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Short Communication
Кратко саопштење

A few remarks on the Triassic paleogeography and geodynamic link between the Dinarides and the Serbo-Macedonian Unit

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Abstract. A recently recycled tectonic hypothesis in which the Serbo-Macedonian Unit rifted off during Ladinian from the Dinarides is tested. The Triassic rifting, according to this concept, led to the opening and the formation of a northwestern branch of Neotethys (=Vardar Ocean). Similar concept explains the developments within the Inner Hellenide allochoton (Serbo-Macedonian Unit and Pelagonides). The testing of early Alpine configuration in Serbia shows, however, that the two crystalline basement units have significant paleogeographic variances. The study moreover includes the differences in Paleozoic metamorphic grades between two inliers, their exhumation times, etc. The investigated pre-Triassic paleogeographic and geodynamic variances unambiguously contradict any connection before and during Triassic (Ladinian). In this regard, by using the available field data, and the juxtaposed Late Paleozoic Variscan tectonometamorphic differences, the paper underscores the large differences in the (pre)Triassic plate configurations and paleogeography. The synthesis displays the two separate positions of these microplates situated along with the length of this segment of the Triassic Eurasian continental margin.

Key words:
Ladinian paleogeography, Drina-Ivanjica block, Serbo-Macedonian Unit, Variscan orogeny.

Апстракт. У раду је тестирана тектонска хипотеза према којој је Српско-македонска једница рифтована од Динарида током тријаса (ладинског ката). Према наведеном концепту тријаски рифтинг је резултирао отварањем и формирањем северозападног крака Неотетиса (Вардарског океана). Овакав концепт је од неких аутора предложен као део унутрашњег хеленског аутохтона (Inner Hellenides), где је препознат слични раноалпски геодинамички сценарио (Српско-македноска једница и Пелагониди). Тестирана раноалпска конфигурација Србије указује на постојање два различита кристалинска ентитета који се битно разликују по палеогеографским особеностима. Анализирана студија је укључивала резултате различитих степена метаморфизма између два бејсментска ентитета, времена ексхумације, итд.
Истраживање пре-тријаских палеогеографских и геодинамичких сценарија прелиминарно указује на непостојање било какве међусобне интеракције пре и током тријаса (ладинског ката). На основу резултата

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Кључне речи:
Ладинска палеогеографија, Дринско-ивањички блок, Српско-македонска јединица, варисцијска орогенеза.

анализа постојећих података и упоредном анализом каснопалеозојских – варисцијских тектонских и метаморфних разлика потврђене су разлике у (пре)тријаској конфигурацији плоча и палеогеографији. У овој синтези се предочавају две одвојене палеогеографске позиције микроплоча лоциране на истраживаном делу тријаске евроазијске континенталне маргине.

Introduction

The highly complex configuration of the NW Neotethys (=Vardar Ocean) is recorded and dispalyed between the Apulia/Adria microplate (Dinarides) and a fragment of Euroasian foreland represented by the Serbo-Macedonian Unit (Fig. 1). The complex evolution of Neotethyan ocean represents a topic of long-lasting debates involving several generations of geologist (e.g., Suess, 1880; Aubuin et al., 1970; Channell & Horvath, 1976; Pamić, 1984; Channel & Kozur, 1997; Dimitrijević, 2001; Csontos et al., 2004; Schmid et al., 2008, 2020; Robertson et al., 2009; Robertson, 2012; Jolivet et al., 2016; Spahić et al., 2018; Spahić & Gaudenyi, 2019b). Despite a long history of the early Alpine (Permian–Triassic) investigations (for a review see Robertson, 2012), there is no consensus on the Neotethyan evolution imprinted across the Western Balkan countries and its ophiolite belts. The versatile reconstructions still struggle with the Permian-Triassic active plate margins. The activity along these Paleotethyan active margin(s) would presumably affect the rifting and opening of the Triassic Tethyan ocean (or branches) in the back-arc position. Majority of the reconstructions assume an existence of an oceanic gulf extended westwards across the central Mediterranean region (e.g., Fig. 3 in Robertson, 2012 and references therein). The essential question is the precise location of this segment of western Palaeotethys ocean or whether a Triassic imprint across Western Balkans could belong to a rifted Neotethyan oceanic basin? Another important ambiguity is whether western Paleotethyan gulf (paleogeographically situated between Dinarides and Serbo-Macedonian Unit?) was closed in the Triassic or the early Alpine Triassic transition into the Neotethys was rather smooth?

