (tentative Variscan- and confirmed Middle Jurassic involvement; numeric data provided by Milovanović (1984); Porkoláb et al., (2018). In addition to the previously reported comprehensive comparison (Đoković & Pešić, 1985), the Jadar- and Drina-Ivanjica Paleozoic systems emphasize the two entirely different paleo-depositional settings whereas the former may record a Paleotethyan interference.

The here proposed discrete paleogeographic position allocated at former south European Pangea margin (Jadar block) *vs*. Apulia/Adria microplate (Drina–Ivanjica block) demands a reassessment of the imposed cross-lithospheric up-thrusting of the massive West Balkan ophiolite massifs of Alpine age. To summarize, the proposed alternative early Alpine paleogeographic scenario may outline a separate position of the Jadar block along the SE European margin.

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Резиме

Разлике у палеозојском развићу Јадарског и Дринско-ивањичког блока

Јадарски блок (Србија; Слика 1) – Медведница (Хрватска) – Бик (Мађарска) су сегменти који се најчешће сврставају као део Апуљско-јадранске микроплоче (Слика 2). Међутим, Јадарски блок као дистални сегмент поседује особености у односу на суседне блокове, пре свега разликом према Дринско-ивањичком блоку. Такође, одликује се и веома занимљивом пермо-тријаском сукцесијом (према Filipović et al., 2003). Ова сукцесија поседује одређене сличности, како хроностратиграфску тако и палеогеографску сличност са тзв. варисцијско-кимеријским бејсментом источног Медитерана (сегмент Пелагонида; Scherreiks et al., 2014) тј. некадашњим делом Палеотетиског океана.

Јадарски блок по својим карактеристикама поседује веома важне разлике у односу на суседни Дринско–ивањички блок, иако су оба ентитета сматрана за део Апуљско-јадранске микроплоче. Неке од најважнијих разлика су: (1) Одсуство творевина неопротерозојско-доњопалеозојске старости у Јадарском блоку; (2) Присуство далеко мање изражених деформација

у односу на Дринско–ивањички блок: мањи степен метаморфизма који је једва променио оригинални склоп (присуство јасне слојевитости у Јадарском блоку, док се Дринско–ивањички палеозоик карактерише фацијом зелених шкриљаца, интензивно пренабраних и са присуством транспозиције; Đoković, 1985), (3) Присутво пермско - јурске сукцесије; субсиденција као и депозиција за време поменутог периода није забележена у овиру Дринско-ивањичког дисталног дела микроплоче.

Најмлађа сукцесија у Дринско–ивањичом блоку је карбонске старости (Đoković, 1985; Đoković & Pešić, 1985). Присуство горњопермске до тријаске седиментационе средине (укључујући ладинске тј. пре-карнијске мета-андензите) може одговарати раноалпској екстензији али такође и развићу везаном за најзападнији део Палеотетиса и могућу близину његове „пивот тачке“ тј. места где су се некада спајале маргине јужне Европе и северне Африке у пермо-тријаском времену.

Различито предложене палеопозиције Јадарске јединице су распоређене дуж некадашњег европског дела Пангее, тј. њеног јужноевропског обода, а које су највероватније биле насупрот или у близини Апуљско-јадранске микроплоче (као нпр. код Korn et al., 2010).. Ова реинтерпретација је у сагласности са појавама пермо-тријаских творевина у Пелагонидима (Грчка), потврђеним од стране Mountrakis (1986); Stampfli (2000) и Scherreiks et al. (2014). Такође, Јадарски блок се налази у близини Зворничког шава (према Gerzina & Csontos, 2003; Gerzina, 2010). Овај транскуренти систем може представљати сегмент главног мега-раседа који се развио на некадашњем контакту дела Европе и северне Африке, који су одвојени најзападнијим делом Палеотетиског океана (види палеогеографску рекострукцију у Stampfli, 2000). Предложена позиција Јадарског блока је уз обод јужно-Европског форланда. Предложени “алтернативни” сценарио уобличава позицију Јадарског блока као посебан (микро)сегмент некадашње Варисцијске и пост-Варисцијске јужноевропске маргине, која је била под утицајем затварања Палеотетиса. Даља детаљна истраживања могу бити од значаја за (i) утврђивање тачне палеогеографске позиције истраживаног блока током касноварисцијске етапе и пермо-тријаса, као и (ii) преиспитивање модела обдуковања неотетијских офиолита преко целокупног Јадарског блока (Schmid et al., 2008, 2020; van Hinsbergen et al., 2020).

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