MESOZOIC BASINS ON THE ADRIATIC CONTINENTAL MARGIN – A CROSS-SECTION THROUGH THE DINARIDES IN MONTENEGRO

MEZOZOJSKI BAZENI NA KONTINENTALNEM ROBU JADRANSKE PLOŠČE – PRESEK ČEZ DINARIDE V ČRNI GORI

Špela GORIČAN[1,2], Martin ĐAKOVIĆ[3], Peter O. BAUMGARTNER[4], Hans-Jürgen GAWLICK[5], Tim CIFER[1,2], Nevenka DJERIĆ[6], Aleksander HORVAT[1,2], Anja KOCJANČIČ[1,2], Duje KUKOČ[7] & Milica MRDAK[3,6]

http://dx.doi.org/10.3986/fbg0099

ABSTRACT

Mesozoic basins on the Adriatic continental margin – a cross-section through the Dinarides in Montenegro

The Dinarides, together with the Albanides and Hellenides, preserve stratigraphic successions derived from the eastern margin of the Adriatic microplate and remnants of ophiolites obducted from the Maliac-Vardar branch of the Neotethys Ocean. The main stages in the Mesozoic geodynamic history are: 1) rifting leading to opening of the Maliac Ocean in the Late Anisian, 2) onset of an east-dipping intra-oceanic subduction in the Early-Middle Jurassic and seafloor spreading in a supra-subduction setting (Vardar Ocean), 3) formation of ophiolitic mélanges in trench-like basins, westward obduction of young supra-subduction ophiolites in the Middle-Late Jurassic and accumulation of flysch-type deposits in foreland basins in the latest Jurassic to Early Cretaceous, 4) subaerial exposure of the newly formed nappes followed by middle to Late Cretaceous transgression, and 5) continental collision in the Maastrichtian and Paleogene. On the continental margin, the Middle Triassic to Early Jurassic extension created a complex horst-and-graben geometry that is apparent in the stratigraphic record. The present day NW-SE striking tectonic units are in rough accordance with the Mesozoic paleogeography. Hence, the inferred configuration for the most complete SW to NE transect through Montenegro and Serbia is as follows:

IZVLEČEK

Mezozojski bazeni na kontinentalnem robu Jadranske plošče – presek čez Dinaride v Črni gori

V Dinaridih, Albanidih in Helenidih so ohranjena stratigrafska zaporedja vzhodnega roba Jadranske mikroplošče in ostanki ofiolitov, narinjenih na kontinent iz oceana Maliak-Vardar, ki je bil del Neotetide. Glavne stopnje v mezozojski geodinamični evoluciji tega ozemlja so bile: 1) rifting, ki je v zgornjem aniziju privedel do odprtja oceana Maliak, 2) v spodnji do srednji juri začetek intraoceanske subdukcije in raztezanje oceanskega dna v suprasubdukcijskem okolju Vardarskega oceana, 3) v srednji do zgornji juri formacija ofiolitnega melanža v jarkom podobnih bazenih in obdukcija mladih suprasubdukcijskih ofiolitov proti zahodu ter na koncu jure in v spodnji kredi akumulacija flišnih sedimentov v predgornih bazenih, 4) emerzija novo nastalih pokrovov in nato transgresija v srednji do zgornji kredi, 5) kolizija kontinentov v maastrichtiju in paleogenu. Kontinentalni rob se je med ekstenzijo od srednjega triasa do spodnje jure diferenciral na horste in grabne, kar se odraža v stratigrafskem zapisu. Današnje NW-SE usmerjene tektonske enote v Dinaridih se v grobem ujemajo z mezozojsko paleogeografijo, iz česar sklepamo, da je bila konfiguracija kontinentalnega roba v prečnem preseku čez Črno goro in Srbijo naslednja: Dalmatinska karbonatna platforma, Budvanski bazen, karbonatna platforma Visokega Krasa, Bosanski bazen, Durmi-

[1] ZRC SAZU, Paleontološki inštitut Ivana Rakovca, Novi trg 2, SI-1000 Ljubljana, Slovenia. spela.gorican@zrc-sazu.si; tim.cifer@zrc-sazu.si; aleksander.horvat@zrc-sazu.si; anja.kocjancic@zrc-sazu.si
[2] Podiplomska šola ZRC SAZU, Novi trg 2, SI-1000 Ljubljana, Slovenia.
[3] Geological Survey of Montenegro, Jaglike Adžić bb, 81000 Podgorica, Montenegro. comanski@gmail.com; mrdak.milica@yahoo.com
[4] Institut des Sciences de la Terre ISTE, Université de Lausanne, Géopolis, CH-1015 Lausanne, Switzerland. peter.baumgartner@unil.ch
[5] Montanuniversitaet Leoben, Department of Applied Geosciences and Geophysics, Petroleum Geology, Peter-Tunner Strasse 5, 8700 Leoben, Austria. E-mail: Hans-Juergen.Gawlick@unileoben.ac.at
[6] University of Belgrade, Faculty of Mining and Geology, Kamenička 6, 11000 Belgrade, Serbia. nevenka.djeric@rgf.bg.ac.rs
[7] Hrvatski geološki institut, Ul. Milana Sachsa 2, HR-10000 Zagreb, Croatia. dkukoc@hgi-cgs.hr

The Dalmatian Carbonate Platform, the Budva Basin, the High Karst Carbonate Platform, the Bosnian Basin, the Durmitor High, the Lim Basin, the Drina-Ivanjica High, and the deep-marine distal continental-margin domain.

We present a short description of the stratigraphy for these tectonic/paleogeographic units and discuss their possible connection with other units of the Dinarides and Hellenides. The field guide focuses on deep-water deposits, in which radiolarians are the crucial tool for dating. We describe the complete Mesozoic succession of the Budva Zone, the Middle Triassic pelagic episode of the High Karst Zone, the Upper Triassic and Jurassic pelagic rocks of the Lim Zone and two localities with radiolarites associated with ophiolites.

The largest part of the guide is devoted to the Budva Zone, a deeply rifted trough in the continuation of the Pindos Basin. The Budva Zone with its external location in the Dinaric orogen was a site of continuous pelagic sedimentation from the Middle Triassic to the end Cretaceous. Radiolarites characterize the Middle Triassic, Hettangian–Sinemurian, Aalenian to Tithonian, and Hauterivian–Barremian to lower Turonian; pelagic limestones prevail in the Upper Triassic, Berriasian–Valanginian and upper Turonian to Maastrichtian. Calcareous turbidites from the adjacent High Karst Carbonate Platform are interstratified in all units and completely replace radiolarites in the Pliensbachian.

Pelagic sequences also occur in the High Karst Zone, but are confined to the Middle Triassic syn- and early postrift deposits. A 20 m thick unit of Middle Triassic nodular limestone and radiolarite within shallow-water carbonates is a typical example.

More internally, the western Ćehotina Subzone of the Lim Zone records pelagic sedimentation from the Middle Triassic to early Cretaceous, when synorogenic mixed carbonate-siliciclastic deposition began. This zone has been less investigated than the Budva Zone. A 100 m thick Norian to Rhaetian succession of limestone with chert nodules is dated with conodonts. A Callovian-early Oxfordian age of lime-free cherts is determined with radiolarians. The Mihajlovići Subzone that may have been part of the Drina-Ivanjica paleogeographic unit shows Triassic shallow-water carbonates and a Jurassic deepening upward sequence ending with Oxfordian radiolarites.

The last two field-trip stops show upper Bathonian-lower Callovian radiolarites in an ophiolitic mélange and upper Anisian radiolarites in direct contact with basalt. These ages, obtained in the south-westernmost ophiolite remnants of the Dinarides, agree with previously documented ophiolite ages in the wider region.

In comparison with the Southern Alps and the Apennines, pelagic deposits of the Dinarides are characterized by an earlier onset and considerably higher proportions of silica with respect to carbonate throughout the Mesozoic. The Dinaric basins were connected with the central Neotethys, where the high fertility of surface waters enabled radiolarite formation since the oceanisation (Anisian or earlier) until the early Late Cretaceous, when planktonic foraminifera and calcareous nannoplankton began to dominate worldwide.

Key words: Dinarides, Neotethys, radiolarites, continental margin, ophiolitic mélange

torski prag, Limski bazen, prag Drina-Ivanjica in globokomorski distalni kontinentalni rob.

V članku je najprej na kratko opisan stratigrafski razvoj tektonskih oziroma paleogeografskih enot tega preseka in domnevna povezava z drugimi enotami v Dinaridih in Helenidih. V nadaljevanju so opisane ogledne točke ekskurzije s poudarkom na globokomorskih sedimentnih kamninah, ker so za določanje starosti teh kamnin radiolariji najpomembnejši in pogosto edini fosili. Podrobno predstavljamo celotno mezozojsko zaporedje Budvanske cone, srednjetriasno pelagično epizodo v coni Visokega Krasa, zgornjetriasne in jurske pelagične kamnine Limske cone in dve lokaliteti z radiolariti v ofiolitih.

Največji del vodnika je posvečen Budvanski coni v Zunanjih Dinaridih. V mezozoiku je bila ta cona globokomorski jarek v nadaljevanju bazena Pindos s kontinuirano pelagično sedimentacijo od srednjega triasa do konca krede. Radiolariti so značilni za obdobje srednjega triasa, hettangija in sinemurija, aalenija do tithonija ter hauterivija-barremija do spodnjega turonija. Pelagični apnenci prevladujejo v zgornjem triasu, berriasiju in valanginiju ter od zgornjega turonija do maastrichtija. Karbonatni turbiditi, prinešeni s sosednje karbonatne platforme Visokega Krasa, so interstratificirani v vseh formacijah, v pliensbachiju pa prevladujejo in popolnoma izpodrinejo pelagične sedimente.

Pelagična zaporedja v coni Visokega Krasa so omejena na sinriftne in zgodnje postriftne sedimente. Kot tipičen primer predstavljamo 20 m debelo zaporedje srednjetriasnih gomoljastih apnencev in radiolaritov znotraj plitvovodnih karbonatov.

V bolj interni Limski coni je za podcono Ćehotina značilna pelagična sedimentacija od srednjega triasa do začetka krede, ko so se začeli odlagati sinorogeni mešani karbonatno-siliciklastični sedimenti. Stratigrafsko zaporedje te podcone do sedaj ni bilo podrobneje proučeno. V članku je prvič datiran 100 m debel profil apnencev z gomolji roženca, ki smo ga s konodonti uvrstili v norij in retij. Z radiolariji smo dokazali callovijsko do spodnjeoksfordijsko starost plastovitih rožencev brez karbonata. V podconi Mihajlovići je stratigrafski razvoj podoben kot v enoti Drina-Ivanjica. Triasnim plitvovodnim karbonatom sledijo jurski apnenci, ki kažejo na postopno poglabljanje sedimentacijskega okolja. Zaporedje se konča z oxfordijskimi radiolariti.

V Črni gori so ohranjeni najbolj jugozahodno ležeči ostanki ofiolitov v Dinaridih. Zadnji dve točki prikazujeta bathonijske do spodnjecallovijske radiolarite v ofiolitnem melanžu in zgornjeanizijske radiolarite v kontaktu z bazaltom. Te starosti se ujemajo z do sedaj znanimi datacijami v ofiolitih širše regije.

V primerjavi z Južnimi Alpami in Apenini je za pelagične sedimente Dinaridov značilno, da so se začeli odlagati prej in da so skozi ves mezozoik vsebovali znatno višji delež kremenice glede na karbonat. Dinarski bazeni so bili povezani s centralno Neotetido, kjer je visoka produktivnost površinskih voda omogočala nastanek radiolaritov od oceanizacije (v aniziju ali še prej) do sredine zgornje krede, ko so po vsem svetu začeli prevladovati foraminifere in kalcitni nanoplankton.

Ključne besede: Dinaridi, Neotetida, radiolariti, kontinentalni rob, ofiolitni melanž

1 INTRODUCTION

The Dinarides, Albanides and Hellenides (Figure 1) form a single mountain chain that shares a common Mesozoic history of rifted continental margins of the Adria microcontinent, facing branches of the Neotethys Ocean (Stampfli & Borel 2004). After the closure of the Paleotethys, at least two successive small branches of the Neotethys opened during the Middle Triassic. Towards the SW (W in present day coordinates) the short-lived Pindos Ocean in the Montenegro transect is merely represented by a deeply rifted trough, the

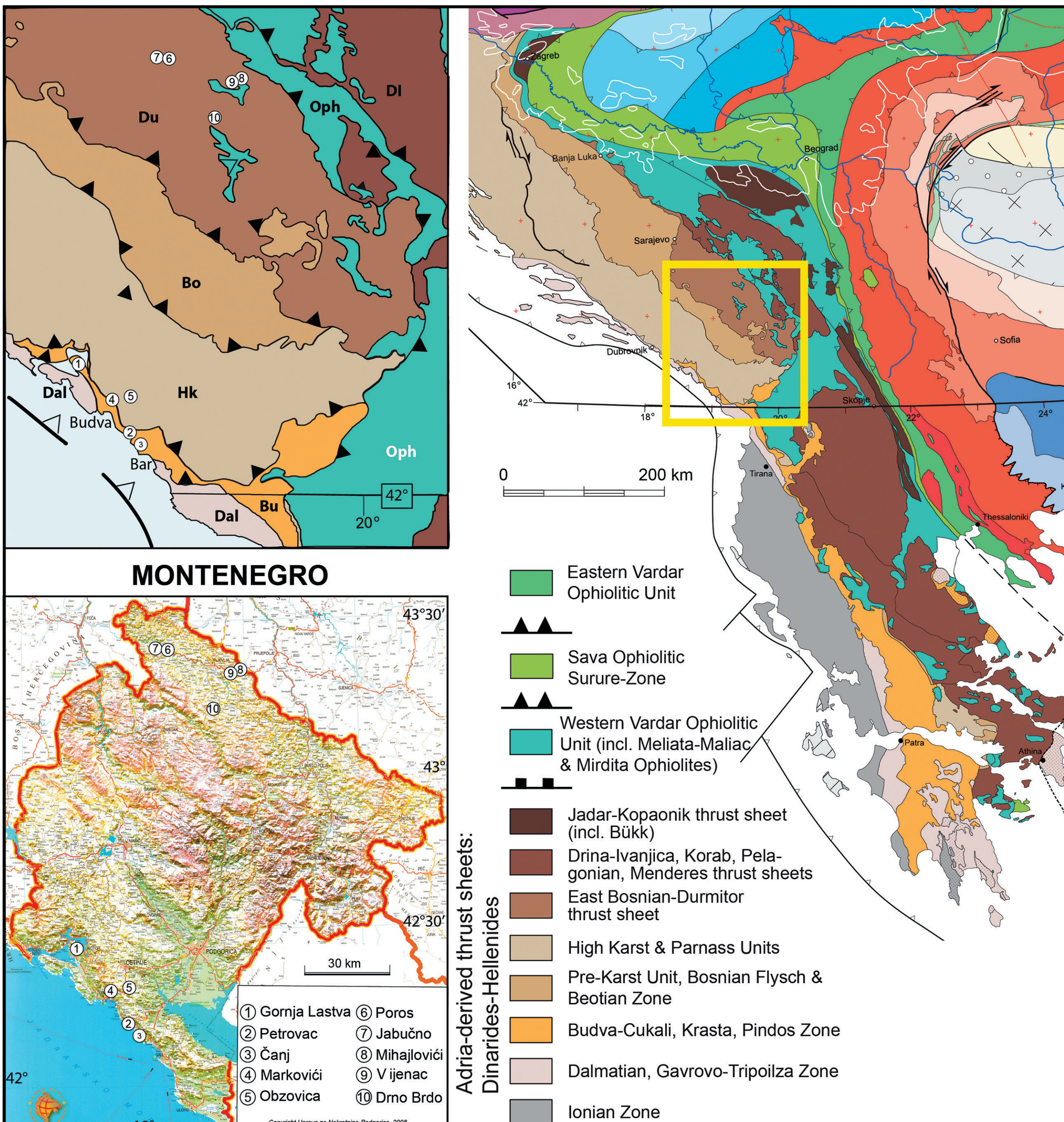


Figure 1: Right: Tectonic map of the Dinarides–Hellenides after Schmid et al. (2008, 2020, polygons courtesy of S. Schmid), showing the continuity of large scale tectonic/paleogeographic units. Yellow rectangle marks location of inset to the left with field stops marked 1–10.

Budva Zone, whereas in southern Greece and Crete, ophiolite remnants testify for an oceanic basement.

To the N (NE in present day coordinates) the main branch of the Neotethys, called the Maliac Ocean by many authors (Ferrière et al. 2016) or Vardar by others (Robertson et al. 2013) or jointly Meliata-Maliac-Vardar (Schmid et al. 2008, 2020), opened in the late Anisian-early Ladinian (Ferrière et al. 2015) (Figure 2). The ophiolite nappes of the Dinarides-Hellenides were, for a large majority of authors, derived from this eastern oceanic realm (Bernoulli & Laubscher 1972; Bortolotti et al. 2013, Schmid et al. 2008; Gawlick & Missoni 2019). The Pindos-Budva paleogeographic realm cannot be the origin of the ophiolites because this realm is materialized by a contiguous, conformable Middle Triassic to Paleogene pelagic sequence, unaffected by Jurassic nappe emplacement.

Between these two oceanic realms, Middle Triassic to Early Jurassic extension produced a system of tectonic highs (horsts) covered by carbonate platforms, and troughs (grabens) filled with pelagic sediments. This realm has been associated with the Pelagonian *s.l.* microcontinent in the Hellenides (Robertson et al. 1991; Robertson & Karamata 1994; Dilek et al. 2005). It is preserved today in a SW-vergent nappe stack with excellent outcrops in the Montenegro transect. Classically, each tectonic unit was defined by distinct Mesozoic facies and paleogeography ("zones isopiques" of Aubouin et al. 1970). This is still a valid first order concept. In contrast, major paleo-fault zones such as the Skutari–Peć Line in northern Albania and the Sperchios fault zone in Central Greece, dissect the paleogeographic domains and have been interpreted as ancient transform faults that affected the Mesozoic margin (Dercourt 1968). As a consequence, the external Triassic–Paleogene carbonate platforms are discontinuous: The Parnassos platform of Central Greece exists only south of the Sperchios line largely disconnected from the High Karst Zone in a similar paleogeographic position. The more internal Durmitor Platform

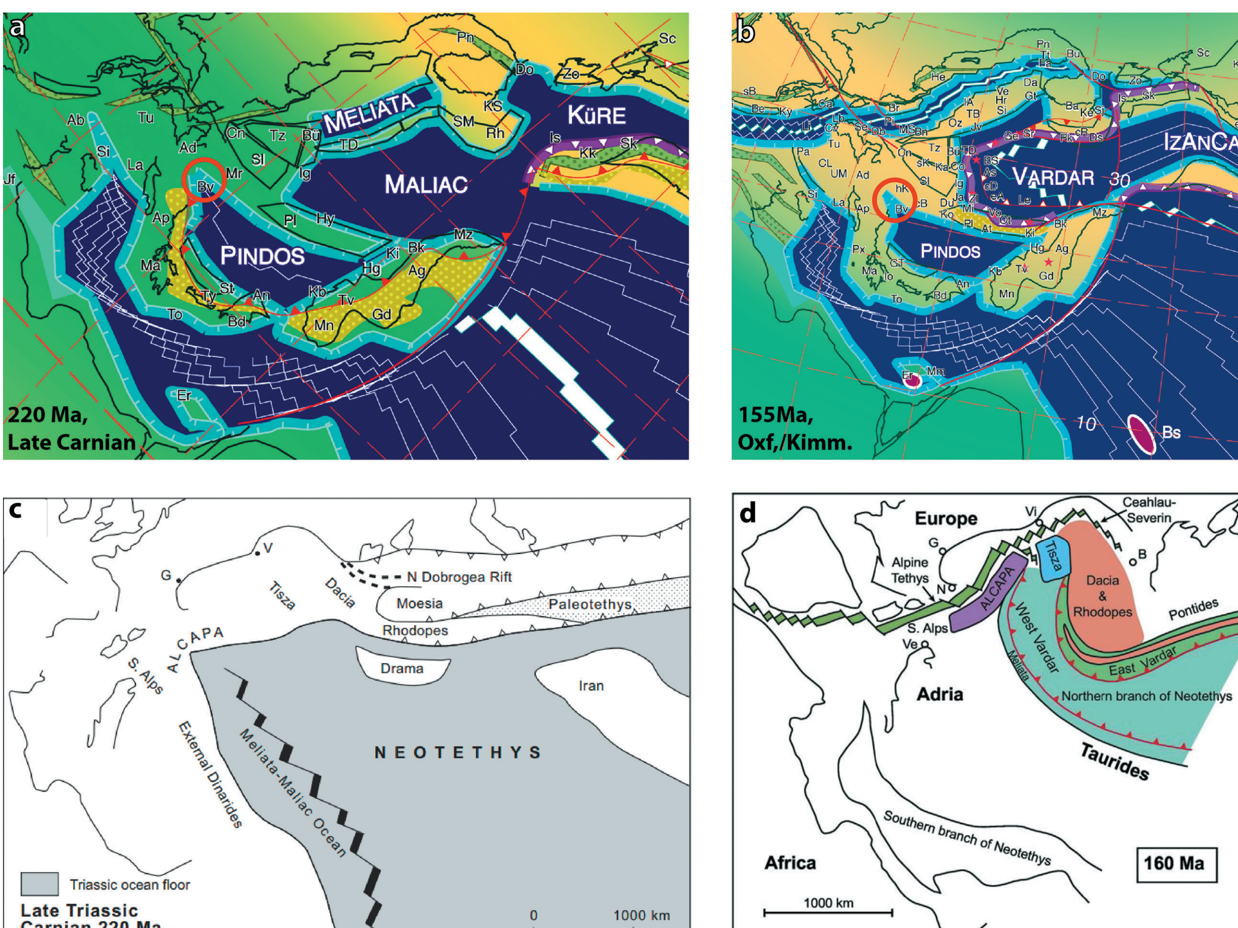


Figure 2: Paleogeographic reconstructions for the Late Triassic (a, c) and the Late Jurassic (b, d). (a, b: from Stampfli & Borel 2004, c: from Schmid et al. 2008, d: from Schmid et al. 2020). Paleogeographic location of field trip marked with a red circle.

has no similar equivalent in Greece, since the Pelagonian margin became successively pelagic during the Jurassic (Baumgartner 1985; Scherreiks et al. 2010).

Progressive closure of the Eastern ("Maliac") oceanic realm began in the Middle Jurassic as an eastward dipping, intra-oceanic subduction outboard of the Pelagonian-Korab-Durmitor-Drina-Ivanjica margin that became the lower plate (Figure 3). A consequence of this subduction was the creation of supra-subduction ocean floor of Middle Jurassic age, often associated with the name Vardar, today represented by the main ophiolite nappes of the Dinarides (e.g. Schmid et al. 2008, 2020).

Convergence progressively consumed the Triassic Maliac ocean floor and seamounts were accreted in a wedge, now represented by accretionary mélanges of Middle Jurassic age. Some of the Triassic ocean floor remained in the upper plate (e.g. Furka Unit, Othris, Central Greece, Ferrière et al. 2016; parts of the Vardar Zone in western Serbia, Vishnevskaya et al. 2009; Medvednica and Kalnik in the Internal Dinarides in Croatia, Halamić & Goričan 1995). When the Pelagonian-Korab-Durmitor-Kuci margin became the lowermost unit of this wedge, subduction ceased and the young Vardar backarc spreading centre obducted over the accretionary wedge, including the margin. Further westward thrusting of composite units (mostly during Late Cretaceous–Early Cenozoic) emplaced composite ophiolite nappes as far as the external Pindos-Cukali-Budva zones. Emplacement and exposure/erosion of the ophiolites during the Middle to Late Jurassic is largely diachronous along the Pelagonian-Korab-Durmitor margin and is in part synchronous with the ongoing formation of Vardar (suprasubduction) oceanic crust. Ophiolitic debris continued during the Early Cretaceous to be shed in the tectonic foreland of the Jurassic orogen ("Premier Flysch du Pinde", Boeotian Flysch, Bosnian Flysch).

Radiolarian biostratigraphy has been fundamental for the reconstruction of the paleogeographic and paleotectonic history of the area, since both the oceanic realms and the rifted troughs commonly are represented by radiolarian-bearing pelagic sediments, largely radiolarites, typical for the Ladinian, lowest Jurassic, and Middle Jurassic to Lower Cretaceous intervals.

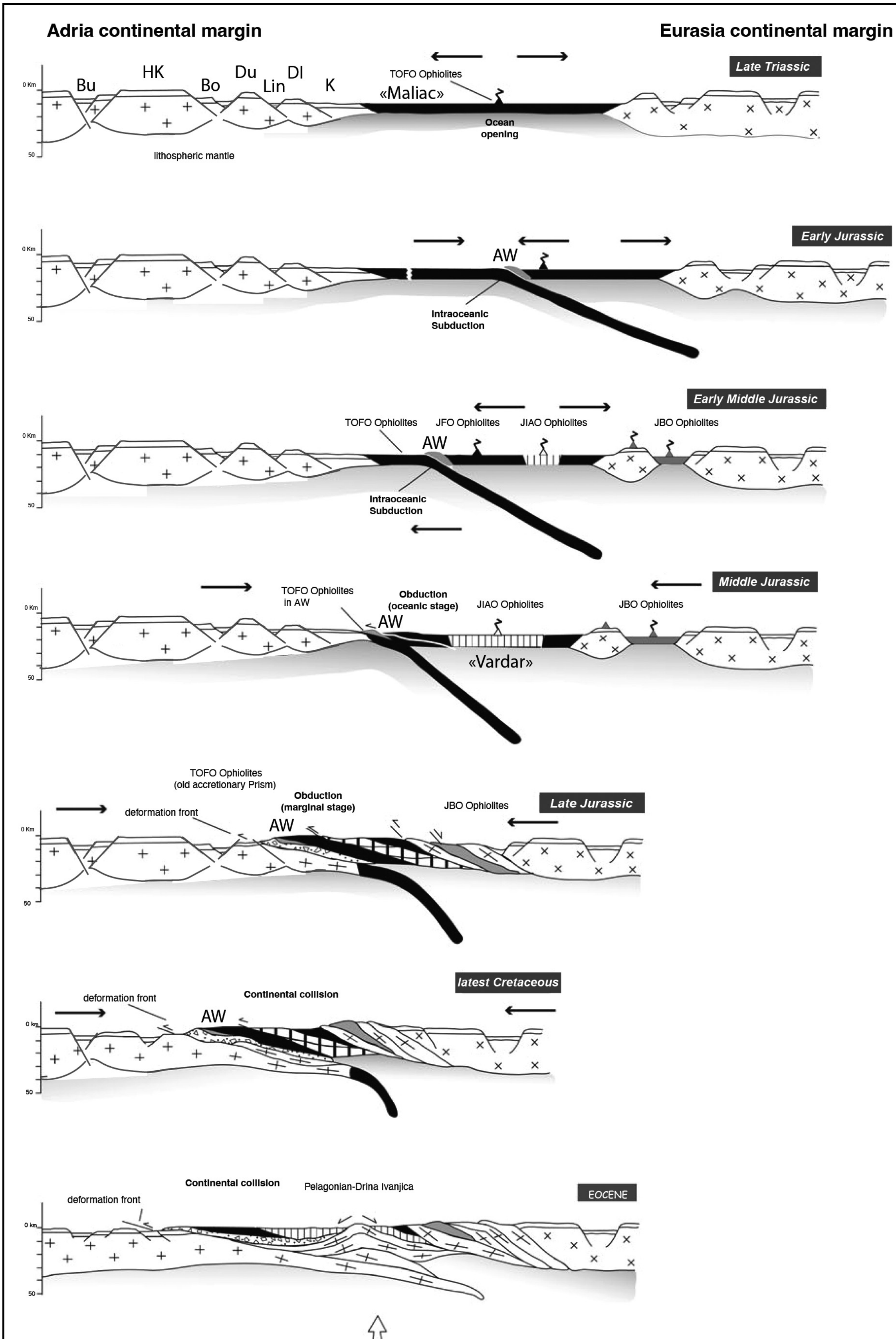
The present day NW-SE striking tectonic units of the Dinarides are in rough accordance with the Mesozoic paleogeography and allow for a relatively easy palinspastic restoration. Each tectonic zone corresponds to a different facies belt on the continental margin. Regional studies in the 1970s (Aubouin et al. 1970; Rampnoux 1974; Blanchet 1975; Cadet 1978; Charvet 1978) provided a good stratigraphic framework for the continental-margin Mesozoic successions and also demonstrated the horst-and-graben topography that was created during the Middle Triassic to Early Jurassic rifting. The deeply subsided rift basins that existed through most of the Mesozoic were recognized but the pelagic successions could not be precisely dated because at that time radiolarians were too poorly known to be widely used in biostratigraphy. Radiolarian research in Montenegro was initiated in the late 1980s (Goričan 1987, 1994; Obradović & Goričan 1988) and is ongoing (Gawlick et al. 2012; Kukoč 2014).

The complete SW to NE transect through Montenegro and Serbia preserves the following paleotopographic units (Figure 3): The Dalmatian Carbonate Platform, the Budva Basin, the High Karst Carbonate Platform (also called the Dinaric Carbonate Platform), the Bosnian Basin, the Durmitor High, the Lim Basin, the Drina-Ivanjica High, the deep-marine environment of the distal continental margin, and the oceanic crust, whose remnants are now preserved in the structurally overlying ophiolite nappe. The proximal margin from the Budva Basin to the Lim Basin and the ophiolitic mélange will be visited. The field trip aims to discuss the sedimentary evolution of these Mesozoic basins and to stress the importance of radiolarians for accurate dating. Regional geodynamic setting is introduced to understand to what extent the stratigraphic record was controlled by synsedimentary tectonic events. A Tethyan-wide stratigraphic correlation with other deep-marine basins is presented to place the local radiolarian-bearing pelagic sediments within an interregional paleogeographic and paleoceanographic framework.

2 GEOLOGICAL AND PALEOGEOGRAPHICAL OUTLINE

During the past decades, a general consensus has been reached on the regional arrangement of ocean realms and continental margins. Nevertheless, the Mesozoic geodynamic evolution is still actively debated. Palaeogeographic reconstructions contrast (Figure 2), but agree on a northeastern origin of the obducted ophiolites representing remnants of Neotethys.

The Dinarides-Albanides-Hellenides in the western Neotethys realm underwent in Triassic to Early Cretaceous times more or less the same geodynamic history,



Adria continental margin
Eurasia continental margin
Late Triassic
Bu
HK
Bo
Du
Lin
Dl
K
TOFO Ophiolites
«Maliac»
Ocean opening
lithospheric mantle
0 Km
50
Early Jurassic
AW
Intraoceanic Subduction
Early Middle Jurassic
TOFO Ophiolites
JFO Ophiolites
JIAO Ophiolites
JBO Ophiolites
Middle Jurassic
TOFO Ophiolites in AW
Obduction (oceanic stage)
«Vardar»
Late Jurassic
TOFO Ophiolites (old accretionary Prism)
Obduction (marginal stage)
deformation front
latest Cretaceous
Continental collision
EOCENE
Pelagonian-Drina Ivanjica

reflecting a complete Wilson cycle from initial rifting to ophiolite obduction, erosion and formation of flysch and molasse basins:

1. Late Permian to Middle Anisian rift stadium with sedimentation of siliciclastics and carbonate ramp deposits.
2. Middle Anisian to Middle Jurassic passive margin evolution following the late Anisian oceanic breakup. A complex configuration of the continental margin from the inner shelf (platform facies) to the outer shelf (open-marine facies) was established in the Middle to Late Triassic; pelagic platforms were formed in the Early to Middle Jurassic.
3. Middle to Late Jurassic convergent tectonic regime initiated by an intraoceanic subduction and followed by obduction of young, suprasubduction ophiolites ("active continental margin evolution"); the process includes thrusting, trench and trench-like basin formation, and the onset and growth of carbonate platforms on top of the newly formed nappes.
4. Erosion of the Jurassic nappe stack from the Kimmeridgian/Tithonian boundary onwards and filling of the deeply submerged foreland basins with the erosional products of the uplifted orogeny.

In the late Early Cretaceous a new tectonic cycle began which resumed in the Paleogene with thrusting and the formation of new foreland basins.

2.1 Middle Triassic rifting

The Dinarides consist of a number of superposed SW-vergent nappes derived from the Adriatic continental margin (Figures 1, 2c–d, 3). The differentiation of the relatively uniform area of shallow-marine carbonates started in the Anisian. The upper Middle to Upper Anisian Bulog Formation (red nodular limestone), indicating platform drowning, was more than a century ago dated with ammonoids (e.g. Hauer 1888). Further stratigraphic research on deep-water Middle Triassic sedimentary sequences and research on petrology of associated volcanic rocks (Pietra Verde) enabled inferences on rifting processes ascribed either to continental breakup (e.g., Bechstädt et al. 1978; Pamić 1984) or to formation of inter-arc basins in a convergent setting related to the subduction of the Paleotethys realm (e.g., Bébien et al. 1978; Stampfli & Borel 2004). The first biostratigraphic constraints on Triassic age of sedimentary cover of MOR basalts were published in the 1980s, first in Hungary (De Wever 1984; Kozur & Réti 1986), then in Serbia (Obradović & Goričan 1988). Since then, good age constraints have been obtained for a continuous sea-floor spreading from the Late Anisian to the Norian along the entire length of this oceanic branch, i.e. from southern Slovakia and Hungary through Croatia, Serbia, Albania, and Greece (e.g., Ozsvárt & Kovács 2012; Goričan et al. 2005; Chiari et al. 2012; Gawlick et al. 2008, 2016 a, b; Ferrière et al. 2015, 2016, with references). A considerable dataset on the age and geochemistry of Triassic oceanic basalts is now available but the paleogeographic reconstructions are still debated. Some authors interpret the Middle Triassic events as continental rifting preceding the opening of a single oceanic branch (Pamić et al. 2002; Schmid et al. 2008, 2020; Bortolotti et al. 2013). Other authors argue for a convergent regime implying Palaeotethys subduction and opening of back-arc basins (Ziegler & Stampfli 2001; Stampfli & Borel 2004; Stampfli & Kozur 2006; Slovenec et al. 2020; for a review of different models see Robertson 2012).

On a regional scale, including the external zones, Middle Triassic magmatism is very heterogeneous, represented by basic, and more commonly by intermediate and acid plutonic and volcanic rocks with calc-alcaline affinity; pyroclastic rocks (Pietra Verde), intercalated in sedimentary sequences or in lava flows are com-

Figure 3: 2D representation of a model of the geodynamic evolution between the Adria and the Eurasian plates from Triassic to Eocene, modified after Bortolotti et al. (2013, their Figure 10). The upper left shows a simplified sketch of the rifted Adria margin, with the Budva (BU), High Karst (HK), Bosnian (Bo), Durmitor (Du), Lim (Lim), Drina-Ivanjica (DI), and Kopaonik (K) paleogeographic domains. Note that in the Budva and Bosnian realms rifting must have thinned the continental crust. The Triassic ocean-floor ophiolites (TOFO) are here termed "Maliac" (Ferrière et al. 2016). During initial, intra-oceanic subduction an accretionary wedge (AW) developed. During the Early-Middle Jurassic fore-arc (JFO), and intra-oceanic-arc (JIAO) ophiolites formed, here termed "Vardar" (Stampfli & Borel 2004). Jurassic back-arc basin ophiolites (JBO, Guevgueli) formed within the Eurasian margin. During the late Middle to Late Jurassic the AW reached and incorporated the Adria margin. Obduction initiated. The AW then included from top to bottom: JIAO, JFO, metamorphic soles, TOFO, sub-ophiolitioc mélanges with a Middle Jurassic matrix and TOFO, and at its base, mixed ophiolithic-continental margin mélanges of Middle to Late Jurassic age. The short-lived JBO (Guevgueli) also became incorporated in the wedge, without forming a slab. An early Late Cretaceous development of passive margins and ocean floor volcanism along the remaining "Vardar" basin (documented in the Sava Zone, Schmid et al. 2008, 2020, and Adheres, Argolis Peninsula, Baumgartner in Ferrière et al. 2016) is not illustrated in this model. Continental collision may have started during latest Cretaceous and continued until the Eocene, when orogenic uplift separated the ophiolites into two belts.

mon (e.g., Pamić 1984). Although the composition of syn-rift volcanic rocks is in favour of subduction-related convergent movements (e.g., Bébien et al. 1978), the idea of continental rifting is a viable alternative that conforms better to field relationships with the underlying rocks of the continental crust (Cadet 1978; Pamić 1984). The considerable compositional variation can be compatible with a continental rift setting if we consider that the rifting occurred on a pre-existing Variscan orogen that could contribute an inherited subduction signature to rift-related magmas (Robertson 2012; Saccani et al. 2015).

A strong argument in favour of continental rifting is the overall architecture of horsts and grabens that is remarkably similar to that of the North Atlantic (Bernoulli & Laubscher 1972; Cadet 1978; see Peron-Pinvidic & Manatschal 2010, for the configuration of crustal blocks in the North Atlantic). If we consider that the present-day distribution of tectonic units and facies belts basically corresponds to the distribution of paleotopographic units, the margin in the transect through Montenegro and western Serbia can be divided into several basins and swells (Figure 3a). The Durmitor High and the Drina-Ivanjica High (equivalent of the Pelagonian Platform in Greece) terminate towards NW in eastern Bosnia. The High Karst Platform continues to the north but is cut-off to the south along the Skutari-Peć Line in northern Albania but may have paleogeographically equivalent platforms in continental Greece, such as the Olympus and Parnassos. Likewise, the Durmitor High has no direct continuation in the Hellenides but may be represented by shallow areas of the Pelagonian. The morphological highs were spatially limited, partially or completely isolated and the configuration varied substantially along the margin. The inferred geometry is closely similar to the present-day eastern margin of the North Atlantic, where continental ribbons (the Faroes, Hatton Bank, Rockfall Bank and Porcupine Bank) are surrounded by deep basins (Peron-Pinvidic & Manatschal 2010). We further notice that, like in the North Atlantic, the basins in the studied transect were V-shaped. They were oriented parallel to the mid-ocean ridge but with opposite direction of the "V" – the Budva Basin and possibly also the Lim Basin widened towards south, whereas the Bosnian Basin was wider to the north and disappeared towards south.

2.2 Middle to Late Jurassic intra-oceanic subduction and obduction

The closing of the Neotethys (Meliata-Maliac) Ocean started in the Early-Middle Jurassic with the onset of an east-dipping intra-oceanic subduction (Figure 3). In the mean time sea-floor spreading (Vardar) occurred in a supra-subduction setting. The majority of the ophiolite sequences preserved in the Dinarides and Hellenides, especially those including mantle rocks belong to the Jurassic SSZ ophiolites. On the western (Adriatic) side of the ocean, trench and trench-like basins were formed and were filled with ophiolitic mélange (see figures 19 B, C in Gawlick & Missoni 2019). On the eastern (Eurasian) side, an island arc formed on continental crust and a short-lived back-arc basin with supra-subduction ophiolites (Guevgueli Ophiolite Complex; Eastern Vardar ophiolites of Schmid et al. 2008, 2020) evolved behind the arc (Figure 3) (Saccani et al. 2008).

Ophiolite obduction on the Adriatic continental margin is diachronous and lasted from the Late Jurassic to the earliest Cretaceous (Schmid et al. 2008, 2020) or, according to some authors, may have started already in the Middle Jurassic (Gawlick et al. 2016b, 2020; Gawlick & Missoni 2019). The progressive development of trench-like basins in front of the propagating nappes is best documented in the age and composition of sedimentary mélanges; towards west, mélanges become younger and contain less ophiolite-derived material but more and more blocks reworked from the continental margin. Gawlick and co-workers (Gawlick et al. 2017b; Gawlick & Missoni 2019) distinguished two types of mélanges: 1) the ophiolitic mélange composed of serpentinites, basalts, cherts and in places carbonate blocks, and 2) the Hallstatt Mélange containing continental-margin limestone and chert blocks in a radiolaritic-argillaceous matrix. They further subdivided the Hallstatt Mélange according to the provenance of continental-margin blocks; mélanges with outer-shelf Hallstatt-limestone blocks were deposited during the Bathonian to Oxfordian and those containing Triassic reef blocks were formed in the Callovian to Oxfordian.