The aim of this paper is to highlight the Variscan to early Alpine paleogeography of the two distinct systems belonging to the Dinarides and the Serbo-Macedonian Unit. In particular, we underline the Variscan position of the Serbo-Macedonian Unit (belongs to a Carpathian-Balkan orogen). We also provide a short comparison of the essential differences with a goal to outline the past position of a distal most segment of the "Dacia Terrane" referred as the Serbo-Macedonian Unit (hereinafter SMU).

Evaluating the Ladinian configuration of former south European foreland (Western Balkans): early Neotethys stage

A few earlier hypotheses proposed the Permian-Triassic amalgamation of the Dinarides and SMU (see Robertson, 2012 or a discussion). Other rather scarce newer studies favor separate Paleozoic plate-tectonic evolution (see Spahić & Gaudenyi, 2019a Spahić et al., 2018 for a discussion). Based on the innovative tools (Koymans et al., 2016 and references therein) and the scarce paleomagnetic data, the most recent paleogeographical study (van Hinsbergen et al., 2020) reconstructs the NW Neotethyan opening involving a complex allochtonous configuration of Western Balkan countries (Fig. 1). The study proposed a Ladinian position of the "Dacia Terrane" next to the Dinarides. This rather intuitive concept (already introduced a while ago by Robertson & Dixon, 1984; Dercourt et al., 1986, 1990) outlines the "Dacia Terrane" (Euroasian margin in the Ladinian reference) in the abutting position i.e. along with the length of eastern boundary of the Apulia/Adria microplate (Fig.2; Fig. 46 of van Hinsbergen et al., 2020). Such configuration imposes the

