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From deep-marine stratigraphic condensation to mass-transport deposition: Illyrian stepwise extension recorded in a red nodular limestone drowning sequence (Bulog Formation) of the Ravni Carbonate Ramp (Seljani area, Montenegro)

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Abstract

New biostratigraphic data obtained by studying ammonoids, calcareous algae, conodonts, and foraminifera from the westernmost part of the East Bosnian – Durmitor mega-unit in northern Montenegro, result in a detailed reconstruction of the Middle – Late Anisian (Pelsonian-Illyrian) subsidence history related to tectonic motions. Two independent times of extension with formation of a horst-and-graben structure and neptunian dikes can be distinguished. During the first phase of extension, a rapid deepening of the footwall block during late Pelsonian times can be recognized. The initial late Pelsonian deepening is characterized by the formation of neptunian dikes in the older Pelsonian shallow-water limestones, which are filled with open-marine red micrite showing a microfacies typical for shallow deep-swells. This initial phase is only preserved in the infilling of neptunian dikes and represents the onset of the drowning sequence. The final late Pelsonian depositional deep-swell environment is preserved in a level with stratigraphic condensation, but a deep-water microfacies. The second (late Illyrian) deepening also resulted in the formation of neptunian dikes, a horst-and-graben topography, and the mobilization of mass-transport deposits related to the onset of intense volcanism.

1. INTRODUCTION

The Middle – Late Anisian depositional history in the Western Tethys Realm reflects the opening of the Neo-Tethys Ocean and is reflected in A) a break-up unconformity (horst-and-graben morphology) and B) the drowning of the shallow-water carbonate ramp of the Ravni Formation (SUDAR et al., 2013 and references therein). This remarkable turnover (Reifling turnover: SCHLAGER & SCHÖLLNBERGER, 1974) marks the change from deposition in a continental graben to deposition on the passive continental margin (GAWLICK & MISSONI, 2019 and references therein) of the newly formed Neo-Tethys Ocean in the sense of SUESS (1888, 1901). In the Dinarides, the general depositional evolution of this drowning history, that is the drowning of the Ravni Carbonate Ramp and its overlying red nodular limestones, or mass-transport deposits of the Bulog Group has been known since the 19th century (SUDAR et al., 2023a and references therein). A general deepening trend during deposition of the Bulog Group has been known since KITTL (1904), but was never studied in detail (compare SUDAR et al., 2013 and references therein). Even if a lot of stratigraphic details have been obtained since KITTL (1904), especially regarding the biostratigraphic age of the Bulog Limestone (e.g. VINASSA DE REGNY, 1903; MARTELLI, 1904, 1906; SALOPEK, 1911; FISCHER & JACOBSHAGEN, 1976; SUDAR, 1986; SUDAR et al., 2023a, b and references therein), several open questions remain. Important open questions are still related to the relative water depth of the newly created basins and horsts and their complicated subsidence history during the formation of the horst-and-graben topography, even though it is known that the water depth of these basins did not exceed a few hundred metres (GAWLICK et al., 2012). Furthermore, the recently detected stepwise deepening with at least two independent stages of creation of a horst-and-graben topography in A) the late Pelsonian, and B) around the middle/late Illyrian boundary, with time-equivalent formation of neptunian dikes and deposition of mass-transport deposits (GAWLICK et al., 2023; SUDAR et al., 2023a, b; MRDAK et al., 2024a and references therein), is still not fully understood throughout the Dinarides.

While Triassic sediments, all belonging to the Outer Dinarides (SCHMID et al., 2008, 2020: East Bosnian – Durmitor mega-unit = Inner Dinarides) cover more than the half of the total territory of Montenegro, understanding of their deposition through time and space is still rather weak. Until recently, it was believed that deposition in the Triassic was more or less continuous (DIMITRIJEVIĆ, 1997; KOVÁCS et al., 2010,

2014) and that huge shallow-water carbonate platforms were formed continously during Middle – Late Triassic times in the Outer Dinarides, only disconnected by some intraplatform basins with continous deep-water sedimention (Lim Basin, Bosnian Basin: AUBOUIN et al., 1970; RAMPNOUX, 1974; CHARVET, 1978, 1980). The last important studies on the various Triassic lithologies (BEŠIĆ, 1936; PANTIĆ, 1967; RAMPNOUX, 1974; MIRKOVIĆ, 1983; DIMITRIJEVIĆ, 1997 and references therein) lack modern microfacies and micropaleontological age dating. Only in the area of the Budva unit have several modern studies been carried out (summarized in GORIČAN et al., 2022). New studies demonstrated that autochthonous Triassic deep-water basins in between the carbonate platforms never existed in the Dinarides (GAWLICK et al., 2017a, b, 2018; GAWLICK & MISSONI, 2019; SUDAR et al., 2025). Furthermore, several tectonic events, volcanism as well as biological crises affected the believed continuous deposition, resulting in cases in a very heterogenous topography and the repeated demise of shallow-water carbonate production, in cases expressed as long-lasting stratigraphic gaps (MISSONI & GAWLICK, 2012; SUDAR et al., 2013; GAWLICK et al., 2017a; MRDAK et al., 2023, 2024a).

Analysis of the neptunian dike and sill infillings (for details see WENDT, 2017 and references therein) which occur in the middle Pelsonian Ravni Formation provide overlooked insights in the depositional history of the drowning sequence above the Ravni Carbonate Ramp. In such dikes/sills, sediments can be preserved which often cannot be recognized in the normal overlying succession. Such infillings can therefore fill a gap in knowledge in the depositional history triggered by extension and subsequent rapid subsidence after the demise of shallow-water carbonate production.

In the westernmost part of the East Bosnian – Durmitor mega-unit (Fig. 1) in the village of Seljani (Plužine), an Anisian section composed of the Ravni Formation with two generations of neptunian dikes and the overlying Bulog Formation was investigated in respect of their biostratigraphic age by conodont and ammonite dating, and their depositional environment using microfacies analysis. This paper aims to describe the evolution of a rapidly subsiding footwall block as part of the break-up unconformity and subsequent deposition on a deep-marine swell during late Pelsonian to middle Illyrian times. Around the middle/late Illyrian boundary, parts of the deep swell were affected by a second pulse of extension after the onset of volcanism. Former horsts were flooded and dissected by normal faults, the deep-marine swell received reworked material, and further deepening. This history is documented based on microfacies analysis, XRD-analysis, the diagenetic overprint using the Conodont Colour Alteration Index (CAI), and biostratigraphic age dating based on algae, foraminifera, conodonts, and ammonoids.

2. GEOLOGICAL AND STRATIGRAPHIC SETTING

The studied section at Seljani (Fig. 1, Fig. 2, GPS coordinates of the section: from 43°05′23.59′′N/18°50′53.26′′E to 43°05′22.14′′N/18°50′54.52′′E), is located west of the East Bosnian – Durmitor mega-unit (DIMITRIJEVIĆ, 1997; SCHMID et al., 2008) (Fig. 1) in an isolated thrust sliver. In it´s frontal part the East Bosnian – Durmitor mega-unit, i.e. the Durmitor nappe (HRVATOVIĆ, 2006), was imbricated during Palaeogene thrusting and overrode the Pre-Karst + Bosnian "Flysch" unit (SCHMID et al., 2008, 2020), i.e. the Sarajevo sigmoid in the sense of DIMITRIJEVIĆ (1997) or the Kuči unit in sense of MIRKOVIĆ (1980). According to MIRKOVIĆ (1980) and MIRKOVIĆ et al. (1979) this tectonic sliver with the studied section Seljani does not belong to the East Bosnian – Durmitor mega-unit and should be an uplifted part of the easternmost Pre-Karst + Bosnian "Flysch" unit, i.e. the Kuči unit. In the view of the Triassic arrangement of the facies zones, the study area has a closer palaeogeographic affinity to the East Bosnian – Durmitor mega-unit than to the Pre-Karst + Bosnian "Flysch" unit. In the Triassic the Palaeogene East Bosnian – Durmitor mega-unit (or nappe) and the Pre-Karst + Bosnian "Flysch" unit and the adjacent High Karst unit (Fig. 1) were a part of the same southwest – northeast trending depositional belt. In its eastern part, the Triassic sequence of the Pre-Karst unit is covered by Jurassic to Palaeogene sedimentary rocks, and therefore nothing is known about their facies due to the lack of outcrops. However, we attribute the study area to be a part of the East Bosnian – Durmitor mega-unit *sensu lato* and not to the Pre-Karst + Bosnian "Flysch" unit.