The Jurassic ophiolites were first dated radiometrically; igneous ages and ages of metamorphic soles are closely similar (approximately 160–180 Ma) implying that the initial obduction movements occurred when the ophiolites were still young and hot (Spray et al. 1984). In the 1980s, the first Middle Jurassic radiolarian age in ophiolitic units were obtained in the Argolis Peninsula in Greece (Baumgartner 1984, 1985), now considered as dating the sedimentary cover of an intraoceanic accretionary wedge. A large number of radiolarian dates are now available from Jurassic ophiolites in Greece, Albania, Serbia, Bosnia and Herzegovina, and Croatia (Halamić et al. 1999; Chiari et al. 2003, 2004; Bortolotti et al. 2008; Gawlick et al. 2009; Nirta et al. 2010; Šegvić et al. 2014). The documented ages consistently range from latest Bajocian –

early Bathonian (UAZ 5) to late Bathonian – early Callovian (UAZ 7) according to the zonation of Baumgartner et al. (1995), both in the sedimentary cover of basalts and in the ophiolite-bearing sedimentary mélanges. Radiometric and biostratigraphic dates together with data on petrology, geochemistry and sedimentology were summarized by Bortolotti et al. (2013), but new data have been published since then. The most recently obtained radiolarians from the matrix of the Hallstatt Mélange in Serbia are assigned to UAZ 5–7 (Gawlick et al. 2016b, 2017a, b, c) and UAZ 6–7 (based on *Kilinora spiralis* (Matsuoka) reported by Gawlick et al., 2018). A comprehensive review on mélange units from the entire Meliata-Maliac-Vardar branch of the Neotethys has been also published (Gawlick & Missoni 2019) but the exact depositional age of the ophiolitic mélanges is still a matter of debate (compare e.g. Schmid et al. 2020 and Gawlick et al. 2020). Since these chaotic units are often pervasively sheared, it is not always clear in the field whether the embedded radiolarian chert is the matrix of the mélange or part of a deformed slide block, which could be markedly older.

In a larger regional picture (Figures 2b, d), it is important to note that the onset of intra-oceanic subduction and the formation of ophiolitic mélange in the Neotethys are contemporaneous with the opening of the Alpine Tethys (Liguria-Piemont Ocean, named the Alpine Atlantic by Gawlick & Missoni 2019), where very slow sea-floor spreading began in the Bajocian and continued until the Tithonian (Bill et al. 2001).

For the origin of the Dinaric-Hellenic ophiolites that occur in two separate ophiolite belts (Figure 1) two basic models have been proposed – the first implying a single oceanic basin (the Vardar Ocean) and the second one implying two oceans (Pindos and Vardar oceans separated by the Pelagonian microcontinent). In the one-ocean model, the ophiolites were generated in the Vardar Ocean, located between the Pelagonian continental margin as part of Adria, and the continental margin of Eurasia (Baumgartner 1985; Bortolotti et al. 2005; Schmid et al. 2008, 2020; Saccani et al. 2011; Ferrière et al. 2016; Chiari et al. 2011; Gawlick & Missoni 2019 with references). This hypothesis was first formulated by Bernoulli & Laubscher (1972) who interpreted the Dinaric-Hellenic ophiolite belts as far-travelled nappes thrust over the Pelagonian unit. The alternative model considers the Pelagonian unit as a microcontinent between the Pindos Ocean in the west and the Vardar Ocean in the east; ophiolites from both oceans were obducted with opposite vergence onto the Pelagonian microcontinent (Robertson et al. 1991; Robertson & Karamata 1994; Robertson & Shallo 2000; Dilek et al. 2005). A comparison of both basic models and their modifications are discussed in detail in several papers (Saccani et al. 2011; Robertson 2012; Gawlick et al., 2017b, 2018). The interpretation that both ophiolite belts were derived from one oceanic basin located to the east of the Pelagonian domain has been widely accepted in recent literature and is also adopted in this paper (Figure 3). We only note that the common origin of ophiolites from the eastern ocean does not contradict the existence of a western ocean-like Pindos Basin whose oceanic basement may have been entirely consumed by underthrusting (e.g. Stampfli & Borel 2002; Ferrière et al. 2012; Argnani 2018).

2.3 From obduction to continental collision (Late Jurassic to Paleogene)

The orogeny occurred in two main phases. The first phase of orogenic deformation was the emplacement of ophiolites on top of the Adriatic continental margin that is well documented in different types of mélange deposited in trench-like basins in front of the advancing nappes (Gawlick & Missoni 2019 with references). Isolated carbonate platforms evolved internally in the uplifted areas of the newly formed nappe stacks. These platforms were first documented in the Northern Calcareous Alps (Schlagintweit et al. 2005; Gawlick & Schlagintweit 2006). In the Dinarides–Hellenides genetically similar carbonate platforms are known indirectly from reworked clasts in gravity-flow deposits of the adjacent basins (Schlagintweit et al. 2008; Kukoč et al. 2012; Gawlick et al. 2020 with references). On the foreland (western) side, the load of the ophiolite nappe induced lithospheric doming of the continental crust and local emersion events on the external carbonate platform (Vlahović et al. 2005 with references). In the foreland basin, the accumulation of flysch-type deposits, the Bosnian Flysch, started in the Tithonian–Berriasian (Blanchet et al. 1969; Mikes et al. 2008 with references). The convergence between Adria and Europe continued into the Early Cretaceous and, in the internal parts of the orogen, resulted in further nappe stacking, burial and green-schist facies metamorphism dated to an interval of early Eoalpine ages between 135 and 110 Ma (Valanginian to early Albian) (Borojević Šoštarić et al. 2012; van Gelder et al. 2015). The mountain chain that resulted from this orogenic episode was named the Paleodinarides (Rampnoux 1970; Aubouin et al. 1970).

The Paleodinarides were subaerially exposed for a prolonged period as evidenced by wide spread laterites on top of the ophiolites. The overstepping successions, in literature also known as the Gosau-type deposits, consist of basal conglomerates followed by a fining-upward sequence of fluvial deposits and then by shallow-marine mixed carbonate-clastic sediments or carbonates including Turonian rudist reefs (Schmid et al. 2008; Chiari et al. 2011; Nirta et al. 2020). The mid-Cretaceous transgression marked by the onset of marine sedimentation is slightly diachronous along the Dinarides-Hellenides and varies from the early Aptian to the late Albian (Nirta et al. 2020 with references). The Upper Cretaceous part of the succession is in places entirely of deep-water origin and is composed of calcareous turbidites and cherty limestone, which yielded Santonian to early Campanian radiolarians (Djerić et al. 2009; Bragina et al. 2014, 2018, 2020; Đerić & Gerzina 2014).

In the Maastrichtian and Paleogene, flysch deposition was dominant throughout the Dinarides and was linked to the final closure of the Neotethys oceanic realm in the area and to the continental collision of the Adriatic and European plates (Schmid et al. 2008, 2020; Ustaszewski et al. 2009). The Sava Zone, best exposed in inselbergs between Zagreb and Belgrade (Figure 1) is considered the Paleogene suture zone between the two continents (Schmid et al. 2008). This zone includes a Campanian back-arc igneous succession proving that the oceanic domain was open in the Late Cretaceous (Ustaszewski et al. 2009). The timing of collision throughout the Dinarides and Hellenides is still debated. Schmid et al. (2008, 2020) inferred that the continent-continent collision occurred in the latest Cretaceous to Paleogene along the entire orogen. Contrary to this, some authors working in Albania and Greece (e.g. Bortolotti et al. 2013), concluded that the ocean was completely closed after the ophiolite obduction, already in the latest Jurassic – Early Cretaceous. Combining both hypotheses, Nirta et al. (2018) proposed that the continental collision was diachronous, earlier in the south and later in the northern sector of the Dinarides–Hellenides.

2.4 Nappe emplacement and post-orogenic evolution (Paleogene to Recent)

The collision propagated from NE to SW and lasted from the Campanian-Maastrichtian to the Eocene (see Figure 4 to compare the time span of flysch deposition between the internal and external zones). This main thrusting phase was followed by the late Oligocene-Miocene extension which was contemporaneous and partly related to the formation of the Pannonian Basin (Matenco & Radivojević 2012). The extension was mainly NE–SW directed, perpendicularly to the strike of the orogen (Van Unen et al. 2019). This extension affected all areas of the Dinarides and created a system of intramontane lakes with a high degree of endemism (Harzhauser & Mandić 2008). Some of these basins accumulated up to 2000 m of sediments (Hrvatović 2006). Thick Miocene lacustrine deposits also occur in NE Montenegro around Berane and Pljevlja and are economically interesting for coal exploitation.

The Miocene extension was followed by an overall inversion that started in the latest Miocene and is still active. This contraction, expressed in strike slip, thrusting, or reverse faulting and folding has a N-S to NNE-SSW direction and is not intrinsic to the Dinarides but is interpreted in relation to the much larger regional Africa-Europe convergence (Van Unen et al. 2019).

3 STRATIGRAPHY OF TECTONIC UNITS IN THE MONTENEGRO–SERBIA TRANSECT

Stratigraphy is described from the external to the internal units in the SW to NE direction (Figure 1) and graphically summarized in Figure 4. The nomenclature and definition of the first-order tectonic units follow the review papers by Schmid et al. (2008, 2020). The reader is referred to these papers to obtain a wider regional framework of tectonic units from the Alps to western Turkey. Abundant references relevant to the units of the described transect and their equivalents outside this transect are cited in these reviews and will not be fully repeated here. Other review papers on the Dinarides were previously provided by Dimitrijević (1997), Pamić et al. (2002) and Karamata (2006), and a review on the history of research was presented by Charvet (2013). More detailed local tectonic subdivisions (Rampnoux 1974; Cadet 1978) are also considered in order to point out stratigraphic (and paleotopographic) variability within a single first-order unit.

The **Dalmatian Zone** is the most external zone in Montenegro and extends from the Montenegro coast further north along the Croatian coast to Split. This unit, equivalent of the Kruja Zone in Albania and the Gavrovo–Tripolitza Zone in Greece, is composed entirely of Mesozoic and lower Paleogene shallow-water carbonates that are followed by Eocene flysch. In Montenegro, only Upper Cretaceous and Paleogene deposits are exposed, and Lower Cretaceous limestones are known from the boreholes. Middle Miocene shallow marine sandstones and limestones from the surroundings of Ulcinj belong to this unit.

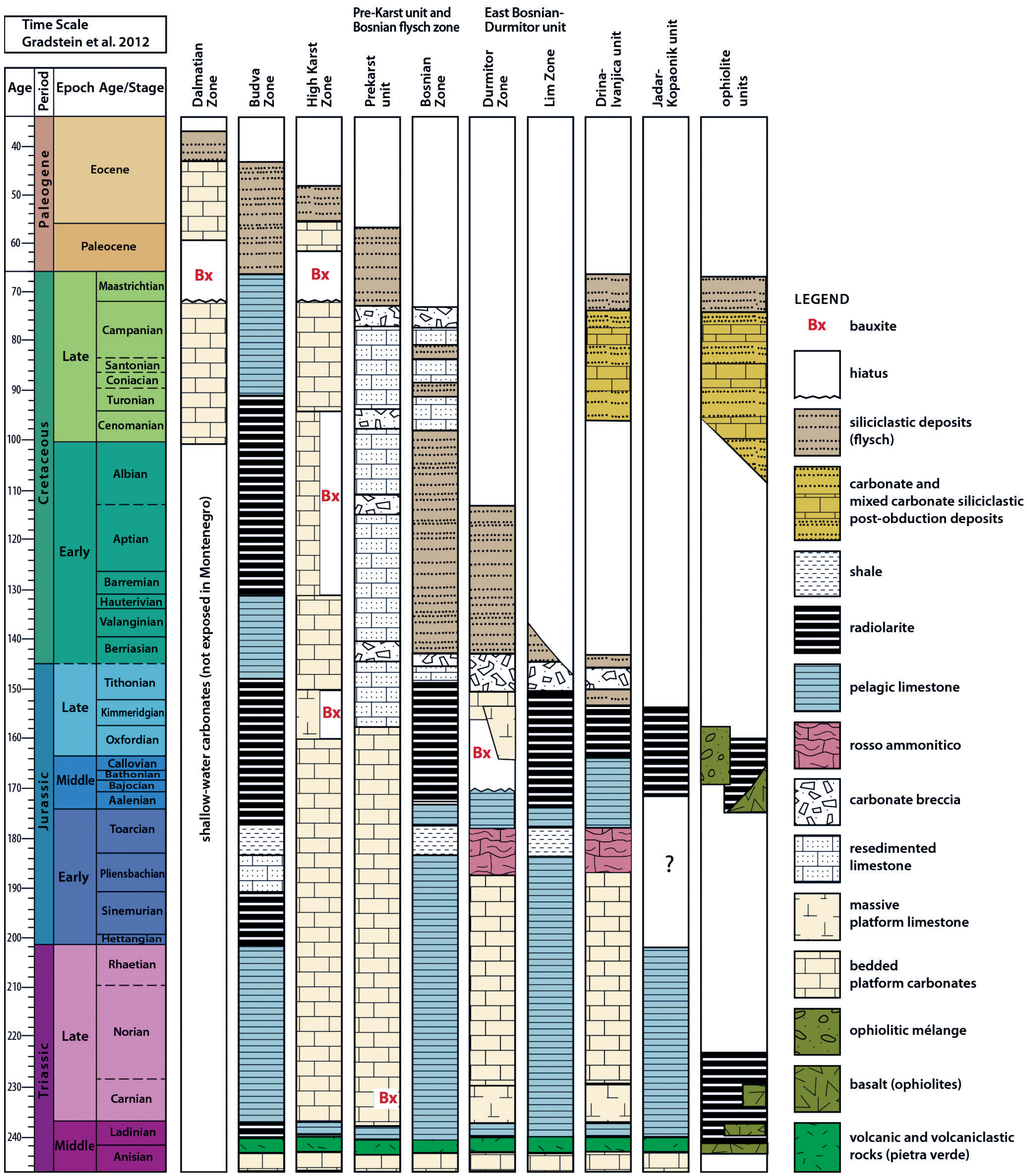


Figure 4: Chronostratigraphic overview of the formations in the Montenegro – west Serbia transect (for location of the transect see Figure 1; references on stratigraphy are given in the text). The stratigraphic column of the Bosnian Zone is compiled from data in Bosnia and Herzegovina because in Montenegro this zone is tectonically reduced and differentiated by the Lower Cretaceous flysch deposits only.

The overlying **Budva Zone** is characterized by deeper-marine sediments from the Middle Triassic to the Paleogene. The Middle Triassic synrift sediments are the nodular Bulog Limestone and a thick clastic unit informally called the "Anisian Flysch". These deposits are overlain by a volcano-sedimentary sequence. The Upper Triassic to Maastrichtian succession displays and alternation of pelagic limestones, radiolarites and resedimented carbonates. The succession ends with Paleocene to lower Eocene flysch. The Budva Zone continues to the south to the Krasta–Cukali Zone in Albania and to the Pindos Zone in Greece. To the north, it wedges out near Konavlje, about 20 km north of the Montenegro-Croatian border. The Dalmatian Zone is northwards in a direct thrust contact with the High Karst Zone as far as Split, where it runs offshore.

The **High Karst Zone** consists of a several thousand-meters thick series of Triassic to Upper Cretaceous platform carbonates, overlain by Paleogene flysch. In certain stratigraphic levels (e.g. Anisian–Ladinian, Cenomanian–Turonian) pelagic facies locally occur. Some other levels (e.g. Upper Jurassic, Aptian–Albian) are characterized by local occurrences of lagoonal to lacustrine facies with charophytes and/or bauxite. The High Karst Zone extends far north to Slovenia and north-eastern Italy. Paleogeographically it represents a large carbonate platform, known as the High Karst or Dinaric Carbonate Platform or, mostly in the Italian literature, also as the Friuli Carbonate Platform. The Dalmatian and the High Karst platforms, when regarded as one paleogeographic entity are called the Adriatic Carbonate Platform (Vlahović et al. 2005). This view is justified in Croatia but is not applicable in Montenegro, where the Budva Basin divides the "single" platform in two units. To the SE, the High Karst Zone abruptly ends at the Skutari–Peć Line. The Skutari–Peć transverse zone in northern Albania (Figure 1) now separates the Dinarides from the Hellenides but its location is paleogeographically predetermined (e.g. Dercourt 1968; Bernoulli & Laubscher 1972). The only possible southern equivalent of the High Karst Zone is the Parnassos Zone (Aubouin et al. 1970), a relatively small isolated unit of platform carbonates located north of the Gulf of Corinth.

The **Pre-Karst Subzone** (defined as a subzone of the High Karst Zone by Blanchet et al. 1970) is composed of several thrust sheets that constitute the NE border of the High Karst Zone along its entire length. The Triassic facies are identical to those of the High Karst Zone, whereas the Jurassic and Cretaceous are slope facies with resedimented carbonates originating from the High Karst Platform. Coarse-grained breccias and calcareous turbidites with interlayers of variegated pelagic limestone are common in the Cretaceous (Cadet 1978). The typical siliciclastic flysch is Maastrichtian to Paleocene in age (Cadet 1978; Mirković 1983). This flysch is well exposed on Mt. Durmitor and is traditionally called the Durmitor flysch (e.g., Mirković 1983; Dimitrijević 1997). The name Durmitor flysch entered common usage (e.g., Schmid et al. 2008, 2020) but one should bear in mind that this formation is not part of the Durmitor nappe.

The **Bosnian Zone** is an almost continuous facies belt in front of the Durmitor nappe, extending from the Albanian Alps to central Bosnia and the Pannonian Basin. This zone is best discriminated in southern Bosnia and Herzegovina where complete Mesozoic successions are exposed (described in Cadet 1978). The post-Anisian sediments are exclusively deep marine and include pelagic limestones, radiolarian cherts and turbidites. The most characteristic lithostratigraphic unit is the Bosnian Flysch, which records an early arrival of siliciclastics with ophiolite debris already in the Berriasian. The Bosnian Flysch is subdivided into the lower, predominantly siliciclastic Vranduk Formation (Berriasian to Cenomanian) (Rampnoux 1974; Cadet 1978), and the upper carbonate-dominated Ugar Formation (Cenomanian? to Maastrichtian) (Charvet 1978; Hrvatović 2006; Mikes et al. 2008 with references).

In Montenegro, the Bosnian Zone is tectonically reduced to a narrow NW-SE trending belt, which disappears below the Durmitor Mountain, along a distance of approximately 50 km, so that the Pre-Karst and the Durmitor units are in a direct contact (see tectonic maps in Aubouin et al. 1970; Rampnoux 1974; Cadet 1978). The stratigraphic succession is also incomplete. Mostly the Bosnian Flysch is exposed; pelagic Triassic rocks occur only in a half-window near Kolašin in central Montenegro (Rampnoux 1974). The thrust contact with the underlying Pre-Karst unit is difficult to recognize because it juxtaposes highly deformed flysch deposits of both tectonic units. Biostratigraphic studies demonstrated that the Berriasian to Cenomanian Bosnian Flysch tectonically overlies the Maastrichtian flysch of the Pre-Karst Zone (Rampnoux 1974). The thrust contact with the overlying Durmitor nappe is everywhere clearly expressed in landscape because it brings a thick succession of platform carbonates on top of flysch deposits. Lateral equivalents of the Bosnian Flysch are the Vermoshi Flysch in northern Albania (Marroni et al. 2009) and the Boeotian Flysch in Greece (Nirta et al. 2015, 2018). The Lower Cretaceous flysch deposits can be traced to the Hellenides but we note that there is no evidence of Triassic pelagic rocks in the corresponding zones south of Montenegro. It is possible that the Bosnian Basin, which originated in the Middle Triassic, was initially smaller and was prolonged southwards only later, during subsequent subsidence pulses in the Jurassic and Cretaceous.

According to Schmid et al. (2008, 2020) the **Pre-Karst unit and the Bosnian flysch zone** are together considered as a single first-order tectonic unit (Figure 1a). The next structurally higher first-order unit, the **East Bosnian-Durmitor** unit, mainly corresponds to the unit of the same name defined by Dimitrijević (1997), but includes also more internal tectonic units that are overthrust by ophiolitic mélange and were by Dimitrijević (1997) discriminated as the Dinaric Ophiolite Belt. The East Bosnian-Durmitor unit is a synonym of the Serbian Zone (*sensu* Aubouin et al. 1970), which was subdivided in two zones – the Durmitor Zone and the Lim Zone (Rampnoux 1970, 1974; Figure 5). Schmid et al. (2008, 2020) considered these two zones as sub-units and thus did not differentiate them in the geological map (Figure 1).

The **Durmitor Zone** extends from the “Sarajevo sigmoid” (Dimitrijević 1997), an S-shaped north-western thrust contact with the underlying Bosnian Flysch, to the Skutari-Peć transverse zone (Figure 1). No proper equivalent of the Durmitor Zone exists in the Hellenides. The stratigraphic succession (Rampnoux 1970, 1974; Mirković 1983) is characteristic of a morphological high and consists mainly of shallow-water Triassic and Jurassic carbonates. “Ammonitico rosso” facies occurs in the upper Anisian and in the Toarcian. The Toarcian to Middle Jurassic sequence is reduced to a few meters and is disconformably overlain by Upper Jurassic reef and *Clypeina*-bearing limestone. The disconformity is marked by a considerable erosion, in places cutting down to the Middle Triassic, and locally also by bauxite deposits. The Upper Jurassic reef limestone is overlain first by coarse-grained conglomerate and then by Berriasian flysch-type sediments. The stratigraphic succession of the Durmitor Zone differs from that of the High Karst Zone by a much earlier onset of flysch deposition (Berriasian vs. Maastrichtian in the Pre-Karst unit). On the other hand, the Upper Jurassic bauxite and reefs distinguish the Durmitor Zone from the more in-

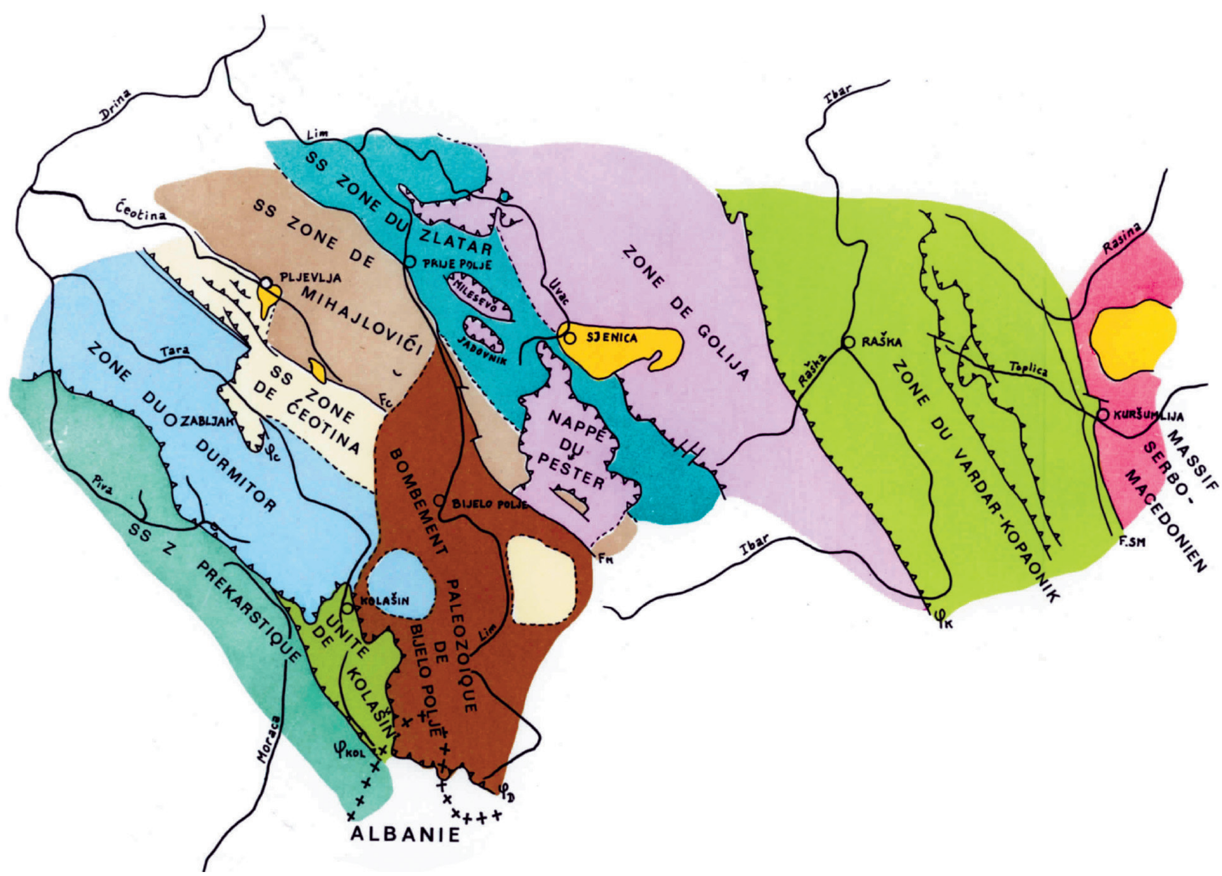


Figure 5. Tectonic sketch of northern Montenegro and south-western Serbia (reproduced from Rampnoux 1974). The dark yellow areas indicate Miocene lacustrine deposits.

ternal Drina-Ivanjica Zone, in which no shallow-water carbonates younger than the Toarcian occur.

The **Lim Zone** was subdivided into three subzones. From SW to NE these subzones are the Ćehotina Subzone, the Mihajlovići Subzone and the Zlatar Subzone (Rampnoux 1970, 1974; Figure 5). The Mihajlovići Subzone disappears towards NW in Bosnia, where only an external and an internal domain within the Lim Zone are distinguished (Cadet 1978). The stratigraphic evolution of the Mihajlovići Subzone is characteristic of a Triassic–Early Jurassic carbonate platform that submerged in the Pliensbachian. The Ćehotina and Zlatar subzones that border the Mihajlovići Subzone to SW and NE, respectively, are characterized by deep-water sediments from the Middle Triassic to the beginning of the Cretaceous. These three subzones are stratigraphically clearly distinguished but their structural superposition is less evident because the gently dipping thrust contacts are strongly obliterated by steep younger faults. It is thus possible that the Mihajlovići Subzone is not placed structurally below the Zlatar Subzone but was originally a klippe of the next higher Drina-Ivanjica unit (Figure 1), which is stratigraphically nearly identical. Moreover, several relatively large klippen of the Drina-Ivanjica unit have already been mapped on top of the Lim Zone, e.g. the Pešter Nappe in western Serbia (Rampnoux 1974; Figure 5) and the Semeć Nappe in Bosnia (Cadet 1978). In terms of paleogeography, this reinterpretation implies that the Mihajlovići Subzone is not necessarily a remnant of a separate Mesozoic submarine high but was more probably part of the larger Drina-Ivanjica continental ribbon.

The **Drina-Ivanjica thrust sheet** (the Drina-Ivanjica Element of Dimitrijević 1997) is a synonym of the Golija Zone of the French authors (Figure 5, Rampnoux 1969, 1974; Aubouin et al. 1970). This unit is characterized by a pre-Mesozoic basement followed by a Triassic–Jurassic succession typical of a morphological high. The late Anisian rifting-related drowning event is evidenced by red nodular limestone (Bulog facies) or by grey cherty limestones with shallow-water debris (Rid Formation of Sudar et al. 2013) on top of a Steinalm-type carbonate ramp. Upsection, Upper Anisian to Lower Ladinian hemipelagic limestones occur and are then followed by Wetterstein and Dachstein-type platform facies (Missoni et al. 2012; Sudar et al. 2013; Gawlick et al. 2017a). Jurassic rocks are preserved in a few outcrops in the external parts of this zone. Rampnoux (1970, 1974) regarded the Krš Gradac locality as the typical Jurassic succession of his Golija Zone. The section, later re-studied several times, overlies the Dachstein Limestone and consists of Lower Jurassic oncoidal limestone, Toarcian ammonitico rosso, Bathonian to Oxfordian/Kimmeridgian radiolarite, and Tithonian polymictic carbonate turbidites (with Cr spinels) overlain by radiolarites with intercalations of ophiolitic sandstones (Radoičić et al. 2009; Gawlick et al. 2009, 2017a, 2020).

The Drina-Ivanjica unit continues to the Korab unit in Albania, Kosovo and North Macedonia and further south to the Pelagonian unit in North Macedonia and Greece (Aubouin et al. 1970). The stratigraphic succession consists of Upper Triassic to Lower Jurassic platform limestones, Middle Jurassic open-marine facies and Oxfordian–Kimmeridgian debris flow deposits with reef fragments; laterites, indicating a Callovian subaerial unconformity, occur below the reefs (Scherreiks et al. 2010). Schmid et al. (2008, 2020) linked the Drina-Ivanjica and Korab units to the Upper Pelagonian, which is characterized by weak to strong metamorphism of the basement but the Mesozoic cover is non-metamorphic. Consistently with this correlation, they proposed that the Lower Pelagonian unit, which is entirely metamorphic and includes a several km thick sequence of Mesozoic marbles, could be the equivalent of the East Bosnian-Durmitor unit.

The **Jadar-Kopaonik thrust sheet** is the innermost composite nappe of the Dinarides and paleogeographically represents the distalmost continental margin of the Adriatic plate. A typical Mesozoic succession, exposed in the Kopaonik-Studenica area in Serbia, is composed of metasediments exhibiting carbonate platform facies up to the Anisian, which are then followed by Middle Triassic carbonate breccia and tuff, Upper Triassic pelagic limestone and presumably Jurassic radiolarian chert (Schefer et al. 2010). The northern extensions of this unit are the Medvednica Mountain in Croatia and the Bükk Mountains in northern Hungary; southwards the unit extends as a narrow belt to northern Greece (Schmid et al. 2008, 2020).

Ophiolites and ophiolitic mélanges tectonically overlie the continental-margin units. In older literature, these ophiolites and genetically related sedimentary rocks were commonly termed the Diabase-Chert Formation. Schmid et al. (2008, 2020) distinguished between western and eastern Vardar ophiolitic units (Figure 1). The Dinaric and Hellenic ophiolites are the western units that originated from the West Vardar Ocean and were emplaced onto the Adriatic continental margin (Figure 3). In present-day map view, the Western Vardar ophiolites occur in several discontinuous belts; some isolated remnants are found far west from the Sava suture zone, which is interpreted as the boundary between Adria and Europe (Schmid et al., 2008, 2020). This long-distance emplacement resulted from Cretaceous and Cenozoic out-of-sequence thrusting of previously obducted ophiolites. In geological maps (Figure 1), the ophiolitic units include thick layers of ophiolitic mélange underlying the obducted ultramafics and their metamorphic sole. In Montenegro, the westernmost ophiolitic remnants tectonically overlie the East Bosnian-Durmitor unit or, more specifically, the outermost ultramafics occur on top of the Zlatar Subzone and the outermost mélanges on top of the Ćehotina Subzone of the Lim Zone (Rampnoux 1974). Recently, mélanges have gained an increased interest because they are not only crucial to understand the obduction history but also allow us to restore the pre-orogenic configuration of the distal passive margin. From detailed analyses of blocks in the Jurassic sedimentary mélanges of the Dinarides, a complete unmetamorphosed Triassic distal-margin stratigraphic succession could be reconstructed (Gawlick et al., 2017a, 2018; Gawlick & Missoni 2019).

A note on the tectonic units and their stratigraphy, the Mesozoic geodynamic evolution and paleogeography: One of the co-authors (HJG) disagrees with this subdivision of tectonic units, the correlation of tectonic units and in cases also with the summarized Triassic to Early Cretaceous stratigraphic and sedimentological and geodynamic evolution as presented in this field-trip guide. For a summary on the Triassic sedimentary evolution interested readers are referred to Kovács et al. (2011), and for the Jurassic sedimentary evolution to Haas et al. (2011). For the correlation of tectonostratigraphy and the geodynamic evolution interested readers are referred to Gawlick et al. (2008, 2017a, 2020), Gawlick & Missoni (2015, 2019) and references therein.

4 FIELD-TRIP DESCRIPTION

The field-trip will focus on radiolarian-bearing deposits of different tectonic units. The localities are described in SW to NE direction from the most external to more internal zones (Figures 1, 6). Ophiolitic mélanges are described together with the sedimentary succession of the Lim Zone, which they overthrust.

Montenegro is covered by 16 sheets of the Basic Geological Map 1:100,000 (available at the Geological Survey of Montenegro) and by an integral map at scale 1: 200,000 (Mirković et al. 1985). For each locality, the coordinates are given and the corresponding sheet of the Basic Geological Map is cited.

4.1 The Budva Zone

General description

The Budva Zone is a narrow, less than 10 km wide and about 100 km long belt of deep-marine Mesozoic deposits in coastal Montenegro. The zone is composed of several thrust sheets. In the Kotor area, two tectonic subunits are clearly distinguished (Figure 7). The central part between Kotor and Petrovac is more complex, composed of several smaller discontinuous recumbent folds. In general, a subdivision between a lower and an upper tectonic subunit is possible. Stratigraphic research in these units revealed that the Jurassic–Cretaceous redeposited carbonates are thicker and have a more proximal character in the upper than in the lower unit (Goričan 1994). A similar NE to SW direction towards a more distal depositional setting was recognized in Middle Triassic limestone conglomerates (Dimitrijević 1967). These observations imply that only the eastern part of the Budva Basin, which was supplied from the High Karst Carbonate Platform is now preserved in the Budva Zone.

The oldest rocks of the Budva Zone are Middle Permian dark grey shales, sandstones and calcarenites overlain by Middle to Upper Permian dark grey bioclastic limestone with algae, brachiopods, bivalves, gastropods, ammonoids and crinoids (Horacek et al. 2020). The overlying Lower Triassic deposits are sandstones, marls and calcarenites, and laterally also dolomites. The facies associations show considerable lateral variability and a general vertical change from a shallow mixed siliciclastic and carbonate Werfen-type sedimentation to deeper-water marly layers and calcareous turbidites (Krystyn et al. 2019). The lower Anisian is represented by calcareous turbidites or in places by platform limestone. The overlying Pelsonian and Illyrian deposits are limestone conglomerates (including reworked Paleozoic rocks) and mixed siliciclastic-carbonate turbidites traditionally known as the Anisian flysch (Dimitrijević 1967). The conglomerates are now named the Crmnica Formation and the turbidites the Tuđemili Formation (Čadjenović & Radulović 2018) The Crmnica Formation is defined as the basal part of this “flysch” sequence but conglomerates also occur within or on top of the finer-grained turbidites. Nodular red cephalopod limestone in places overlies these turbidites but more commonly occurs directly on top of lower Anisian platform limestones; ammonoids from the upper-

Figure 6: Road map of Montenegro with locations of field-trip sections 1–10.

most parts of "flysch" sediments are characteristic of Pelsonian age (Đaković 2018). The uppermost Anisian to Ladinian unit is a thick volcano-sedimentary sequence, which consists of volcanic and volcanoclastic rocks (Pietra Verde), alternating with radiolarian chert and limestone. Cafiero & De Capoa Bonardi (1980) described bivalves of latest Ladinian age from the uppermost part of this sequence at Bečići.

The Upper Triassic to Maastrichtian succession displays an alternation of pelagic limestones, radiolarites, and resedimented carbonates. The description of lithostratigraphic units is summarized below (according to Goričan 1994, unless otherwise specified). See Figure 8 for general stratigraphic logs of the representative sections and Figure 9 for their chronostratigraphy.

The ***Halobia* limestone** is an approximately 150 m thick succession of bedded limestone with replacement chert nodules and layers, and in places marly intercalations. The Carnian and Norian age is determined with halobiids and conodonts (Cafiero & De Capoa Bonardi 1980, 1981). From the topmost beds in the Čanj section (see Stop 3 below) radiolarians of the upper Rhaetian *Globolaxtorum tozeri* Zone were identified (Črne et al. 2011).

The **"Passée Jaspeuse"** is a unit of bedded calcareous chert alternating with shale or marl. Light grey siliceous micrite beds are intercalated. The unit is 30 to 40 m thick. It contains higher proportions of silica and clay constituents than the *Halobia* limestone and can easily be distinguished by its characteristic dark brownish red and green colours. Siliceous fossils are present in all chert and limestone beds. Sponge spicules prevail over radiolarians, which are very poorly preserved; only a few samples with identifiable specimens were found. At the base of the formation, radiolarians of the lowermost Hettangian *Canoptum merum* Zone were determined (Črne et al. 2011). The top of the formation was placed near the Sinemurian–Pliensbachian boundary.

The **Bar Limestone** is a succession of carbonate gravity-flow deposits. In contrast with the underlying "Passée Jaspeuse" the colour is light grey and the limestone beds contain only a minor amount of silica (10–20 %) in form of replacement chert layers and nodules. The age is constrained with radiolarians from underlying and overlying strata and confirmed by rare benthic foraminifera. The formation is subdivided in two members. The Lower Bar Limestone Member is 50 m to 170 m thick and occurs in the lower as well as in the upper tectonic unit of the Budva Zone. The Upper Bar Limestone Member can be more than 200 m thick and is practically restricted to the upper tectonic unit. The transition between the two members is covered, but shales and marls that overlie the Lower Member in the distal sections suggest that this transition probably correlates to widespread clay-rich deposits of the lower Toarcian.

The grain constituents in both members of the Bar Limestone show the same origin of sediment supply – penecontemporaneous platform-derived debris mixed with semilithified coeval pelagic limestone clasts. The main difference in composition is the amount of ooids. At the base of the Lower Bar Limestone Member, the ooids are rare and relatively small; from the middle part to the top of the Lower Member their proportion increases but does not exceed 40 % of shallow-water grains. In the Upper Member, on the contrary, ooid packstone facies containing only about 10 % of other grains is common. Oolites occur as part of a turbidite sequence or as independent deposits. Pure oolite beds show no grading and can be more than 20 m thick. Compared to the Lower Bar Limestone Member, the overall succession of the Upper Member exhibits a coarser grained composition, thicker bedding and proportionally less lime mudstone beds associated.

The **Lastva Radiolarite** is a sequence of rhythmically alternating chert and shale layers; beds of silici-

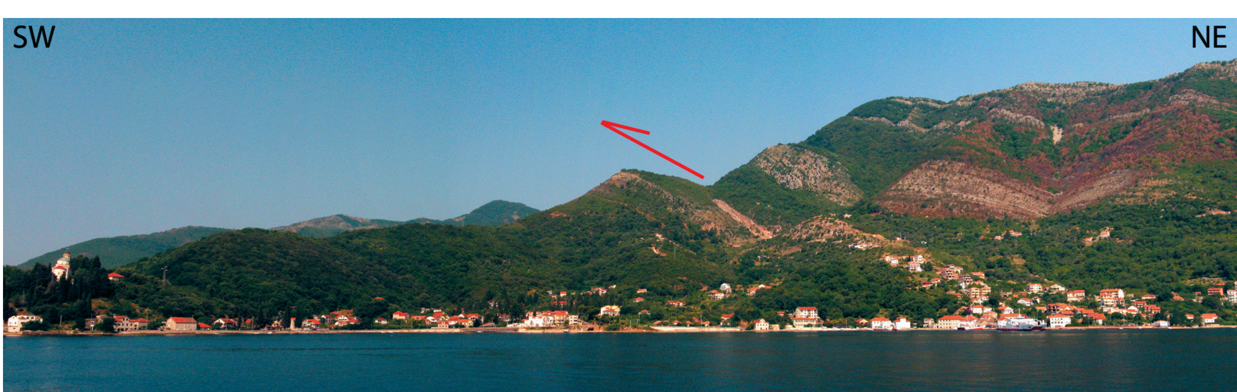


Figure 7: View to the two superposed tectonic units of the Budva Zone in NW Kotor Bay above the town of Bijela.

fied calcarenites are interstratified. The formation includes the supposedly lower Toarcian shales, which directly overlie the Lower Bar Limestone Member but are too poorly exposed to be defined as a separate lithostratigraphic unit. The oldest age determined with radiolarians is Aalenian-early Bajocian. The top of the formation is characterized by a transition to pelagic limestone and is dated to the middle Tithonian. The Lastva Radiolarite is partly the lateral equivalent of carbonate gravity-flow deposits hence, the thickness (Figure 8) and the time span (Figure 9) of this formation vary considerably across and along the basin.