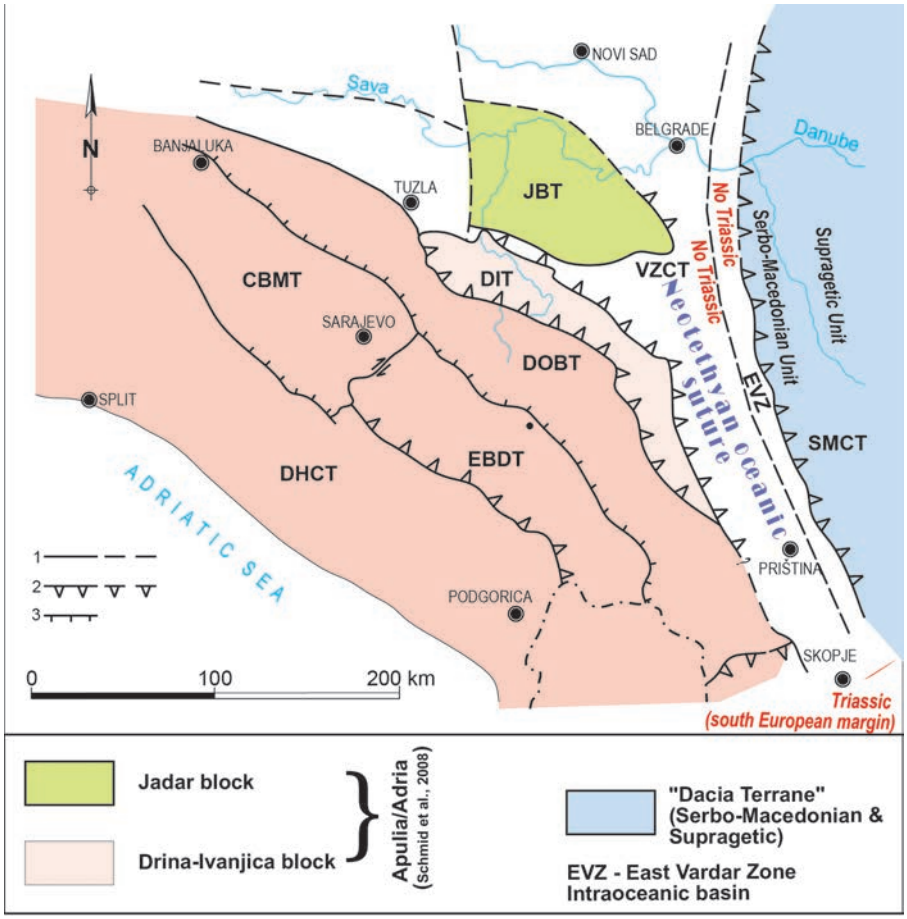

Fig. 1. *Tectonic sketch of West Balkan geotectonic units according to the geotectonic concept of* Karamata *(2006), modified. The concept outlines the modern-day configuration explained by the 'multiple ocean concept' by imposing several oceanic domains distributed across Western Balkans countries. The main tectonic units are as follows:* ***VZCT,*** *Vardar Zone Composite Terrane (Neotethyan suture zone),* ***DIT,*** *Drina-Ivanjica Terrane (pale red),* ***DOBT,*** *Dinaridic Ophiolite Belt Terrane,* ***EBDT,*** *East Bosnian-Durmitor Terrane,* ***CBMT,*** *Central Bosnian Mountains Terrane,* ***SMCT,*** *Serbian-Macedonian Composite Terrane,* ***JBT,*** *Jadar Block Terrane (light green) and* ***DHCT,*** *Dalmatian-Herzegovinian composite Terrane,* ***EVZ,*** *East Vardar Zone a subzone of* ***VZCT****. Numbers:* ***1,*** *Geological boundary,* ***2,*** *Boundary (thrust) between Terranes,* ***3,*** *Tectonized boundary (faulted and reactivated). The sketch additionally highlights the position of the Adria-Apulia plate (light red) vs. European foreland (Serbo-Macedonian Unit including the Supragetic Unit) or "Dacia Terrane" (light blue). There is no evidence of any Triassic record along western SMU, because this unit was a segment of an early Alpine European foreland thus being not rifted off from the Apulia/Adria microplate as proposed by* van Hinsbergen *et al. (2020).*

(1) "Dacia Terrane" within the pre- and early Alpine context of peri-Moesian terranes

The Moesian microplate, positioned to the southwest of the Baltican craton was a Variscan docking point for a cluster of the Avalonian-Cadomian-type terranes (Iancu et al., 2005; for a review, see Spahić & Gaudenyi, 2019a, and references therein; Fig. 1). The high-grade gneiss-dominating SMU (westernmost segment of the "Dacia Terrane") is a Cadomian-type terrane (*sensu* Aleksić et al., 1988; Antić et al., 2016). This unit as a segment of the larger ribbon-shaped terrane amalgamation was separated from the north Gondwana at the expense of the Lower Paleozoic subduction – accretion processes (Antić et al., 2016; Spahić & Gaudenyi, 2019a, 2020b; Ustaomer et al., 2019).

(pre)Ladinian paleogeographic/paleotectonic constraints of SMU/Supragetic basement

The SMU (westernmost segment of the Supragetic basement; Kräutner & Krstić, 2002) is a crystalline terrane amalgamated on the Moesian promontory during the Variscan nappe stacking (Getic/Supragetic nappe of Iancu et al., 2005; Fig. 1). The evidence of Variscan agglomeration includes the field-documented presence of the Variscan age foliation, isocline ductile folding (e.g., Dimitrijević, 1997; Antić et al., 2017). Importantly, the emplacement of the magmatic bodies of

accretion between the Apulia/Adria microplate and the "Dacia Terrane" somewhere during a pre-Ladinian timeframe. In Greece and North Macedonia, the Vertiskos terrane (analog unit of the SMU) collided with the Pelagonian microblock somewhere during Late Paleozoic (*e.g.*, Spahić et al., 2019; Šoster et al., 2020).