In a different interpretation, the Sarajevo sigmoid (DIMITRIJEVIĆ, 1997) or Kuči unit (MIRKOVIĆ, 1980) in

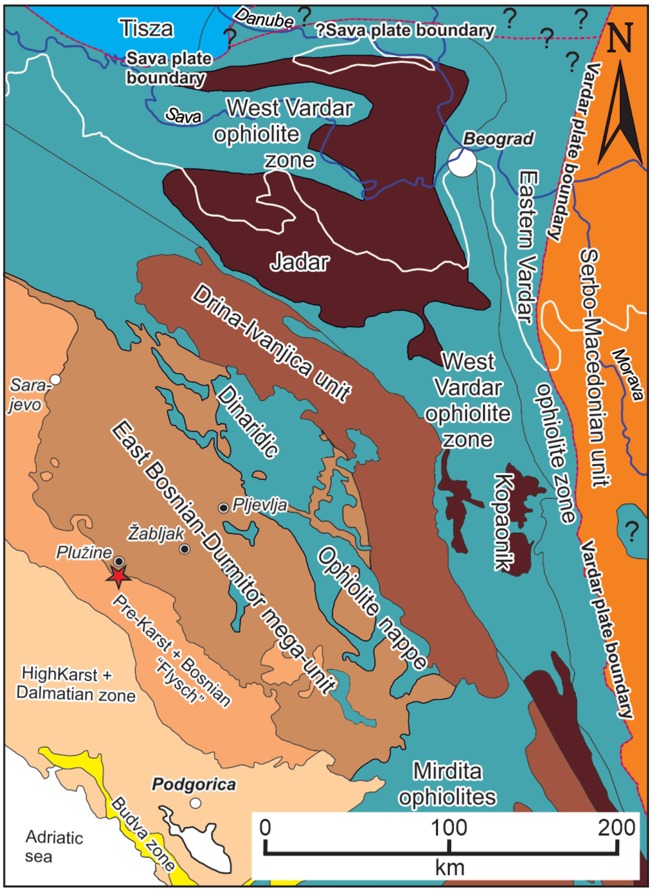

Figure 1. Overall tectonic map of the Dinarides in Bosnia and Herzegovina, Serbia, Montenegro, and adjacent countries, redrawn after SCHMID et al. (2008, 2020), SUDAR et al. (2023a), based on new results (GAWLICK et al., 2017a, 2023; RADIVOJEVIĆ, 2023; DJERIĆ et al., 2024). Red star indicates the studied section at Seljani.

its easternmost part should belong to the so-called Bosnian zone (GORIČAN et al., 2022 and references therein). This tectonic zone should be characterized by a Middle – Late Triassic (to Jurassic – Cretaceous) continous deep-water evolution and should strike from Bosnia – Herzegovina (Sarajevo area) via Montenegro to Albania and Greece (see CHARVET et al., 1974; CHARVET, 1978; RAMPNOUX, 1974; CADET, 1976). CHARVET et al. (1974) and CHARVET (1978, 1980) assigned the region around Sarajevo with Bulog and Hallstatt Limestones as part of the "Zone Bosniaque + Zone Serbe in parts", and correlated this zone with the Mirdita zone in Albania and the zone maliaque? in Greece (compare DERCOURT et al., 1993). South of Sarajevo, CHARVET (1980) placed the areas with Triassic deep-water sedimentary rocks into the internal zone Bosniaque and the zone Serbe, interpreted as an autochthonous deep-water basin between the Durmitor and the High Karst/Pre-Karst (see BLANCHET et al., 1970). This autochthonous model of long-lasting Middle – Late Triassic deep-water basins between shallow-water carbonate platforms is disproved in Bosnia – Herzegovina (SUDAR et al., 2025), Serbia (GAWLICK et al., 2017a, b, 2018), Montenegro (GORIČAN et al., 2022; MRDAK et al., 2024b), Albania (GAWLICK et al., 2008; GAWLICK & MISSONI, 2019), and Greece (KOSTAKI et al., 2024). In fact all these Middle – Late Triassic deep-water sequences represent allochthonous far-travelled units from the east, resting as nappes or mélanges on parauchthonous units with Late Triassic shallow-water carbonates (Fig. 3).

A current controversial discussion centres on how to use the terms middle Illyrian or late Illyrian. The *Aplococeras avisianum* Zone is presently included in many ammonoid zonations as the youngest subzone of the *Reitziites reitzi* Zone (BALINI et al., 2010; JENKS et al., 2015) of the middle Illyrian. While the conodonts of this age are mainly described as late Illyrian, to correlate the ammonoid and conodont zonations, the First Appearance Datum (FAD) of *Aplococeras avisianum*