Considering the colour, shale content and bedding style, several radiolarite facies can be distinguished. In all sections, these facies occur in the same stratigraphic order but are laterally diachronous and their sequence is rarely complete (Figure 9). From base to top these facies are:

The **variegated facies** (V) is in the lower part (V1) characterized by a very high proportion of dark green or

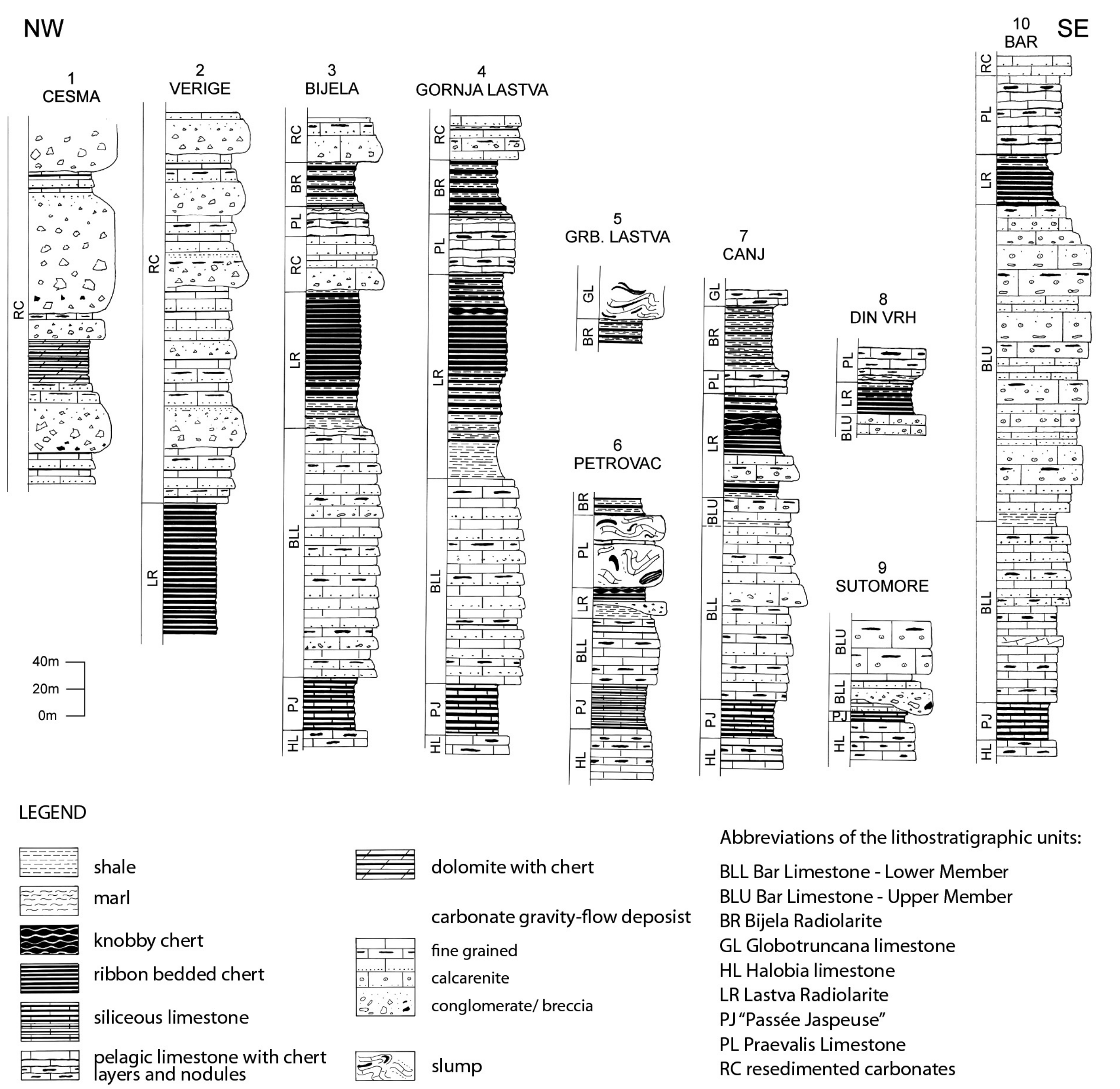


Figure 8: Schematic lithological columns of different sections in the Budva Zone (from Goričan 1994). Stratigraphic range of the formations is shown in Figure 9. For detailed columns of the field-trip sections at Gornja Lastva, Petrovac and Čanj see Figures 10, 12, 15.

brownish shale alternating with thin, about 5 cm thick grey laminated sandstone consisting of densely packed sponge spicules and radiolarians and centimeter-thick layers of dark variegated argillaceous chert. Chert beds do not exceed 30 % of the sequence. Higher in the sections (V2) the shale constituent gradually decreases. Dark reddish-green chert beds are thicker (5–10 cm), sometimes nodular, and are progressively less argillaceous. Siliceous sandstone beds disappear. Cherts represent 60 – 90 % of the sequence. The preservation of radiolarians is poor in the lower and moderate in the upper part. Some slightly argillaceous chert beds contain very well preserved and diverse fauna.

The **green radiolarite** (G) generally consists of thicker (average 10 cm) unevenly bedded, sometimes laminated greyish-green chert. Thin interlayers of slightly argillaceous yellowish-green chert are present at joints. These layers can yield pyritized radiolarians but the average preservation is poor. The content of chert varies from 95 % to 100 % of the sequence. Where the green radiolarite extends to the Kimmeridgian (Figure 9), up to 20% shale interlayers are present.

The **greenish-red** (GR) knobby radiolarite is characterized by 3 cm to 15 cm thick undulating chert beds alternating with a maximum 5 % shale. This facies is only a few meters thick and always interstratified between the green radiolarite and the red knobby radiolarite. Chert beds are red in the middle part and green at the margins. Radiolarians are abundant, diverse and well preserved.

The **red knobby** radiolarite (Rk) facies consists of decimeter-sized nodular chert beds with a high pinch

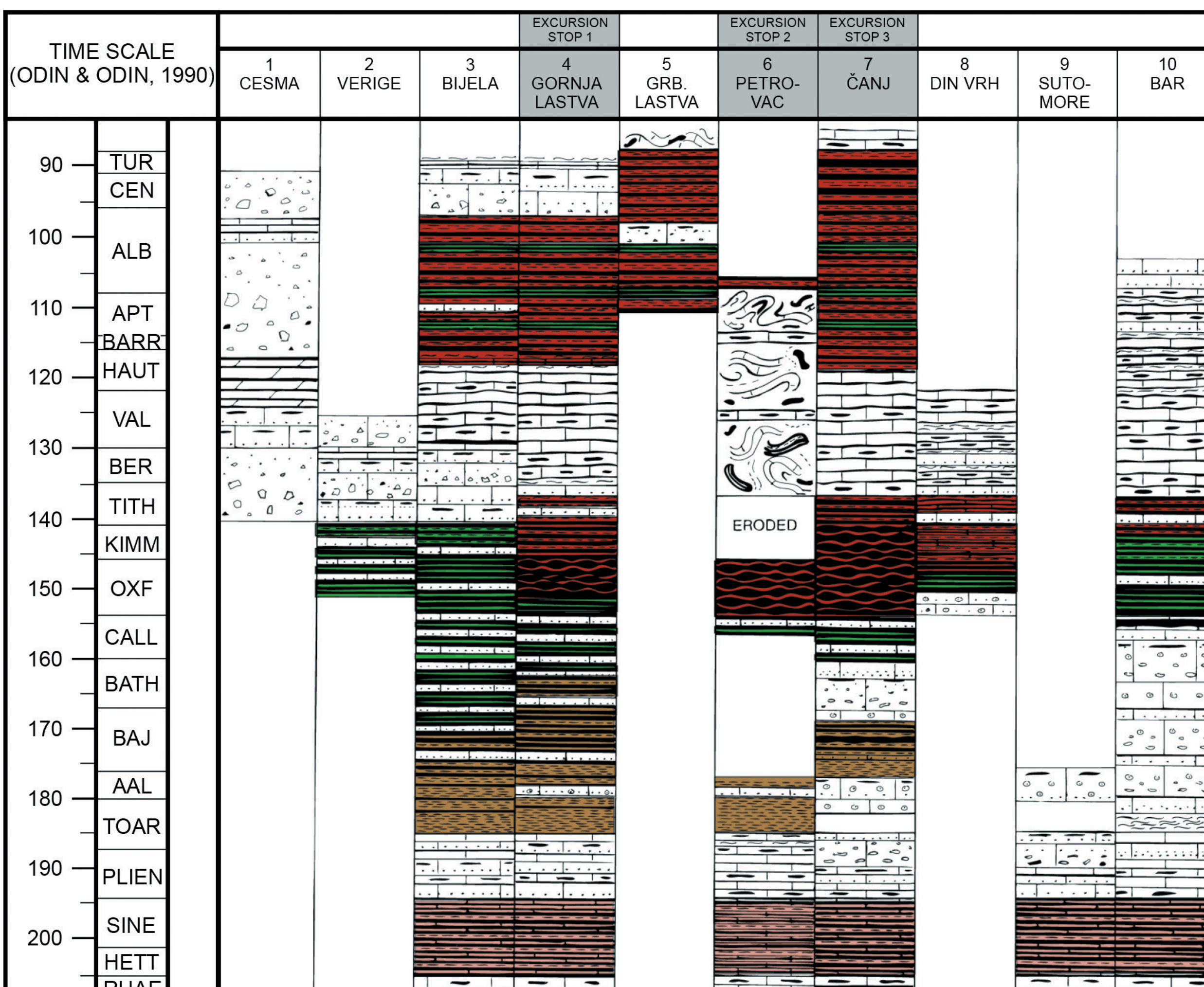


Figure 9: Chronostratigraphic view of lithofacies in the sections of Figure 8 (from GORIČAN 1994). Legend same as Figure 8. Radiolarian cherts and shales are colored according to their natural color. Sections 3 to 7 are part of the lower tectonic unit, other sections are part of the upper tectonic unit.

to swell ratio. No shale is interlayered. At Čanj, where this facies is best exposed, it changes from orange-red through dark red to brick-red upsection. Radiolarians are well preserved.

The **red ribbon** (Rr) radiolarite displays a very regular alternation of dark brownish-red argillaceous chert (beds 3 to 6 cm) and centimeter-sized shale interlayers. The content of chert beds varies from 80 % to 90 %. Radiolarians are abundant but moderately well preserved and usually compressed because of the compaction of the relatively clay-rich sediment.

In addition to radiolarians, sponge spicules and rhaxes occur through all the radiolarite succession. They are especially abundant in the lower variegated facies, where they prevail over radiolarians.

Carbonate gravity-flow deposits are intercalated throughout the Lastva Radiolarite. Calcarenite beds are silicified, generally 5–20 cm thick, rarely up to 30–40 cm. A few thicker graded turbidites, which escaped complete silicification are interstratified.

The **Praevalis Limestone** is composed of bedded marly micrite (beds 10–20 cm) with replacement chert nodules and layers. The general colour of limestone is light red to violet red, rarely white to pale green; cherts are vivid red. Bedding planes are undulated. In the upper part of the formation, reddish marls are intercalated. The limestone beds contain a maximum of 15 % calcified radiolarians in a mud matrix. Very rare calpionellids were found in the lower part of the formation. Relatively abundant and well-preserved radiolarians were extracted from chert nodules. The formation is up to 50 m thick and ranges from the Upper Tithonian to the Hauterivian–Barremian; in the SE part of the basin (see section Bar in Figures 8 and 9) the formation ranges to the Aptian–early Albian. The entire formation locally consists of chaotic beds interpreted as highly evolved slump to debris-flow deposits (see Stop 2 below).

The transition from the Praevalis Limestone to the overlying **Bijela Radiolarite** is gradual, marked by a progressive increase in clay and silica content. The base of the radiolarite is defined where the sequence has a typical radiolarite aspect of thin siliceous beds alternating with clayey marls. The predominant Bijela Radiolarite consists of thin-bedded (1–3 cm) dark red chert and a very high proportion of shale that makes up to 80 % of the sequence. Several levels, ranging in thickness from 0.5 to 1.5 m, of green radiolarite are interstratified. Chert beds in these green levels are also thin (1–3 cm) but the percentage of shale interlayers is much lower (5–20%) than in the red radiolarite. The maximum estimated thickness of the formation is 60 m. Cherts yield abundant but moderately preserved radiolarians and sponge spicules. The base of the Bijela Radiolarite is assigned to the Hauterivian–lower Barremian. The youngest age obtained for the top is early Turonian.

The Mesozoic succession ends with the ***Globotruncana* limestone**, a predominantly reddish Scaglia-type pelagic limestone that contains chert nodules and layers. The formation is up to 150 m thick. Planktonic foraminifera are abundant, especially in the Campanian and Maastrichtian (Danilova 1958).

Tithonian and Cretaceous resedimented carbonates are commonly interstratified in pelagic sequences and may, in the proximal sections, completely replace radiolarite and micritic limestone. The predominant deposits are turbidites consisting of graded fine breccia or calcarenite, to calcisiltite sequences, occasionally with thin marl interbeds. Up to several- meters thick debris-flow breccias are characteristic of the NW part of the Budva Zone. In contrast to the Bar Limestone, which contains penecontemporaneous platform-derived material, are the Tithonian–Maastrichtian resedimented limestones mostly composed of angular lithoclasts derived from the erosion of somewhat older platform limestones. Subrounded carbonate-mudstone clasts with pelagic fauna are very rare. Fine-grained beds are often silicified; the overall succession contains 15–25 % of replacement chert.

Stop 1: Gornja Lastva near Tivat

Lower tectonic unit, Hettangian to Upper Campanian.

Location: near Tivat, along the road from Donja Lastva to Gornja Lastva, the section starts at N 42°27'08", E 18°42'01", Basic Geological Map sheet Kotor (Antonijević et al. 1969).

A continuous Jurassic and Cretaceous section consists of 40 m of the "Passée Jaspeuse", 150 m of the Bar Limestone, 150 m of the Lastva Radiolarite, 50 m of the Praevalis Limestone, 35 m of the Bijela Radiolarite and continues with more than 70 m of carbonate gravity-flow deposits and *Globotruncana* limestone (Figure 10 a–f).

The "Passée Jaspeuse" with a sharp contact overlies grey micritic limestone (bed thickness 10–15 cm) with chert nodules. In the lowermost part some silicified calcarenites are interstratified; the remaining "Passée Jaspeuse" consists of thin-bedded brownish to greenish highly siliceous limestone. The internal part of beds usually contains replacement chert. Some beds contain less silica and are light grey in colour. The proportion of shale/marl interlayers is high; in the middle part of the section, these interlayers attain up to 60 % of the sequence. Rare decimeter-sized beds of intraformational breccia occur in the lower half of the sec-

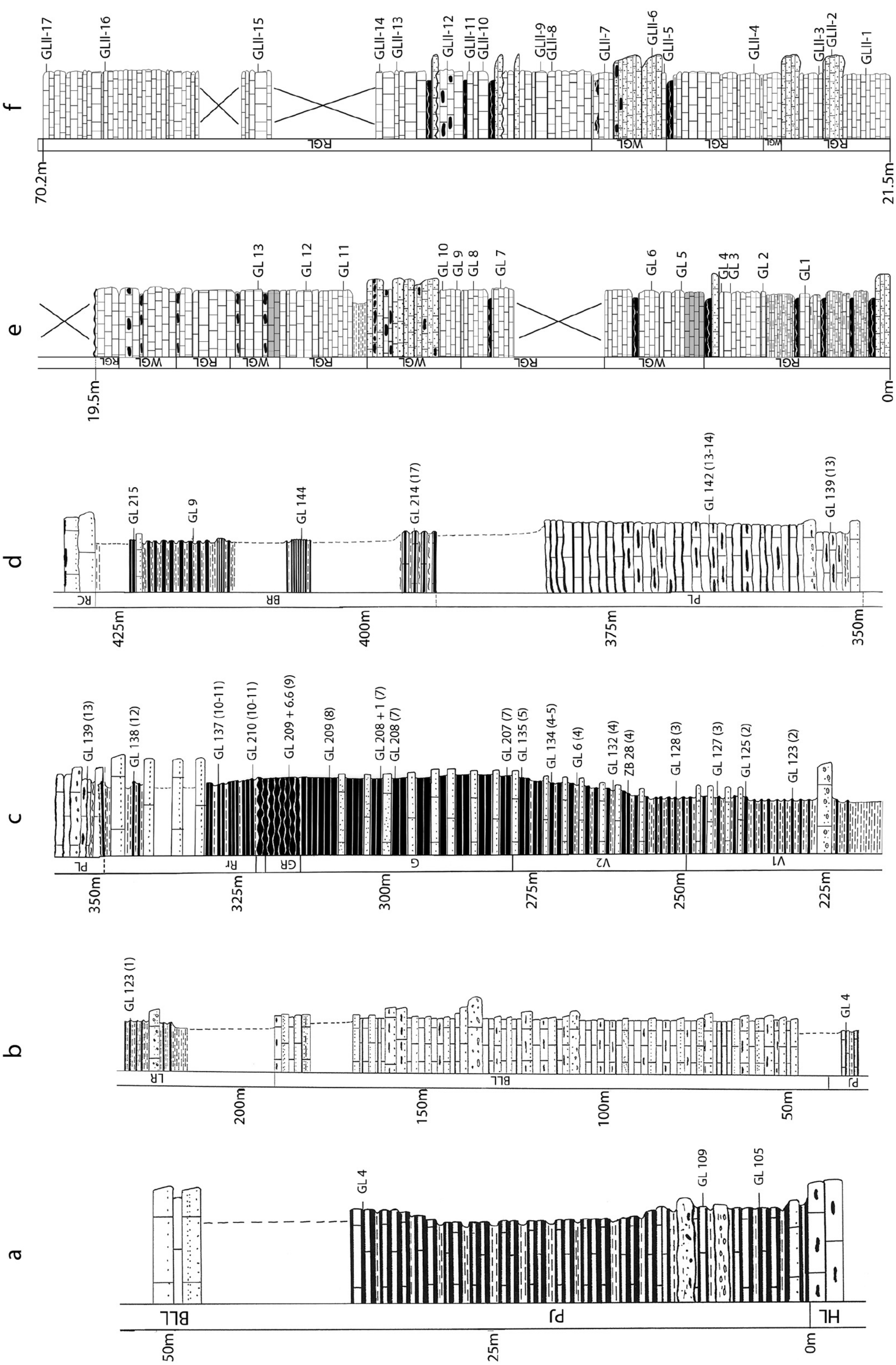


Figure 10: Lithological columns of the Gornja Lastva section (Stop 1). a) "Passée Jaspeuse" Formation, b) Bar Limestone, c) Lastva Radiolarite and transition to the Praevalis Limestone, d) Praevalis Limestone and Bijela Radiolarite, e, f) Globotruncana limestone. Legend same as Figure 8. Note that the columns are not drawn at the same scale. Numbers in brackets refer to UA Zones of Baumgartner *et al.* (1995).

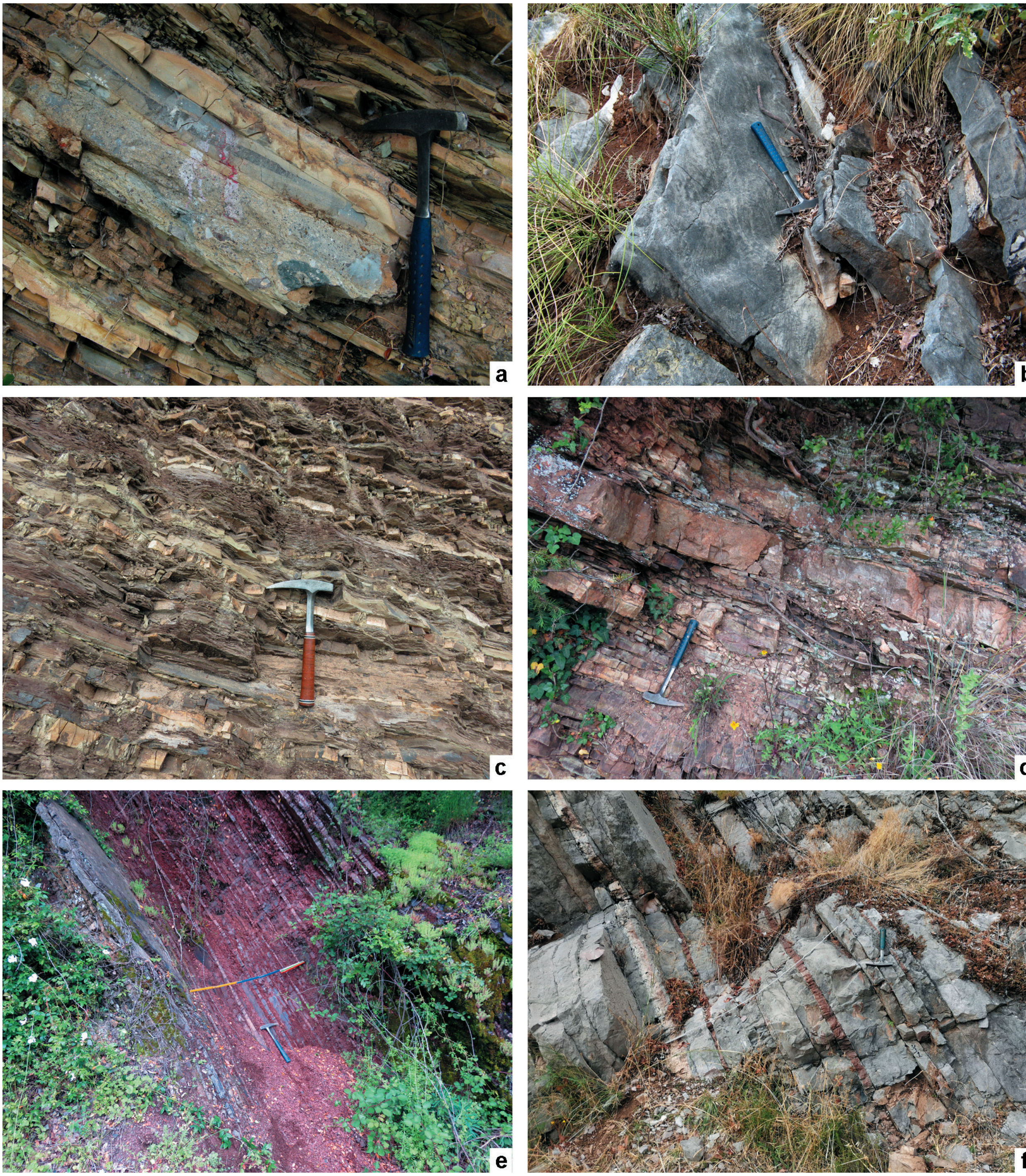


Figure 11: Jurassic and Cretaceous formations of the Gornja Lastva section.
a) Thin-bedded siliceous limestone and intra-formational breccia with chert and micrite clasts in the "Passée Jaspeuse" formation.
b) Ripple marks in the Lower Bar Limestone Member.
c) Variegated facies of the Lastva Radiolarite.
d) Upper variegated radiolarite with a decimeter-thick bed of silicified calcarenite.
e) Bijela Radiolarite. Albian part in which the proportion of shale is the highest.
f) Bedded calcarenite with chert at the base of the Globotruncana *limestone.*

tion (Figure 11a). Three poorly preserved radiolarian assemblages were analysed from this section (Figure 10a; Goričan 1994). The samples GL 105 and GL 109 contain *Pantanellium tanuense* Pessagno & Blome, which is regarded as a Hettangian index (Pessagno et al. 1987; Carter et al. 1998). Sample GL 4 above contains the genus *Wrangellium*, whose first appearance is documented in the Late Sinemurian (O'Dogherty et al. 2009b).

The overlying Bar Limestone (Figure 10b) mostly consists of classical turbidites that start with a graded calcarenite unit. A few tens of centimeters thick bed of clast-supported conglomerate to pebbly calcarenite rarely occurs at the base. On the other hand, fine-grained turbidites composed of base-absent Bouma sequences are common and make up more than 10 meters thick packages. The entire succession is organized in roughly three larger fining-upward sequences.

This section is the type section of the Lastva Radiolarite, which here consists of the complete sequence of different facies from the lower variegated facies at the base to the red ribbon radiolarite at the top (Figures 10c, 11c, d). The lowermost productive sample GL 123, found 40 m above the top of the Bar Limestone, correlates with UA Zone 2 (Upper Aalenian) of Baumgartner et al. (1995). The uppermost sample GL 138, collected 8 m below the boundary with the Praevalis Limestone is assigned to UA Zone 12 (Lower – lower Upper Tithonian). The age assignments of all other productive samples, expressed in UA zones of Baumgartner et al. (1995), are indicated in Figure 10c. The chronostratigraphy of individual radiolarite facies and their correlation with other sections of the Budva Zone is shown in Figure 9.

The contact with the overlying Praevalis Limestone (Figure 10d) is sharp. Only the lowermost beds of micrite limestone with replacement chert nodules still contain some marly interlayers and also a thin bed of carbonate breccia. The remaining 30 m of the Praevalis Limestone are free of resedimented carbonates and consist of 5–15 cm thick beds of white or light reddish to greenish micrite and up to 5 cm thick beds, lenses and nodules of dark red replacement chert. The replacement chert makes approximately 30% of the succession. Radiolarians in sample GL 139 at the base of the formation correlate to UAZ 13 of Baumgartner et al. (1995).

The boundary with the Bijela Radiolarite (Figure 10d) is transitional and poorly exposed. The thickness of beds decreases, the silica content is higher and marly interlayers are present again. Sample GL 214 contains *Aurisaturnalis variabilis* (Squinabol) that is characteristic of the Hauterivian to early Barremian age. Higher up, the section consists of thin-bedded chert and 40–60% shale (Figure 11e). Silicified calcarenites are interstratified in the upper 8 meters of the formation. Based on *Thanarla spoletoensis* O'Dogherty, sample GL 215 near the top of the radiolarite is assigned to the Albian–lowermost Cenomanian Spoletoensis Zone of O'Dogherty (1994).

The following 70 meters of the section start with thick-bedded (60–100 cm) calcarenite with a high content of replacement chert (Figure 11f). The first planktonic foraminifera were found in light pink micrite approximately 2 m above the last thick calcarenite bed (Figure 10e, sample GL 1). The remaining part of the section consists of an alternation of *Globotruncana*-bearing micrite, marly limestone, cherts layers and calcarenite. Micritic limestone without fossils is also common. Higher in the section, reddish *Globotruncana* limestone prevails. The section is divided into several red (RGL - Red *Globotruncana* Limestone) and white to light ocher (WGL - White *Globotruncana* Limestone) units. The preliminary analysis of the planktonic foraminifera suggests that the age of the lower RGL part (Figure 10e) is Early Campanian based on rare occurrence of *Globotruncanita stuartiformis* (Dalbiez), abundant *Contusotruncana fornicata* (Plummer), *Globotruncana linneiana* (d'Orbigny), *Globotruncanita elevata*, abundant specimens of the genus *Planoheterohelix*, and the absence of marginotruncanids. Planispiral forms are also very common. The uppermost RGL towards the end of the section has abundant *Globotruncanita plummere* (Gandolfi), *Globotruncana bulloides* (Vogler) and a lesser amount of *G. elevata* (Brotzen). *Contusotruncana walfischensis* (Todd) and *Radotruncana subspinosa* (Pessagno) are also present in some samples, suggesting Late Campanian age. Further and more detailed analyses are in progress (by A.K.).

The Gornja Lastva village is built on the *Globotruncana* limestone, which is the uppermost stratigraphic unit at this locality. The Vrmac Mountain above the village belongs to the upper thrust sheet of the Budva Zone.

Stop 2: Petrovac

Lower tectonic unit, Upper Triassic to upper Aptian–lower Albian.

Location: near Petrovac, along the road from Petrovac to Podgorica, at the junction with the littoral road Budva – Bar; the section starts at N 42°12'39", E 18°56'41", Basic Geological Map sheet Budva (Antonijević et al. 1969).

The measured section consists of 35 m of the "Passée Jaspeuse", 50 m of the Bar Limestone, approximately 30 m of the Lastva Radiolarite and approximately 50 m of the Praevalis Limestone in contact with the Bijela Radiolarite (Figures 12a–d). This succession is part of the reversed limb of a syncline, which, in addition, is intensely folded internally.

The Triassic cherty limestone at this section is well exposed in a thickness of nearly 150 m and ranges from the Middle Triassic to the Rhaetian (Cafiero & De Capoa Bonardi 1980, 1981; Goričan 1994). The "Passée Jaspeuse" contains a relatively high proportion of carbonate and is lighter in colour than in the other sections. The transition with the underlying and also with the overlying formation is thus more gradual. The sample PK 20 near the top of the formation (Figure 12a) includes the genus *Gigi*, whose FAD is in the Lower Pliensbachian (O'Dogherty et al. 2009b). It is thus possible that the "Passée Jaspeuse" ranges to the base of the Pliensbachian.

The Bar Limestone is only 50 m thick and consists of fine, often faintly laminated cherty limestone with thin interbeds of marl. In the slightly reddish upper part, bioturbation is frequent. The entire sequence is characterized by a uniform basin-plain facies association.

The overlying green and violet shale is supposedly Early Toarcian in age (Figure 13). A breccia, consisting of large blocks of limestone, radiolarite and shale follows upsection. It wedges out in a distance of a few meters. Blocks and clasts of Upper Triassic limestones are the most abundant and evoke the Hallstatt Limestone of the Northern Calcareous Alps. The Lower Norian components consist of grey radiolarian-filament bearing wackestones and correspond to the Massiger Hellkalk. The upper Lower Norian to Middle Norian components are red radiolarian-filament limestone with small chert nodules corresponding to the Hangendrotkalk. The Upper Norian to Lower Rhaetian components are radiolarian wackestones with rare filaments corresponding to the Hangendgraukalk. Rhaetian conodonts appear in grey siliceous radiolarian-rich wackestones. Spicules-rich grey siliceous components are most likely of Early Jurassic age. The reworked sed-

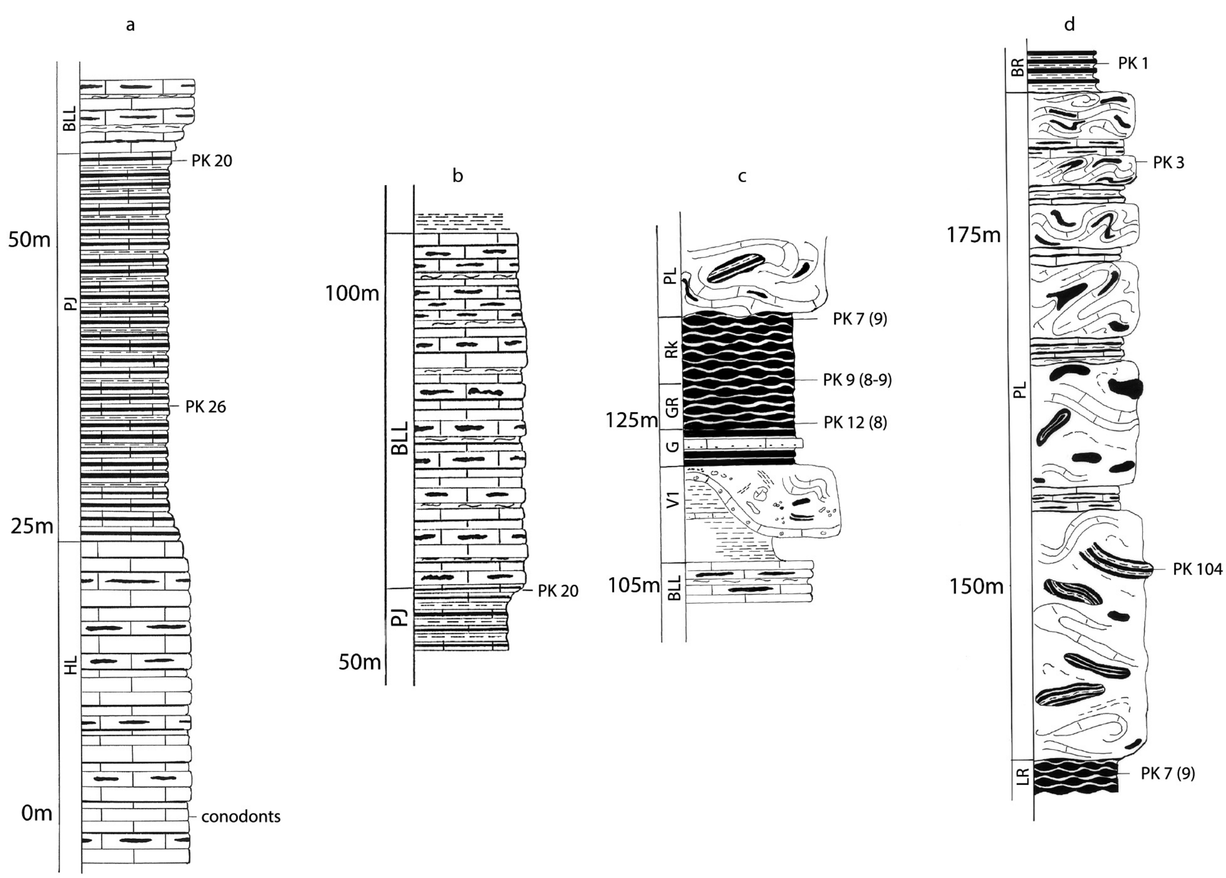


Figure 12: Lithological columns of the Petrovac section (Stop 2). a) "Passée Jaspeuse" Formation, b) Bar Limestone, c) Lastva Radiolarite and base of the Praevalis Limestone, d) Praevalis Limestone and base of Bijela Radiolarite. Legend same as Figure 8. Note that the columns are not drawn at the same scale. Numbers in brackets refer to UA Zones of Baumgartner et al. (1995).

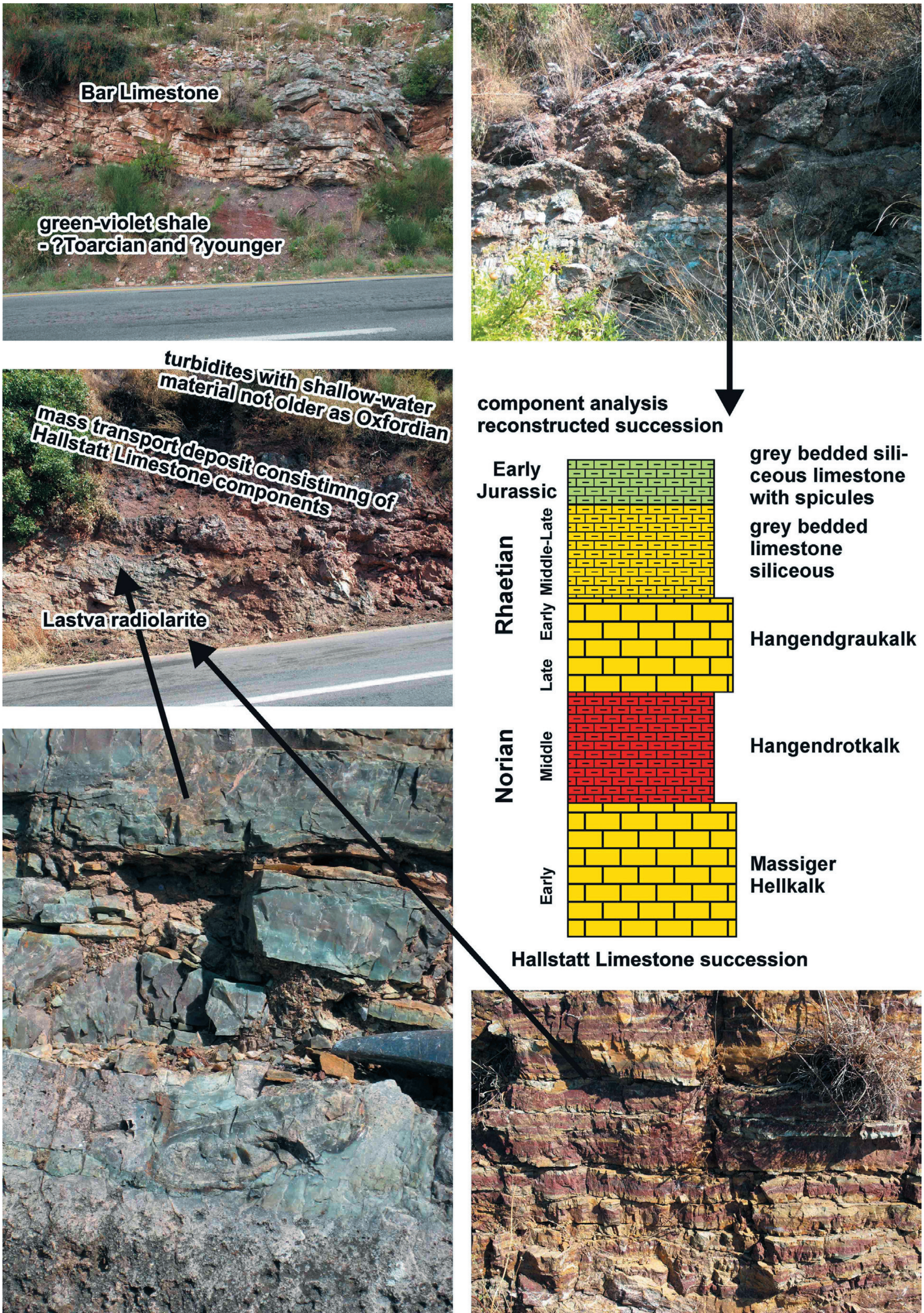


Figure 13: Jurassic formations of the Petrovac section and reconstruction of the Upper Triassic succession reworked in the Jurassic breccia. Explanation on the photographs. Note the section is in overturned position.

imentary sequence resembles a classical Hallstatt Limestone succession as known in the whole western Tethys realm (Krystyn 2008). Redeposition of this Hallstatt Limestone sequence is age equivalent with the Hallstatt Mélanges known in all mountain ranges in the eastern Mediterranean (Gawlick & Missoni 2019 and references therein). Similar Hallstatt Limestone successions are also known in the Budva unit, e.g. in the Čanj embayment (Gawlick & Missoni 2015). Below the mass transport deposit with the Hallstatt Limestone components turbiditic layers with ooids and other shallow-water grains, including *Protopeneroplis* sp., occur.

The Lastva Radiolarite consists of three facies: green, green-red knobby and red knobby radiolarite and ranges from UA Zone 8 (middle Callovian – early Oxfordian) in sample PK 12 to UA Zone 9 (middle–late Oxfordian) in sample PK 7 (Figure 12b). These data clearly show that the base and the top of the radiolarite sequence are cut-off (Figure 9).

The most conspicuous feature of the Petrovac section is thick chaotic beds of the Praevalis Limestone (Figure 12d). They are 1 m to several meters thick, separated by a few tens of centimeters of undisturbed bedded limestone. The encompassed cherts show considerable deformation; they have a form of ruptured, folded layers or rotated nodules (Figures 14a, b). In the lower part of the section, up to 1 m large clasts of Tithonian ribbon radiolarite are incorporated in these megabeds (Figure 14a). The chaotic beds at Petrovac are interpreted as highly evolved slumps to debris-flow deposits, which moving downslope eroded the underlying sediments. The base of the overlying Bijela Radiolarite (sample PK 1) is assigned to the upper Aptian-lower Albian based on *Turbocapsula costata* (Wu).

Stop 3: Čanj

Lower tectonic unit, Rhaetian to Campanian.