the Variscan age is well-documented (numeric ages by Deleon et al., 1972). Namely, a cluster of the Variscan age gneiss-granites are documented along with the interface with the Supragetic Unit (Stalać area, Central Serbia; numeric age by Deleon et al., 1972; Fig. 1). The record of the aforementioned isocline folding and development of the precursory Variscan foliation is interpreted within a gneiss-dominated matrix. Moreover, the exhumation times of the interface zone between SMU and Supragetic basement units (opposite or eastern side of the SMU) exhibited the late Variscan time (Antić et al., 2017). This further implies a late Paleozoic northward accretion of the SMU, during the same tectonic stage that agglomerated rest of the Carpathian-Balkan basement assembly (Spahić & Gaudenyi, 2019a). There is no documented basement interference zone with the Apulia/Adria microplate (because in the intervening position is the Kopaonik block; *sensu* Dimitrijević, 1997). The documented interface zone between two blocks (SMU and Dinarides) should be a compulsory input for the concept of the Triassic rifting. The here illustrated Variscan position of the SMU rules out a possibility that this crystalline assembly was a segment of North African margin during Permo-Triassic (as it was suggested earlier by Robertson & Dixon, 1984; Robertson, 1991).

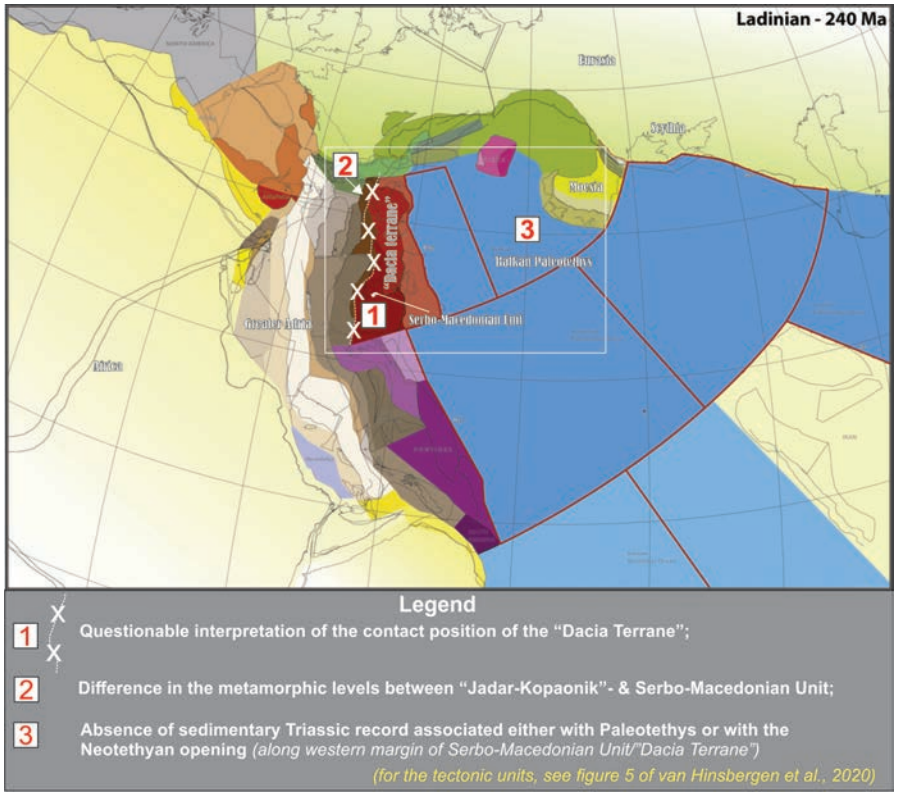

Fig. 2. *The map of the Mediterranean region for the Ladinian (240 Ma), for a denomination of the tectonic units, see Fig. 5* of *van Hinsbergen et al. (2020), modified. A West Balkan section of the map uses the post-Ladinian paleomagnetic rotation, however deformations, magmatism across the Serbian segment of the"Dacia Terrane" suggest a Variscan Peri-Moesian involvement of the latter (Point#1). Point#2: There is an obvious difference in the metamorphic level between "Jadar-Kopaonik"/Drina-Ivanjica block & Serbo-Macedonian Unit (segment of "Dacia Terrane") implying a different Ladinian – (pre)Ladinian evolution of the two important discrete paleogeographic entities. Point#3: There is no single proof of the sedimentary Triassic along western margin of "Dacia Terrane" ruling out the proposed rifting-off of the "Dacia Terrane" from the eastern Apulia/Adria.*

(2) Difference in the metamorphic grading ("Dacia Terrane" vs. Apulia/Adria microplate)