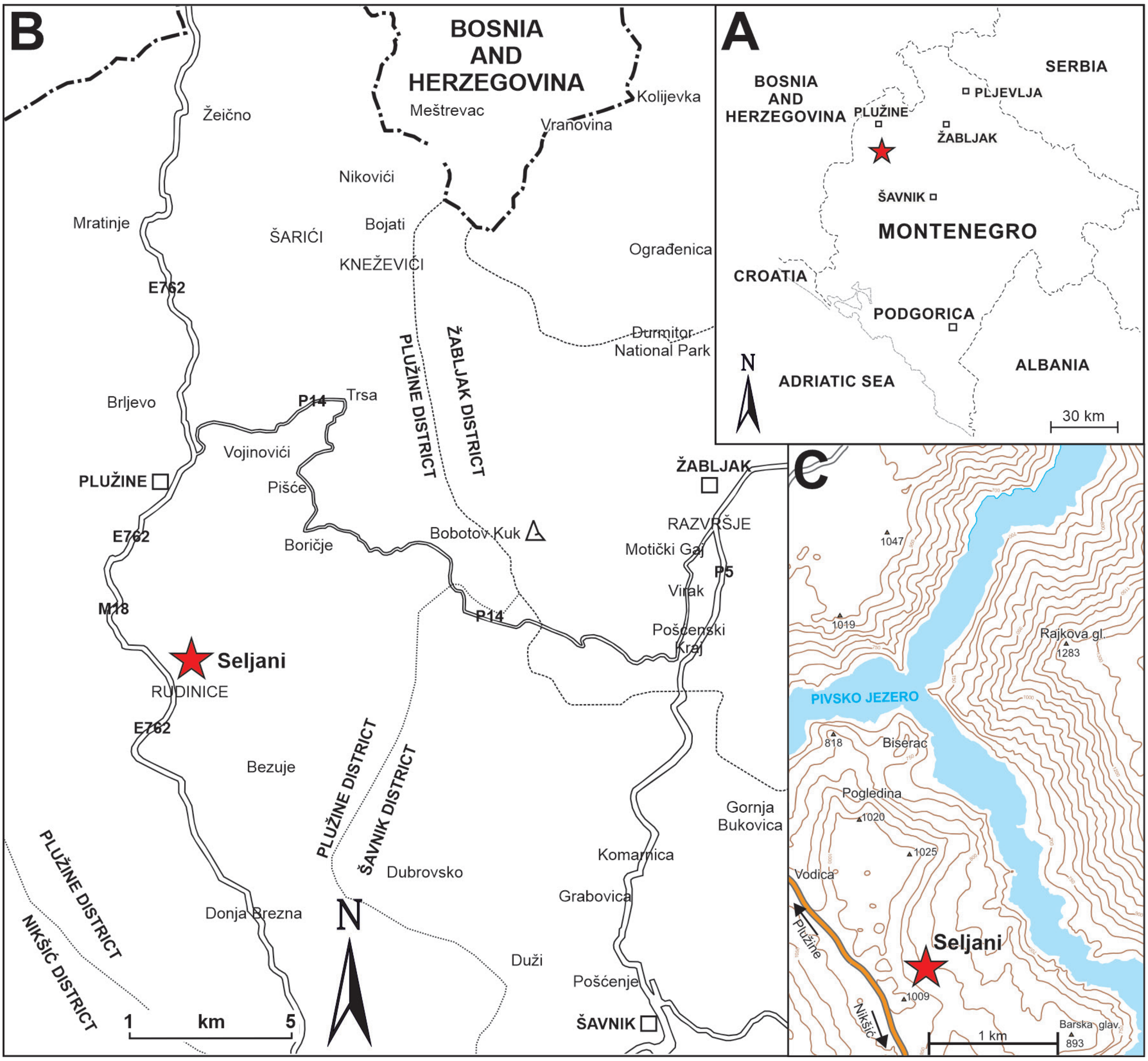

Figure 2. a Geographic sketch map of Montenegro with the location of the studied section at Seljani in northern Montenegro (see also Fig. 1); **b** The Seljani section is approximately 5 km south of the city of Plužine (compare BEŠIĆ, 1949a, b); **c** Detailed topographic map with position of the studied section.

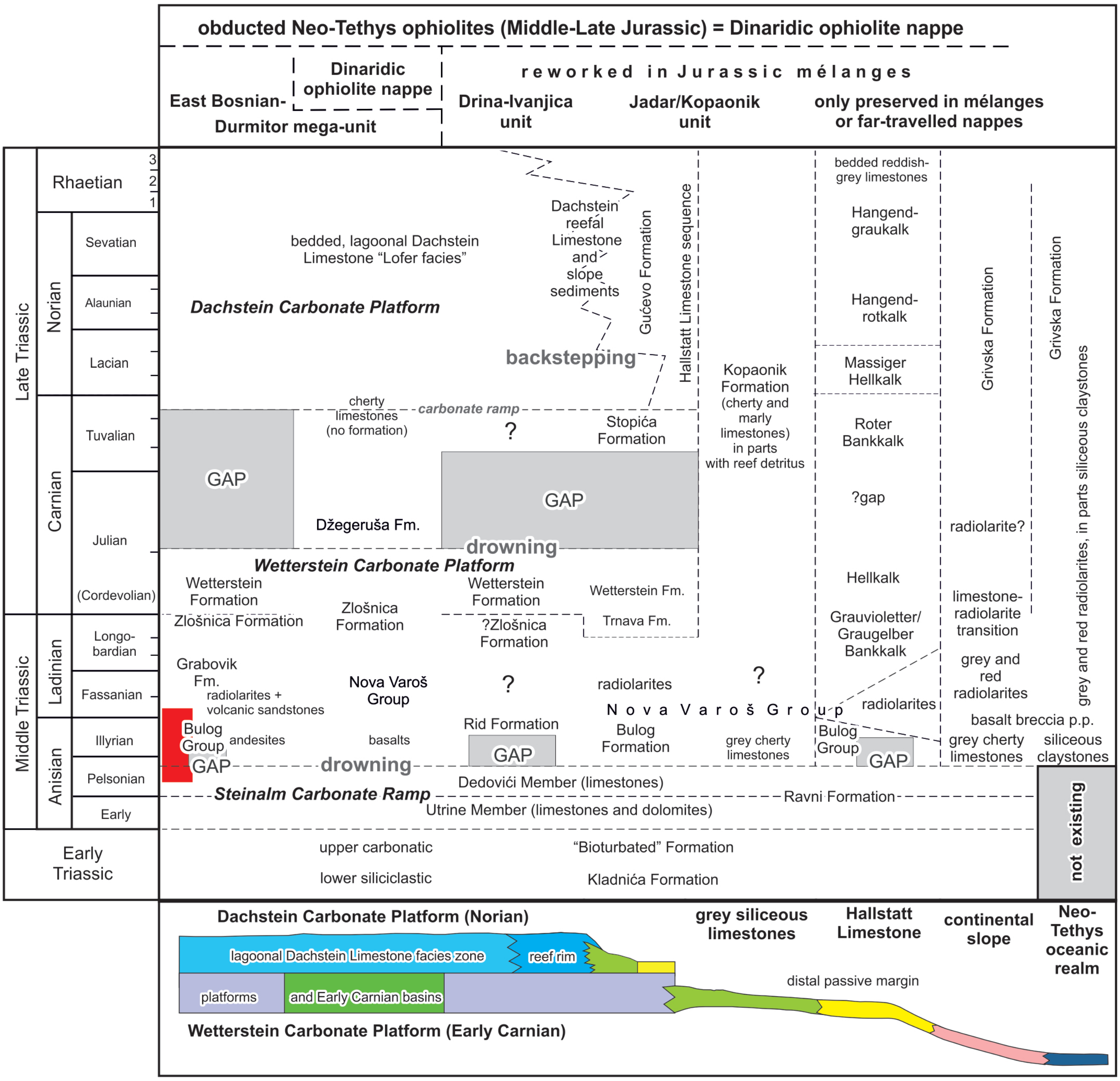

Figure 3. Triassic stratigraphic table of the Inner to Outer Dinarides, modified after GAWLICK et al. (2017a, 2023) and GAWLICK & MISSONI (2019). Early Triassic to early Middle Triassic modified after DIMITRIJEVIĆ (1997) and JOVANOVIĆ (1998). Generation of Neo-Tethys oceanic crust started around the Middle/Late Anisian boundary, contemporaneously with the drowning of the Ravni/Steinalm Carbonate Ramp. For description, definition and emendation of several formations see SUDAR et al. (2013), SUDAR & GAWLICK (2018), GAWLICK et al. (2017a, 2023), and SUDAR et al. (2023a, b; 2025). The geometric arrangement of the different formations is in accordance with the Late Triassic carbonate platforms and passive continental margin configuration after GAWLICK et al. (2008, 2016), and is also characteristic for the different defined tectonic units in the Dinarides (Fig. 1). The position of the studied section at Seljani is indicated by the red box.

(MOJSISOVICS) could be proposed as the base of the late Illyrian, as was previously done in the Bagolino section for the base of the Ladinian by MIETTO et al. (2003). In this sense, faunas with *Aplococeras avisianum* (MOJSISOVICS) should be considered a separate zone. For geological reasons and correlation with other organism groups (e.g. conodonts, radiolarians – KRYSTYN, 1983; KOZUR, 2003) we plead for an independent *Aplococeras avisianum* Zone which should be incorporated into the late Illyrian. For a more detailed discussion see MRDAK et al. (2024a) and ĐAKOVIĆ et al. (2025).

The geographic position of the studied section is plotted into the stratigraphic table for the Triassic comprising the Inner Dinarides to the East Bosnian – Durmitor mega-unit (Fig. 3). Note, that the stratigraphic evolution of the Pre-Karst unit in the Triassic is quite similar to that of the East Bosnian – Durmitor mega-unit, both belonging to the Outer Dinarides.