Location: two nearby localities near the tourist village Čanj: Pečinj Bay (N 42°09'40", E 18°59'30" E) for the Rhaetian to Pliensbachian, Čanj Beach (N 42°09'45", E 18°59'43") for the Middle Jurassic to Upper Cretaceous; Basic Geological Map sheets Budva (Antonijević et al. 1969) and Bar (Mirković et al. 1968).

The section consists of the *Halobia* limestone, 30 m of the "Passée Jaspeuse", 150 m of the Bar Limestone, 80 m of the Lastva Radiolarite (including a 20 m thick unit of resedimented carbonates), 20 m of the Praevalis Limestone, approximately 50 m of the Bijela Radiolarite, and more than 30 m of the *Globotruncana* limestone (Figures 15a–e).

The *Halobia* limestone consists of cherty micrite and fine-grained resedimented limestone beds (Figure 16a). Slump and intra-formational debris-flow deposits containing clasts of red chert occur in the upper part (Figures 15a, 16b). Thin marly intercalations are common between pelagic limestone beds. The overlying "Passee Jaspeuse" is an easily mappable dark brownish-reddish unit of siliceous limestone alternating with shale (Figures 16 c–e). Texturally, these highly siliceous limestones are mostly calcisiltites or mudstones to packstones containing radiolarians. A few beds with clasts of siliceous limestone are present in the middle part of the formation where slump folds also occur and the amount of interstratified shale is the highest (Figure 15a). Near the top of the "Passée Jaspeuse", the limestone beds are thicker and the carbonate content is higher.

A detailed 20 m thick section across the boundary between the *Halobia* limestone and the "Passée Jaspeuse" was measured and sampled bed by bed for radio-

Figure 14: Lower Cretaceous Praevalis Limestone Formation, Petrovac section.
a) Large clasts of Tithonian ribbon radiolarite in the lower part of the formation (at 152 m in the lithological column, Figure 12d).
b) Folded chert layers and rotated nodules float in a deformed micritic matrix (at 160 m in the lithological column, Figure 12d).

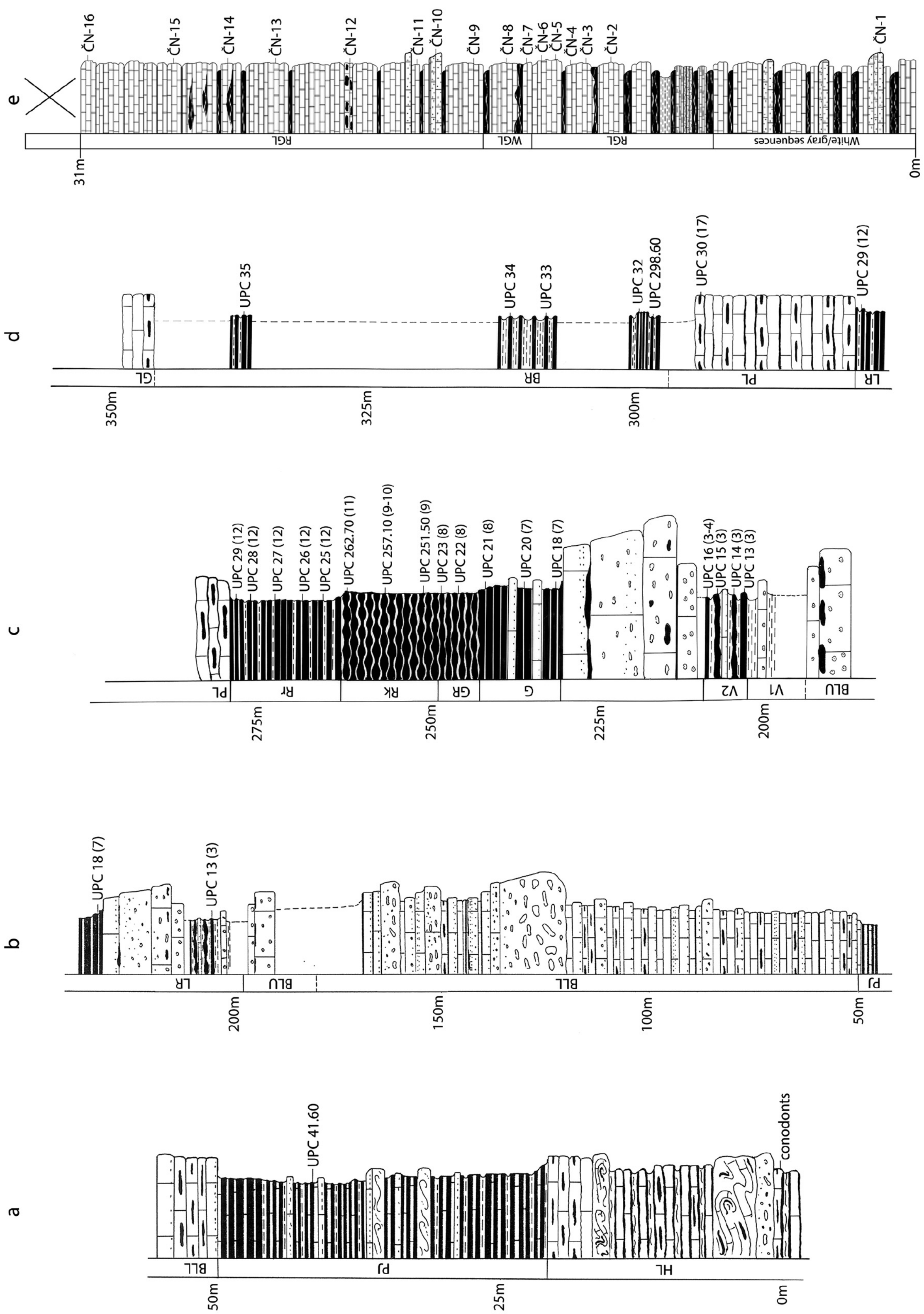


Figure 15: Lithological columns of the Čanj section (Stop 3). a) “Passée Jaspeuse”, b) Bar Limestone, c) Lastva Radiolarite, d) Praevalis Limestone and Bijela Radiolarite, e) Globotruncana limestone. Legend same as Figure 8. Note that the columns are not drawn at the same scale. Numbers in brackets refer to UA Zones of BAUMGARTNER *et al. (1995).*

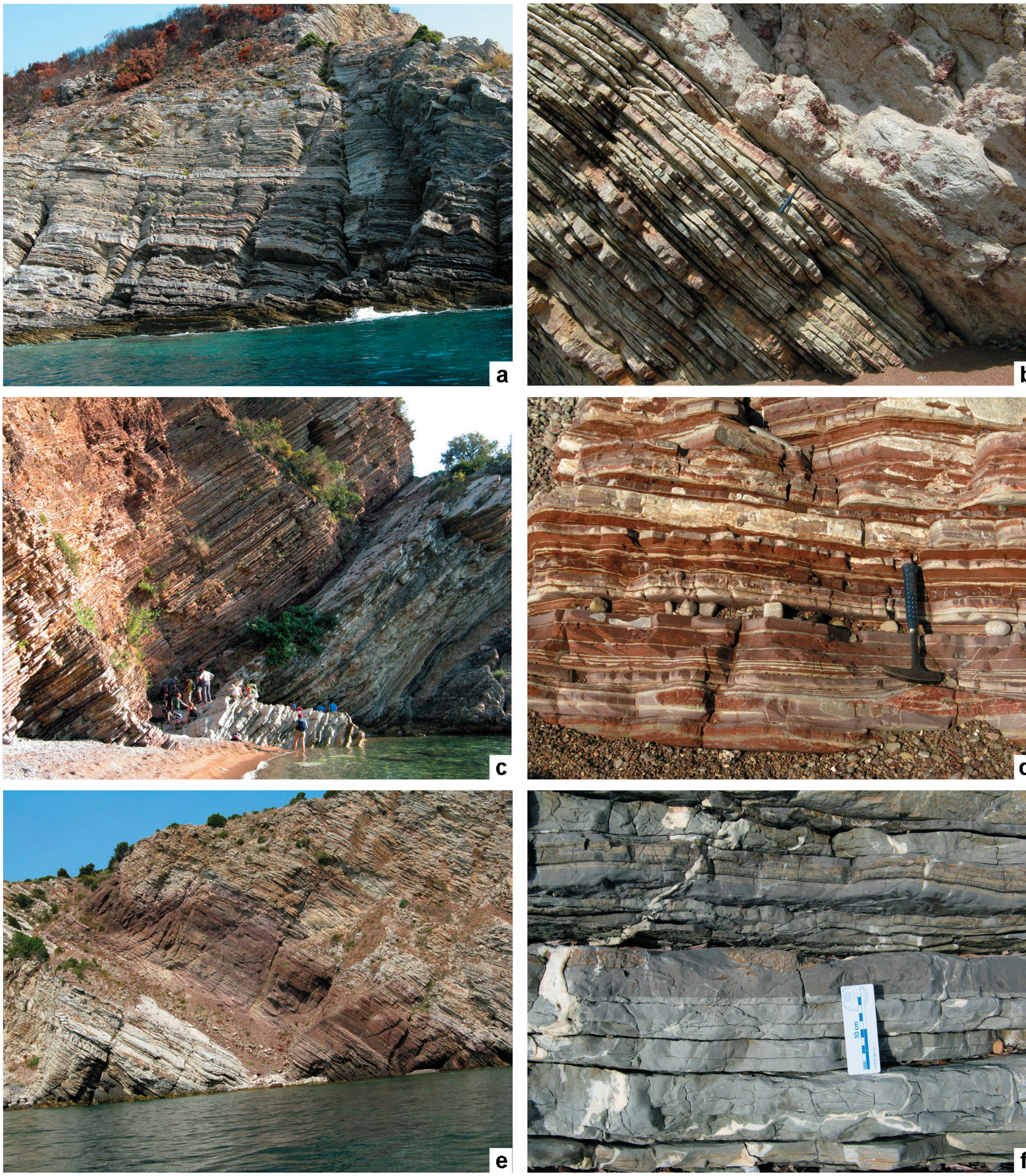


Figure 16: Upper Triassic and Lower Jurassic formations of the Čanj section.
a) Halobia *limestone; micrite with chert nodules.*
b) Closer view of the Halobia *limestone 20 m below the boundary with the "Passée Jaspeuse". Limestone beds separated by thin marly interlayers; base of an intraformational debris-flow conglomerate with clasts of red chert visible on the right.*
c) Well-exposed contact between the Halobia *limestone and the "Passée Jaspeuse". The section of Figure 17 was measured at this outcrop.*
d) Siliceous limestone and marl of the "Passée Jaspeuse".
e) The brownish unit in the middle part of the photograph is the 30 m thick "Passée Jaspeuse", which lies between the Halobia *limestone below and the Bar Limestone above.*
f) Lime-mud dominated turbidites in the lower part of the Lower Bar Limestone Member.

larians and stable carbon isotope analyses (Črne et al. 2011). The sharp lithological boundary coincides with the Triassic–Jurassic boundary as determined with radiolarians of the *Globolaxtorum tozeri* Zone near the top of the *Halobia* limestone and radiolarians of the *Canoptum merum* Zone at the base of the "Passée Jaspeuse" (see Figure 17 for the position of productive radiolarian samples). Faunal changes across the system boundary are comparable to those recognized in Haida Gwaii, British Columbia, and in Japan (Carter & Hori 2005; Longridge et al. 2007). A negative spike in the stable carbon isotope curve, measured in bulk carbonate and in bulk organic matter, was detected at the very base, in the boundary shales of the "Passée Jaspeuse" and is coincident with the rapid drop in carbonate content from more than 80 % to less than 10 % (Figure 17). The contemporaneous negative anomaly in both, bulk carbonates and bulk organic matter, as well as the comparison with other stable carbon isotope records across the Triassic–Jurassic boundary confirm that the anomaly reflects a global perturbation of the carbon cycle. The simultaneous drop in carbonate content can be a result of accelerated carbonate dissolution, or more probably a consequence of reduced carbonate input due to a biocalcification crisis. A biocalcification crisis *sensu lato* includes not only a

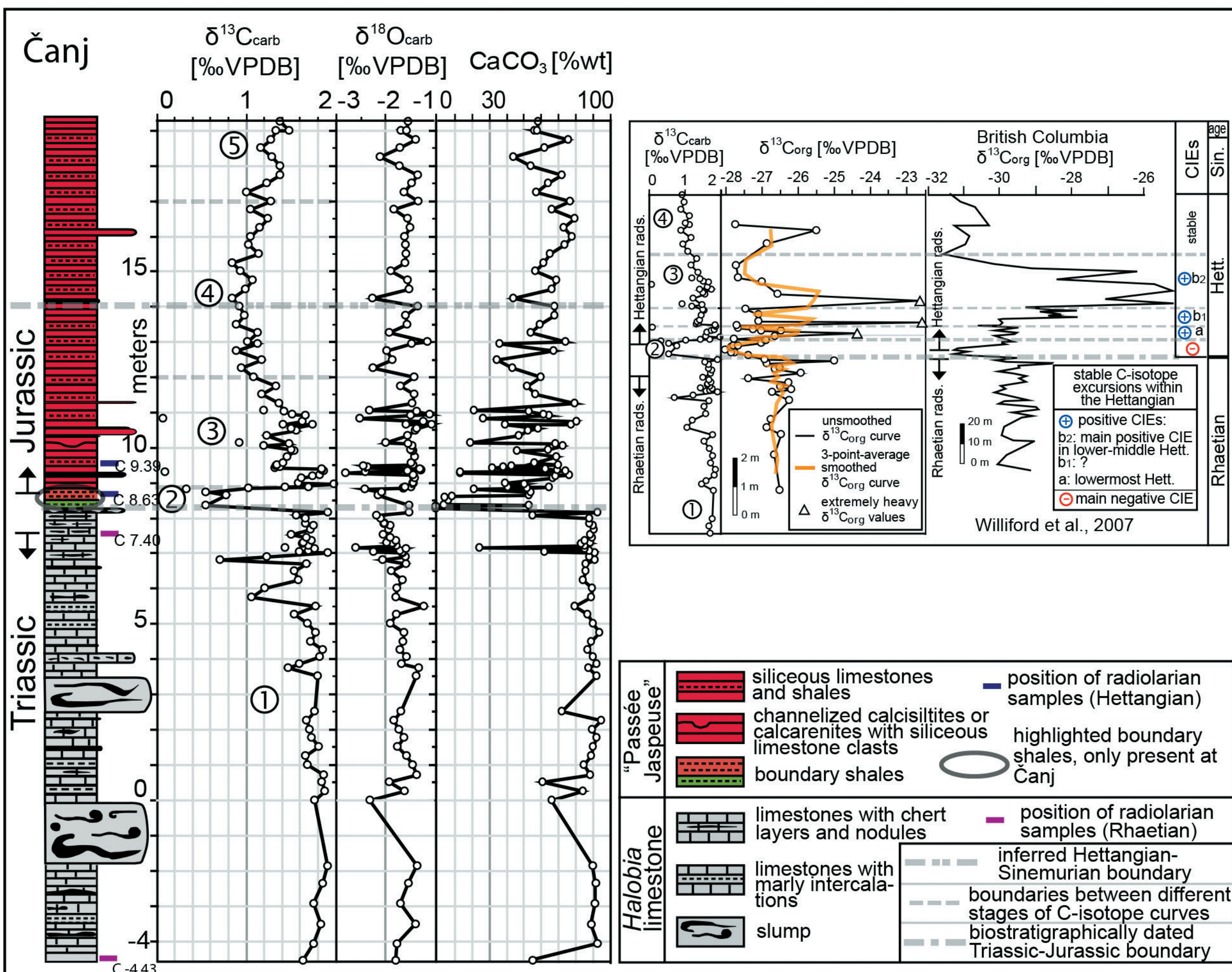


Figure 17: (reproduced from Črne et al. 2011):
Detailed stratigraphic log of the Triassic–Jurassic boundary section with stable carbon and oxygen isotope curves, carbonate content curves and marked position of radiolarian samples (red and blue bars with sample numbers). The intervals of the carbon isotope curve (1–5) were correlated with the published curves; the position of the Hettangian–Sinemurian boundary, 5.5 m above the Triassic–Jurassic boundary is based on this correlation.
Upper right frame: Stable carbon isotope curves for bulk carbonate (δ13Ccarb) and bulk organic matter (δ13Corg) from Čanj section and comparison with stable carbon isotope curve from bulk organic matter in British Columbia (Williford et al. 2007). The Triassic–Jurassic boundary of both sections is precisely dated with radiolarians.

lowered production of shallow-water carbonate but also a change in the carbonate production mode from skeletal to microbial, which would have equally led to reduced offshore shedding. Both scenarios are compatible with increased CO_2, SO_2 and CH_4 fluxes due to the Central Atlantic magmatic province volcanism causing undersaturation of ocean with respect to calcium carbonate (see Črne et al. 2011, for more details).

The lower half of the Lower Bar Limestone Member (Figure 15b) is dominated by fine-grained turbidites organized in base-cut-out Bouma sequences (Figure 16f). Medium-grained turbidites prevail in the upper part. Four levels of clast-supported conglomerates capped by normally graded pebbly mudstone are intercalated. The thickest conglomerate bed reaches 16 m and consists of large (up to 20x50 cm) densely packed calcilutite clasts (when visiting this stop, note that some plurimetric blocks broken off the thickest conglomerate unit are nicely exposed on the beach). These conglomerate levels are distal equivalents of disorganized debris-flow breccias exposed at the Sutomore section, which is located in close vicinity but is part of the upper tectonic unit (see figure 2.2 in Goričan 1994, for the correlation of these two sections).

The Upper Bar Limestone Member, well distinguished by its pure oolitic limestone beds constitutes a few-meters thick unit above a covered interval and below the first outcropping radiolarian chert (Figure 15b). Another 20 m thick unit of oolite, coarse-grained graded conglomerate and calcarenite is interstratified in the Lastva Radiolarite (Figures 15b, c); this unit was

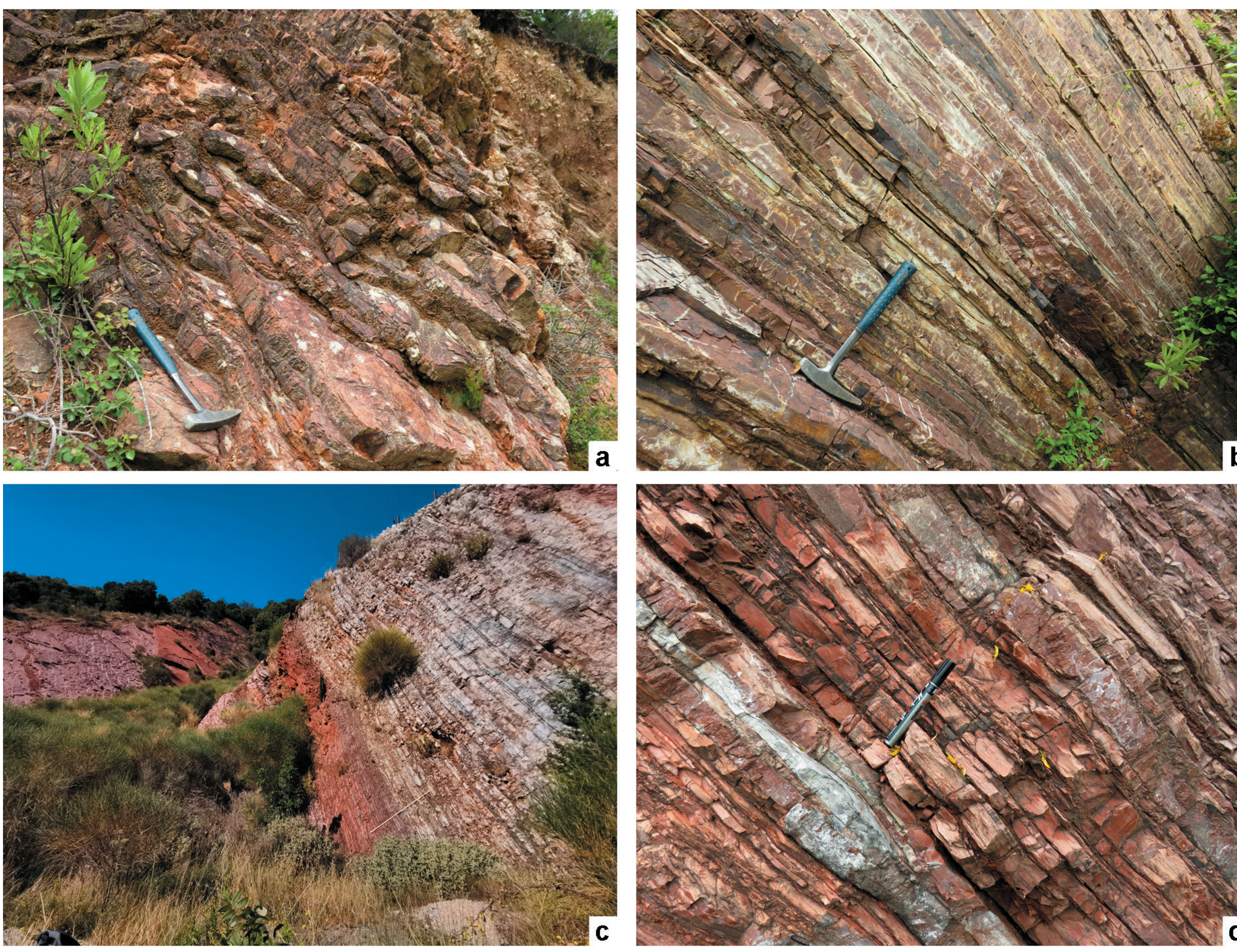


Figure 18: Upper Jurassic and Upper Cretaceous formations of the Čanj section.
a) Lastva Radiolarite Formation, red knobby radiolarite, Oxfordian–Kimmeridgian.
b) Lastva Radiolarite Formation, red ribbon radiolarite, Lower Tithonian.
c) Red and white units of the Globotruncana *limestone. The red limestone visible as dip slope in the background belongs to the Lower Cretaceous Praevalis Limestone. The mostly covered depression between the two formations corresponds to the Bijela Radiolarite.*
d) Siliceous limestone of the lower red unit of the Globotruncana *limestone.*

interpreted as a single compound gravity-flow deposit. Middle–late Bajocian radiolarians (UAZ 3 of Baumgartner et al. 1995) were found in the variegated radiolarite below the oolite. Latest Bathonian–Callovian radiolarians (UAZ 7 were found in the green radiolarite above. The remaining few meters of green radiolarites, also assigned to UAZ 7, include beds of silicified calcarenite, but the following red-green and red radiolarites (Figures 18a, b) are devoid of resedimented carbonates. The uppermost sample collected in red ribbon radiolarite 0.5 m below the boundary with the Praevalis Limestone belongs to the Lower to lower Upper Tithonian UAZ 12. For the age assignments of all productive radiolarian samples, expressed in UA zones see Figure 15c. The chronostratigraphy of individual radiolarite facies and their correlation with other sections of the Budva Zone is shown in Figure 9.

The Praevalis Limestone consists of reddish micrite with red replacement chert lenses. The overlying Bijela Radiolarite is poorly exposed; its thickness was estimated to 50 meters (Figure 15d). The radiolarian assemblage in sample 298.60 near the base of the formation contains *Aurisaturnalis carinatus perforatus* Dumitrica & Dumitrica Jud, whose range is restricted to the Upper Barremian – Lower Aptian (Dumitrica & Dumitrica Jud 1995). The topmost sample contains *Hemicryptocapsa polyhedra* Dumitrica and *Afens liriodes* Riedel & Sanfilippo that first appear in the lower Turonian (O'Dogherty 1994) together with abundant *Pseudodictyomitra pseudomacrocephala* (Squinabol) that last appears in the Turonian (Pessagno 1977). The Turonian age is the youngest age recorded in the Bijela Radiolarite (Figure 9). In comparison with other sections so far studied in the Budva Zone, the Čanj section is the only section where the entire Berriasian to Turonian succession consists exclusively of distal pelagic facies (radiolarite and pelagic limestone) without carbonate gravity-flow deposits.

The overlying *Globotruncana* limestone is subdivided into several reddish to light pink and white units (Figures 15e, 18c, d). The studied section is 31 m thick and starts with several 10 cm to 18 cm thick layers of white-gray micrite. Upward, these limestone layers reach thickness of up to 70 cm and are interbedded with thin horizons of dark gray chert and layers of resedimented carbonates up to 20 cm thick (Figure 15e; White/gray sequences). The occurrence of Upper Cretaceous planktonic foraminifera in this part of the section is rare. The exception is the first resedimented carbonate layer (Figure 15e; ČN-1), where the assemblage of planktonic foraminifera such as *Globotruncanita elevata* (Brotzen), the high abundance of *Globotruncana linneiana* (d'Orbigny), and the low abundance of *Globotruncanita stuartiformis* (Dalbiez) indicate the Early Campanian age. The following unit is an 8.4 m thick package of alternating reddish and light pink micrite (up to 20 cm thick), thin layers of reddish marly limestones, and layers of gray to reddish chert up to 30 cm thick. Planktonic foraminifera were not found in these beds. The following sequence is composed of reddish to light pink *Globotruncana* limestones (RGL), red chert beds and pink calcarenite layers with red grains. This RGL section is interrupted once by a 1.5 m thick sequence of white-grey to light ocher *Globotruncana* limestone and chert (WGL). The first occurrence of *Globotruncanita atlantica* (Caron) in the lower RGL section (Figure 15e; ČN-6) confirms the Early to Middle Campanian age. In the WGL beds (Figure 15e; ČN-8) zonal marker *Contusotruncana plummerae* (Gandolfi) appears for the first time and is present throughout the upper RGL section along with abundant *Globotruncanita stuartiformis* (Dalbiez) and decreased amount of *G. elevata* (Brotzen), suggesting the Late Campanian age. The research on the Upper Cretaceous of the Budva Zone is in progress (by A.K.). Since Coniacian and Santonian ages have not been documented, we plan to examine more closely especially the transition from the Bijela Radiolarite to the *Globotruncana* limestone.

Stop 3-supplement: Čanj center

Middle Triassic chert in a thrust sheet above the main Čanj section.

Location: Čanj village, in front of hotel Jadranski Biser (N 42°09'46", E 18°59'38"). Basic Geological Map, sheet Bar (Mirković et al. 1968).

Ladinian radiolarites occur in a deep-water succession, comparable to the succession of the outer shelf facies in the Northern Calcareous Alps and Inner Dinarides (stratigraphic log in Figure 19). Radiolarians of the Upper Ladinian *Muelleritortis cochleata* Zone (Kozur & Mostler 1994) were found in the red radiolarian cherts.

Stop 4: Markovići

Lower tectonic unit, Middle Triassic.

Location: on the road from Budva to Cetinje, about 8.5 km NE from Budva (N 42°18'06", E 18°51'25", Basic Geological Map sheet Budva (Antonijević et al. 1969).

The section consists of three units – the Tuđemili Formation in the lower part, a megabreccia in the middle, and tuffitic layers of Pietra Verde in the upper part of the section (Figure 20).

The Tuđemili Formation in this section is represented by alternation of fine calcarenites with marly layers, 19 meters in thickness, representing the distal part of this formation. Otherwise very fossiliferous, the outcrop of this formation in Markovići does not contain any megafossils. In other localities the formation is well dated with crinoids, bivalves and brachiopods (Dimitrijević 1967), and recently with ammonoids (Đaković 2018) of Pelsonian age.

Overlying the Tuđemili Formation is a megabreccia, 8 meters thick. The matrix of this bed is a gray clayey-marly sediment, similar to marls of the underlying Tuđemili Formation. Blocks in this bed are built of Permian reefal limestones (Krystyn, personal communication) along with crinoidal and brachiopod limestones, nodular limestones with ammonoids, shallow water limestones etc., all of Anisian age. A block of nodular limestone contains ammonoid species *Gymnites toulai*, *Metasturia gracilis*, *Acrochordiceras* sp. etc., of Pelsonian age (Đaković, unpublished). Considering that the limestones blocks from this megabreccia do not contain any fossils younger than Pelsonian, the assumed age of the matrix is Illyrian.

The upper part of the succession is separated by a subvertical fault from the underlying breccia and is built of green tuffs, the so-called Pietra Verde, approximately 30 m thick. This uniform series contains rare interlayers of chert or limestone, but without recognizable fossils in the Markovići section. As already indicated, Cafiero & De Capoa Bonardi (1980) described bivalves of latest Ladinian age from the uppermost part of this sequence in Bečići.

The section ends at a thrust contact with the Bijela Radiolarite. A sample in this radiolarite contained *Pseudodictyomitra macrocephala* (Squinabol) and other typical mid-Cretaceous taxa. No radiolarians have so far been extracted from the Triassic rocks of the Markovići section.

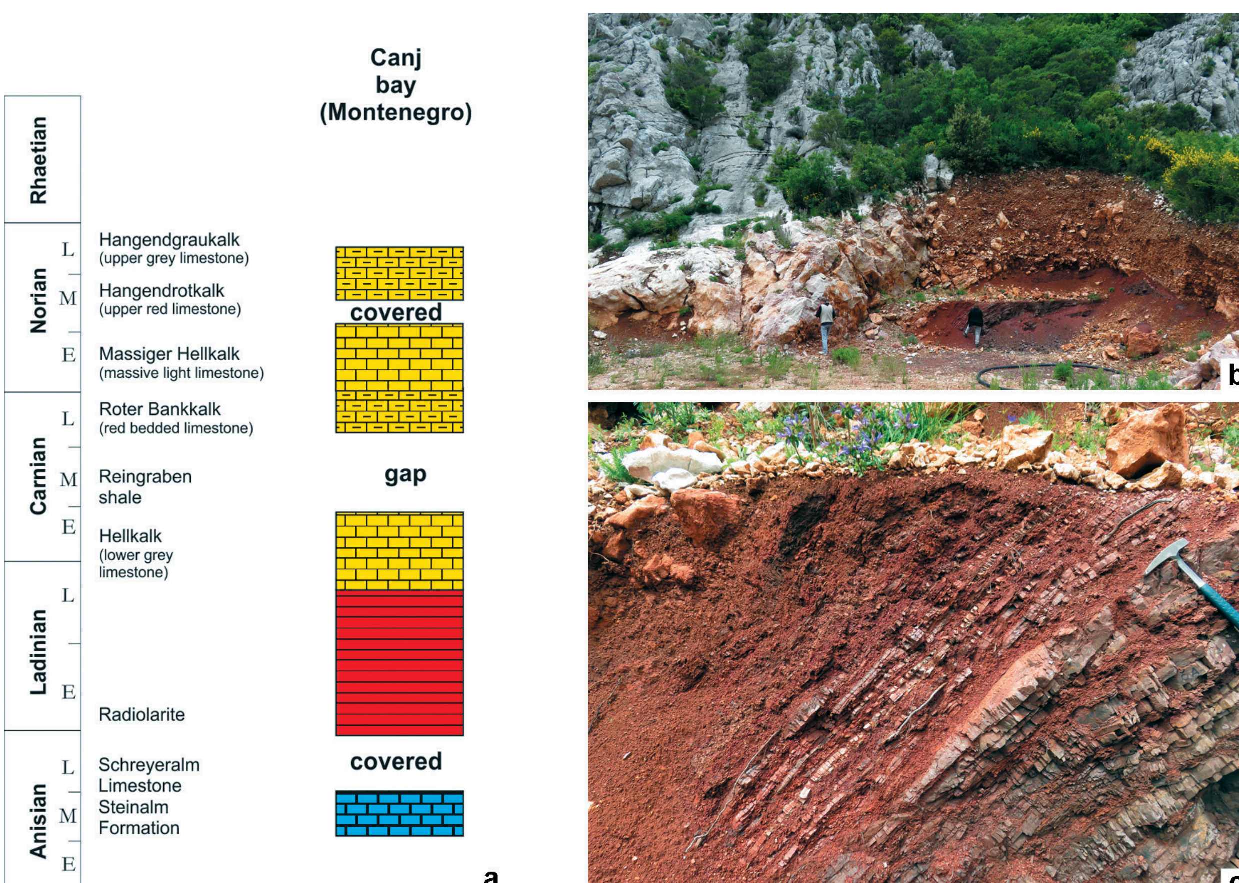


Figure 19: Triassic radiolarite in the center of village Čanj. Stratigraphic position (a), general view (b) and detail of the outcrop (c). The lithological column (a) according to Gawlick & Missoni (2015).

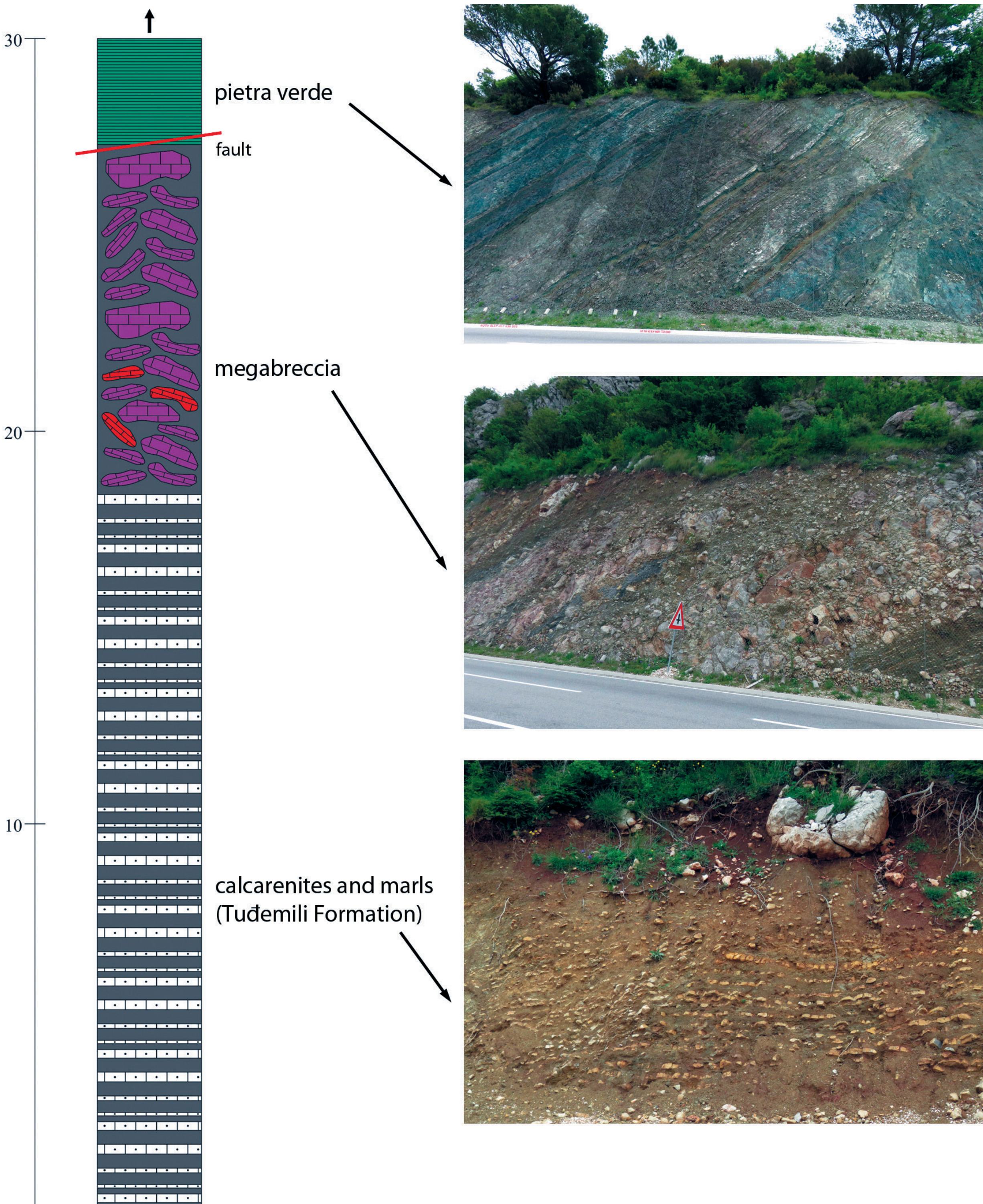


Figure 20: Lithological column of the Markovići section and field photographs of the three stratigraphic units.

Sedimentary evolution of the Budva Basin and correlation with the High Karst Carbonate Platform

Different localities across the Budva Zone preserve Mesozoic carbonate-gravity flow deposits as well as fully pelagic sequences. The correlation among these successions allows us to make inferences on local factors controlling the carbonate supply from the adjacent platform, and on regional Tethyan-wide paleoceanographical conditions affecting pelagic sedimentation.

During the Early Triassic, the areas of the present Budva and High Karst zones were occupied by a uniform sedimentation of red marine sandstones, dolomites and marly limestones (Živaljević 1989). The differentiation of this paleogeographic realm started in the Anisian with the deposition of limestone conglomerates (the Crmnica Formation) and mixed carbonate-siliciclastic Tuđemili Formation formerly known under the name "Anisian flysch". These deposits are overlain by volcanic and volcaniclastic rocks associated with limestone and chert.

A different opinion on the onset of subsidence was recently proposed by Krystyn et al. (2019) describing deeper water facies in the Lower Triassic of the Budva Zone, containing conodonts and ammonoids (Đaković et al. 2022). These sediments differ from time equivalent Werfen type deposits that can be found withing the High Karst in Brajići (Antonijević 1969) or elsewhere in the Dinarides (e.g. Aljinović et al. 2018). This would imply that the Budva Basin was already differentiated from the High Karst zone in the Smithian and that Crmnica and Tuđemili formations belong exclusively to the Budva Zone (Krystyn et al. 2019). Cherty limestones of Bithynian age, containing ammonoids and conodonts, have also been described from the Budva Zone (Đaković et al. 2018), representing a deeper water facies than the time equivalent rocks of the High Karst Zone (e.g. Čađenović et al. 2014).

The Budva Basin remained a deep-sea trough through the entire Mesozoic. In the Triassic and Jurassic, the great majority of carbonate mud in deep-sea sediments was of platform origin. It was not until the latest Jurassic that calcareous nannoplankton had their first bloom and not until mid-Cretaceous that planktonic foraminifera became an important component of pelagic limestones. The proportion of biogenic silica in sediments of deep continental-margin basins was thus primarily determined by the amount of lime mud shed from the adjacent platforms; this platform/basin correlation is well perceivable in Mesozoic deposits of the Budva Zone (Figure 21).

The prominent Rhaetian–Hettangian facies change from pelagic limestones to carbonate-poor siliceous deposits is correlated to the facies change on the margin of the High Karst Carbonate Platform, where the thick-bedded Upper Triassic Dachstein limestone with abundant Rhaetian fauna is overlain by medium-bedded Lower Jurassic micritic limestones containing almost exclusively peloids and only rare foraminifera (Črne & Goričan 2008). This facies change marks the drowning of the southwestern part of the High Karst Carbonate Platform. The drowning event on the platform margin was possibly amplified by accelerated tectonic subsidence and a sea-level rise.

The carbonate production on the platform was restored by the end of the Sinemurian. The margin of the High Karst Carbonate Platform was a southwest dipping ramp with lithiotid limestones in the inner ramp, peloidal packstones in mid-ramp and peloidal packstones with abundant chert in outer ramp; ooid banks formed in the mid-ramp setting in times of warm climate and high sea-level temperatures, i.e. in the late Early Pliensbachian (Črne 2009). During the Early Toarcian, the platform margin was flooded again; marls and marly limestones accumulated. The recovery phase from the middle Toarcian to the Aalenian was marked by deposition of bioclastic limestone with echinoderm fragments, brachiopods and filaments (Črne & Goričan 2008; Črne 2009).