The principal difference between the E-NE segment Apulia/Adria microplate ("Jadar-Kopaonik Unit" including Drina-Ivanjica block; Schmid et al., 2008, 2020; Fig. 1) and "Dacia Terrane" (i.e. SMU) is the level and the age difference of the metamorphic imprint(s) (*cf.*, Đoković & Pešić, 1985; Spahić & Gaudenyi, 2020a). Unlike the weakly deformed Paleozoic succession of the Jadar block (anchizonal with a preserved original layering; Filipović et al., 2003; Fig. 1), the Drina-Ivanjica block underwent peculiar greenschist-facies level conditions in a course of Jurassic (Milovanović, 1984; Porkoláb et al., 2018). Both imprints within these two different blocks are in contrary with these recoded within the SMU. The SMU underwent medium- to high-grade over-

print (Balogh et al., 1994). The pre-Variscan metamorphic imprint documented within the SMU excludes any pre-Triassic or Variscan or late Paleozoic connection with the supposable undeformed Drina-Ivanjica block (if we presume a Jurassic time of the metamorphism of the Drina-Ivanjica block; Milovanović, 1984). The eastern realm of the SMU records a late Variscan exhumation (numeric age by Antić et al., 2017). Unlike well-documented Variscan involvement with the peri-Moesian nappe pile, we remind that the Variscan accretion of the Apulia/Adria microplate has been poorly documented. Single evidence is provided by Đoković (1985) who indicated the presence of ductile folding within the Drina-Ivanjica segment.

To summarize, the presented evidences impose the following discrete events: the SMU underwent a high-grade metamorphic conditions separately from the both, the Drina-Ivanjica block and the Jadar block. This event resulting in a high-grade metamorphic imprint occurred within a pre-Triassic timeframe. Significant differences in the deformational history further impose a different paleogeographical position of the two inliers during Permian–Triassic.

(3) No evidence of the post-Ladinian rifting-off along the western "Dacia Terrane": Absence of sedimentary Triassic associated with the Neotethys opening (western margin of the SMU, segment in Serbia)

To the west and underneath of the modern-day NNE–SSW-striking SMU (former Neotethyan margin; Fig. 1; Petrović et al., 2015) are the fragments of former Neotethyan crust. This ophiolite- and flysch-bearing fragments likely belong to Neotethyan fore-arc basin (former introceanic arc; Gallhofer et al., 2016; Maffione & van Hinsbergen, 2018). This segment has often been referred to as the East Vardar Zone (Fig. 1). Until now, no rocks older than the Middle Jurassic have ever been proven to exist here (also in Maffione & van Hinsbergen, 2018) (for a development of the local West Balkan Triassic successions see Dimitrijević, 1997, 2001; Argnani, 2018). The sedimentary Triassic begins more towards the south, Inner Hellenides in Greece (*e.g.*, Asvesta & Dimitriadis, 2010; Spahić et al., 2019, 2020; see Fig. 1). These Triassic occurrences belong to the rifted south European marginal basin likewise Maliac ocean (Ferriére et al., 2016). Towards the Supragetic side of the SMU, the Triassic exhumation of the Božica complex (246 ± 1 Ma; numeric age by Antić *et al.*, 2017) is driven by the formation of a south Euroasian marginal basin. Consequently, the Variscan-post Variscan peri-Moesian paleogeography questions any (pre)early Alpine connection with the Drina-Ivanjica block i.e. Apulia/Adria microplate.

Rifting along the western Serbo-Macedonian Unit (Greece)

On the contrary to the western SMU marginal segment in Serbia, very strong evidence of Triassic rifting exists along the southern margin of the Serbo-Macedonian zone in northern Greece (Spahić et al., 2020). The segment referred as the Circum-Rhodope belt carries the evidence of the Permian-Triassic rifting of this segment of continental margin. However, this Triassic ocean referred to as the Maliac ocean (*sensu* Ferriére et al., 2016) is recently constarined as a marginal ocean opened at the expense of nortward-directed Paleotethys subducting plate separating the SMU and Pelagonian microplate (Spahić et al., 2020 and references therein). There is indeed a continuation of the Late Paleozoic–Late Triasic sequence in southern Serbia, however positioned within the peculiar Kopaonik block (Sudar & Kovács, 2006). This unit might be an extension of the, so-called, 'Veles Series' (Spahić et al., 2019). Despite a recent suggestions of its Dinaric inheritance (Scheffer et al., 2010), the geodynamic and paleogeographic origin of this sequence needs further study. With regards to the here investigated Triassic configuration, the Kopanik block clearly devides the SMU and Drina-Ivanjica block (Fig. 1).