3. METHODS AND SAMPLES

Twelve important and indicative samples are highlighted in Figure 4. A Panalytical X'Pert3 Powder Diffractometer (chair of Energy Geoscience – Montanuniversität Leoben) with a Cu anode measuring from 0° – 90° was used for XRD measurements to investigate the volcanic ash sample. A copper anode was used as the radiation source to generate the low-

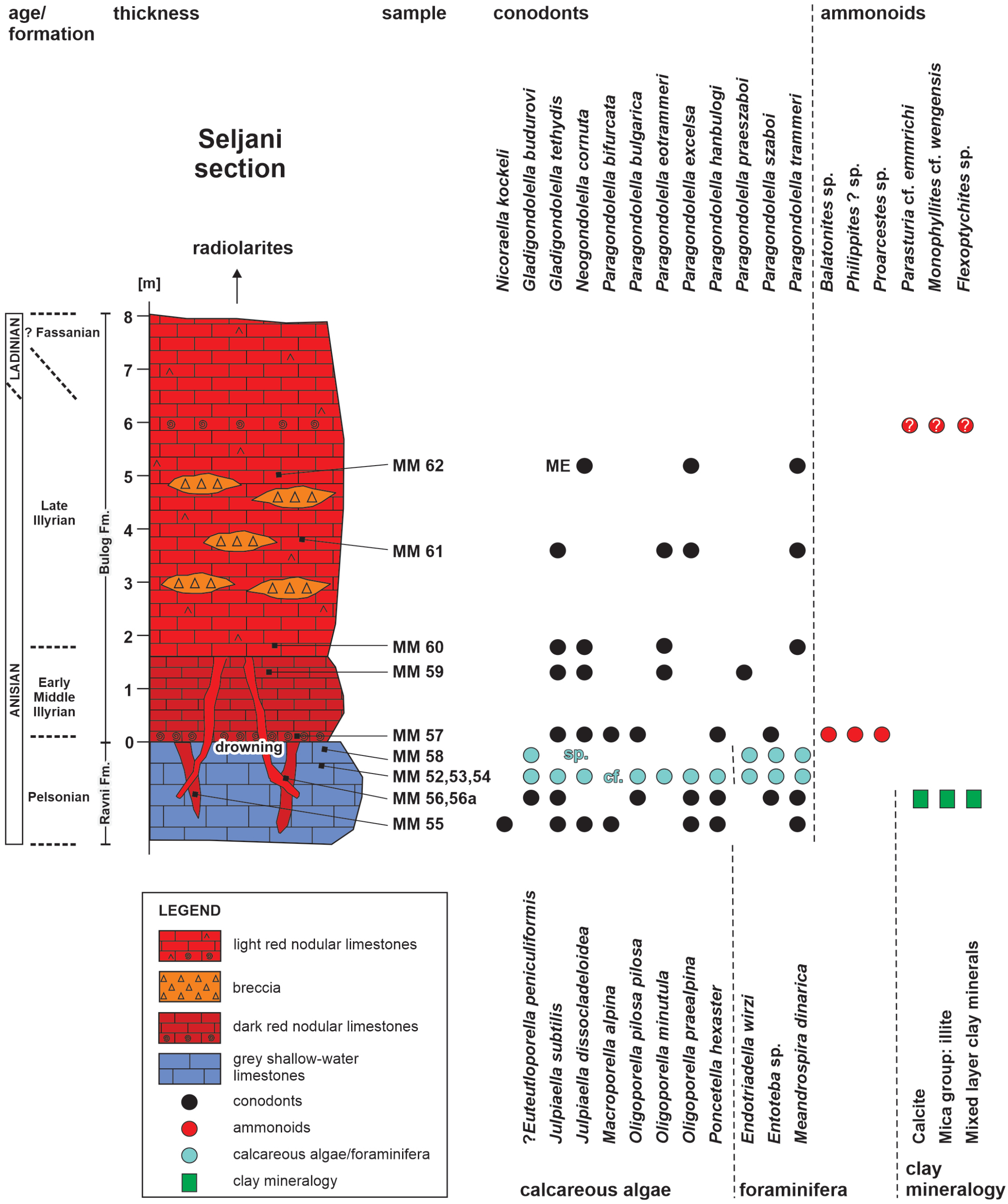

Figure 4. The Middle Anisian (Pelsonian) to ?Fassanian (Ladinian) section at Seljani. Drowning of the shallow-water Ravni Carbonate Ramp to deposition of the drowning sequence of the Bulog Formation. Sample numbers of the described samples with the age diagnostic organisms in the Ravni and Bulog formations and their position in the section are indicated. In addition, the clay mineralogy of the green-grey clays are indicated (sample MM 56a).

energy X-rays, and a characteristic line spectrum (Kα and Kβ components) was emitted under a high voltage of 40 kV and a current of 40 mA. Monochromators were used to reduce the K component to the Kα1 wavelength. The acquired angular range was between 2.51°2Θ and 65.99°2Θ, the step size of the measurements covered 0.0167°Θ, and the goniometer speed was 0.5°2Θ/minute.

Microfacies analysis was carried out according to FLÜGEL (2004). Conodonts were used for biostratigraphy and estimation of the diagenetic overprint using the Conodont Colour Alteration Index (CAI) method (EPSTEIN et al., 1977; REJEBIAN et al., 1987). Seven conodont-bearing samples (4.3 – 4.7 kg each, Fig. 4) were dissolved in acetic acid (ca. 8%) to avoid any influence on the conodont apatite by the dissolution process. Residue was dried at a max. of 50 °C to avoid any influence on the CAI or internal structure or colour of the conodonts. CAI-values were visually determined using a standard set and following the classification schemes of EPSTEIN et al. (1977) and REJEBIAN et al. (1987), see also GAWLICK et al. (1994). The number of isolated specimens from the processed samples varied between 20 and 130. A Keyence Digital-Microscope VHX 6000 (chair of Geology and Economic Geology –Montanuniversität Leoben) was used to photograph the specimens. The biostratigraphic age dating of the revised and newly studied sections follow the slightly revised conodont biostratigraphic age ranges, which are given

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according to KRYSTYN (1983) and CHEN et al. (2016), but we also took into consideration other recently published conodont age ranges (ORCHARD, 2010; KILIÇ et al., 2017; PLASENICIA et al., 2018; SMIRČIĆ et al., 2020; RIGO et al., 2018; KOLAR-JURKOVŠEK & JURKOVŠEK, 2019; KILIÇ, 2021; KARÁDI et al., 2022). Beside the taxonomic determinations from the above mentioned papers, the nomenclature of BUDUROV & SUDAR (1990) and CHEN et al. (2016) was also used. However, even if some biostratigraphic age ranges of some conodont species seem to be slightly inaccurate, the biostratigraphic age based on assemblage-level composition is more accurate than ages based on the stratigraphic ranges of individual conodont species. In addition, the used age ranges of the Late Illyrian conodont assemblages in the East Bosnian – Durmitor mega-unit in Montenegro were recently improved by their correlation with ammonoid-bearing levels (MRDAK et al., 2024a; ĐAKOVIĆ et al., 2025). The determination of ammonoids follows the classification given by TOZER (1981), as well as by VÖRÖS (2003, 2018) and MONNET & BUCHER (2005). They are stored in the Geological Survey of Montenegro in Podgorica. Determination and age dating of algae and foraminiferal assemblages follows in general OTT (1972a, b), BYSTRICKY (1964, 1986), BUCUR et al. (1994), GRANIER & DELOFFRE (1994), GRANIER & GRGASOVIĆ (2000), BUCUR (1999) – for algae, and SALAJ et al. (1983, 1988), RETTORI et al. (1994) – for foraminifera. All determined conodonts, calcareous algae, and foraminifera are stored at the Montanuniversität Leoben. Inventory numbers are the sample numbers as described in this publication.

4. RESULTS

In the investigated profile, in the upper part of the shallow-water Ravni Formation, beds consisting of calcareous algae together with crinoid-rich layers appear, both overlain by a condensed layer of slightly siliceous red nodular limestones (the Bulog Formation), with deep-water fossil groups: e.g. ammonoids, conodonts, and radiolarians (Fig. 4). Litho- and microfacies indicate a rapid change in the depositional environment from shallow-water to deeper-water conditions. In the Ravni Formation at the Seljani location two generations of neptunian dikes filled with red nodular limestone are preserved. The older generation of neptunian dikes, late Pelsonian in age, contain red limestones with thin-shelled bivalves and some Ravni Limestone clasts. This microfacies indicates a much shallower deep-marine environment, i.e. deposition on a hemipelagic swell. In such neptunian dikes BEŠIĆ (1949a) found a rich and well-preserved brachiopod fauna. Condensed deposition prevailed until the middle/late Illyrian boundary. Around the middle/late Illyrian boundary, neptunian dikes were formed again and the following late Illyrian Bulog Limestone is characterized by slightly siliceous and marly nodular limestones with intercalated channelized mass-transport deposits (breccia layers), which contain thin-shelled bivalve components deposited on a hemipelagic swell. Above these parts with breccia layers is another condensed horizon with ammonoids appearing in the marly radiolarian-rich wackestones. Up-section, the red limestones become more and more siliceous and finally radiolarites deposited.