The Early Toarcian flooding corresponds to the boundary between the Lower and the Upper Bar Limestone members. The Upper Member differs from the Lower Member by a higher proportion of ooids, coarser grain-size, thicker bedding and less lime-mudstone beds associated. Thick pure oolitic beds are present. Laterally, it is less expanded than the Lower Member (Figure 21). The differences in composition and lateral distribution were caused by a reorganization of the platform margin after the Toarcian. The Pliensbachian low relief carbonate ramp with smaller discontinuous oolitic shoals supplied large volumes of detritus to the relatively gentle slope and to the basin. The Middle Jurassic platform margin, in contrast, was dominated by oolitic bars (Radoičić 1982), which provided the major platform component displaced to the basin. In addition, they seem to have trapped and hampered the transport of lagoonal-mud offshore. As a consequence, the gravity flows travelled shorter distances, produced steeper slopes, and allowed the accumulation of lime-free radiolarite (Lastva Radiolarite) distally.

A radical change in platform margin architecture took place at the beginning of the Late Jurassic with the development of a coral-stromatoporoid reef complex (Radoičić 1982). Early cementation welded the reef margin into a rigid wave-resistant mass, which efficiently blocked the offshore sediment transport. The Oxford-

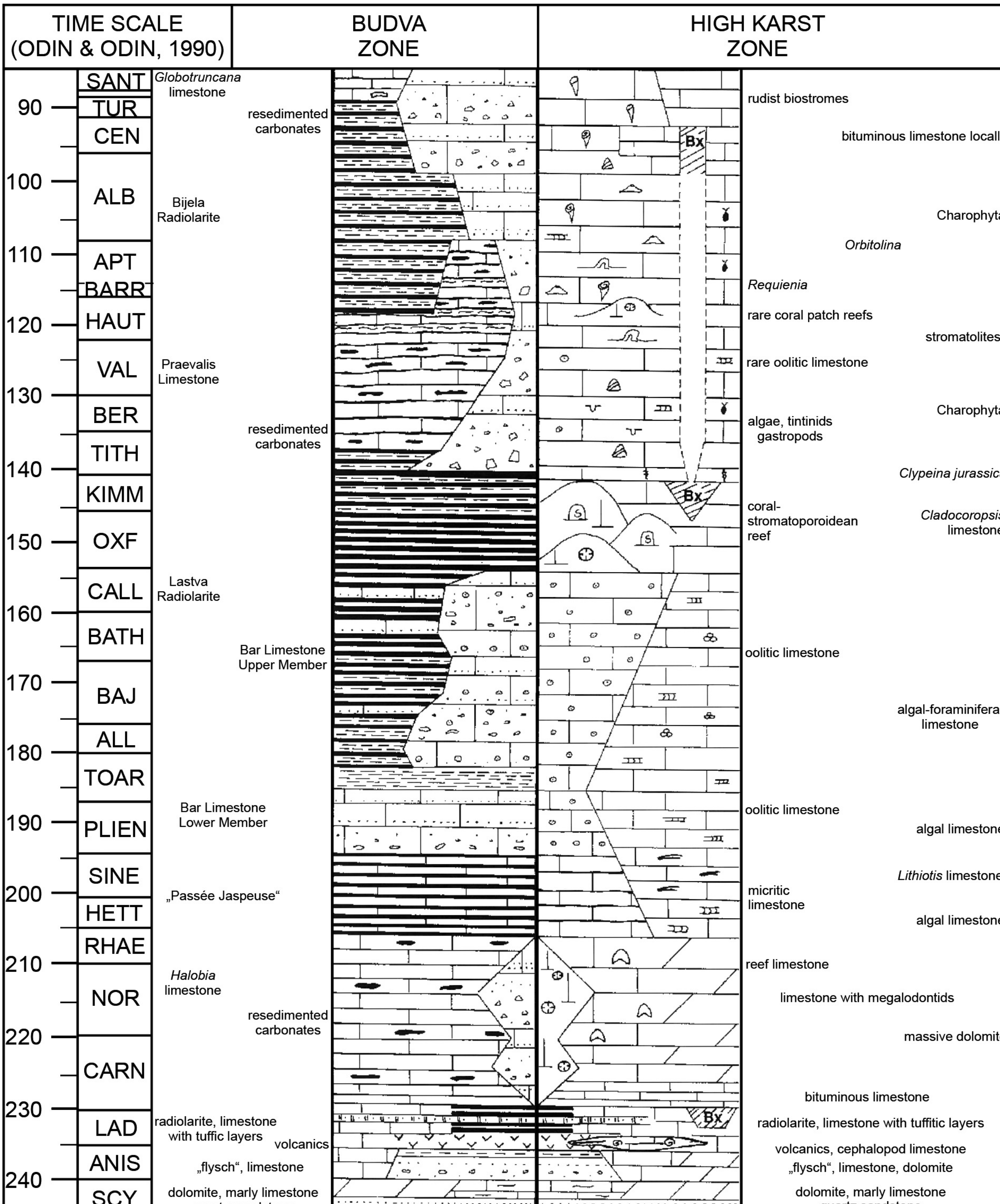


Figure 21: Basin-platform facies relationship through time between the Budva Basin and the High Karst Platform (from Goričan 1994).

ian-Kimmeridgian time interval was therefore a period of most widely expanded radiolarite sedimentation. Distal sequences, characterized by lime-free deposition from the Middle Jurassic, recorded a drastic reduction of interstratified calcarenites.

Green radiolarites, wide-spread in the Budva Basin before the Oxfordian, were replaced by red radiolarites in the Late Jurassic times. This facies change was diachronous; oxygen depleted conditions persisted longer in near-platform areas (Figures 9, 21). The Budva Basin is comparable to the Recent Guaymas Basin, Gulf of California, with the basin sill situated below the core of oxygen minimum layer (Ingle 1981). The progressive change to more expanded oxygenated conditions through the Late Jurassic may have been a result of progressively increasing bottom water circulation or lowered productivity and hence a thinner oxygen minimum layer.

In the Late Jurassic, the composition and distributional pattern of resedimented carbonates changed significantly. Prior to that time, carbonate gravity flow deposits were composed of remobilized pelagic sediments and penecontemporaneous platform debris. Contrary to this, since the Tithonian the bulk of the resedimented carbonates was derived from the erosion of lithified shallow water limestones. This facies change is related to the evolution from an extensional to a compressive regime, which, in the external zones of the foreland system induced a differential uplift of the High Karst Platform. The uplift is inferred from several charophyte-bearing horizons and well documented Upper Jurassic and mid-Cretaceous bauxite deposits (Figure 21).

During the Jurassic and Cretaceous, two different depositional areas could be recognized along the axis of the Budva Basin and, since the Tithonian, the discrepancies between the north-western and the south-eastern area were more pronounced. Abundant coarse-grained resedimented carbonates became restricted to the north-western depositional area, whereas in the south-eastern area pelagic to hemipelagic carbonates prevailed even in the environment close to the carbonate platform (Figure 22). These differences along the basin axis correlate well with the distribution of bauxite deposits, which are limited to only a part of the High Karst Zone NW of Podgorica (Burić 1966) and suggest that the tectonic uplift was more pronounced in the NW than in the SE part of the High Karst Platform.

Facies changes in distal successions of the Budva Basin reflect regional paleoceanographic conditions. In the late Tithonian, radiolarian cherts were replaced by pelagic limestones (Praevalis Limestone). In the Hauterivian–Barremian, inversely, radiolarite sedimentation (Bijela Radiolarite) replaced pelagic carbonates

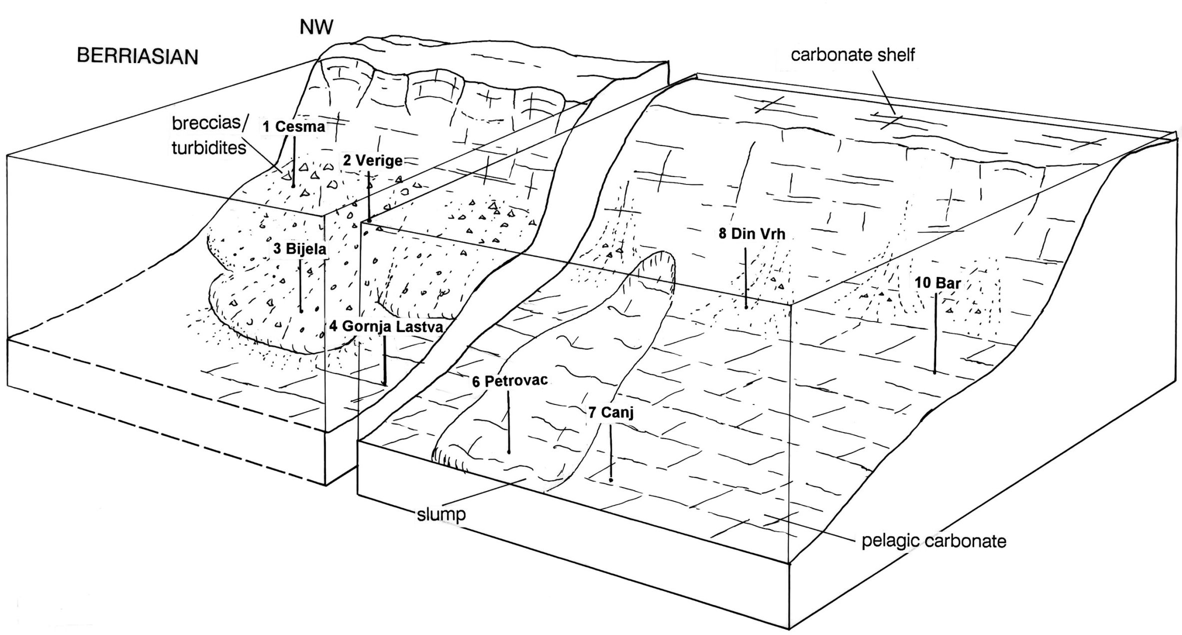


Figure 22: Reconstruction of depositional environment of the Budva Basin and the adjacent High Karst Platform margin in the Berriasian (from Goričan 1994).

and persisted to the Turonian. Meter-scale green levels in generally red Bijela Radiolarite were most probably related to mid-Cretaceous oceanic anoxic events (Figure 9). In the Turonian, pelagic sedimentation turned again to carbonate with the *Globotruncana* limestone. Comparable facies changes occur in the Southern Alps and Apennines. The first is the mid-Tithonian shift from radiolarites to the Maiolica (or Biancone) limestone, followed by a shift to lime-poor and clay rich Scisti a Fucoidi (or Scaglia variegata alpina) and then a shift back to limestones of the Scaglia Bianca and Scaglia Rossa. The Budva Basin, however, differs from other basins of the western Tethys by a higher proportion of silica in Jurassic and Cretaceous pelagic sediments. In addition, the Cretaceous shifts in carbonate/silica ratio are not exactly synchronous across different basins; in the Budva Basin, siliceous sediments were dominant through longer time intervals. Namely, the Bijela Radiolarite, which extends up to the Turonian, is time equivalent of the Scisti a Fucoidi (Aptian–lower Albian) and also of the Scaglia Bianca (upper Albian–lower Turonian).

4.2 Middle Triassic pelagic episode on the High Karst Carbonate Platform

General description

The Middle Triassic rifting-related extension and differential subsidence created a horst-and-graben topography with relatively deep basins and structural highs but the internal topography of these larger units was also differentiated. In the early-middle Anisian, prior to the main rifting phase, the future Adriatic continental margin was occupied by a uniform carbonate deposition in an epicontinental sea (Ravni Carbonate Ramp in the Dinarides, Gutenstein/Steinalm Formations in the Northern Calcareous Alps, Contrin Formation in the Southern Alps). In the late Middle Anisian (Late Pelsonian), the carbonate ramp was dissected into blocks. Some blocks drowned and the first deep-water carbonates were deposited. The elevated blocks were also flooded in the Late Illyrian so that deep-water deposition prevailed on horsts and in grabens until the Ladinian–Carnian boundary. When carbonate platforms on the elevated blocks started to prograde, they filled in the relatively shallow depressions (see Figure 23a for the general stratigraphy). In the early Carnian, the small-scale topographic differences were mostly levelled and the structural highs were again the site of shallow-water carbonate deposition (Wetterstein Formation in the Northern Calcareous Alps and in the Dinarides, Schlern Formation in the Southern Alps).

The short-lived Middle Triassic basins have been documented in the Southern Alps (e.g., Brack & Rieber 1993; Kozur et al. 1996; Celarc et al. 2013) and in the Dinarides (e.g., Goričan et al. 2005; Gawlick et al. 2012, 2017a). The typical sediments are nodular cephalopod limestones (named the Bulog Formation in the Dinarides), limestones with chert nodules and, more rarely pure radiolarian cherts. Coarse-grained breccias were deposited close to steep paleo-escarpments. Late Anisian to Ladinian volcanic and volcaniclastic rocks are widespread but may be locally absent or represented by only thin tuffaceous intercalations. In the upper shallowing-upward part of the basin fill, calcarenites with platform-derived debris prevail. The entire succession bounded by shallow-water carbonates below and above is generally a few tens of meters and only exceptionally more than one hundred meters thick. It is thus reasonable to conclude that the maximum depositional depth of these pelagic sediments was relatively shallow and did not exceed a few hundred meters (see discussion in Gawlick et al. 2012).

The example at Stop 5 – Obzovica described below is part of the High Karst Nappe. Across the Montenegro–Serbian transect (Figure 1), Middle Triassic basins of comparable stratigraphic evolution exist also in the Durmitor Zone (Rampnoux 1974; Mirković 1983), in the Drina-Ivanjica unit (Sudar et al. 2013) and as kilometer-sized blocks in mélanges (Missoni et al. 2012).

Stop 5: Obzovica

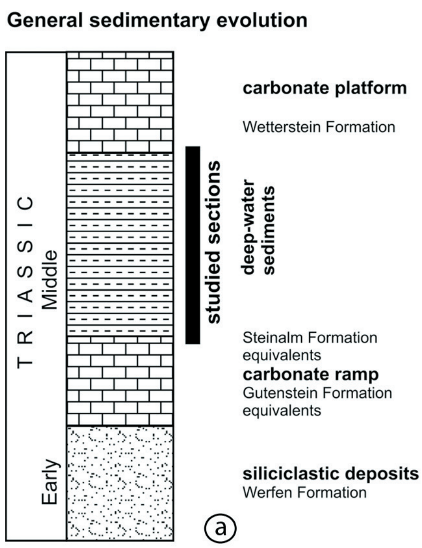
SW margin of the High Karst Zone.

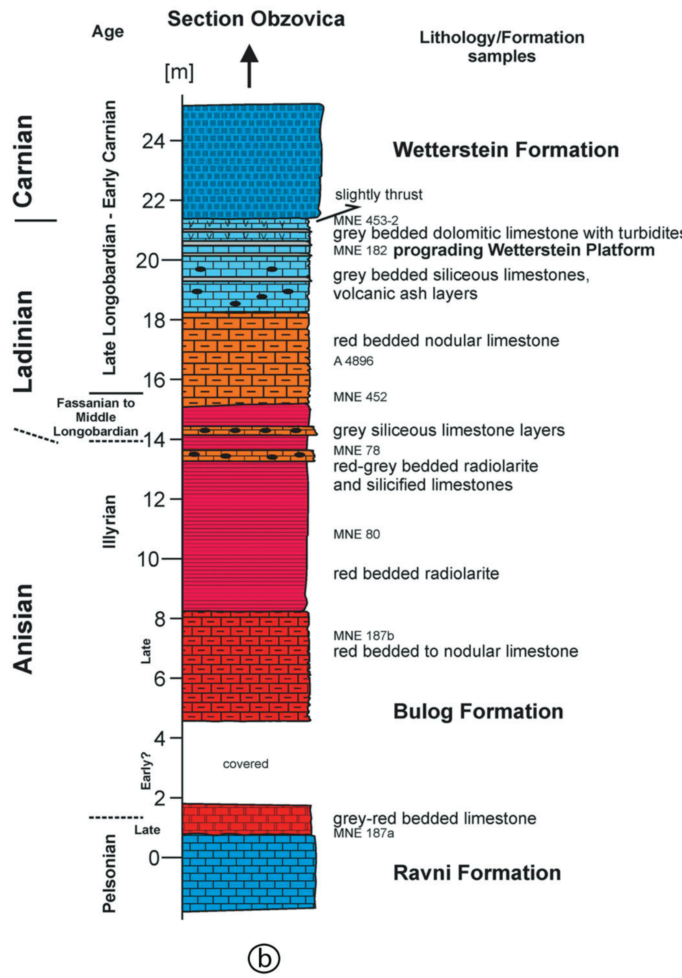
Location: near the Obzovica village along the road from Budva to Cetinje (N 42°18'52", E 18°56'10"); Basic Geological Map sheet Budva (Antonijević et al. 1969).

An approximately 20 m thick Upper Anisian to Ladinian unit of hemipelagic limestone and radiolarian chert occurs within a succession of shallow-water carbonates (Figure 23b). The description is summarized from Gawlick et al. (2012) and updated.

The section above the shallow-water Ravni Formation starts with a few meters of bedded grey to red limestones with red marly intercalations (Figure 24a). The limestone beds consist of packstones with bivalves, echinoderm fragments and rare benthic foraminifera that grade into wackestone with calcified radiolarians and thin-shelled bivalves. The reddish marly limestone is composed of alternating laminae of packed thin-shelled bivalves (Figure 24b) and radiolarians.

Reddish bedded and nodular limestones below the radiolarite succession belong to the Upper Pelsonian-Illyrian Bulog Formation. A five-meters thick succession follows that is composed of reddish and partly grey well-bedded radiolarites, silicified limestones with filaments (Figure 24c) and centimeter-thick volcanic ash layers. From the reddish radiolarites (sample MNE 80, Figure 23c) we isolated a moderately well preserved Illyrian radiolarian fauna. The stratigraphically most important species are *Baumgartneria bifurcata* Dumitrica and *Falcispongus calcaneum* Dumitrica, both restricted to the *Spongosilicarmiger italicus* Zone (Kozur & Mostler 1994). In the upper part of the radiolarite sequence, intercalated turbiditic filament-bearing limestones up to ten centimeters thick are of latest Anisian age based on radiolarians and conodonts (sample MNE 78). Radiolarian fauna in this sample is very well preserved. Nassellarians are abundant and diverse (Figure 23c), but stratigraphically important spumellarians, e.g., characteristic detached spines of Oertlispongidae, have not been found. The sample is probably still Anisian in age,





Species / Samples	MNE 80	MNE 78
Anisicyrtis italica Kozur and Mostler		x
Baumgartneria bifurcata Dumitrica	x	
Baumgartneria cf. *yehae* Kozur and Mostler	x	
Celluronta sp.		x
Conospongocyrtis ? sp.		x
Cryptostephanidium cornigerum Dumitrica	x	x
Cryptostephanidium cf. *verrucosum* Dumitrica		x
Eptingium manfredi Dumitrica	x	
Eptingium ramovsi Kozur, Krainer and Mostler	x	
Falcispongus calcaneum Dumitrica	x	
Hinedorcus aff. *fassanicus* (Kozur)		x
Hozmadia pyramidalis Goričan		x
Hozmadia reticulata Dumitrica, Kozur and Mostler		x
Hozmadia spinosa Kozur and Mostler		x
Katorella bifurcata Kozur and Mostler		x
Monospongella rotunda Kozur and Mostler		x
Oertlispongus inaequispinosus Dumitrica, Kozur and Mostler	x	
Parasepsagon asymmetricus Kozur and Mostler	x	
Planispinocyrtis sp.		x
Pseudostylosphaera japonica (Nakaseko and Nishimura)	x	
Silicarmiger sp.		x
Spongostephanidium sp.	x	
Tetraspinocyrtis sp.		x
Triassocampe deweveri (Nakaseko and Nishimura)	x	x
Triassocampe scalaris Dumitrica, Kozur and Mostler	x	x
Yeharaia annulata Nakaseko and Nishimura		x

c

Figure 23:
a) General stratigraphy of the short-lived Middle Triassic basins in the Dinarides.
b) Stratigraphic log of the Obzovica section with position of radiolarian samples (from Gawlick et al. 2012).
c) Occurrence of radiolarian species in samples MNE 80 and MNE 78.

as suggested by the well-known range of *Yeharaia annulata* Nakaseko & Nishimura (Kozur & Mostler 1994). Moreover, the genus *Anisicyrtis* does not extend above the Anisian (O'Dogherty et al. 2009a, 2010).

Upsection, the dominance of radiolarian cherts decreases rapidly and radiolarian-bearing wacke- to packstones were deposited instead. The age of these rocks is most probably Early to early Late Ladinian as indicated by the occurrence of late Longobardian conodonts from the red nodular limestones above the siliceous rocks (Figure 23b, sample MNE 452). The radiolarian-rich interval is overlain by about 5 meters of red limestones that provided a Late Ladinian age (sample A 4896). These reddish limestones pass continuously into grey deep-water limestones showing an increasing proportion of shallow-water debris of Late Ladinian age (sample MNE 182, Figure 24d), again with intercalated volcanic ash layers. This sequence is topped by reefal dolomites of Early Carnian age (sample MNE 453-2). The transition of the thick-bedded basinal dolomites with shallow-water turbidites and intercalated volcanic ash layers and the more massive dolomitized reefal rudstones of the Wetterstein Carbonate Platform is slightly tectonically overprinted.

4.3 The Lim Zone and the overlying ophiolite mélanges

General description of the Lim Basin

The Lim Basin is a typical continental-margin basin that formed during the Middle Triassic rifting and then persisted as a deep-marine basin until the arrival of the

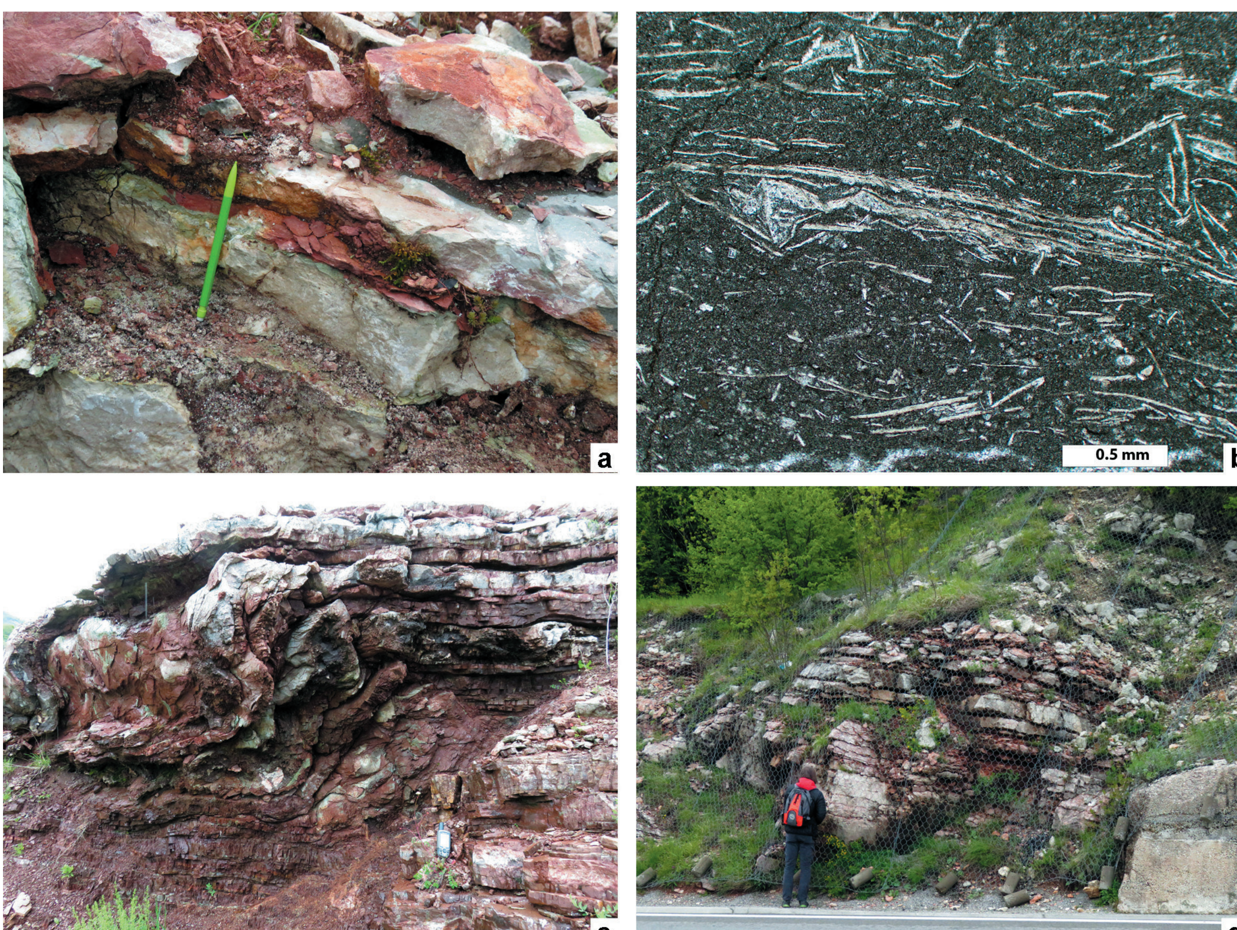


Figure 24: Middle Triassic rocks of the Obzovica section.
a) Grey bioclastic limestone with reddish marly intercalations near the base of the section.
b) Limestone rich in filaments; thin section of the 1-cm thick reddish bed in the middle of Figure 24a.
c) Radiolarian chert overlain by filament-rich cherty limestone. The cherty limestone yields well-preserved radiolarians.
d) Upper part of the section with increasing proportion of bioclastic limestone.

first synorogenic sediments in the Late Jurassic – earliest Cretaceous. The Mesozoic stratigraphy of the Lim Basin was less systematically studied than that of the Budva Basin. Here we mainly summarize the general study carried out by Rampnoux (1974) in the Ćehotina and Zlatar subzones (Figure 5) in Montenegro and western Serbia, and complement this review by some recently obtained local biostratigraphic dates (Figure 25). The Mihajlovići Subzone of Rampnoux (1974, Figure 5) is excluded from this summary and is presented separately (under Stop 8 – Mihajlovići below) because its stratigraphy is typical of a Jurassic submarine high and not of a pelagic basin.

The Lower Triassic rocks of the entire Lim Zone are bioturbated grey limestones, a characteristic lithostratigraphic unit of the Southern Alps and Dinarides, in older literature known as the upper member of the Werfen formation or the Campil beds. They locally overlie red sandstones of the lower Werfen formation or, in places, Carboniferous synorogenic Variscan Culm-type deposits. The lower Anisian unit consists of 50–200 m of massive shallow water limestone with abundant algae, gastropods and foraminifera. The first deeper-water unit is a few meters thick condensed "ammonitico rosso" type Bulog Formation, which is ascribed to the Upper Anisian Trinodosus Ammonoid Zone. The upper Upper Anisian volcanic and volcaniclastic rocks follow but laterally vary considerably and may be up to 60 m thick or completely absent. The Ladinian to Lower Jurassic unit is a uniform 200 to 350 m thick succession of bedded pelagic limestone with chert nodules. Except for the Ladinian, well dated with ammonoids and bivalves, the age of this thick formation is poorly constrained. Conodont studies have recently been introduced to refine the Upper Triassic stratigraphy in the area (see Stop 6 – Poros below). The Lower Jurassic limestones of this succession are generally thinner-bedded and more marly; rare belemnites, aptychi, calcispheres and foraminifera were found in this upper part of the succession (Rampnoux 1974). The pelagic limestones are overlain by green and red radiolarite. A few meters thick radiolarite unit was dated to the Callovian–Oxfordian (see Stop 7 – Jabučno below). In the upper part, the radiolarite is interlayered with breccia beds that contain clasts of pelagic limestone and chert but also include clasts of oolitic limestone, Upper Jurassic reef limestone with *Ellipsactinia* and *Sphaeractinia*, benthic foraminifera and the Tithonian alga *Aloisalthella sulcata* (former *Clypeina jurassica*). The topmost stratigraphic unit is a flyschoid series composed of fine sandstones, greywackes with fragments of chert and volcanic rocks, breccias with carbonate clasts,

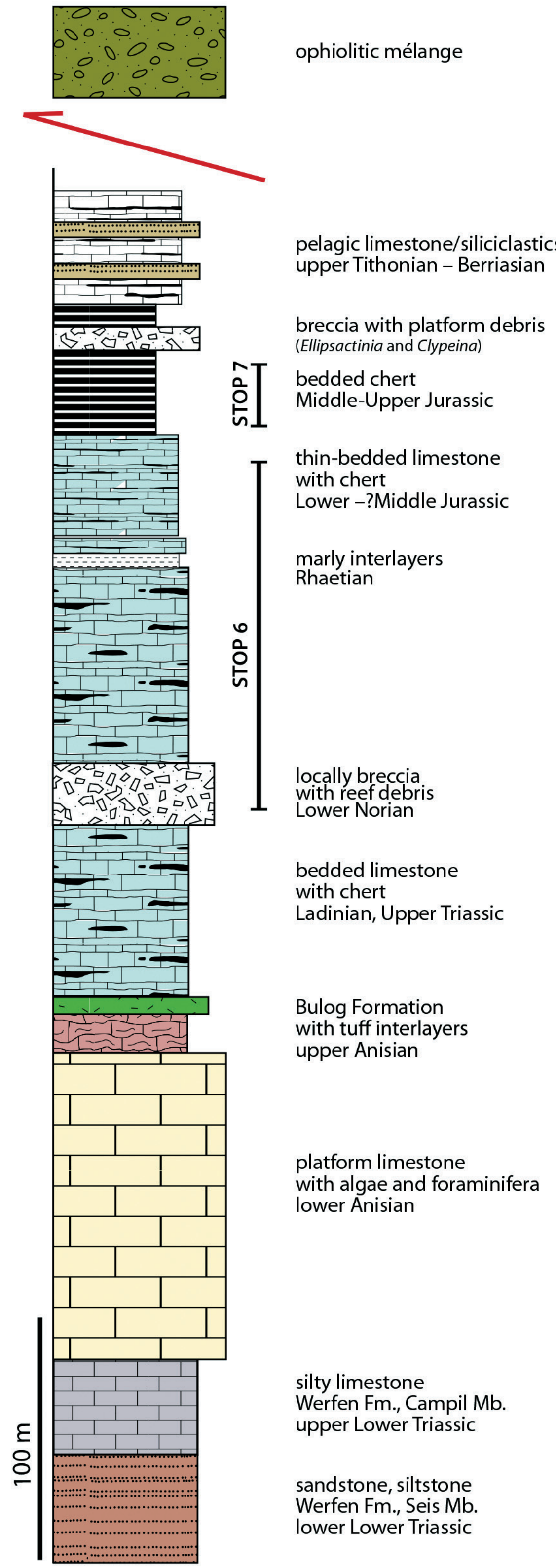


Figure 25: Schematic stratigraphic column of the Ćehotina Subzone NW of Pljevlja (according to Rampnoux 1974) with position of stops 6 and 7.

and thin-bedded pelagic limestone. Calpionellas in the pelagic limestone indicate a late Tithonian – early Berriasian age. The flyschoid series exists only in the western Ćehotina Subzone.

A part of the Ćehotina Subzone, as defined by Rampnoux (1970, 1974) is exposed in south-eastern Montenegro near Berane, but is separated from the NW part near Pljevlja by a large area where only Paleozoic rocks are exposed (Figure 5). Both parts of the Ćehotina Subzone are composed of deep-water sediments from the Anisian to the end of the Jurassic and thus correlate well in general outlines but may differ in details. Lime-free radiolarites are probably thicker and have a longer range in the southern sector. Near Berane, the oldest radiolarian cherts, which characteristically occur in a shale-dominated interval, are Aalenian in age; upsection, red radiolarian cherts with rare calcarenite intercalations were assigned to the latest Bajocian – early Bathonian (Kukoč 2014).

Stop 6: Poros

Ćehotina Subzone.

Location: W of Pljevlja, along the road from Gradac to Šuplja Stijena (N 43°24'03", E 19°08'45"); Basic Geological Map sheet Pljevlja (Mirković et al. 1978).

A more than 120 m thick overturned Upper Triassic succession of reef limestone and bedded siliceous limestones (Figures 26, 27) is exposed. The section is slightly tectonized, with folded slump deposits in the central part, so that only some parts of the section can be accurately measured. The results presented here are the first results of the current study by one of us (M.M.).

The section starts with a roughly 20 m thick reef to fore-reef limestone succession with deep-water matrix in the upper part (Lacian 2 in age with conodonts *Epigondolella rigoi* and *Norigondolella* sp.). Near the base the reef limestone is thick bedded to massive, higher up in the section variously bedded. We consider these reef limestones as part of the Dachstein Reef Limestone, interestingly with a deepening upward sequence from the middle Lower Norian onwards. Around the Lacian 2-3 boundary the depositional characteristics change relatively abruptly. The next 30 m thick part consists of dm-bedded limestones with chert nodules and layers, grey limestones and reddish limestones. Conodont dating shows that the age of this part of the section is Lacian 3 to Alaunian 3 in the upper part (dated by *Epigondolella abneptis, E. spatulata* to *E. slovakensis* and *E. serrulata*). The higher Alaunian 3 to Sevatian (with *E. bidentata*) is characterized by a thick series of slump deposits with carbonate turbidite intercalations. In these slumps, mainly grey siliceous thin-bedded limestones of the higher Alaunian, dated with e.g. *E. slovakensis*, appear. Polymictic breccias (debris flows) and turbiditic microbreccias with older (Lacian and Alaunian proven with conodonts) open-marine hemipelagic components follow upsection. The overlying dm-bedded grey-reddish siliceous limestones with red chert nodules are Rhaetian in age dated with the appearance of *Misikella posthernsteini*. The higher Lacian to Upper Norian part of the succession corresponds to the reef-near facies belt in open shelf position, known in the type-area in the Northern Calcareous Alps as the Gosausee Limestone facies. The section Poros shows during the Norian a general deepening trend.

Bedded grey siliceous and slightly marly limestones (bed thickness 5–10 cm) follow upsection in a thickness of less than 20 m and are overlain by roughly 10 m of dm-bedded red-grey siliceous limestones with red marl to claystone intercalations. These reddish limestones are again overlain by bedded grey siliceous and slightly marly limestones. An exact age of this part of the series could not be determined; only conodont multielements could be isolated in several parts of the succession. The age is most likely Rhaetian 2-3, but earliest Jurassic for some parts of the folded sequence cannot be excluded.

The upper part of the section consists of dark red highly siliceous thin-bedded limestone (Figures 28 a, b). Replacement chert nodules and layers are more abundant than in the limestones below. Ten samples from this and the previous unit have been processed to extract siliceous microfauna. Sponge spicules are abundant but no radiolarians have been found.

Stop 7: Jabučno

Ćehotina Subzone.

Location: Along the road from Gradac to Šuplja Stena, 6 km west from Stop 6, N 43°24'26", E 19°05'44"; Basic Geological Map sheet Pljevlja (Mirković et al. 1978).

An isolated 5 m thick outcrop of variegated chert; according to Rampnoux (1974), this chert occurs above a stratigraphic succession similar to that of the Poros section (Stop 6) in the general stratigraphic column of the Ćehotina Subzone (Figure 25).

The outcropping section (Figures 29a–c) consists of green, variegated green and red, and violet red weathered cherts. These cherts contain no dispersed carbonate and the succession is also devoid or resedimented carbonates. Four samples have been processed with diluted hydrofluoric acid. Sponge spicules (mostly small and large monaxones) are abun-

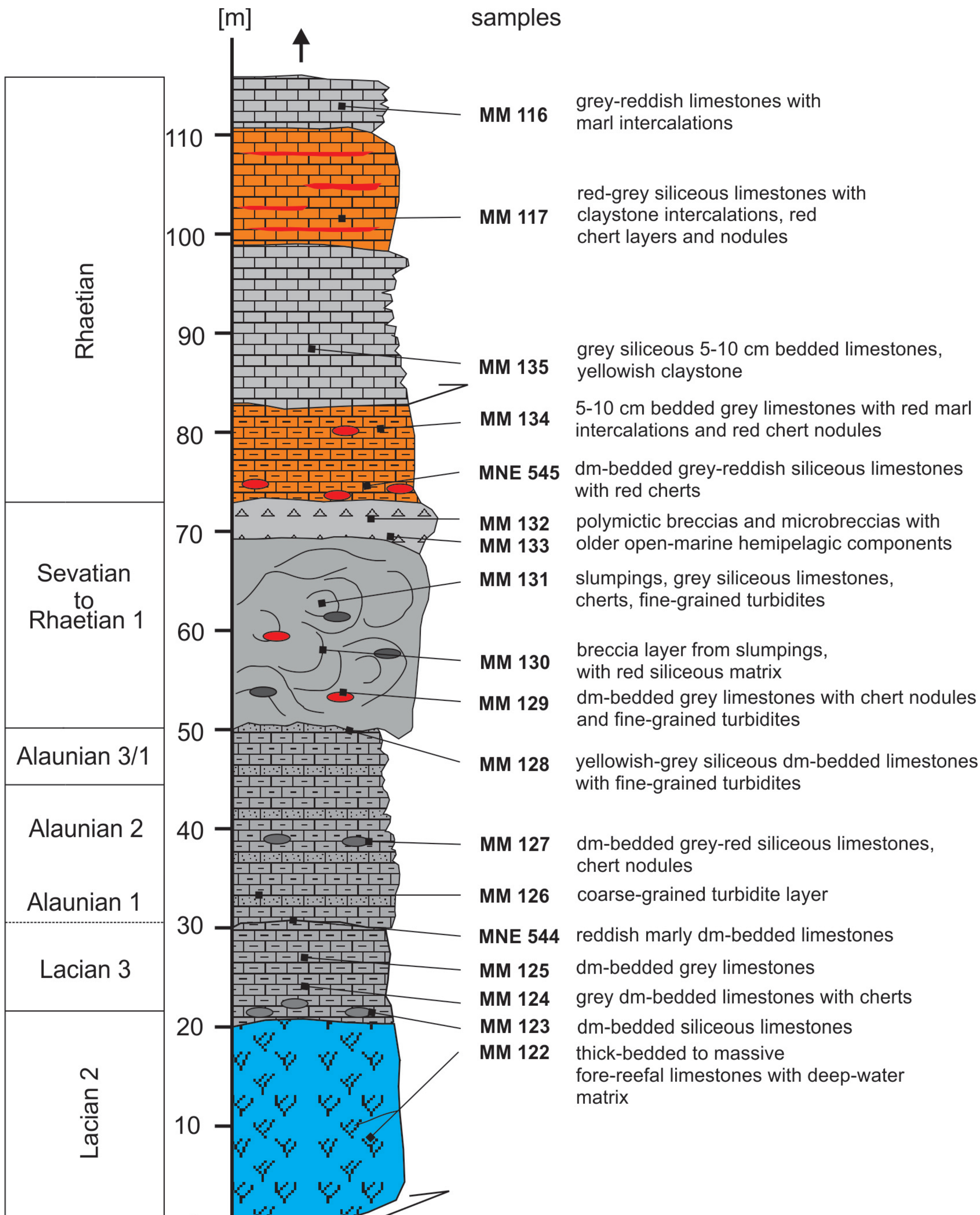


Figure 26: The nearly 120 m thick overturned Late Triassic sedimentary sequence of the reef to reef near facies belt in the Poros area.

dant and practically rock-forming in all samples. Only one sample (no. JB 3) yielded some determinable radiolarians. Also in this sample, sponge spicules account for more than 95% of the siliceous fauna. Among the identified radiolarians (Figure 30), the co-occurrence of *Cinguloturris carpatica* Dumitrica (FAD in UAZ 7) and *Hemicryptocapsa marcucciae* (Cortese) (LAD in UAZ 8) indicates a late Bathonian-early Callovian to middle Callovian-early Oxfordian age according to Baumgartner et al. (1995).