Summary and conclusions

The study emphasizes several aspects of modern geological investigation in highly active orogenic

areas. Firstly, it is obvious that paleomagnetic data are of limited use in paleogeographic reconstructions of stacked allochtonous complex. In particular, the data are of limited use in orogenic areas with mult-stranded active margins, likewise the Alpine-dominated Western Balkans countries. Thus, applying paleomegnetic data without significant insight in pre Mesozoic or pre-Alpine basement behavior can lead to ambigous interpretations. Secondly, the study questioning the early Alpine rifting concept which led to the opening of the Neotethyan ocean in a marginal highly active coastal fragment of Pangea (modern-day Western Balkans): (i) the involvement of the SMU with the peri-Moesian Variscan crustal thickening event; (ii) the exhibited metamorphic inconsistencies between the Apulia/Adria and SMU; (iii) including the missing Triassic succession to the west of SMU. The study provides moreover the following guidelines with a purpose to decipher important early Alpine paleogeographic inferences:

(1) There is no evidence within the Drina-Ivanjica- or Jadar block (distal most segments of Apulia/Adria microplate; e.g. Schmid et al., 2008, 2020) of the presence of medium to high-grade facies metamorphism. This metamorphic level is extensively documented across the entire SMU (Serbia, North Macedonia and Greece; Spahić & Gaudenyi, 2019a). Significant differences in the metamorphic levels exclude any pre-Alpine or pre-Ladinian or even Paleozoic connection between the SMU and Apulia-Adria microplate;
(2) There is no evidence of any Triassic record along the western margin of modern-day SMU (its central part, Serbia) associated with the Neotethys. The Triassic is developed more to the west within the peculiar "Kopaonik block" prior the opening of the East Vardar Zone;
(3) A better insight into the Permian-Lower Triassic paleogeography of the segment of former European margin including the processes explaining the Paleozoic metamorphic record should better serve as the starting point in any time-lapsed Alpine orogeny restoration attempts, not exclusively focus to the last one.

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Резиме

Неколико напомена о тријаским палеогеографским приликама и геодинамици између Динарида и Српско-македонске јединице

Палеогеографска реконструкција веома сложеног медитеранског простора, у чијем се средишњем делу налази простор земаља Западног Балкана, представља изазов за многе истраживаче. Фокус овог рада је отварање Неотетиса на поменутим просторима (Fig. 1), као и утицај каснопалеозојских догађаја на наведени догађај. Van Hinsbergen et al. (2020) дају палеогеографску реконструкцију истраживаних простора према којој се током ладинског ката позицинирају Динариди и Српско-македонска јединица као јединствена целина која је потом рифтована током ладинског ката. Поменути аутори као могуће решење предлажу истоветну ладинску палеогеографску позицију „Дакијског терана" ("*Dacia terrane*") где је његова Српско-македонска „подјединица" илустрована у виду сегмента Апуљско-јадранске микроплоче (Динариди; Fig. 2). Иако се поменуто решење чини као веома вероватно, верификација оваквог сценарија тражи детаљније усаглашавање са постојећим подацима. Овом приликом се указује на неколико кључних чињеница које нису у сагласности са предложеним решењем датим од стране van Hinsbergen et al. (2020) тј. да се Српско-македонска јединица може ставити у исту палеогеографску позицију (током ладинског ката) са Динаридима:

„Дакијски теран" у пери-мезијском раноалпском контексту: (пре)ладинска палеогеографска/палеотектонска позиција Српско-македонске јединице као део „Дакијског терана"