4.1. Biostratigraphy and microfacies

4.1.1. Ravni Formation (Pelsonian)

In the uppermost part of the Ravni Formation (Dedovići Member – DIMITRIJEVIĆ, 1997), layers rich in calcareous algae with some foraminifera were deposited. In addition, crinoids are common in these layers. These layers appear shortly before the drowning sequence (Bulog Formation). They were deposited above shallow-water limestones predominantly consisting of microbially formed components and show a more open-marine influence regarding the underlying shallow-water limestones.

The following calcareous algae (Fig. 5) were determined in the different samples:

– Sample MM 52: *Julpiaella subtilis* (PIA), *Oligoporella pilosa pilosa* PIA, *Oligoporella minutula* (GUEMBEL), and ?*Teutloporella* sp.
– Sample MM 53: *Macroporella* cf. *alpina* PIA, *Oligoporella pilosa pilosa*, and *Poncetella hexaster* (PIA).
– Sample MM 54: *Julpiaella* cf. *dissocladeloidea* (PIA), *Julpiaella subtilis*, *Macroporella* cf. *alpina*, *Oligoporella pilosa pilosa*, *Oligoporella praealpina* (PIA), *Oligoporella minutula*, and *Poncetella hexaster*.
– Sample MM 58: ?*Julpiaella* sp., ?*Oligoporella* sp., ?*Euteutloporella peniculiformis* (OTT), and algae fragments.

The following foraminifera (Fig. 6) were determined in the different samples:

– Sample MM 54: *Endotriadella wirzi* (KOEHN-ZANINETTI), *Meandrospira dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ, *Endoteba* sp., and Duostomonidae.
– Sample MM 58: *Endotriadella wirzi*, *Endoteba* sp., *Meandrospira dinarica*, and Textulariaceae.

The calcareous algal association as well as the foraminifera are typical of the Pelsonian Ravni Formation. The Ravni Formation in its upper part is dissected by two generations of neptunian dikes (see below). Some of these neptunian dikes present most probably sills (WENDT, 2017), but this cannot be determined by the preserved infillings. However, the existence of sills is proven by brachiopod findings described by BEŠIĆ (1949a).

4.1.2. Bulog Formation (late Pelsonian to ?Fassanian)

The drowning sequence of the Ravni Carbonate Ramp is represented by the condensed red nodular limestones of the Bulog Formation (SUDAR et al., 2023b). The approximately 8 m-thick Bulog Formation of the section at Seljani can be subdivided into two different lithological types, a strongly condensed slightly siliceous lower part of dark red nodular limestones with an ammonoid-rich 5 – 10 cm-thick bed at its base and a more light red and slightly marly-siliceous and marly upper part, with intercalated mass-transport deposits in channels. Further up-section, after the part with mass-transport deposits, another horizon with ammonoids is observed and is overlain by siliceous radiolarian wackestones. These siliceous radiolarian wackestones transition to reddish radiolarites further up-section, which are mainly covered. In this covered area it is not visible whether volcanic ash layers are intercalated between the radiolarite beds. The radiolarians are completely

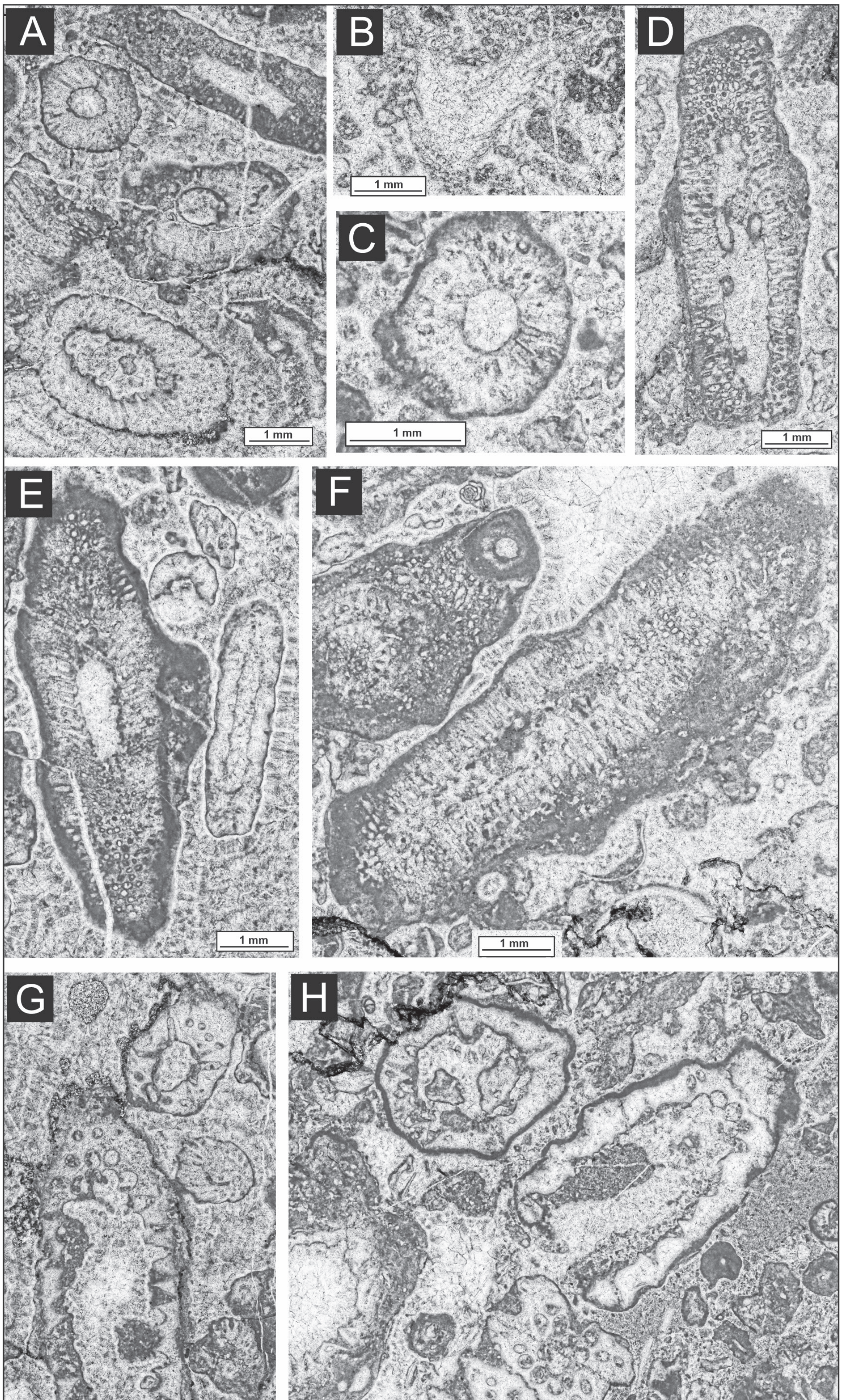

Figure 5. Dasycladalean algae from the topmost Ravni Formation (Pelsonian). **a** *Julpiaella subtilis* (PIA), sample MM 52; **b** ?*Euteutloporella peniculiformis* (OTT), sample MM 58; **c** *Poncetella hexaster* (PIA), sample MM 54; **d** *Poncetella hexaster* (PIA), sample MM 53; **e** *Julpiaella subtilis* (PIA) and *Oligoporella minutula* (GUEMBEL), sample MM 54; **f** *Poncetella hexaster* (PIA), sample MM 54; **g** *Oligoporella pilosa pilosa* PIA and *Oligoporella minutula* (GUEMBEL), sample MM 52; **h** *Oligoporella praealpina* (PIA), sample MM 58.