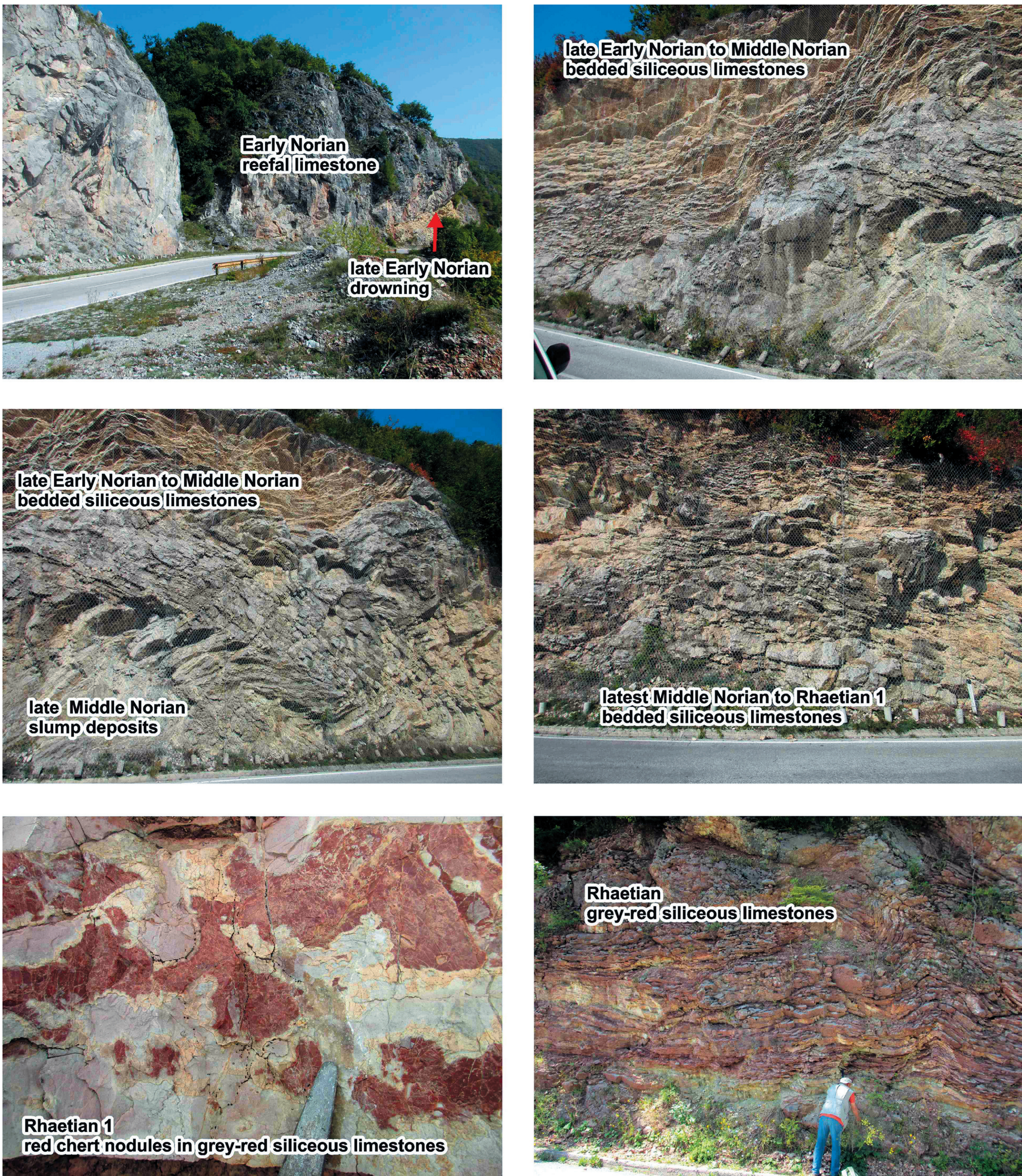


Figure 27: Field views of the Upper Triassic Poros section. Explanation in the photos.

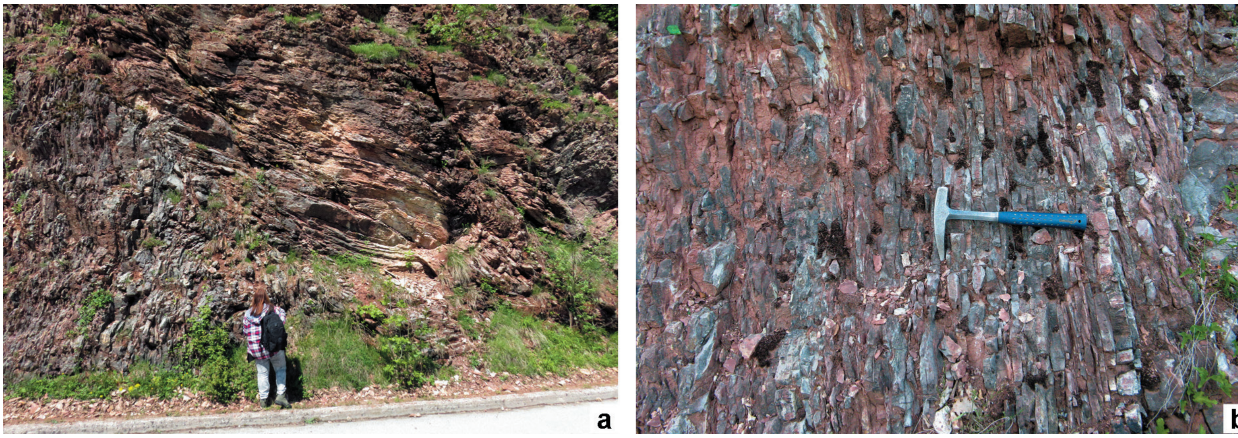


Figure 28: Upper part of the Poros section.
a) Lower Jurassic thin-bedded highly siliceous limestone cut with E–W striking subvertical faults.
b) Close up of figure a. The limestone is rich in sponge spicules but devoid of radiolarians.

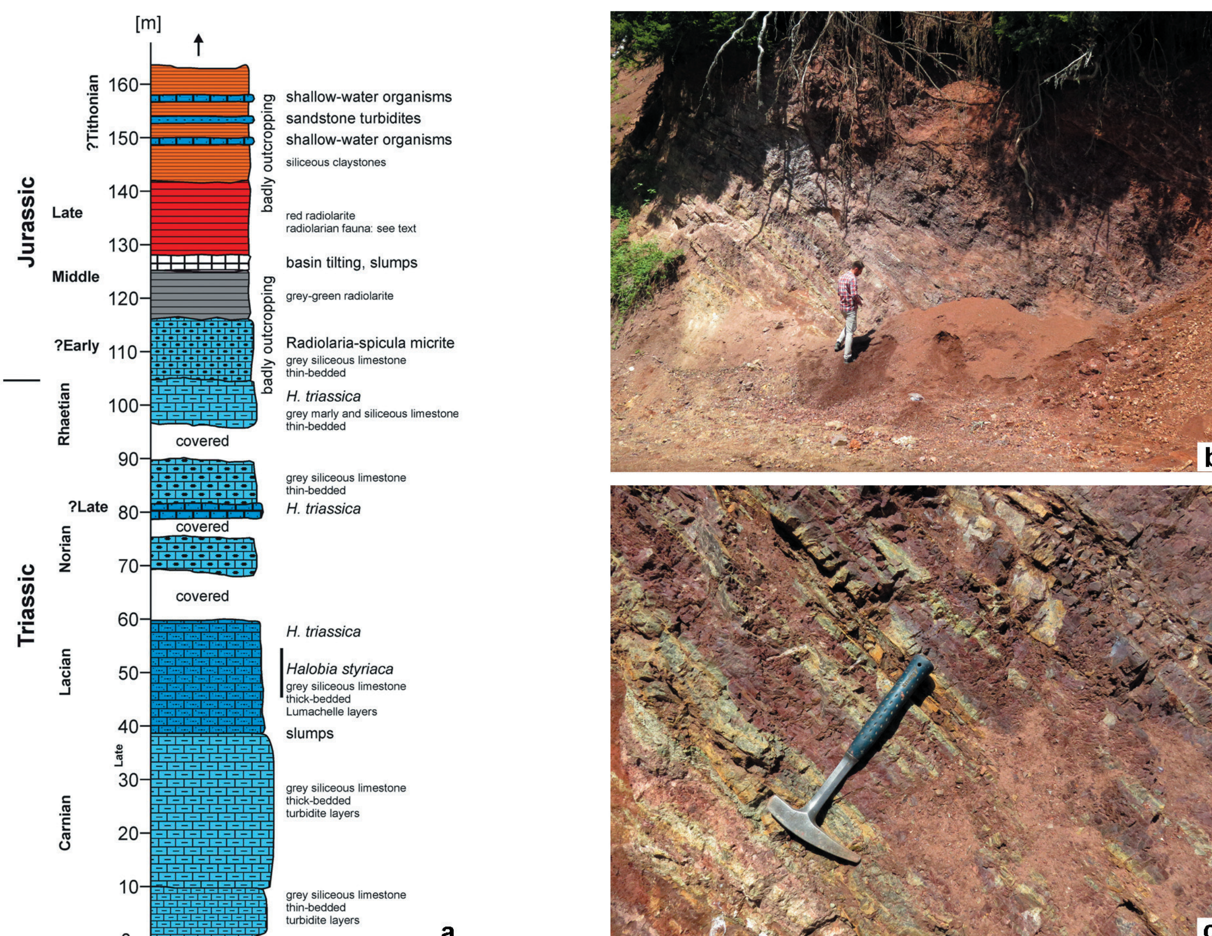


Figure 29: Jurassic radiolarite at Jabučno.
a) Stratigraphic column of the Jabučno area; the radiolarite of b–c is marked in red.
b) General view of the outcrop.
c) Red and green cherts in the lower part of the outcrop in b.

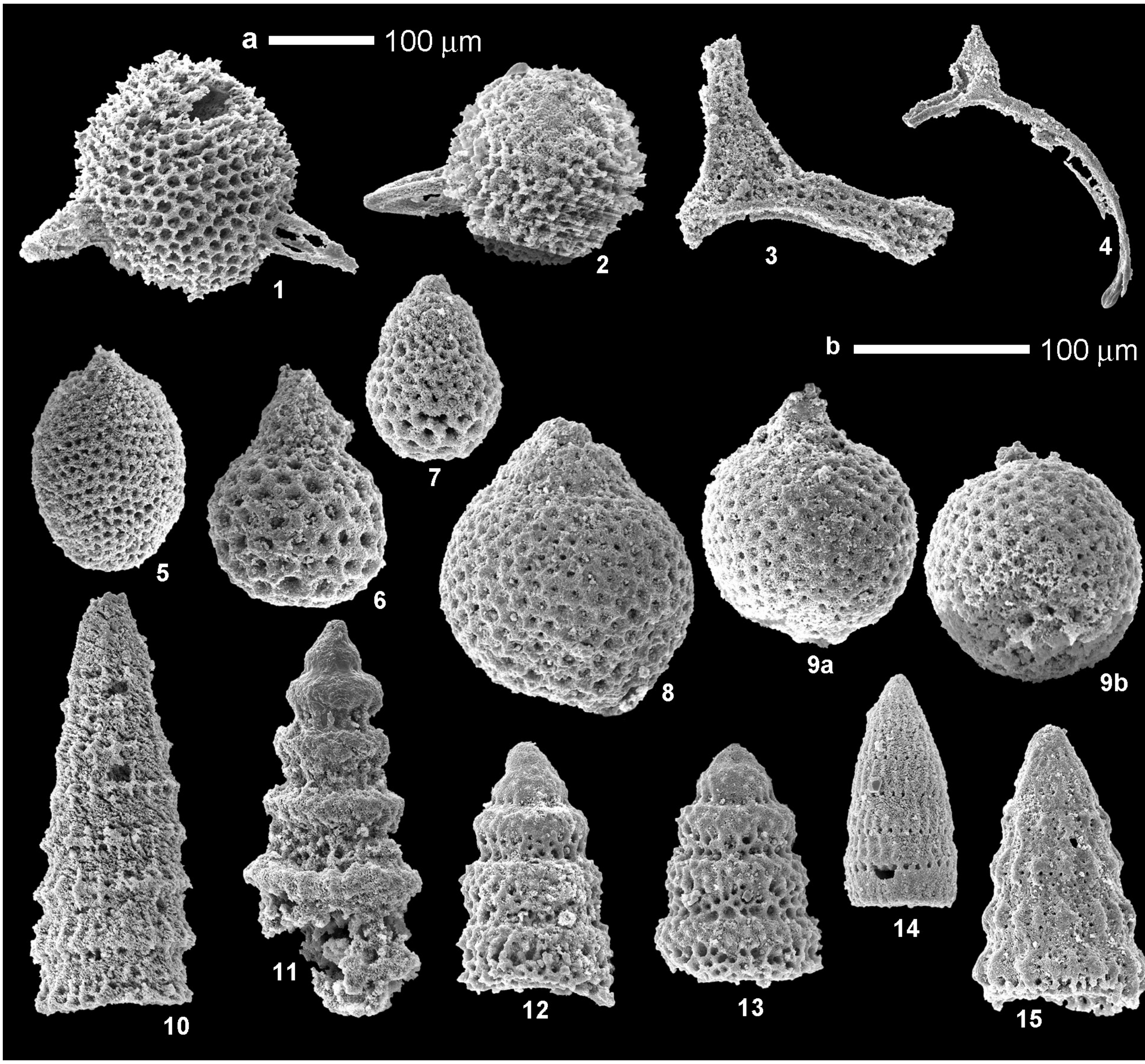


Figure 30: Late Bathonian – early Callovian to middle Callovian – early Oxfordian (UAZ 7–8) radiolarians from sample JB 3 at Jabučno.
1: Triactoma enzoi *Beccaro, scale bar a.*
2: Triactoma blakei *(Pessagno), scale bar a.*
3: Angulobracchia *cf.* digitata *Baumgartner, scale bar a.*
4: Dicerosaturnalis angustus *(Baumgartner), scale bar a.*
5: Kilinora *cf.* spiralis *(Matsuoka), scale bar b.*
6: Crococapsa *cf.* hexagona *(Hori), scale bar b.*
7: Theocapsomella? kiesslingi *(Hull), scale bar b.*
8: Zhamoidellum ventricosum *Dumitrica, scale bar b.*
9a-b: Hemicryptocapsa marcucciae *(Cortese), a: lateral view, b: antapical view, scale bar b.*
10: Transhsuum brevicostatum *(Ožvoldova), scale bar b.*
11–13: Cinguloturris carpatica *Dumitrica, scale bar b.*
14: Loopus venustus *(Chiari, Cortese & Marcucci), scale bar b.*
15: Transhsuum crassum *Chiari, Marcucci & Prela, scale bar b.*

The rocks directly underlying these radiolarites are not exposed, but the Upper Triassic succession in the continuation below is somewhat different from the Poros section; no reef limestone, which is well marked in the Poros section occurs below the Jabučno section. The Triassic section (work in progress by H.-J.G. and M.M.) starts with a thick-bedded (10–25 cm) series of bedded slightly siliceous limestones with very fine-grained carbonate turbidite intercalations, but without shallow-water grains (only automicrite clasts). The dipping in the upper part changes rapidly without any clear direction indicating slump deposits. The age of this part of the section cannot be exactly determined, conodont samples yielded only multielements, but is most likely Late Carnian (Tuvalian). Higher up in the succession a series of lumachelle layers with predominantly *Halobia* aff. *styriaca* indicate a lowermost Norian age. Above these lumachelle layers follow a roughly 40 m thick series of grey siliceous limestones, in cases with chert nodules and chert layers. Generally, the series is in that part thin-bedded (5–10 cm), turbidites are generally missing with one exception in the middle part of this series. This fine-grained turbidite layer with filaments most likely corresponds to the resedimentation event in the latest Middle to Late Norian.

Also this part of the section cannot be exactly dated by conodonts: the sediments consist of radiolarian biomicrites without resediments. Only *Hindeodella triassica*, indicating a Late Triassic age, could be isolated, also in the more marly thin-bedded part in the highest part of this series. On top of these marly siliceous limestones appears a 1–2 cm thick layer of grey claystones, which marks an abrupt change in the microfacies characteristics. Upsection follow grey thin-bedded biomicrites rich in radiolarians and sponge spicules that resemble the Lower Jurassic successions known widespread in the Western Tethys realm. The Triassic part of the section can be attributed to the Grivska Formation.

Stop 8: Mihajlovići

Mihajlovići Subzone

Location: Along the road from Pljevlja to Jabuka, about 10 km east-southeast from Pljevlja, several outcrops between N 43°20’19”, E 19°27’08’ and N 43°20’28.5”, E 19°27’09”. Basic Geological Map sheet Pljevlja (Mirković et al. 1978).

The succession consists of Triassic shallow-water limestone and a Jurassic deepening-upward sequence, overthrust by ophiolitic mélage (Figure 31). This succession was first described nearly a hundred years ago; the Lower to Middle Jurassic sequence has been recently well dated with ammonites and foraminifera (Rabrenović et al. 2012; Metodiev et al. 2013; Gawlick et al. 2020; Đaković et al. 2021; see the last two publications for the complete list of references).

The Upper Triassic is represented by Norian-Rhaetian Dachstein Limestone developed in an open lagoonal facies. The Lower to Middle Jurassic rocks belong to the Krš Gradac Formation and represent a stepwise deepening sequence in the transitional facies belt between the Adriatic Carbonate Platform (*sensu lato*) basement and the Neo-Tethys open shelf (Đaković et al. 2021). The formation is subdivided into four members reflecting the deepening.

The ?Middle/Upper Hettangian–Sinemurian member consists of shallow-subtidal micro-oncoidal limestones, mainly grain- and packstones with abundand benthic foraminifera, crinoids and only a few open-marine organisms. Foraminifera assemblages from these limestones (Rabrenović et al. 2012; Gawlick et al. 2020) have a wider biostratigraphic range, but are most common during Hettangian and Sinemurian of the Eastern Alps, Dinarides etc. (Đaković et al. 2021 and references therein). The lower part of this unit is dominated by large micro-oncoids with several layers. The number of layers/laminae decreases upsection. Contrary to this, the variability of the benthic foraminifera and the amount of crinoid fragments increase, indicating a slight deepening trend during the ?Middle/Late Hettangian-Sinemurian.

Following a hardground/gap, Pliensbachian is represented by wackestones with thick shells (brachiopods, ?bivalves), crinoids, some foraminifera and ammonoid shells, and only a few levels with micro-oncoids, mainly with foraminifera as core. In the uppermost level of this member ammonoids of *Fuciniceras lavinianum* Zone were found, below the upper hardground surface with the Middle Toarcian ammonoids. According to these finds, the age of this member was assigned to ?Early Pliensbachian to early Late Pliensbachian (Đaković et al. 2021). The hardground at the base of this member may represent a gap of the uppermost Sinemurian to the Early Pliensbachian. The hardground above the early Late Pliensbachian ammonoids would represent a longer gap in the depositional history, i.e. the rest of the Pliensbachian and the lowermost Toarcian. Around the level with the Early Domerian ammonoids the limestones are more condensed, represented by densely packed ammonoid-crinoid-foraminifera packstones. These microfacies types point to deposition in a relatively low-energy deeper-water enviroment, indicating ongoing deepening.

The Toarcian part of the Lower Jurassic succession at Mihajlovići is represented by deeper open-marine nodular, condensed limestones. The lowermost layer contains a rich Middle Toarcian ammonoid fauna (Rabrenović et al. 2012; Metodiev et al. 2013; Đaković et al. 2021). The hardground consists of a Fe/Mn-crust indicating a lithified sea floor and a gap in deposition. Ammonoids appear slightly above this hardground again in a micro-oncoidal facies and in crinoid-framinifera-ammonoid limestones. These micro-oncoids are much smaller, not as common as in the ?Upper Hettangian–Sinemurian and have mainly only

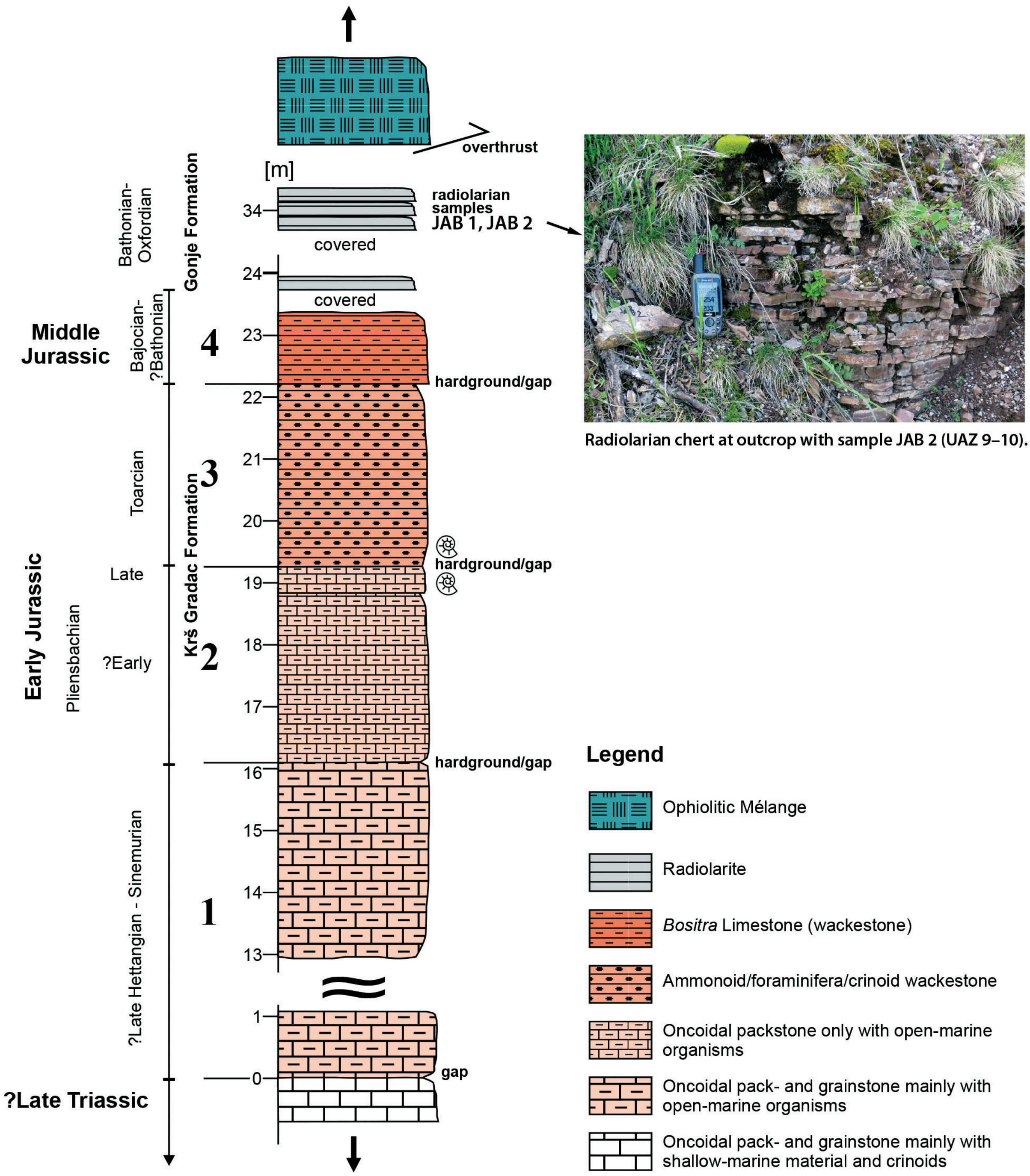


Figure 31: Stratigraphic column of the Mihajlovići section (from Gawlick et al. 2020; Đaković et al. 2021) and field photograph of Oxfordian radiolarite in the upper part of the section.

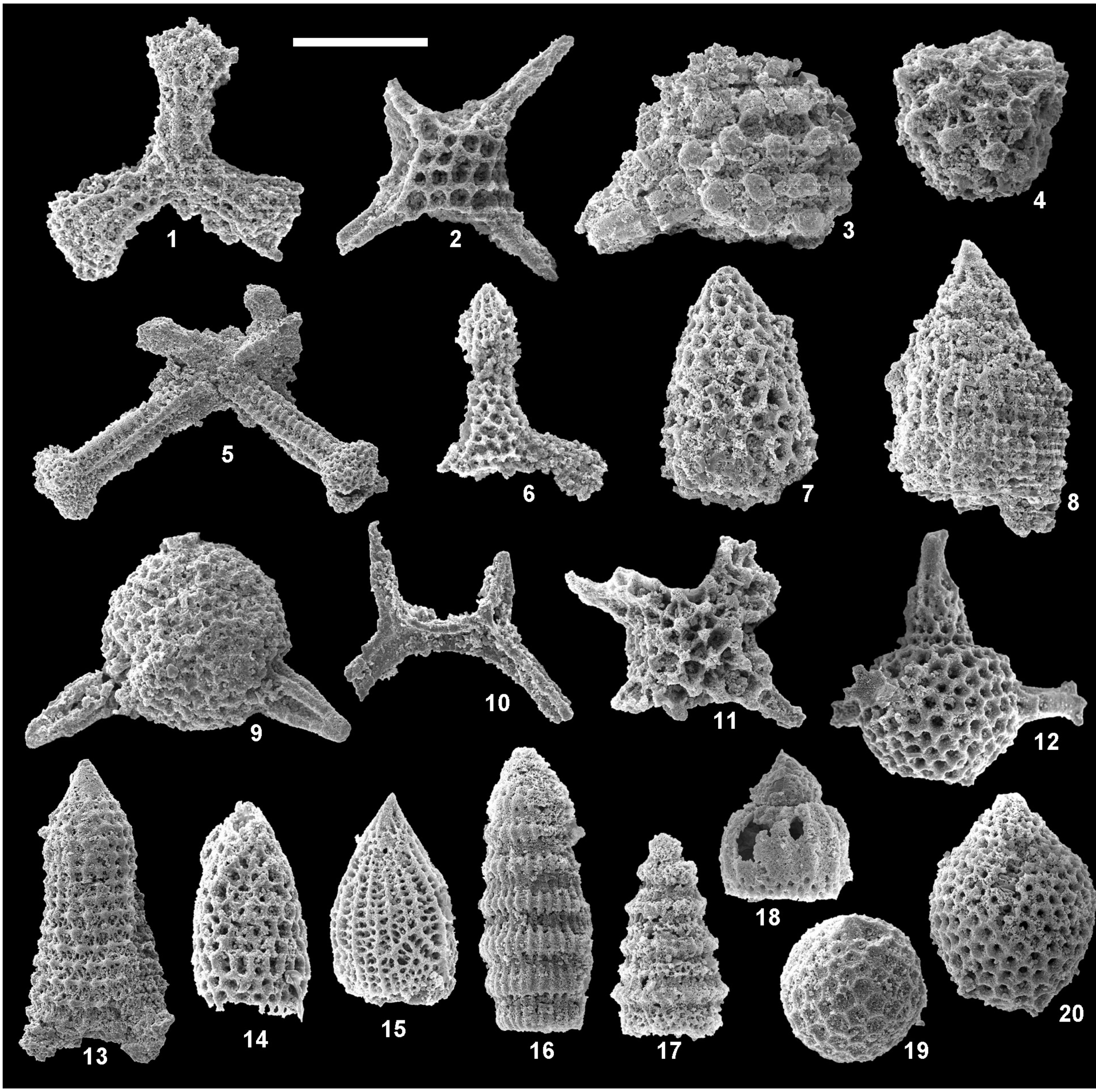


Figure 32: Late Jurassic radiolarians from samples JAB 1 (1–8) and JAB 2 (9–20) at Mihajlovići.

Sample JAB 1 (UAZ 10–11).
1: Tritrabs exotica *(Pessagno), scale bar 133 µm.*
2: Emiluvia sedecimporata *(Rüst), scale bar 133 µm.*
3–4: Emiluvia orea ultima *Baumgartner & Dumitrica, scale bar 133 µm.*
5: Tetratrabs bulbosa *Baumgartner, scale bar 266 µm.*
6: Angulobracchia *sp., scale bar 133 µm.*
7: Campanomitra tuscanica *(Chiari, Cortese & Marcucci), scale bar 100 µm.*
8. Parahsuum *sp., scale bar 100 µm.*

Sample JAB 2 (UAZ 9–10).
9: Triactoma blakei *(Pessagno), scale bar 133 µm.*
10: Hexasaturnalis nakasekoi *Dumitrica & Dumitrica-Jud, scale bar 100 µm.*
11: Emiluvia bisellea *Danelian, scale bar 133 µm.*
12: Spinosicapsa spinosa *(Ožvoldova), scale bar 133 µm.*
13: Ristola altissima *Rüst, scale bar 200 µm.*
14: Campanomitra tuscanica *(Chiari, Cortese & Marcucci), scale bar 133 µm.*
15: Hsuum obispoense *Pessagno, scale bar 133 µm.*
16: Archaeodictyomitra minoensis *(Mizutani), scale bar 100 µm.*
17: Cinguloturris carpatica *Dumitrica, scale bar 100 µm.*
18: Eucyrtidiellum ptyctum *(Riedel & Sanfilippo), scale bar 100 µm.*
19: Gongylothorax favosus *Dumitrica, scale bar 100 µm.*
20: Zhamoidellum ovum *Dumitrica, scale bar 100 µm.*

one or two rims. Wacke- to packstones with common ammonoid fragments, foraminifera and crinoids are the dominant microfacies throughout the Toarcian part of the section. A prolonged hardground formation is indicated by common lithoclasts, in cases with Fe/Mn-crusts, shells with indications of boring organisms and layered hardgrounds. Gastropods and benthic foraminifera are also common. This microfacies indicates deposition in a low-energy relatively deep-water environment (open shelf environment).

Following a long stratigraphic gap, the Toarcian red nodular limestones are overlain by Middle Jurassic (Bajocian-?Bathonian) *Bositra* Limestone characterized by condensed red nodular limestones with juvenile ammonoids, crinoids and *Bositra* shells. The microfacies with a lot of lithoclasts, Fe/Mn crusts and the extreme enrichment of shells indicate a very slow depositional rate, as typical of hemipelagic open marine settings with less carbonate production causing stratigraphic condensation. Important to note, that radiolarians, normally quite typical of the *Bositra* facies, are rare or practically missing. Deposition of such limestones started after the Toarcian Oceanic Anoxic Event in the Late Toarcian (Böhm 1992) and prevail until the Kimmeridgian in cases. The *Bositra* Limestone in the Mihajlovići section is of Bajocian/?Bathonian age, confirmed with *Globochaete alpina* Lombard, *Globuligerina oxfordiana* (Grigelis) and *Trochammina globoconica* Tyszka & Kaminski from the upper part of the *Bositra* Limestone (Rabrenović et al. 2012).

The uppermost part of the succession is dark gray and dark red radiolarites of the Middle–Upper Jurassic Gonje Formation (Gawlick et al. 2020). The Lower–Middle Jurassic limestones and the radiolarites crop out at several places along the Pljevlja–Jabuka road, but the contacts are poorly preserved and the radiolarites are never exposed in thickness of more than three meters. The radiolarians presented herein (Figure 32) were collected a few kilometers east of the Mihajlovići section described by Gawlick et al. (2020) and Đaković et al. (2021).

We studied two samples (JAB 1 and JAB 2) of dark red laminated chert (Figure 31) from two separate outcrops. In both samples radiolarians are moderately well preserved (Figure 32); large sponge spicules and rhaxes co-occur. The age of sample JAB 1 is determined to UAZ 10–11 (late Oxfordian–early Kimmeridgian to late Kimmeridgian–early Tithonian) with the range of *Emiluvia orea ultima* Baumgartner & Dumitrica. The age of sample JAB 2 is constrained to UAZ 9–10 (middle-late Oxfordian to late Oxfordian–early Kimmeridgian) based on first appearance of *Archaeodictyomitra minoensis* (Mizutani) and last appearance of *Gongylothorax favosus* Dumitrica.

Stop 9: Vijenac

Ophiolitic mélange, tectonically overlying the Mihajlovići Subzone.

Location: (N 43°20'35", E 19°25'51"). Basic Geological Map sheet Pljevlja (Mirković et al. 1978).

The ophiolitic mélange ovethrusts the succession described in the previous section. The contact is covered today, but it was in the past visible and described (Nöth 1956).

The mélange consists of plurimetric blocks of radiolarite, sandstone and basalt in a shaley matrix (Figure 33). A block of dark grey chert yielded a radiolarian assemblage dominated by small nassellarians (Figure 34). The assemblage is assigned to UAZ 7 (Late Bathonian–early Callovian) based on *Cinguloturris carpatica* Dumitrica that first appears and several species that last appear in this zone. These species are *Kilinora spiralis* (Matsuoka), *Striatojaponocapsa naradaniensis* (Matsuoka), *Striatojaponocapsa conexa* (Matsuoka), and *Mizukidella kamoensis* (Mizutani & Kido).

Stop 10: Drno Brdo

Blocks in ophiolitic mélange, tectonically overlying the Ćehotina Subzone (Rampnoux 1974), part of the East-Bosnian Durmitor unit (Figure 1).

Location: Along the road from Pljevlja to Žabljak near Eco Camp Drno Brdo (N 43°12'57.78"; E 19°20'41.58"), Basic Geological Map sheet Žabljak (Mirković & Vujisić 1989).

Middle Triassic radiolarian chert and basalt with gabbroic dykes.

The basalts at the Drno Brdo locality cover a surface of approximately 6 by 3 km and represent one of the largest blocks/slides of volcanic rocks in the ophiolitic mélange of Montenegro (Mirković et al. 1985). Contrary to the Jurassic ophiolitic rocks and radiolarites that were incorporated in the mélange as olistoliths originating from the accretionary prism, the large Triassic blocks of basalt and pelagic sediments must have been scraped off the old oceanic crust or the distal continental slope (Gawlick et al. 2017a; Schmid et al. 2020).

Two outcrops 150 m apart have been inspected for radiolarians. The first outcrop is a block of radiolarite incorporated in a sandy-shaley matrix (Figure 35, sample ZAB 1). In the second outcrop, radiolarian chert (sample ZAB 4) is an interpillow sediment in direct contact with basalt, which is penetrated by gabbroic dykes (Figure 36). Both radiolarian samples are dark red chert without filaments; radiolarians are rare and poorly preserved. The age of sample ZAB 4 (Figure 37: 1–6) is based on *Oertlispongus inaequispinosus* Dumitrica, Kozur & Mostler, which spans the Late Anisian and Early Ladinian (Stockar et al. 2012). Sample ZAB 1 (Figure 37: 7–13) contains only Oertlispongidae with straight spines (*Paroertlispongus*) that are less diagnostic for age determination. The most useful element of this assemblage is the genus *Celluronta*, which

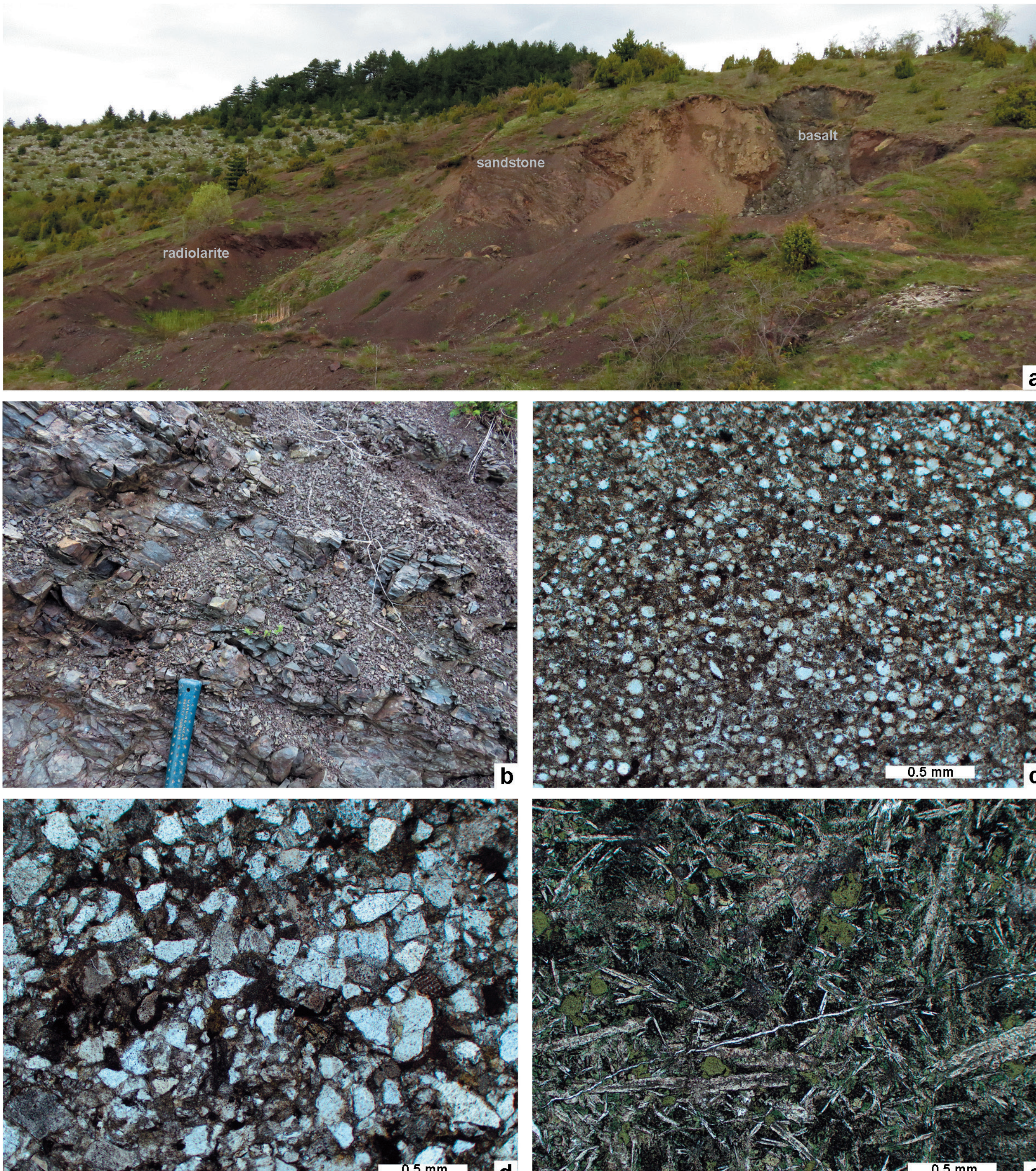


Figure 33: Ophiolitic mélange at Vijenac with blocks of radiolarite, sandstone and basalt (a). Close up of radiolarian chert with sample JAB 3 (b) and microfacies of this chert with densely packed radiolarians (c). Photomicrographs of quartz sandstone (d) and basalt (e).

is known from the Anisian and Early Ladinian (Dumitrica 2017). The Late Anisian–Early Ladinian age is in good agreement with the oldest age documented for sea-floor spreading in the Dinarides–Hellenides, e.g. in the Fourka Unit of Othris (Ferrière et al. 2015) and the Miraka section in Albania (Gawlick et al. 2008).