Српско-македонска јединица (најзападнији део тзв. „Дакијског терана") је изграђена претежно од гнајсева. Овај бејсментски комплекс је део варисцијског перимезијског конвергентног система и као такав је навлачен на бејсментске јединице распоређене уз Мезијску микроплочу (у Румунији се Српско-македонска јединица води као сегмент Гетске/Супрагетске навлаке, види у Iancu et al., 2005; Fig.1). Као реликт варисцијске орогенезе јавља се јасно изражена фолијација, док присуство изоклиних набора формираних у дуктилној фази указује на преалпску тј. варисцијску старост (Dimitrijević, 1997; Antić et al., 2017). Један од важнијих тектонских маркера који потврђује варисцијску старост је каснопалеозојски емплејсмент магматита, и то

на страни према Супрагетику (гнајс-гранити, околина Крушевца, Сталаћ; Deleon et al., 1972; Fig. 1) што је супротно од наводног положаја према Апуљско-јадранској микроплочи (Fig. 2).

Одвајање „Дакијског терана" од Апуљско-јадранске микроплоче: Неусаглашеност степена метаморфизма Српско-македонске јединице и сегмената Апуљско-јадранске микроплоче

За разлику од слабо метаморфисане палеозојске сукцесије Јадарског блока (анхизонално промењен комплекс са очуваном примарном слојевитошћу (према Filipović et al., 2003; Fig. 1)), Дринско-ивањички блок је био изложен метаморфизму, што потврђује метаморфни ниво фације зелених шкриљаца чија је старост под знаком питања (Milovanović, 1984; Porkoláb et al., 2018). Нижи ниво метаморфних промена Дринско-ивањичког блока је мањи од документованог средњег до високог нивоа промена Српско-македонске јединице (матрикс је углавном гнајсни, са кластичним протолитом неопротерозојске до доњопалеозојске старости; Dimitrijević, 1997).

Одсуство тријаских творевина: нема доказа пост-ладинског рифтовања (седиментног тријаса) и измештања западне маргине „Дакијског терана" (дуж Српско-македонске јединице).

Западно од данашње позиције Српско-македонске јединице (маргине Неотетиса) налази се сегмент некадашњег интраокеанског лука (Gallhofer et al., 2016; Maffione & Van Hinsbergen, 2018; Spahić & Gaudenyi, 2019b). Овај сегмент Вардарске зоне је познат као Источна вардарска зона (Fig. 1). Према досадашњим истраживањима нису још увек идентификоване стене тријаске старости. Највероватнији разлог је настанак интраокеанског лука који је могуће оверпринтовао и изместио евентуалне прејурске седиментне стенске записе (нпр. Копаонички блок?). Најстарије стене откривене на поменутом потезу су горњојурско-доњокредне старости (за преглед развића седиментног тријаса погледати нпр. Dimitrijević, 1997; Argnani, 2018). Тријаска седиментна сукцесија на поменутом потезу почиње тек у близини Хеленида (нпр. Asvesta & Dimitriadis, 2010). Такво развиће тријаса на ободу јужног дела Европе је повезано са рифтовањем некадашње маргине Пангее и развојем локалног маргиналног океана познатог под називом Малиак (Ferriére et al., 2016).

Док је Дринско-ивањички блок условно био сегмент јужног дела варисцијске Евроазијске амалгамације, Српско-македонска јединица је потврђени учесник овог акреционог догађаја. Међутим, разлике у нивоу метаморфних измена између Српско-македонске јединице и Апуљско-јадранске микроплоче (конкретно Дринско-ивањички и Јадарски блок), као и непостојање тријаса дуж западне маргине „Дакијског терана" (Српско-македонске јединице) указују на другачију палеогеографско-тектонску конфигурацију од оне у Грчкој, а приказане у раду van Hinsbergen et al., 2020.

Овом студијом се указује на неопходност да свака реконструкција алпског орогеног циклуса, који обухвата геолошке просторе западног Балкана, осим палеогеографских података (палеомагнетизам) захтева и познавање структурно-геолошких пре-тријаских прилика (као и петролошко-тектонску историју). Закључно се може рећи, да за сада не постоје докази који упућују на ладинску повезаност Апуљско-јадранске микроплоче и Српско-македонске јединице. Међутим, даља истраживања су недвосмислено потребна за утврђивање комплексне пермо-тријаске палеогеографске ситуације.

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