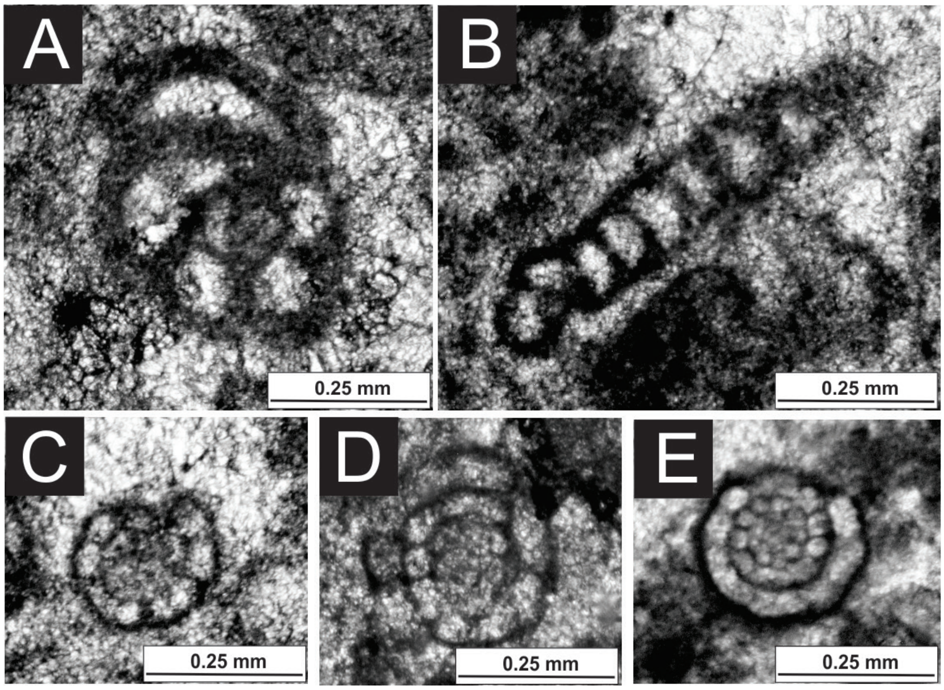

Figure 6. Characteristic foraminifera from the topmost Ravni Formation (Pelsonian). **a** *Entoteba* sp., sample MM 58; **b** *Endotriadella wirzi* (KOEHN-ZANINETTI), sample MM 58; **c** *Meandrospira dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ, sample MM 58; **d** *Meandrospira dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ, sample MM 54; **e** *Meandrospira dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ, sample MM 54.

recrystallized to quartz and cannot be extracted, as is the entire radiolarite interval.

The older type of the Bulog Formation above the Ravni Formation shows the following evolution: Directly above the Ravni Formation, the first bed of the Bulog Limestone contains ammonoids, broken thin-shelled bivalves (“filaments“), radiolarians, and conodonts. In sample MM 57 from this 5 – 10 cm-thick, slightly siliceous bed, a mixed late Pelsonian and early Illyrian conodont fauna, indicating stratigraphic condensation, is observed (Fig. 4), containing: *Paragondolella bifurcata* BUDUROV & STEFANOV, *Paragondolella bulgarica* BUDUROV & STEFANOV, *Paragondolella hanbulogi* SUDAR & BUDUROV, *Neogondolella cornuta* BUDUROV & STEFANOV, *Paragondolella szaboi* (KOVÁCS), and *Gladigondolella tethydis* (HUCKRIEDE). This stratigraphic condensation is also proven by the formation of locally appearing hardgrounds (Fig. 7a). The variability of the preserved microfauna is minor and consists only of broken thin-shelled bivalves and some recrystallized radiolarians. This is also confirmed by the strong corrosion of the ammonoid shells in this bed. In most cases the shells are dissolved or strongly corroded. Very often, only moulds of the ammonoids are preserved. This facies contrasts the normally known depositional characteristics for hemipelagic swells, where red nodular limestones deposited (BÖHM, 1992; WENDT, 1973, 2017; FLÜGEL, 2004 and references therein). From the condensed bed (sample MM 57) an ammonoid fauna was collected (Fig. 8a–c). Due to poor preservation, only a few ammonoids from this level could be determined: *Balatonites* sp., *Philippites* ? sp., and *Proarcestes* sp. indicating a Pelsonian age.

Higher up in the section in sample MM 59 (Fig. 4), *Neogondolella cornuta*, *Paragondolella eotrammeri* (KRYSTYN), *Paragondolella praeszaboi* (KOVÁCS, PAPŠOVA & PERRI), and *Gladigondolella tethydis* indicate an early to middle Illyrian age. The microfacies characteristics of this higher, but still early/middle Illyrian Bulog Limestone is nearly identical to the lowermost bed. Only any indications for hardground formation are missing. Beside the red colour, indicating an oxygenating diagenetic environment, sedimentary layering, e.g. lamination, is also absent. Irregular, distributed, broken shells indicate strong bioturbation as well as the nodular fabrics. It is beyond the scope of the paper to discuss the formation of nodular limestone. The interested reader is referred to JENKYNS (1971), and FLÜGEL (2004 and references therein).

The younger type of the Bulog Limestone with intercalated oligomictic breccias (Figs. 4, 7), which appear in channels (Fig. 4) contains radiolarians, “filaments“, and rare volcanic grains (e.g. biotite in the residue), but is strongly recrystallized and siliceous, in some cases marly in the upper parts (Fig. 7). In the lowermost part, this Bulog Limestone contains *Gladigondolella tethydis* and *Gladigondolella*-ME sensu KOZUR & MOSTLER, *Paragondolella eotrammeri*, *Paragondolella trammeri* (KOZUR) and *Neogondolella cornuta* (sample MM 60) indicating the late Illyrian age. Higher up *Gladigondolella tethydis* and *Gladigondolella*-ME, *Paragondolella eotrammeri*, *Paragondolella excelsa* (MOSHER), *Paragondolella trammeri*, and *Neogondolella cornuta* in sample MM 61 prove a late Illyrian – Fassanian age. In the highest part (sample MM 62) of the more strongly recrystallized and silicified Bulog Limestone, a similar age is proven by the presence of *Gladigondolella*-ME, *Neogondolella cornuta*, *Paragondolella excelsa*, and *Paragondolella trammeri.* The age of the matrix and the reworked material could not be distinguished on the basis of the conodont faunas. Above the part with the reworked material another level with ammonoids was deposited (Fig. 4).