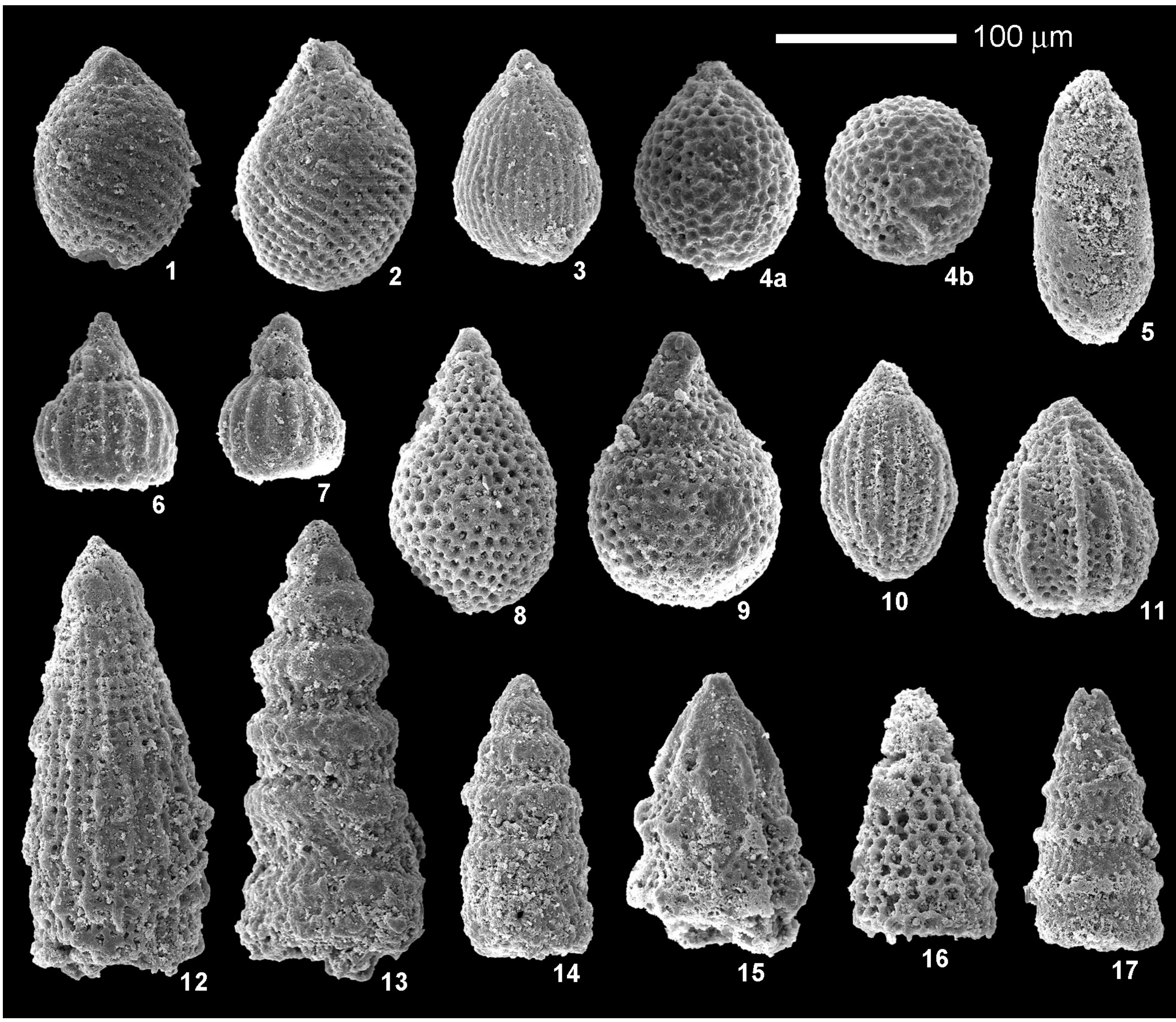


Figure 34: Late Bathonian – early Callovian (UAZ 7) radiolarians from sample JAB 3, Vijenac.
Scale bar 100 µm for all illustrations.
1–2: Kilinora spiralis *(Matsuoka)*
3: Striatojaponocapsa naradaniensis *(Matsuoka)*
4a–b: Striatojaponocapsa conexa *(Matsuoka), a: lateral view, b: antapical view.*
5: Guexella nudata (Kocher)
6–7: Eucyrtidiellum ptyctum *(Riedel & Sanfilippo)*
8–9: Praewilliriedellum convexum *(Yao)*
10: Protunuma japonicus *Matsuoka & Yao*
11: Unuma gordus *Hull*
12: Transhsuum maxwelli *(Pessagno)*
13–14: Cinguloturris carpatica *Dumitrica*
15: Xitus skenderbegi *(Chiari, Marcucci & Prela)*
16: Takemuraella *cf.* schardti *(O'Dogherty, Goričan & Dumitrica)*
17: Mizukidella kamoensis *(Mizutani & Kido)*

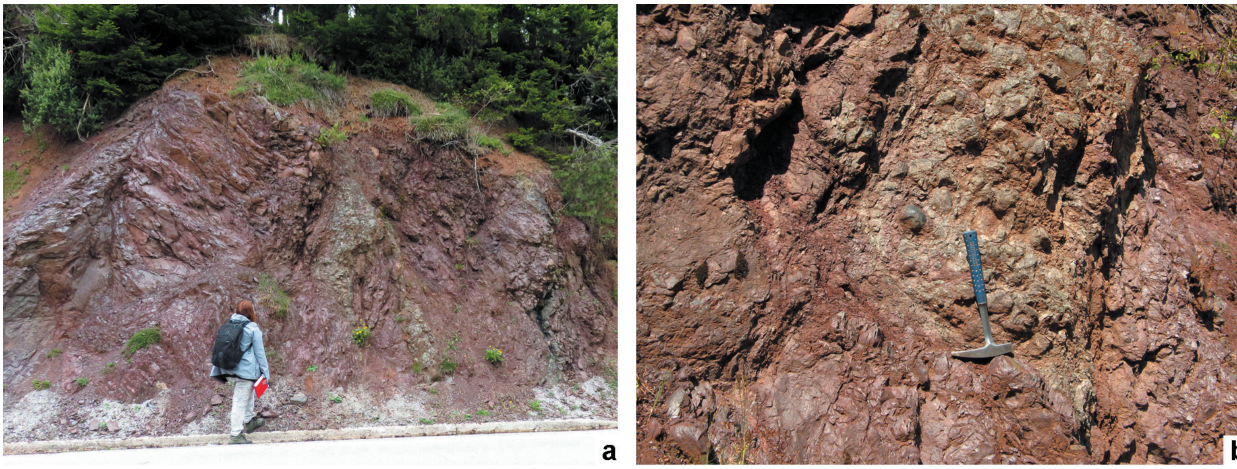


Figure 35: Block of Triassic chert at Drno Brdo (a) and a detail of block showing conglomerate with clasts of basalt (b). Radiolarian sample Z1 (Figure 37: 7–13) was collected in this block.

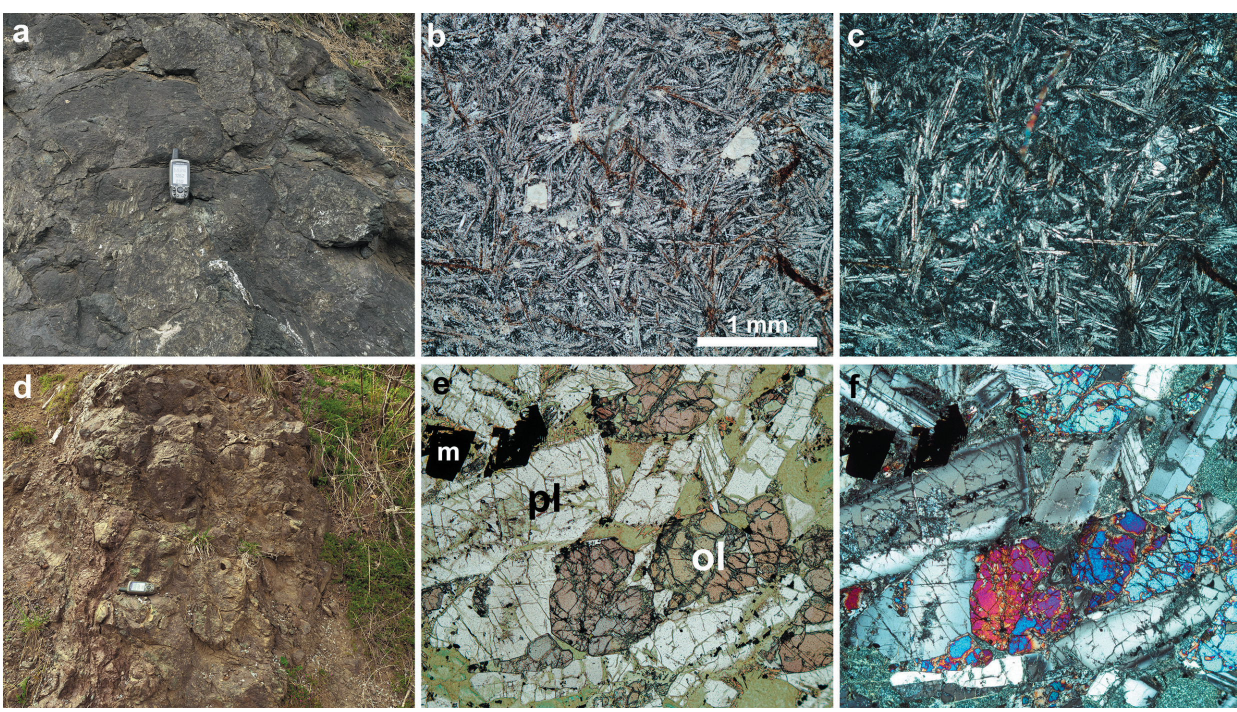


Figure 36: Ophiolite lithologies with radiolarites in sedimentary contact along the road from Pljevlja to Žabljak near Eco Camp Drno Brdo, about 150 m E of radiolarites in Figure 35.
a-c) basaltic pillow lava, a: outcrop, b: normal, c: cross polarized light, photomicrographs of a thin section showing an intersertal texture of plagioclase needles, the dark matrix represents volcanic glass replaced by secondary minerals.
d-f) same locality, a disrupted olivine bearing micro-grabbro dyke cutting through radiolarite. e: normal, f: cross polarized light, photomicrographs of a thin section showing plagioclase (pl), fresh olivine (ol), magnetite (m) and secondary epidote and chlorite in the light green patches in normal light.

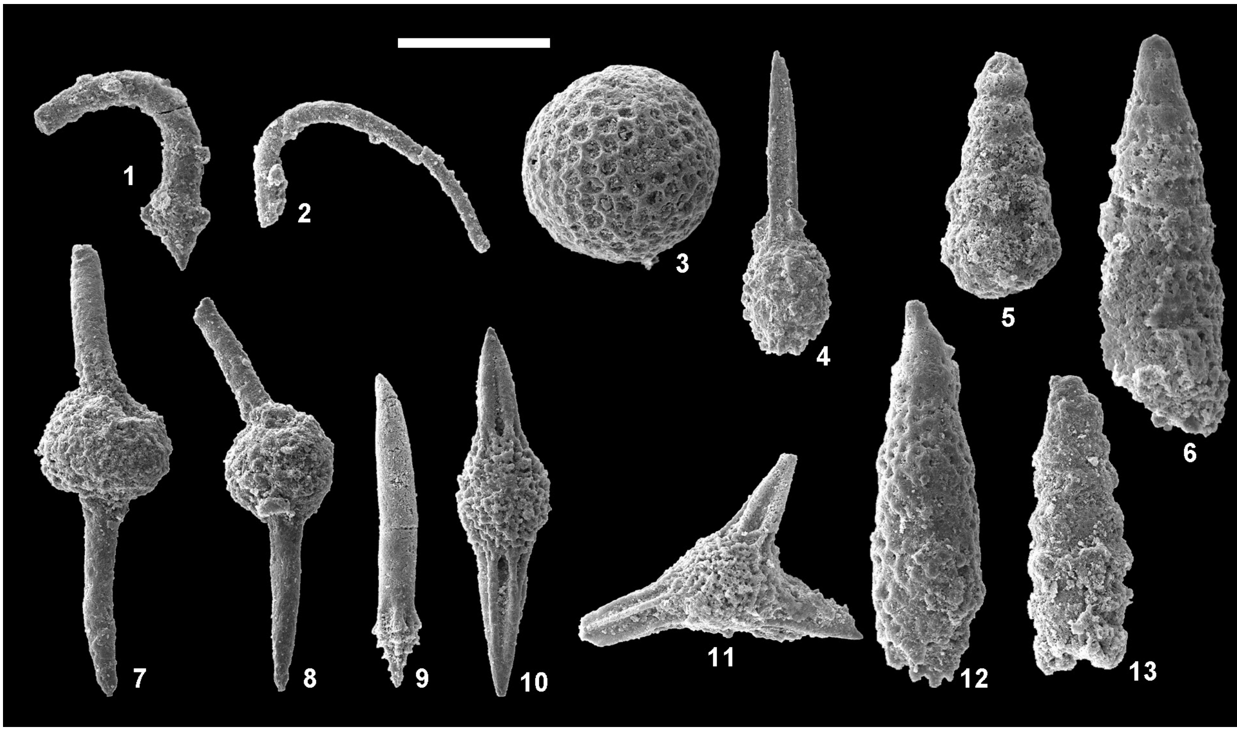


Figure 37: Late Anisian radiolarians from samples Z4 (1–6) and Z1 (7–13), Drno Brdo.
Sample Z4 (N 43°13'02.1"; E 19°20'47.46"):
1–2: Oertlispongus inaequispinosus *Dumitrica, Kozur & Mostler, scale bar 133 µm.*
3: Arhaeocenosphaera *sp., scale bar 133 µm.*
4: Pseudostylosphaera *sp., scale bar 200 µm.*
5: Pararuesticyrtium *sp., scale bar 100 µm.*
6: Triassocampe scalaris *Dumitrica, Kozur & Mostler, scale bar 100 µm.*
Sample Z1 (N 43°12'57.78"; E 19°20'41.58"):
7–8: Paroertlispongus *aff.* diacanthus *(Sugiyama), scale bar 133 µm. This species differs from typical* P. diacanthus *by having shorter and thicker spines.*
9: Paroertlispongus *sp., scale bar 133 µm.*
10: Pseudostylosphaera acrior *(Bragin), scale bar 133 µm.*
11: Eptingium manfredi *Dumitrica, scale bar 133 µm.*
12: Celluronta donax *Sugiyama, scale bar 100 µm.*
13: Pararuesticyrtium *sp., scale bar 100 µm.*

5 DINARIC BASINS, REGIONAL PALEOCEANOGRAPHY AND RADIOLARITES

The paleoceanography of Dinaric basins is discussed in the regional context both for Mesozoic rift basins underlain by thinned continental crust and for branches of the Neotethys underlain by oceanic crust such as the Meliata-Maliac, the Vardar oceans and the more southern Pindos ocean, a mere rift trough in the Montenegro transect. Pelagic oceanography and sedimentary processes are independent from their substrate, once it is below the thermocline. In contrast, the proximity of shallow margins may largely modify pelagic sedimentation by the input of peri-platform ooze or detrital clay preventing the formation of bedded cherts.

Mesozoic radiolarians are fundamental for the chronology of these basins. They have been recovered from both pelagic siliceous limestones, siliceous mudstones and from radiolarites wherein they are the main constituent. More recently, a case has been made for the presence of *Synechococcus*, a photosynthetic picocyanobacterium that produces, when degrading, EPS with Si-nanoparticles, even under highly Si-undersaturated conditions (Baines et al. 2012; Tang et al. 2014). This organism is thought to have existed since the Proterozoic to Recent, and may constitute an important proportion of the microcrystalline matrix of radiolarian cherts.

Radiolarian productivity is a function of local, regional, and global fluctuations of sea-surface fertility (Baumgartner 1987; DeWever et al. 1994). Radiolarites did not form in "Intra-Pangean" basins, such as the Jurassic Central Atlantic and the Proto-Caribbean (Figure 38). Middle Jurassic to Early Cretaceous radiolarites reported from several Antillean islands belong to exotic terranes of

Pacific origin (Bandini et al. 2011). These basins were poorly connected with the world ocean and had an anti-estuarine circulation pattern, resulting in relatively low surface fertility (Baumgartner 1987, 2013). The abundance of clays during the Middle Jurassic and the onset of oligotrophic nannoplankton productivity did not allow for the formation of ribbon-bedded radiolarites.

In Western Tethys, a "radiolarite window", ranging from early Bajocian to late Tithonian, seems to be related to regional sea-surface fertility changes, explained by Baumgartner (2013) by the "Caribbean River Plume Model" (Figure 39), rather than regional upwelling unlikely in the complicated paleogeography of Western Tethyan basins. Classical concepts (e.g. Bosellini & Winterer 1975; Bernoulli & Jenkyns 2009) interpreted the paleogeographic distribution of pelagic limestone vs. siliceous mudstone/radiolarite in Western Tethys as the result of tectonic subsidence of distal marginal and oceanic seafloors beneath a shallow CCD. Later, radiolarian biochronology revealed that condensed pelagic limestone sedimentation on highs was coeval with rapid basal radiolarite sedimentation (Baumgartner 1990), which could not be explained as a dissolution-resistant residue of marginal carbonates. Baumgartner (2013, p. 312) concluded for the Western Tethyan Middle–Late Jurassic "radiolarite window": "The spatio-temporal distribution of carbonate and silica on Tethyan margins cannot be ex-

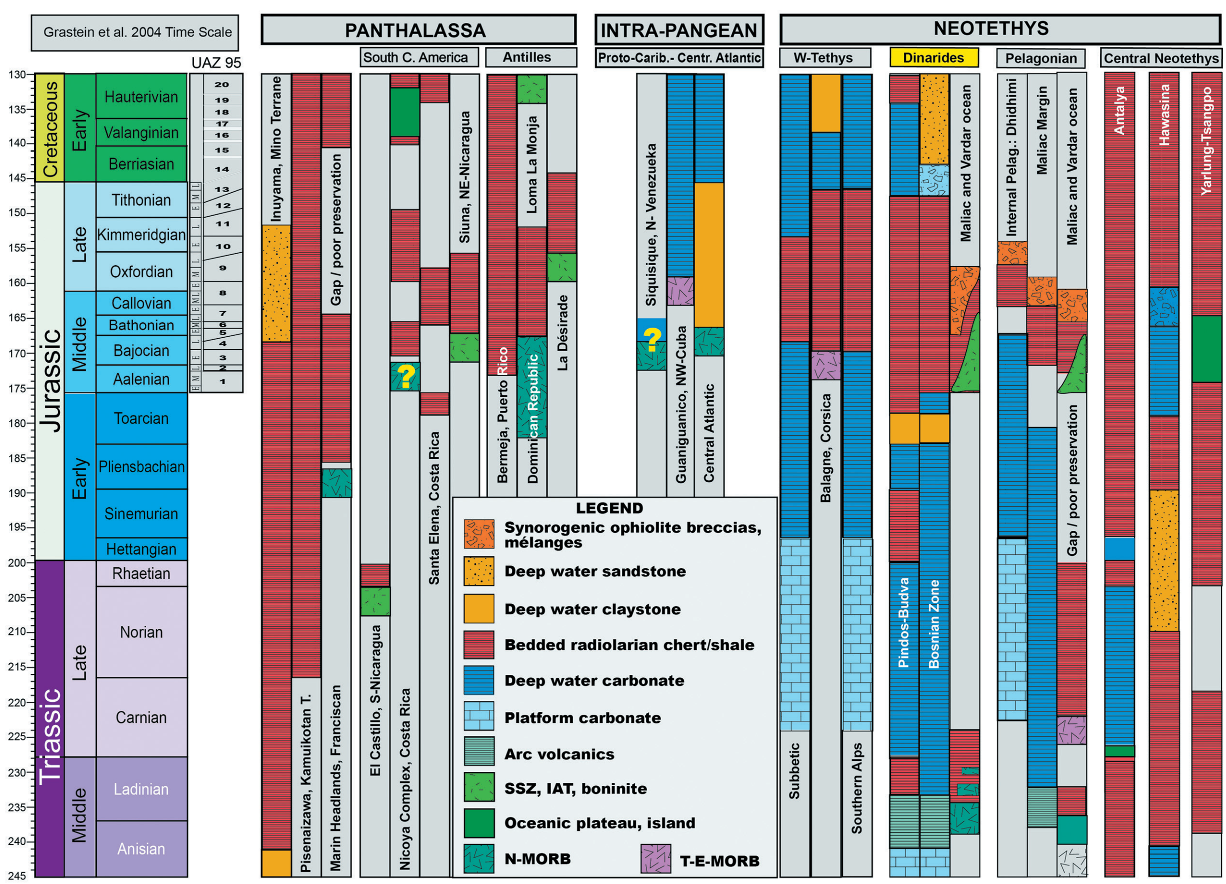


Figure 38: Middle Triassic-Early Cretaceous chronostratigraphy of pelagic facies in typical sections from Panthalassa to the E, through the intra-Pangean basins to Neotethys (modified after Baumgartner et al. 2017). Note the absence of ribbon radiolarites in the intra-Pangean proto-Caribbean and Central Atlantic. In the Dinarides-Hellenides the Western Tethyan Bajocian-Tithonian "radiolarite window" is observed in basins underlain by (thinned) continental crust in the proximity of carbonate platforms. The Budva-Pindos Basin and the Neotehyan Ocean remnants may contain radiolarites since the Middle Triassic. (Sources: Panthalassa: Murchey 1984, Ikeda et al. 2010, Ikeda & Tada 2014; S. central America: Baumgartner et al. 2008; Antilles: Bandini et al. 2011, Baumgartner et al. 2018; Intra-Pangean: Baumgartner 1984, Sandoval Gutierrez 2015; W Tethys: Baumgartner 1984, 1987, 2013; Dinarides: Goričan 1994; Vishnevskaya et al. 2009; Chiari et al. 2011; Pelagonian: Baumgartner 1985; Ferrière et al. 2015; Central Neotethys: Tekin 1999; Blechschmidt et al. 2004; Wang et al. 2002; Ziabrev et al. 2004).

plained by the palaeodepth of the calcite compensation depth (CCD) alone. Extensive lateral transport of radiolarian tests from topographic highs to the basins, and early diagenetic replacement on the highs by calcite may explain the absence of silica and the formation of condensed pelagic limestones coeval with basinal radiolarites. On a larger scale, palaeoclimatic changes, recorded in the carbon isotope curve (e.g., JENKYNS et al. 2002), rather than palaeotectonic changes, seem to have triggered major changes in surface fertility which, in turn, brought about the facies changes observed in Tethyan marginal basins. Regional platform demise, possibly due to eutrophication and a diachronous onset of radiolarites since the Early Bajocian, can be correlated with a positive shift in $\delta^{13}C$ values whereas platform recovery and the end of radiolarite accumulation correlates with a gradual drop-off of $\delta^{13}C$ values," and the installation of the Tithonian dry event (PRICE et al. 2016).

In the Dinaric basins underlain by Triassic carbonate platforms radiolarite accumulation began somewhat earlier (Figure 4). The Budva-Pindos Basin, that widens towards the SE into an ocean, contains the first radiolarites in the Middle Triassic and continuous radiolarite formation from earliest Hettangian to early Turonian, interrupted only by Pliensbachian carbonate resediments and late Tithonian to early Hauterivian pelagic limestones. The Budva-Pindos Basin was certainly connected with the central Neotethys where radiolarites formed, far from carbonate margins, since its oceanisation (Anisian or earlier) until the early Late Cretaceous, when planktonic foraminifera and calcareous nannoplankton began to

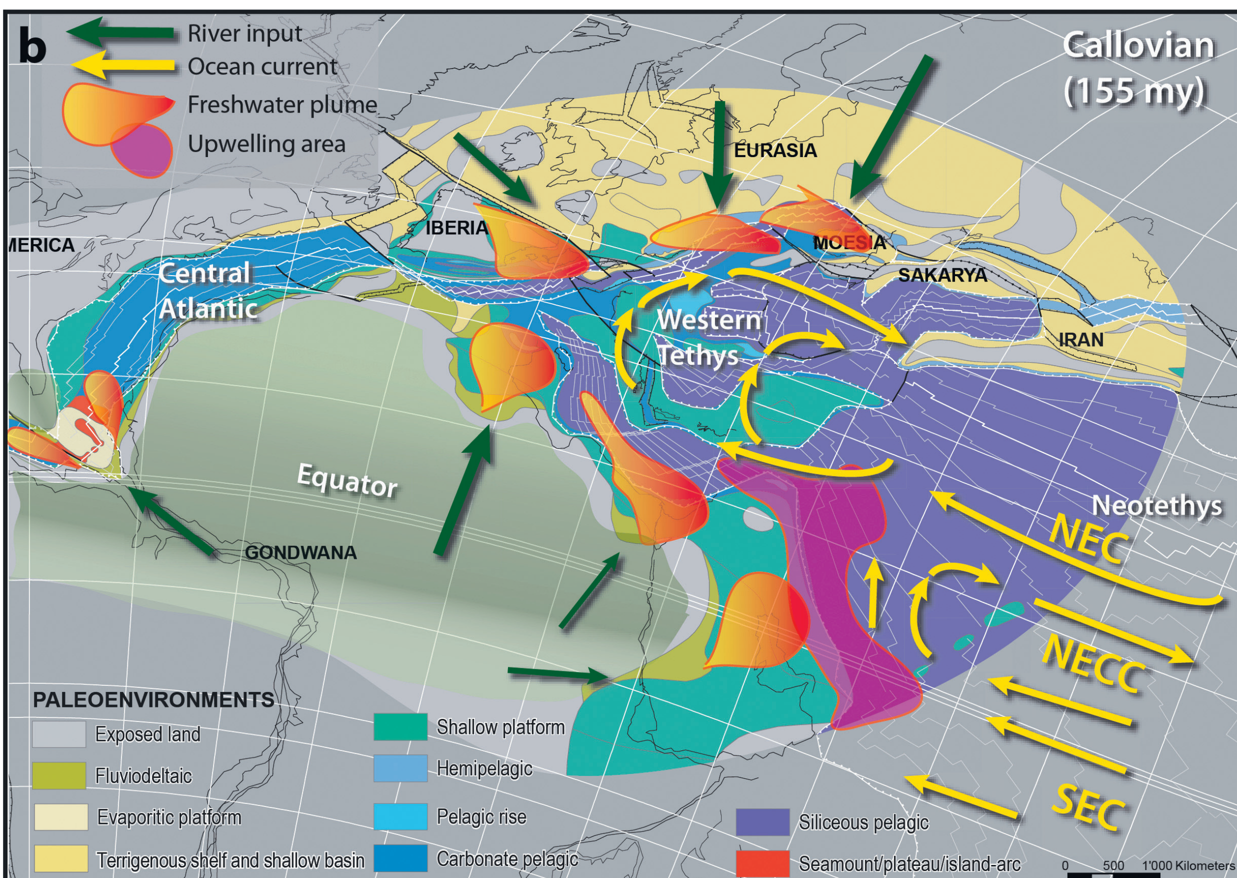


Figure 39: The River Plume Model (after BAUMGARTNER 2013, his Figure 6b). Callovian (155 Ma) reconstruction (after STAMPFLI & BOREL, 2002) of Western Tethys and Central Atlantic with simplified principal sedimentary palaeoenvironments (compiled by C. Wilhem, personal communication). The equatorial current system impinges on the Arabian Margin and is partly deflected into the Western Tethyan realm. Rivers draining tropical Africa and temperate Europe produce river plumes carrying dissolved organic matter that is distributed by anticyclonic surface circulation over the entire realm, including oceanic and epicontinental areas. The Central Atlantic and Proto-Caribbean are restricted 'Mediterranean' basins likely to have experienced excess evaporation, water stratification and widespread dysoxic bottom conditions trapping organic matter (and nutrients).

dominate worldwide. Late Paleozoic to early Late Cretaceous ranges of radiolarites are common in circum-Pacific remnants of Panthalassa (Figure 38). Several authors have inferred a monsoonal climate regime (DeWever et al. 1994, 2014; Arias 2008; Baumgartner 2013; Ikeda et al. 2017) that produced seasonally opposed trade winds over the Neotethys, bounded by the jaws of Eurasia to the north and Gondwana to the south (Figure 40). This regime may have produced important high productivity upwelling systems on both margins, in addition to upwelling beneath the peri-equatorial current system. The Jurassic convergence in the Dinarides-Hellenides, excluding the external Budva-Pindos and High Karst realms, makes an abrupt end to radiolarite deposition in this area, while oceanic crust continued to be formed to the southeast and radiolarites continued to form until the early Late Cretaceous also on the continental margin (e.g., Antalya nappes in southern Turkey, Yurtsever et al. 2003; Pichakun nappes in Iran, Robin et al. 2010; Hawasina units in Oman, Blechschmidt et al. 2004).

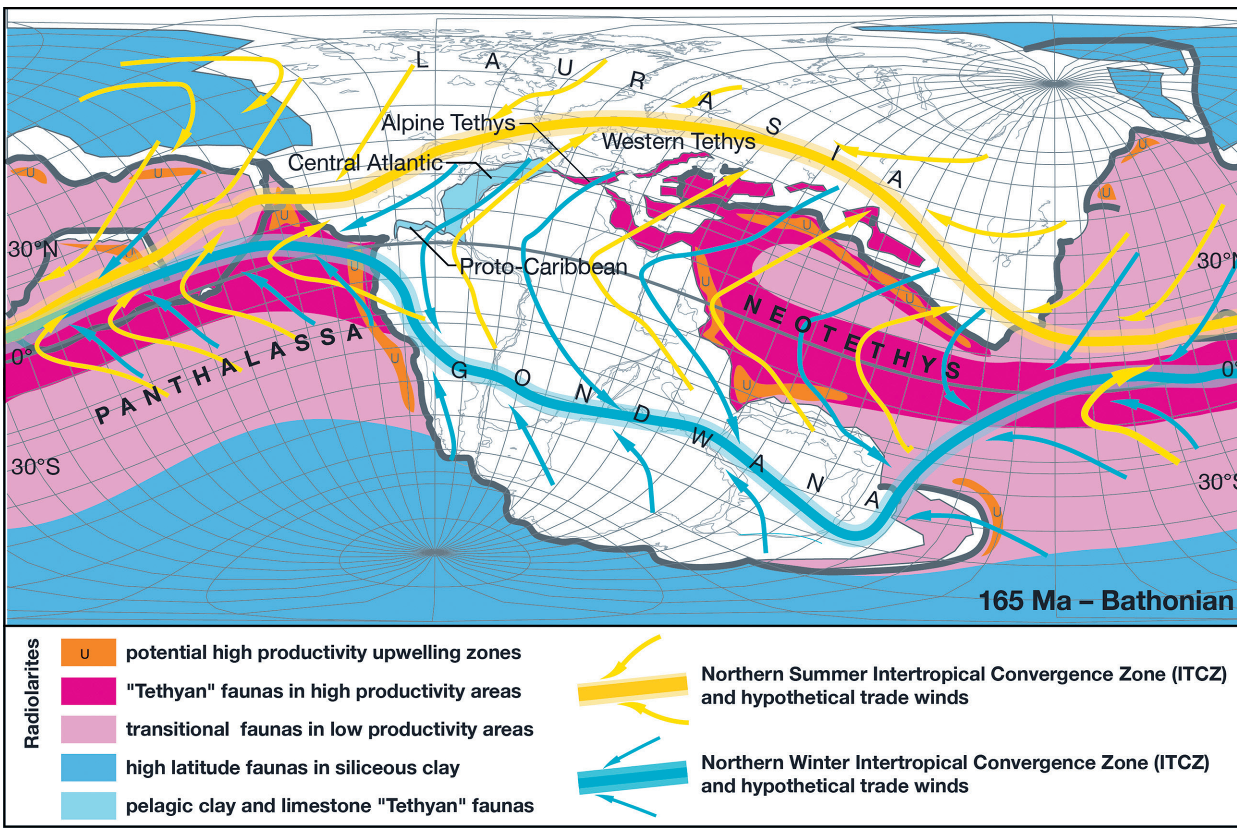


Figure 40: Paleogeographic map for 165 Ma (Bathonian) after Baumgartner et al. (2018) adapted from Bandini et al. (2011b) and Baumgartner (2013), showing major oceanic radiolarian bio-provinces and low/high accumulation of radiolarites. Epicontinental seas and continents are shown in white. Neotethys and Panthalassa oceans were covering wide paleo-latitudes and were well connected with each other. The "Intra-Pangean Basins", i.e. the Central Atlantic and the initial Proto-Caribbean, formed a low-fertility 'Mediterranean' sea with restricted connections to the world ocean. Middle Jurassic radiolarian faunas of that sea are very similar to those of the Tethys–Panthalassan low latitude belt, but accumulation rates were much smaller and episodic, not allowing for radiolarite formation. Northern summer (yellow) and Northern winter (blue) Intertropical Convergence Zones and associated (hypothetical) trade winds are shown, suggesting a "mega-monsoon" situation in Neotethys (Ikeda et al. 2017).

ACKNOWLEDGEMENTS

This study was for the most part financed by the Slovenian Research Agency, through the program P1-0008 Paleontology and Sedimentary Geology. Elizabeth S. Carter is acknowledged for her constructive comments and corrections.

REFERENCES

Aljinović, D., Horacek, M., Krystyn, L., Richoz, S., Kolar-Jurkovšek, T., Smirčić, D. & Jurkovšek, B., 2018: *Western Tethyan epeiric ramp setting in the Early Triassic: An example from the Central Dinarides (Croatia).* Journal of Earth Sciences 29 (4): 806–823.

Antonijević, R., Pavić, A & Karović, J., 1969: *Osnovna geološka karta 1:100 000, listovi Kotor i Budva*. Savezni geološki zavod, Beograd.

Argnani, A., 2018: *Subduction evolution of the Dinarides and the Cretaceous orogeny in the Eastern Alps: Hints from a new paleotectonic interpretation*. Tectonics 37: 621–635.

Arias, C., 2008: *Palaeoceanography and biogeography in the Early Jurassic Panthalassa and Tethys Oceans.* Gondwana Research 14 (3): 306–315.

Aubouin, J., Blanchet, R., Cadet, J.-P., Celet, P., Charvet, J., Chorowicz, J., Cousin, M. & Rampnoux, J.-P., 1970: *Essai sur la géologie des Dinarides.* Bull. Soc. géol. France sér. 7, XII (6): 1060–1095.

Baines, S.B., Twining, B.S., Brzezinski, M.A., Krause, J.W., Vogt, S., Assael, D. & McDaniel, H., 2012: *Significant silicon accumulation by marine picocyanobacteria*. Nature Geoscience 5: 886–891.

Bandini, A.N., Baumgartner, P.O., Flores, K., Dumitrica, P., Hochard, C., Stampfli, G.M. & Jackett, S.J., 2011: *Aalenian to Cenomanian Radiolaria of the Bermeja Complex (Puerto Rico) and Pacific origin of radiolarites on the Caribbean Plate*. Swiss Journal of Geosciences 104: 367–408.

Baumgartner, P.O., 1984: *A Middle Jurassic – Early Cretaceous low-latitude radiolarian zonation based on unitary associations and age of Tethyan radiolarites*. Eclogae geologicae Helvetiae 77: 729–837.

Baumgartner, P.O., 1985: *Jurassic sedimentary evolution and nappe emplacement in the Argolis Peninsula (Peloponnesus, Greece).* Mémoires de la Société helvétique des Sciences Naturelles 99: 1–111.

Baumgartner, P.O., 1987: *Age and genesis of Tethyan Jurassic radiolarites*. Eclogae geologicae Helvetiae 80, 831–879.

Baumgartner, P.O., 1990: *Genesis of Jurassic Tethyan radiolarites – the example of Monte Nerone (Umbria-Marche Apennines).* Atti 2. Convegno, Fossili Evoluzione Ambiente. Editore Comitato Centenario Raffaele Piccinini, Pergola, 19–32.

Baumgartner, P.O., 2013: *Mesozoic radiolarites – accumulation as a function of sea surface fertility on Tethyan margins and in ocean basins*. Sedimentology 60, 292–318.

Baumgartner, P.O., Bartolini, A., Carter, E.S., Conti, M., Cortese, G., Danelian, T., De Wever, P., Dumitrica, P., Dumitrica-Jud, R., Goričan, Š., Guex, J., Hull, D.M., Kito, N., Marcucci, M., Matsuoka, A., Murchey, B., O'Dogherty, L., Savary, J., Vishnevskaya, V., Widz, D. & Yao, A., 1995: *Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on Unitary Associations.* In: Baumgartner, P.O., O'Dogherty, L., Goričan, Š., Urquhart, E., Pillevuit, A. & De Wever, P. (Eds.), *Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrences, Systematics, Biochronology.* Mémoires de Géologie (Lausanne) 23: 1013–1048.

Baumgartner, P.O., Flores, K., Bandini, A., Girault, F. & Cruz, D., 2008: *Upper Triassic to Cretaceous Radiolaria from Nicaragua and northern Costa Rica: the Mesquito composite oceanic terrane.* Ofioliti 33: 1–19.

Baumgartner, P. O., Andjic, G., Sandoval-Gutierez, M., Bandini-Maeder, A., Diserens, M.-O., Baumgartner-Mora, C. & Kukoc, D., 2018: *Radiolarian biochronology and paleoceanography of Pacific Terranes in Central America and the Caribbean.* In AAPG Hedberg Research Conference, *Geology of Middle America – the Gulf of Mexico, Yucatán, Caribbean, Grenada and Tobago Basins and Their Margins*, Siguenza, Spain, 10–16, AAPG Datapages, Search and Discovery Article #90330, Tulsa.

Bébien, J., Blanchet, R., Cadet, J.-P., Charvet, J., Chorowicz, J., Lapierre, H. & Rampnoux, J.-P. 1978: *Le volcanisme triasique des Dinarides en Yougoslavie : sa place dans l'évolution géotectonique péri-méditerranéenne*. Tectonophysics 47: 159–176.

Bechstädt, T., Brandner, R., Mostler, H. & Schmidt, K., 1978: *Aborted rifting in the Triassic of the eastern and southern Alps.* N. Jb. Geol. Paläont. Abh. 156 (2): 157–178.

Bernoulli, D. & Laubscher, H., 1972: *The palinspastic problem of the Hellenides*. Eclogae Geologicae Helvetiae 65: 107–118.

Bernoulli, D. & Jenkyns, H.C., 2009: *Ophiolites in ocean–continent transitions: from the Steinmann Trinity to sea-floor spreading.* C.R. Geoscience 341: 363–381.

Bill, M., O'Dogherty, L., Guex, J., Baumgartner, P.O. & Masson, H., 2001: *Radiolarite ages in Alpine-Mediterranean ophiolites: Constraints on the oceanic spreading and the Tethys-Atlantic connection*. GSA Bulletin 113 (1): 129–143.

Blanchet, R., 1970: *Sur un profil des Dinarides, de l'Adriatique (Split-Omiš, Dalmatie) au Bassin pannonique (Banja Luka – Doboj, Bosnie)*. Bull. Soc. géol. France sér. 7, XII (6): 1010–1027.

Blanchet, R., 1975: *De l'Adriatique au Bassin pannonique. Essai d'un modèle de chaîne alpine*. Mémoires de la Société géologique de France 120, 172 pp., 4 pls, 1 map.

Blanchet, R., Cadet, J.-P., Charvet, J. & Rampnoux, J.-P., 1969: *Sur l'existence d'un important domaine de flysch tithonique–crétacé inférieur en Yougoslavie: l'unité du flysch bosniaque.* Bull. Soc. *Géol*. France sér. 7, XI (6): 871–880.

Blechschmidt, I., Dumitrica, P., Matter, A., Krystyn, L. & Peters, T., 2004 : *Stratigraphic architecture of the northern Oman continental margin – Mesozoic Hamrat Duru Group, Hawasina Complex, Oman*. GeoArabia 9: 81–132.

Böhm, F., 1992: *Mikrofazies and Ablagerungsmilieu des Lias und Dogger der Nordöstlichen Kalkalpen*. Erlanger Geol. Abh. 121: 55–217.

Borojević Šoštarić, S., Neubauer, F., Handler, R. & Palinkaš, L.A., 2012. *Tectonothermal history of the basement rocks within the NW Dinarides: new 40Ar/39Ar ages and synthesis*. Geologica Carpathica 63 (6): 441–452.

Bortolotti, V., Marroni, M., Pandolfi, L. & Principi, G., 2005: *Mesozoic to Tertiary tectonic history of the Mirdita ophiolites, northern Albania*. The Island Arc 14: 471–493.

Bortolotti, V., Chiari, M., Marcucci, M., Photiades, A., Principi, G. & Saccani, E., 2008: *New geochemical and age data on the ophiolites from the Othrys area (Greece): implication for the Triassic evolution of the Vardar Ocean*. Ofioliti 33: 135–151.

Bortolotti, V., Chiari, M., Marroni, M., Pandolfi, L., Principi, G. & Saccani, E., 2013. *Geodynamic evolution of ophiolites from Albania and Greece (Dinaric-Hellenic belt): one, two, or more oceanic basins?* International Journal Earth Sciences 102, 783–811.

Bosellini, A. & Winterer, E.L., 1975: *Pelagic limestone and radiolarite of the Tethyan Mesozoic: a genetic model.* Geology 3: 279–282.

Brack, P. & Rieber, H., 1993: *Towards a better definition of the Anisian/Ladinian boundary: New biostratigraphic data and correlations of boundary sections from the Southern Alps*. Eclogae geologicae Helvetiae 86 (2): 415–527.