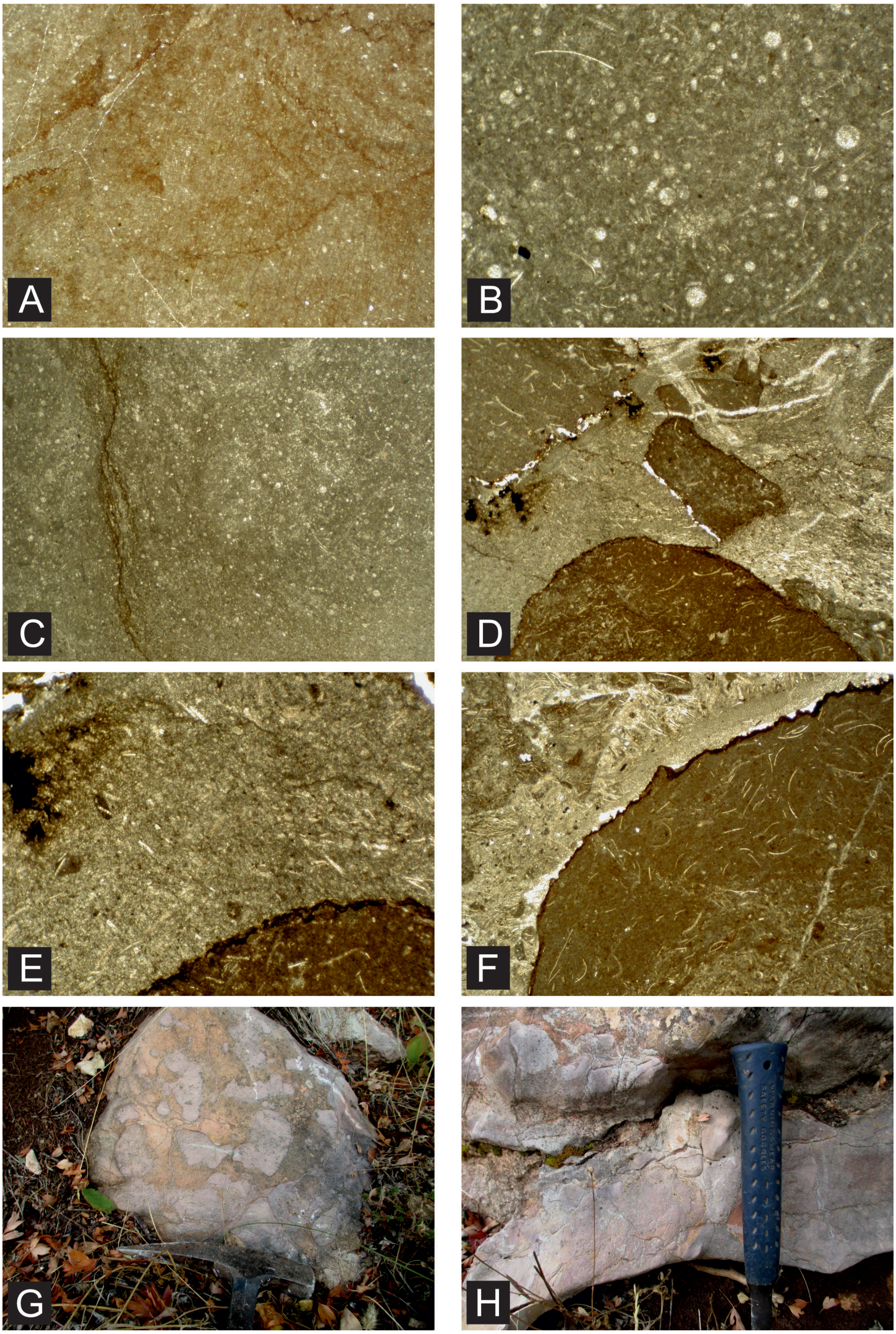

Figure 7. Microfacies characteristics of the latest Pelsonian to late Illyrian Bulog Limestones and lithological features of the intercalated mass-transport deposits in the late Illyrian. **a** Wackestone with a few recrystallized radiolarians, a few broken filaments and some recrystallized undeterminable components beside microbial precipitation of calcite. Unsoluable clayey material is rich in stylolites which overprint locally formed hardgrounds, sample MM 57, width of the photo: 1.4 cm; **b** Radiolarian-filament wackestone, bioturbated, sample MM 59, width of the photo: 0.5 cm; **c** Bioturbated marly radiolarian wackestone with rare "filaments", in cases broken and one nodosariid foraminifera, sample MM 60, width of the photo: 1.4 cm; **d** Oligomictic mass-transport deposit. The "filament"-rich clasts are in cases coated with a dark crust. The matrix consists of a marly wackestone with broken "filaments", sample MM 61, width of the photo: 1.4 cm; **e** Enlargement of sample MM 61 showing details of the marly matrix rich in pyrite; **f** Component of a "filament"-rich wackestone with a coated rim in the "filament"-rich matrix. In addition, angular clasts are visible, sample MM 62; **g** Macroscopic view of the late Illyrian oligomictic breccia with nodular fabrics, hammer as scale; **h** Reddish-grey late Illyrian nodular limestone with thin breccias layers, hammer as scale.

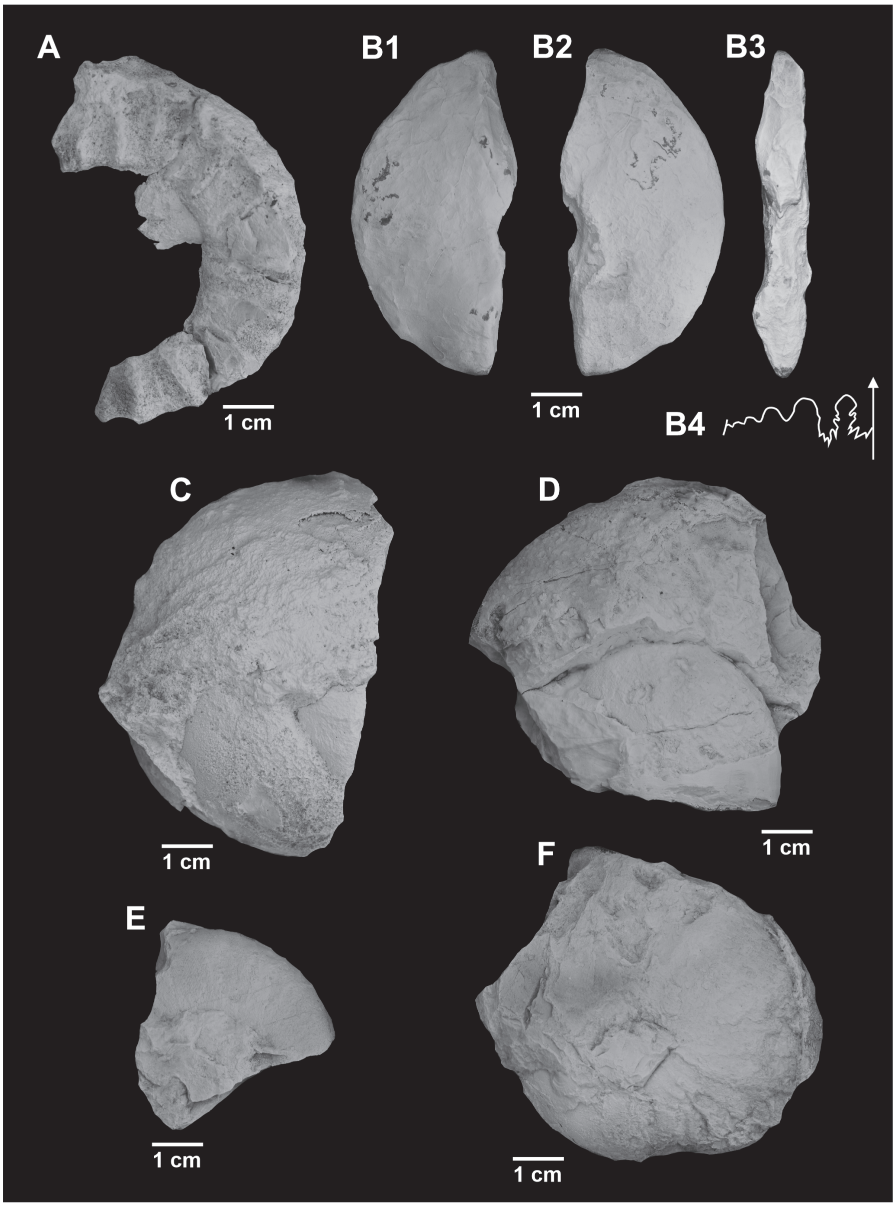

Figure 8. Ammonites from the Bulog Formation. **a–c** are from the base of the older Bulog Limestone (late Pelsonian), and **d–f** were collected in the younger Bulog Limestone. **a** *Balatonites* sp. **b1–4** *Philippites* ? sp. (different views) and suture line (B4); **c** *Proarcestes* sp.; **d** *Parasturia* cf. *emmrichi* (MOJSISOVICS); **e** *Monophyllites* cf. *wengensis* (KLIPSTEIN); **f** *Flexoptychites* sp.