Bragina, L.G., Bragin, N.Yu., Djerić, N. & Gajić, V., 2014: *Late Cretaceous Radiolarians and Age of Flyschoid Sediments in the Struganik Section (Western Serbia).* Stratigraphy and Geological Correlation 22 (2): 202–218.

Bragina, L.G., Bragin, N.Yu., Kopaevich, L.F. & Beniamovsky, V.N., 2018: *Santonian Radiolarians and Foraminifers from Brežđe Section, Western Serbia*. Moscow University Geology Bulletin 73 (4): 333–345.

Bragina, L.G., Bragin, N.Yu., Kopaevich, L.F., Djerić, N. & Gerzina Spajić, N., 2020: *Stratigraphy and Microfauna (Radiolarians and Foraminifera) of the Upper Cretaceous (Upper Santonian–Lower Campanian) Carbonate Deposits in the Area of Struganik Village, Western Serbia)*. Stratigraphy and Geological Correlation 28 (1): 65–87.

Burić, P., 1966: *Geologija ležišta boksita Crne Gore (Géologie des gîtes de bauxite du Monténégro, Yougoslavie).* Geološki glasnik, Sarajevo, Posebna izdanja 8: 1–277.

Cadet, J.-P., 1978: *Essai sur l'évolution alpine d'une paléomarge continentale: les confins de la Bosnie-Herzégovine et du Monténégro (Yougoslavie).* Mémoires de la Société géologique de France (nouvelle série) 133: 1–83, pls. 1–4.

Cafiero, B. & De Capoa Bonardi, P., 1980: *Stratigraphy of the pelagic Triassic in the Budva-Kotor area (Crna Gora, Montenegro, Yugoslavia).* Bolletino della Società Paleontologica Italiana 19 (2): 179–204.

Cafiero, B. & De Capoa Bonardi, P., 1981: *I Conodonti dei calcari ad* Halobia *del Trias superior del Montenegro (Crna Gora, Jugoslavia).* Rivista Italiana di Paleontologia 86 (3): 563–576.

Carter, E.S. & Hori, R.S., 2005: *Global correlation of the radiolarian faunal change across the Triassic-Jurassic boundary.* Canadian Journal of Earth Sciences 42: 777–790.

Carter, E.S., Whalen, P.A. & Guex, J., 1998: *Biochronology and paleontology of Lower Jurassic (Hettangian and Sinemurian) radiolarians, Queen Charlotte Islands, British Columbia*. Geological Survey of Canada, Bulletin 496: 1–162.

Celarc, B., Goričan, Š. & Kolar-Jurkovšek, T., 2013: *Middle Triassic carbonate-platform break-up and formation of small-scale half-grabens (Julian and Kamnik–Savinja Alps, Slovenia).* Facies 59: 583–610.

Charvet, J., 1978: *Essai sur un orogène alpin. Géologie des Dinarides au niveau de la transversale de Sarajevo (Yougoslavie)*. Société géologique du Nord Publ 2:1–554, pls. 1–21.

Charvet, J., 2013: *Le développement géotectonique des Dinarides: évolution des idées et apport des équipes françaises.* Travaux du Comité français d'Histoire de la Géologie. In: Comité français d'Histoire de la Géologie 3ème série 27 (7): 163–220.

Chiari, M., Bortolotti, V., Marcucci, M., Photiades, A. & Principi, G., 2003: *The Middle Jurassic siliceous sedimentary cover at the top of the Vourinos Ophiolite (Greece)*. Ofioliti 28: 95–103.

Chiari, M., Marcucci, M. & Prela, M., 2004: *Radiolarian assemblages from the Jurassic cherts of Albania: new data*. Ofioliti 29: 95–105.

Chiari, M., Djerić, N., Garfagnoli, F., Hrvatović, H., Krstić, M., Levi, N., Malasoma, A., Marroni, M., Menna, F., Nirta, G., Pandolfi, L., Principi, G., Saccani, E., Stojadinović, U. & Trivić, B., 2011: *The geology of the Zlatibor-Maljen area (western Serbia): A geotraverse across the ophiolites of the Dinaric-Hellenic collisional belt*. Ofioliti 36 (2): 139–166.

Chiari, M., Bortolotti, V., Marcucci, M., Photiades, A., Principi, G. & Saccani, E., 2012: *Radiolarian biostratigraphy and geochemistry of the Koziakas massif ophiolites (Greece)*. Bulletin de la Société géologique de France 183(4): 287–306.

Čadjenović, D. & Radulović, N., 2018: *The distribution of terrigenous clastics of Anisian: slope, submarine fan, basins of Crmnica in Montenegro*. 17^{th} Serbian Geological Congress, Book of Abstracts, 91–97.

Čađenović, D., Milutin, J., Đaković, M. & Radulović, N., 2014: *Anisian carbonates of Crmnica and surroundings in Montenegro*. 16^{th} Serbian Geological Congress, Proceedings: 63–71 (In Serbian, English summary).

Črne, A.E., 2009: *Depositional model of Lower Jurassic carbonates on the Dinaric Carbonate Platform margin*. Dissertation, University of Ljubljana, 185 pp.

Črne, A.E. & Goričan, Š., 2008: *The Adriatic-Dinaric Carbonate Platform margin in the Early Jurassic: a comparison between successions in Slovenia and Montenegro*. Bollettino della Società Geologica Italiana 127: 389–405.

Črne, A.E., Weissert, H., Goričan, Š. & Bernasconi, S.M., 2011: *A biocalcification crisis at the Triassic–Jurassic boundary recorded in the Budva Basin (Dinarides, Montenegro)*. GSA Bulletin 123 (1–2): 40–50.

Danilova, A., 1958: *Mikropaleontološki prikaz zona višeg senona u Boki Kotorskoj*. Geološki glasnik Titograd 11: 223–232, pl. 23–27.

Đaković, M., 2018: *Stratigraphy of Triassic formations with ammonoids between Virpazar and Bar (Montenegro)*. Unpublished dissertation, University of Belgrade, 238 pp. (In Serbian, with English abstract).

Đaković, M., Gawlick, H.-J., Čađenović, D., Missoni, S., Milić, M. & Krystyn, L., 2018: *Bithynian cherty limestones of the Rosni virovi locality, Budva zone (southern Montenegro)*. XXI International Congress of the CBGA, Abstracts, p. 64.

Đaković, M., Gawlick, H.-J. & Sudar, M., 2021: *Early-Middle Jurassic stepwise deepening in the transitional facies belt between the Adriatic Carbonate Platform Basement and Neo-Tethys open shelf in northeastern Montenegro evidenced by new ammonoid data from the early Late Pliensbachian (Lavinianum Zone)*. Geološki anali Balkanskoga poluostrva 82 (1): 1–25.

Đaković, M., Krystyn, L. & Sudar, M., 2022: *The Middle Smithian (Early Triassic) ammonoids of Gornji Brčeli (Southern Montenegro)*. Rivista Italiana di Paleontologia e Stratigrafia 128 (2): 427–446.

Dercourt, J., 1968: *Sur l'accident de Scutari-Peć, la signification paléogéographique de quelques séries condensées en Albanie septentrionale*. Annales de la Société géologique du Nord 88: 109–117.

Đerić, N. & Gerzina, N., 2014: *New data on the age of an Upper Cretaceous clastic-carbonate succession in Brežđe (Western Serbia)*. Geologia Croatica 67 (3): 163–170.

Djerić, N., Gerzina, N., Gajić, V. & Vasić, N., 2009: *Early Senonian radiolarian microfauna and biostratigraphy from the Western Vardar Zone (Western Serbia)*. Geologica Carpathica 60 (1): 35–41.

De Wever, P., 1984: *Triassic radiolarians from the Darnó area (Hungary)*. Acta geol. Hungarica 27 (3), 295–306.

De Wever P., Azéma, J. & Fourcade, E., 1994: *Radiolaires et radiolarites: production primaire, diagenèse et paléogéographie*. Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine 18 (1): 315–379.

De Wever, P., O'Dogherty, L. & Goričan, Š., 2014: *Monsoon as a cause of radiolarite in the Tethyan realm*. C. R. Geoscience 346 : 287–297.

Dimitrijević, M., 1967: *Sedimentološko-stratigrafski problemi srednjetrijaskog fliša u terenima između Skadarskog jezera i Jadranskog mora*. Geološki glasnik Titograd 5: 223–275.

Dimitrijević, M.D., 1997: *Geology of Yugoslavia*. Geological Institute GEMINI Special Publication, Belgrade, 187 pp.

Dilek, Y., Shallo, M. & Furnes, H., 2005: *Rift-drift, seafloor spreading, and subduction tectonics of Albanian ophiolites*. International Geology Review 47: 147–176.

Dumitrica, P., 2017: On the status of the Triassic Nassellarian radiolarian family Tetraspinocyrtiidae Kozur and Mostler and description of some related taxa. Revue de micropaléontologie 60: 33–85.

Dumitrica, P. & Dumitrica Jud, R., 1995: Aurisaturnalis carinatus *(Foreman), an example of phyletic gradualism among Saturnalid-type radiolarians*. Revue de Micropaléontologie 38 (3): 195–216.

Ferrière, J., Chanier, F. & Ditbanjong, P., 2012: *The Hellenic ophiolites: eastward or westward obduction of the Maliac Ocean, a discussion*. International Journal of Earth Sciences 101: 1559–1580.

Ferrière, J., Chanier, F., Baumgartner, P.O., Caridroit, M., Bout-Roumazeilles, V., Graveleau, F., Danelian, T. & Ventalon, S., 2015: *The evolution of the Triassic–Jurassic oceanic lithosphere: insights from the supra-ophiolitic series of Othris (continental Greece)*. Bull. soc. géol. France 186 (6): 71–84.

Ferrière, J., Baumgartner, P.O. & Chanier, F., 2016: *The Maliac Ocean: the origin of the Tethyan Hellenic ophiolites*. International Journal of Earth Sciences 105: 1941–1963.

Gawlick, H.-J. & Missoni, S., 2015: *Middle Triassic radiolarite pebbles in the Middle Jurassic Hallstatt Mélange of the Eastern Alps: implications for Triassic-Jurassic geodynamic and palaeogeographic reconstructions of the western Tethyan realm*. Facies 61 (13): 19 pages. DOI 10.1007/s10347-015-0439-3

Gawlick, H.-J. & Missoni, S., 2019: *Middle–Late Jurassic sedimentary mélange formation related to ophiolite obduction in the Alpine-Carpathian-Dinaridic Mountain Range*. Gondwana Research 74: 144–172.

Gawlick, H.-J. & Schlagintweit, F., 2006: *Berriasian drowning of the Plassen carbonate platform at the type-locality and its bearing on the early Eoalpine orogenic dynamics in the Northern Calcareous Alps (Austria)*. International Journal of Earth Sciences 96: 451–462.

Gawlick, H.J., Frisch, W., Hoxha, L., Dumitrica, P., Krystyn, L., Lein, R., Missoni, S. & Schlagintweit, F., 2008: *Mirdita Zone ophiolites and associated sediments in Albania reveal Neotethys Ocean origin*. International Journal of Earth Sciences 97: 865–881.

Gawlick, H.J., Sudar, M., Suzuki, H., Djerić, N., Missoni, S., Lein, R. & Jovanović D., 2009: *Upper Triassic and Middle Jurassic radiolarians from the ophiolitic mélange of the Dinaridic Ophiolite Belt, SW Serbia*. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 253 (2–3), 293–311.

Gawlick, H.-J., Goričan, Š., Missoni, S. & Lein, R., 2012: *Late Anisian platform drowning and radiolarite deposition as a consequence of the opening of the Neotethys ocean (High Karst nappe, Montenegro)*. Bulletin de la Société géologique de France 183 (4): 349–358.

Gawlick, H.-J., Goričan, Š., Missoni, S., Dumitrica, P., Lein, R., Frisch, W. & Hoxha, L., 2016a: *Middle and Upper Triassic radiolarite components from the Kcira-Dushi-Komani ophiolitic mélange and their provenance (Mirdita Zone. Albania)*. Revue de micropaléontologie 59: 359–380.

Gawlick, H.-J., Missoni, S., Suzuki, H., Sudar, M., Lein, R. & Jovanović, D., 2016b: *Triassic radiolarite and carbonate components from a Jurassic ophiolitic mélange (Dinaridic Ophiolite Belt)*. Swiss Journal of Geosciences 109: 473–494.

Gawlick, H.-J., Sudar, M.N., Missoni, S., Suzuki, H., Lein, R., Jovanović, D., 2017a: *Triassic-Jurassic geodynamic evolution of the Dinaridic Ophiolite Belt (Inner Dinarides, SW Serbia)*. Journal of Alpine Geology 55, 1–167.

Gawlick H.-J., Djerić N., Missoni S., Bragin N. Yu., Lein R., Sudar M. & Jovanović D., 2017b: *Age and microfacies of oceanic Late Triassic radiolarite components from the Middle Jurassic ophiolitic mélange in the Zlatibor Mountains (Inner Dinarides, Serbia) and their provenance*. Geologica Carpathica 68 (4): 350–365.

Gawlick, H.-J., Missoni, S., Sudar, M.N., Goričan, Š., Lein, R., Stanzel, A.I. & Jovanović, D., 2017c: *Open--marine Hallstatt Limestones reworked in the Jurassic Zlatar Mélange (SW Serbia): a contribution to understanding the orogenic evolution of the Inner Dinarides*. Facies 63: 29 (25 p.).

Gawlick, H.-J., Missoni, S., Sudar, M.N., Suzuki, H., Méres, Š., Lein, R. & Jovanović, D. 2018: *The Jurassic Hallstatt Mélange of the Inner Dinarides (SW Serbia): implications for Triassic–Jurassic geodynamic and palaeogeographic reconstructions of the Western Tethyan realm*. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 288 (1): 1–47.

Gawlick, H.-J., Sudar, M., Missoni, S., Aubrecht, R., Schlagintweit, F., Jovanović, D. & Mikuš, T., 2020. *Formation of a Late Jurassic carbonate platform on top of the obducted Dinaridic ophiolites deduced from the analysis of carbonate pebbles and ophiolitic detritus in southwestern Serbia*. International Journal of Earth Sciences 109: 2023–2048.

Goričan, Š., 1987: *Jurassic and Cretaceous radiolarians from the Budva Zone (Montenegro, Yugoslavia)*. Revue de Micropaléontologie 30: 177–196.

Goričan, Š., 1994: *Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budva Zone (Dinarides, Montenegro)*. Mémoires de Géologie (Lausanne) 18, 177 pp.

Goričan, Š., Halamić, J., Grgasović, T. & Kolar-Jurkovšek, T. 2005: *Stratigraphic evolution of Triassic arc--backarc system in northwestern Croatia*. Bull. Soc. géol. France 176: 3–22.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M., 2012: *The geological time scale 2012*. Elsevier, Amsterdam.

Haas, J., Kovács, S., Gawlick, H.-J., Gradinaru, E., Karamata, S., Sudar, M., Péró, C., Mello, J., Polák, M., Ogorelec, B. & Buser, S., 2011: *Jurassic evolution of the tectonostratigraphic units of the Circum-Pannonian Region*. Jahrbuch der Geologischen Bundesanstalt 151: 281–354.

Halamić, J. & Goričan, Š., 1995: *Triassic radiolarites from Mts. Kalnik and Medvednica (northwestern Croatia).* Geologia Croatica 48: 129–146.

Halamić, J., Goričan, Š., Slovenec, D. & Kolar-Jurkovšek, T., 1999: *A Middle Jurassic Radiolarite-Clastic Succession from the Medvednica Mt. (NW Croatia)*. Geologia Croatica 52, 29–57.

Harzhauser, M. & Mandić, O., 2008: *Neogene lake systems of central and South-Eastern Europe: Faunal diversity, gradients and interrelations*. Paleogeography, Paleoclimatology, Paleoecology 260 (3–4): 417–434.

Hauer, F.v., 1888: *Die Cephalopoden des bosnischen Muschelkalkes von Han Bulog bei Sarajevo*. Denkschr. K. Akad. Wiss., math.-natw. Kl., 54: 1–50.

Horacek, M., Đaković, M. & Krystyn, L., 2020: *The Permian of the Budva Zone, Montenegro, western Tethys*. Permophiles 69: 32–36.

Hrvatović, H., 2006: *Geological guidebook through Bosnia and Herzegovina*. Geological Survey of Federation Bosnia and Herzegovina, Sarajevo, 172 pp.

Ikeda, M. & Tada, R., 2014: *A 70 million year astronomical time scale for the deep-sea bedded chert sequence (Inuyama, Japan): Implications for Triassic–Jurassic geochronology*. Earth and Planetary Science Letters 399: 30–43.

Ikeda, M., Tada, R. & Sakuma, H., 2010: *Astronomical cycle origin of bedded chert: A middle Triassic bedded chert sequence, Inuyama, Japan*. Earth and Planetary Science Letters 297: 369–378.

Ikeda, M., Tada, R. & Ozaki, K., 2017: *Astronomical pacing of the global silica cycle recorded in Mesozoic bedded cherts.* Nature Communications 8:15532, DOI: 10.1038/ncomms15532.

Ingle, J.C. Jr., 1981: *Origin of Neogene diatomites around the North Pacific Rim*. In: Garrison, R.E., Douglas, R.G. et al. (Eds.): *The Monterey Formation and Related Siliceous Rocks of California*. Spec. Publ. Pac. Sect. Soc. econ. Paleont. Miner., Los Angeles, 159–179.

Jenkyns, H.G., Jones, C.E., Gröcke, D.R., Hesselbo, S.P. & Parkinson, D.N., 2002: *Chemostratigraphy of the Jurassic System: applications, limitations and implications for palaeoceanography*. Journal of the Geological Society London 159: 351–378.

Karamata, S., 2006: *The geological development of the Balkan Peninsula related to the approach, collision and compression of Gondwanan and Eurasian units*. In: Robertson, A.H.F. & Mountrakis, D., (Eds.): *Tectonic Development of the Eastern Mediterranean Region*. Geological Society London Special Publications 260: 155–178.

Kozur, H. & Mostler, H., 1994: *Anisian to Middle Carnian radiolarian zonation and description of some stratigraphically important radiolarians*. Geologisch-Paläontologische Mitteilungen Innsbruck Sonderband 3: 39–255.

Kozur, H. & Réti, Z., 1986: *The first paleontological evidence of Triassic ophiolites in Hungary*. N. Jb. Geol. Paläont. Mh. 5: 284–292.

Kozur, H.W., Krainer, K. & Mostler, H., 1996: *Radiolarians and Facies of the Middle Triassic Loibl Formation, South Alpine Karawanken Mountains (Carinthia, Austria).* Geologisch-Paläontologische Mitteilungen Innsbruck Sonderband 4, 195–269.

Kovács S., Sudar M., Grădinaru E., Gawlick H.-J., Karamata S., Haas J., Péró C., Gaetani M., Mello J., Polák M., Aljinović D., Ogorelec B., Kolar-Jurkovšek T., Jurkovšek B. & Buser S. 2011. *Triassic Evolution of the Tectonostratigraphic Units of the Circum-Pannonian Region*. Jahrbuch der Geologischen Bundesanstalt 151 (3–4): 199–280.

Krystyn, L., 2008: *The Hallstatt pelagics—Norian and Rhaetian Fossillagerstaetten of Hallstatt*. Berichte Geologische Bundesanstalt 76: 81–98.

Krystyn, L., Brandner, R., Đaković, M. & Horacek, M. 2019: *The Lower Triassic of Budva Zone*. Geološki Glasnik 17: 9–22.

Kukoč, D., 2014: *Jurassic and Cretaceous radiolarian stratigraphy of the Bled Basin (northwestern Slovenia) and stratigraphic correlations across the Internal Dinarides*. Dissertation, University of Ljubljana, 257 pp.

Kukoč, D., Goričan, Š. & Košir, A., 2012: *Lower Cretaceous carbonate gravity-flow deposits from the Bohinj area (NW Slovenia): evidence of a lost carbonate platform in the Internal Dinarides.* Bull. Soc. géol. France 183 (4): 383–392.

Longridge, L.M., Carter, E.S., Smith, P.L. & Tipper, H.W., 2007: *Early Hettangian ammonites and radiolarians from the Queen Charlotte Islands, British Columbia and their bearing on the definition of the Triassic–Jurassic boundary.* Palaeogeography, Palaeoclimatology, Palaeoecology 244: 142–169.

Matenco, L. & Radivojević, D., 2012: *On the formation and evolution of the Pannonian Basin: Constraints derived from the structure of the junction area between the Carpathians and Dinarides.* Tectonics 31, TC6007. https://doi.org/10.1029/2012TC003206

Marroni, M., Pandolfi, L., Onuzi, K., Palandri, S. & Xhomo, A., 2009: *Ophiolite-bearing Vermoshi Flysch (Albanian Alps, northern Albana): elements for its correlation in the frame of Dinaric-Hellenic belt*. Ofioliti 34 (2): 95–108.

Metodiev, L., Rabrenović, D., Mojsić, I., Ivanova, D., Koleva-Rekalova, E. & Radulović, V., 2013: *The ammonites of the Bifrons Zone (Toarcian, Lower Jurassic) from Mihailovići (Northern Montenegro).* Comptes rendus de l'Académie bulgare des Sciences 66 (1): 67–76.

Mikes, T., Christ, D., Petri, R., Dunkl, I., Frei, D., Báldi-Beke, M., Reitner, J., Wemmer, K., Hrvatović, H. & von Eynatten, H., 2008: *Provenance of the Bosnian Flysch*. Swiss Journal of Geosciences 101: S31–S54.

Mirković, M., 1983: *Geološki sastav i tektonika planina Durmitora, Pivske planine i Volujaka (Geology and tectonics of Durmitor, Piva and Volujak mountains)* (in Serbian with English summary). Zavod za geološka istraživanja SR Crne Gore, Posebna izdanja Geološkog glasnika 5, 116 pp., 4 foldouts in appendix.

Mirković, M. & Vujisić, P., 1989: *Osnovna geološka karta 1:100 000, list Žabljak*. Savezni geološki zavod, Beograd.

Mirković, M., Kalezić, M. & Pajović, M., 1968: Osnovna geološka karta 1:100 000, list Bar. Savezni geološki zavod, Beograd.

Mirković, M., Pajović, M., Buzaljko, R., Kalezić M. & Živaljević, M., 1978: *Osnovna geološka karta 1:100 000, list Pljevlja.* Savezni geološki zavod, Beograd.

Mirković, M., Živaljević, M., Đokić, V., Perović, Z., Kalezić, M. & Pajović, M., 1985: Geološka karta Crne Gore, 1:200.000. RSIZ za geološka istraživanja, Titograd.

Missoni, S., Gawlick, H.-J., Sudar, M.N., Jovanović, D. & Lein, R., 2012: *Onset and demise of the Wetterstein Carbonate Platform in the mélange areas of the Zlatibor Mountain (Sirogojno, SW Serbia)*. Facies 58: 95–111.

Murchey, B. M., 1984: *Biostratigraphy and lithostratigraphy of chert in the Franciscan Complex, Marin Headlands, California*. In: Blake, Jr. M. C. (Ed.), F*ranciscan Geology of Northern California*. Pacific Section Society of Economic Paleontologists and Mineralogists 43: 51–70.

Nirta G., Bortolotti V., Chiari M., Menna F., Saccani E., Principi G. & Vannucchi P., 2010: *Ophiolites from the Grammos-Arrenes area, northern Greece: geological, paleontological and geochemical data*. Ofioliti 35: 103–115.

Nirta, G., Moratti, G., Piccardi, L., Montanari, D., Catanzariti, R., Carras, N. & Papini, M., 2015: *The Boeotian flysch revisited: new constraints on ophiolite obduction in Central Greece.* Ofioliti 40 (2): 107–123.

Nirta, G., Moratti, G., Piccardi, L., Montanari, D., Carras, N., Catanzariti, R., Chiari, M. & Marcucci, M., 2018: *From obduction to continental collision: new data from Central Greece*. Geological Magazine 155 (2): 377–421.

Nirta, G., Aberhan, F., Bortolotti, V., Carras, N., Menna, F. & Fazzuoli, M., 2020: *Deciphering the geodynamic evolution of the Dinaric orogen through the study of the 'overstepping' Cretaceous successions*. Geological Magazine 157 (8): 1238–1264.

Nöth, L., 1956: *Beiträge zur Geologie von Nordmontenegro. Oberlias in der Umgebung von Pljevlja.* Raimund von Klebelsberg-Festschrift der Geologischen Gesellschaft in Wien 48, 167–191.

Obradović, J. & Goričan, Š., 1988: *Siliceous Deposits in Yugoslavia: Occurrences, Types and Ages.* In: Hein, J. R. & Obradović, J. (Eds.): *Siliceous Deposits of the Tethys and Pacific Regions*. Springer Verlag: 51–64.

O'Dogherty, L., 1994: *Biochronology and Paleontology of Mid-Cretaceous Radiolarians from Northern Apennines (Italy) and Betic Cordillera (Spain).* Mémoires de Géologie (Lausanne) 21: 1–415.

O'Dogherty, L., Carter, E.S., Dumitrica, P., Goričan, Š., De Wever, P., Hungerbühler, A., Bandini, A.N. & Takemura A., 2009a: *Catalogue of Mesozoic radiolarian genera. Part 1: Triassic*. Geodiversitas 31: 213–270.

O'Dogherty, L., Carter, E.S., Dumitrica, P., Goričan, Š., De Wever, P., Bandini, A.N., Baumgartner, P.O. & Matsuoka, A., 2009b: *Catalogue of Mesozoic radiolarian genera. Part 2, Jurassic–Cretaceous*. Geodiversitas 31, 271–356.

O'Dogherty, L., Carter, E. S., Goričan, Š. & Dumitrica, P., 2010: *Triassic radiolarian biostratigraphy.* In: Lucas, S.G. (Ed.), *The Triassic Timescale*. Geological Society London, Special Publication 334: 163–200.

Ozsvárt, P. & Kovács, S., 2012: *Revised Middle and Late Triassic radiolarian ages for ophiolite mélanges: implications for the geodynamic evolution of the northern part of the early Mesozoic Neotethyan subbasins*. Bull. Soc. géol. France 183 (4): 273–286.

Pamić, J., 1984: *Triassic magmatism of the Dinarides in Yugoslavia*. Tectonophysics 109: 273–307.

Pamić, J., Tomljenović, B. & Balen, D., 2002: *Geodynamic and petrogenetic evolution of Alpine ophiolites from the central and NW Dinarides: an overview*. Lithos 65: 113–142.

Peron-Pinvidic, G. & Manatschal, G., 2010. *From microcontinents to extensional allochthons: witnesses of how continents rift and break apart?* Petroleum Geoscience 16, 1–10.

Pessagno, E.A. 1977: *Lower Cretaceous radiolarian biostratigraphy of the Great Valley Sequence and Franciscan Complex, California Coast Ranges*. Cushman Foundation for foraminiferal Research, Special Publication 15:1–87.

Pessagno, E.A.Jr., Blome, C.D., Carter, E.S., MacLeod, N., Whalen, P. & Yeh, K.-Y., 1987: *Studies of North American Jurassic Radiolaria. Part II. Preliminary radiolarian zonation for the Jurassic of North America*. Cushman Foundation Spec. Publ. 23: 1–18.

Price, G.D., Főzy, I. & Pálfy, J., 2016: *Carbon cycle history through the Jurassic-Cretaceous boundary: A new global δ13C stack*. Palaeogeography, Palaeoclimatology, Palaeoecology 451: 46–61.

Rabrenović, D., Metodiev, L.S., Ivanova, D.K., Koleva-Rekalova, E.K., Radulović, V. & Mojsić, I., 2012: *The Lower and the Middle Jurassic facies and biostratigraphy (ammonites and foraminifers) of the Lim River area (Internal Dinarides), Montenegro*. Comptes rendus de l'Académie bulgare des Sciences 65 (12): 1705–1716.

Radoičić, R., 1982. *Carbonate platforms of the Dinarides: the example of Montenegro – west Serbian sector*. Bulletin de l'Académie Serbe des Sciences et des Arts 80, Classe des Sciences naturelles et mathématiques 22: 35–46.

Radoičić, R., Jovanović, D. & Sudar, M., 2009: *Stratigraphy of the Krš Gradac section (SW Serbia)*. Geološki anali Balkanskoga poluostrva 70: 23–41.

Rampnoux, J.-P., 1969: *La géologie du Sandjak: mise en evidence de la nappe du Pešter: confins serbo-monténégrins (Yougoslavie)*. Bull. Soc. géol. France sér. 7, XI (6): 881–893.

Rampnoux, J.-P., 1970: *Regards sur les Dinarides internes yougoslaves (Serbie-Monténégro oriental): stratigraphie, evolution paléogéographique, magmatisme*. Bull. Soc. géol. France sér. 7, XII (6): 948–966.

Rampnoux, J.-P., 1974: *Contribution à l'étude géologiqe des Dinarides: un secteur de la Serbie méridionale et du Monténégro oriental (Yougoslavie). Mémoires de la Société géologique de Fran*ce 119: 99 pp.

Robertson, A. H., 2012: *Late Palaeozoic–Cenozoic tectonic development of Greece and Albania in the context of alternative reconstructions of Tethys in the Eastern Mediterranean region*. International Geology Review 54 (4): 373–454.

Robertson, A.H.F. & Karamata, S., 1994: *The role of subduction–accretion processes in the tectonic evolution of the Mediterranean Tethys in Serbia*. Tectonophysics 234: 73–94.

Robertson, A. & Shallo, M., 2000: *Mesozoic–Tertiary tectonic evolution of Albania in its regional Eastern Mediterranean context*. Tectonophysics 316: 197–254.

Robertson, A.H.F., Clift, P.D., Degnan, P.J. & Jones, G., 1991: Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys. Palaeogeography, Palaeoclimatology, Palaeoecology 87: 289–343.

Robertson, A.H.F., Trivić, B., Đerić, N. & Bucur, I.I., 2013: *Tectonic development of the Vardar ocean and its margins: evidence from the Republic of Macedonia and Greek Macedonia*. Tectonophysics 595–596: 25–54.

Robin, C., Goričan, Š., Guillocheau, F., Razin, P., Dromart, G. & Mosaffa, H., 2010: *Mesozoic deep-water carbonate deposits from the southern Tethyan passive margin in Iran (Pichakun nappes, Neyriz area): biostratigraphy, facies sedimentology and sequence stratigraphy*. In: Leturmy, P., Robin, C. (Eds.) *Tectonic and Stratigraphic Evolution of Zagros and Makran during the Mesozoic–Cenozoic*. Geological Society London, Special Publication 330: 179–210.

Saccani, E., Bortolotti, V., Marroni, M., Pandolfi, L., Photiades, A. & Principi, G., 2008: *The Jurassic association of backarc basin ophiolites and calc-alkaline volcanics in the Guevgueli Complex (Northern Greece). Implication for the evolution of the Vardar Zone*. Ofioliti 33: 209–227.

Saccani, E., Beccaluva, L., Photiades, A. & Zeda, O., 2011: *Petrogenesis and tectono-magmatic significance of basalts and mantle peridotites from the Albanian-Greek ophiolites and sub-ophiolitic melanges. New constraints for the Triassic-Jurassic evolution of the Neo-Tethys in the Dinaride sector*. Lithos 124: 227–242.

Saccani, E., Dilek, Y., Marroni, M. & Pandolfi, L., 2015: *Continental margin ophiolites of Neotethys: Remnants of Ancient Ocean–Continent Transition Zone (OCTZ) lithosphere and their geochemistry, mantle sources and melt evolution patterns*. Episodes 38: 230–249.

Sandoval Gutierrez, M. I., 2015: *Late Mesozoic to Neogene radiolarian biostratigraphy and palaeoceanography in the Caribbean and East Pacific Region*. PhD Université de Lausanne.

Schefer, S., Egli, D., Missoni, S., Bernoulli, D., Fügenschuh, B., Gawlick, H.-J., Jovanović, D., Krystyn, L., Lein, R., Schmid, S. & Sudar, M., 2010: *Triassic metasediments in the Internal Dinarides (Kopaonik area, southern Serbia): stratigraphy, paleogeography and tectonic significance*. Geologica Carpathica 61: 89–109.

Scherreiks, R., Bosence, D., BouDagher-Fadel, M., Meléndez, G. & Baumgartner, P.O., 2010: *Evolution of the Pelagonian carbonate platform complex and the adjacent oceanic realm in response to plate tectonic forcing (Late Triassic and Jurassic), Evvoia, Greece*. International Journal of Earth Sciences 99: 1317–1334.

Schlagintweit, F., Gawlick, H.-J. & Lein, R., 2005: *Mikropaläontologie und Biostratigraphie der Plassen-Karbonatplattform der Typlokalität (Ober-Jura bis Unter-Kreide, Salzkammergut, Österreich)*. J Alp Geol Mitt Ges Geol Bergbaustud Österreich 47: 11–102.

Schlagintweit, F., Gawlick, H.-J., Missoni, S., Hoxha, L., Lein, R. & Frisch, W., 2008: *The eroded Late Jurassic Kurbnesh carbonate platform in the Mirdita Ophiolite Zone of Albania and its bearing on the Jurassic orogeny of the Neotethys realm*. Swiss Journal of Geosciences 101: 125–138.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M. & Ustaszewski, K. 2008: *The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units*. Swiss Journal of Geosciences 101: 139–183.

Schmid, S.M., Fügenschuh, B., Kounov, A., Maţenco, L., Nievergelt, P., Oberhänsli, R., Pleuger, J., Schefer, S., Schuster, R., Tomljenović, B., Ustaszewski, K. & van Hinsbergen, D.J.J., 2020: *Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey*. Gondwana Research 78: 308–374.

Šegvić, B., Kukoć, D., Dragičević, I., Vranjković, A., Brčić, V., Goričan, Š., Babajić, E. & Hrvatović, H., 2014: *New record of Middle Jurassic radiolarians and evidence of Neotethyan dynamics documented in a mélange from the Central Dinaridic Ophiolite belt (CDOB, NE Bosnia and Herzegovina)*. Ofioliti 39: 31–41.

Slovenec, D., Šegvić, B., Halamić, J., Goričan, Š. & Zanoni, G., 2020: *An ensialic volcanic arc along the northwestern edge of Palaeotethys – Insights from the Mid-Triassic volcano-sedimentary succession of Ivanščica Mt. (northwestern Croatia)*. Geological Journal 55: 4324–4351.

Spray, J.G., Bebien, J., Rex, D.C. & Roddick, J.C., 1984: *Age constraints on the igneous and metamorphic evolution of the Hellenic-Dinaric ophiolites*. In: Dixon, J.E. & Robertson, A.H.F. (Eds.) *The Geological Evolution of the Eastern Mediterranean*. Geological Society London, Special Publications 17: 619–627.

Stampfli, G. M. & Borel, G. D., 2002: *A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons*. Earth Planet. Sci. Lett. 196: 17–33.

Stampfli, G.M. & Borel, G.D., 2004: *The TRANSMED transects in space and time: constraints on the paleotectonic evolution of the Mediterranean domain*. In: Cavazza, W., Roure, F., Spakman, W., Stampfli, G.M. & Ziegler, P. (Eds.), *The TRANSMED Atlas: The Mediterranean Region from Crust to Mantle*, Springer, 53–80.

Stampfli, G. M. & Kozur, H. W., 2006: *Europe from Variscan to the Alpine cycles*. In: Gee, D. G., Stephenson, R. A. (Eds.), *European Lithosphere Dynamics*. Geological Society London, Memoirs 32: 57–82.

Stockar, R., Dumitrica, P. & Baumgartner, P.O., 2012: *Early Ladinian radiolarian fauna from the Monte San Giorgio (Southern Alps, Switzerland): systematics, biostratigraphy and paleo(bio)geographic implications*. Rivista Italiana di Paleontologia e Stratigrafia 118 (3): 375–437.

Sudar, M.N., Gawlick, H.-J., Lein, R., Missoni, S., Kovács, S. & Jovanović, D., 2013: *Depositional environment, age and facies of the Middle Triassic Bulog and Rid formations in the Inner Dinarides (Zlatibor Mountain, SW Serbia): evidence for the Anisian break-up of the Neotethys Ocean*. N- Jb. Geol. Paläont. Abh. 269 (3): 291–320.

Tang, T., Kisslinger, K. & Lee, C., 2014: *Silicate deposition during decomposition of cyanobacteria may promote export of picophytoplankton to the deep ocean*. Nature Communications 5: 4143, DOI: 10.1038/ncomms5143.

Tekin, U.K., 1999: *Biostratigraphy and systematics of late Middle to Late Triassic radiolarians from the Taurus Mountains and Ankara region, Turkey*. Geologisch– Paläontologische Mitteilungen Innsbruck, Sonderband 5, 1–297.

Ustaszewski, K., Schmid, S.M., Lugović, B., Schuster, R., Schaltegger, U., Bernoulli, D., Hottinger, L., Kounov, A., Fügenschuh, B. & Schefer, S., 2009. *Late Cretaceous intra-oceanic magmatism in the internal Dinarides (northern Bosnia and Herzegovina): Implications for the collision of the Adriatic and European plates*. Lithos 108: 106–125.

van Gelder, I.E., Matenco, L., Willingshofer, E., Tomljenović, B., Andriessen, P.A.M., Ducea, M.N., Beniest, A. & Gruić, A., 2015: *The tectonic evolution of a critical segment of the Dinarides-Alps connection: Kinematic and geochronological inferences from the Medvednica Mountains, NE Croatia*. Tectonics 34 (9): 1952–1978.

van Unen, M., Matenco, L., Nader, F. H., Darnault, R., Mandic, O. & Demir, V., 2019: *Kinematics of foreland--vergent crustal accretion: Inferences from the Dinarides evolution.* Tectonics 38 (1): 49–76. https://doi.org/10.1029/2018TC005066

Vishnevskaya, V.S., Djerić, N. & Zakariadze, G.S., 2009: *New data on Mesozoic Radiolaria of Serbia and Bosnia, and implications for the age and evolution of oceanic volcanic rocks in the Central and Northern Balkans.* Lithos 108: 72–105.

Vlahović, I., Tišljar, J., Velić, I., & Matičec, D., 2005: *Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics.* Palaeogeography, Palaeoclimatology, Palaeoecology 220: 333–360.

Wang, Y., Yang, Q., Matsuoka, A., Kobayashi, K., Nagahashi, T. & Zeng, Q., 2002: *Triassic radiolarians from the Yarlung Zangbo Suture Zone in the Jinlu area, Zetang County, Southern Tibet.* Acta Micropaleontologica Sinica 19 (3): 215–227.

Williford, K.H., Ward, P.D., Garrison, G.H. & Buick, R., 2007: *An extended organic carbon-isotope record across the Triassic-Jurassic boundary in the Queen Charlotte Islands, British Columbia, Canada*. Palaeogeography, Palaeoclimatology, Palaeoecology 244: 290–296.

Yurtsever, T.Ş., Tekin, U.K. & Demirel, İ.H. 2003: *First evidence of the Cenomanian/Turonian boundary event (CTBE) in the Alakırçay Nappe of the Antalya nappes, southwest Turkey.* Cretaceous Research 24: 41–53.

Ziabrev, S.V., Aitchison, J.C., Abrajevitch, A.V., Badengzhu, Davis, A.M. & Luo, H., 2004. *Bainang Terrane, Yarlung–Tsangpo suture, southern Tibet (Xizang, China): a record of intra-Neotethyan subduction–accretion processes preserved on the roof of the world.* J. Geol. Soc. London 161 (3): 523–539.

Ziegler, P.A. & Stampfli, G.M., 2001: *Late Paleozoic – early Mesozoic plate boundary reorganization: collapse of the Variscan orogen and opening of Neotethys.* Natura Bresciana, Ann. Mus. Civ. Sc. Nat., Monografia 25: 17–34.

Živaljević, M., 1989: *Explanations for Geological Map of SR Montenegro, Scale 1: 200,000.* Geological Survey of Montenegro, 62 p. (In Serbo-Croatian, English summary).