Within this level, only poorly preserved and fragmentary specimens (Fig. 8d–f) could be collected, and *Parasturia* cf. *emmrichi* (MOJSISOVICS), *Monophyllites* cf. *wengensis* (KLIPSTEIN) and *Flexoptychites* sp. are determined indicating a late Illyrian to ?Fassanian age.

4.2. Neptunian dikes in the Ravni Formation

The age of the two generations of neptunian dikes filled with red nodular limestones correspond to the evolution of the overlying Bulog Limestone succession. The dense network of neptunian dikes crosscut the Ravni Formation, the younger generation of neptunian dikes crosscut the Ravni Formation, the older Bulog Formation and the older generation of neptunian dikes, therefore in some cases mixed, conodont faunas appear in a single sample. The dense network of neptunian dikes and fractures result in an apparent brecciated texture in parts of the Ravni Formation. The formation of the older generation of neptunian dikes predates the condensed drowning sequence with the ammonoid-bearing dark red condensed limestones. The two generations of neptunian dikes can be distuinguished by the colour of the infilling (Fig. 9) and their microfacies. The older neptunian dikes are filled with dark-red micrite, whereas the younger neptunian dikes are filled with light-red micrite sometimes containing brachiopod shells. The conodont specimens discovered show the same CAI-values (Fig. 11) in both generations of neptunian dikes. The age of the the formation of these neptunian dikes is constrained by the biostratigraphic age range of every species (see e.g. CHEN et al., 2016).

Within the older generation of fissure fillings (Fig. 9a), crosscut by younger fissures, the following conodonts were determined (sample MM 55, Fig. 4): *Nicoraella kockeli* (TATGE), *Gladigondolella tethydis*, *Neogondolella cornuta*, *Paragondolella bifurcata*, *Paragondolella excelsa*, *Paragondolella hanbulogi*,

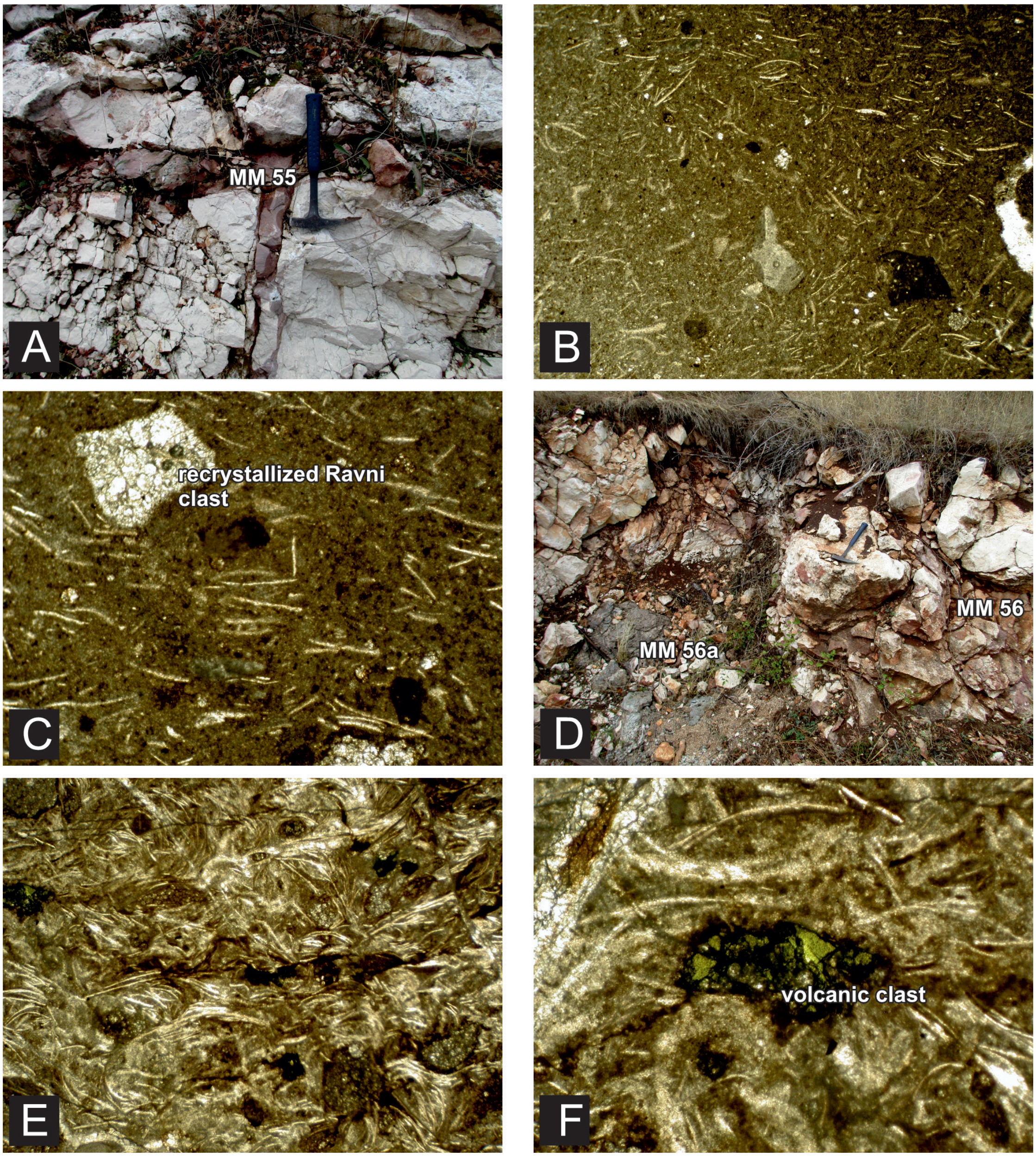

Figure 9. Two generations of neptunian dikes in the upper shallow-water limestones of the Ravni Formation and their microfacies characteristics. **a** A Late Pelsonian dike filled with dark red limestone and the position of the sample, hammer as scale; **b** "Filament"-rich wackestone with a few shallow-water grains and a few recrystallized Ravni Formation clasts. In addtion, hardground clasts are visible, sample MM 55, width of the photo: 1.4 cm; **c** Enlargement of b showing recrystallized angular Ravni Formation clast in a "filament"-rich biomicrite, width of the photo: 0.5 cm; **d** Overview of the upper part of the Ravni Formation with two generations of neptunian dikes and incorprated green-grey marly sediments used for XRD-analysis. The sample locations are indicated, hammer as scale; **e** Slightly recrystallized "filament-limestone" with few volcanic clasts and recrystallized limestone clasts, sample MM 56, width of the photo: 1.4 cm; **f** Detail of a volcanic clast in the slightly recrystallized "filament-limestone", width of the photo: 0.5 cm.

and *Paragondolella trammeri*. In this older generation of neptunian dikes "filament"-rich wackestones are observed with a few shallow-water grains, hardground clasts and a few recrystallized angular Ravni Formation clasts (sample MM 55; Fig. 9b, c).

In the younger light red generation of neptunian dikes (Fig. 9d) also crosscutting the older generation, the following conodonts were determined (sample MM 56; Fig. 4): *Gladigondolella budurovi* KOVÁCS & KOZUR, *Gladigondolella tethydis*, *Paragondolella bulgarica*, *Paragondolella hanbulogi*, *Paragondolella excelsa*, *Paragondolella szaboi*, and *Paragondolella trammeri*. In this younger generation of neptunian dikes slightly recrystallized "filament-limestones" with few volcanic clasts (sample MM 56) and recrystallized limestone clasts occur (Fig. 9e, f).

In both sets of neptunian dikes mixed conodont faunas appear. This mixed fauna indicates two different ages within one sample, namely the late Pelsonian-early Illyrian and the late Illyrian (to Fassanian). In the older neptunian dike infilling only *Paragondolella trammeri* indicate the younger age, wheras all other conodonts belong to the older (late Pelsonian – earliest Illyrian) age. These are *Nicoraella kockeli*, *Neogondolella cornuta*, *Paragondolella bifurcata*, and *Paragondolella praeszaboi*, *Gladigondolella tethydis* and

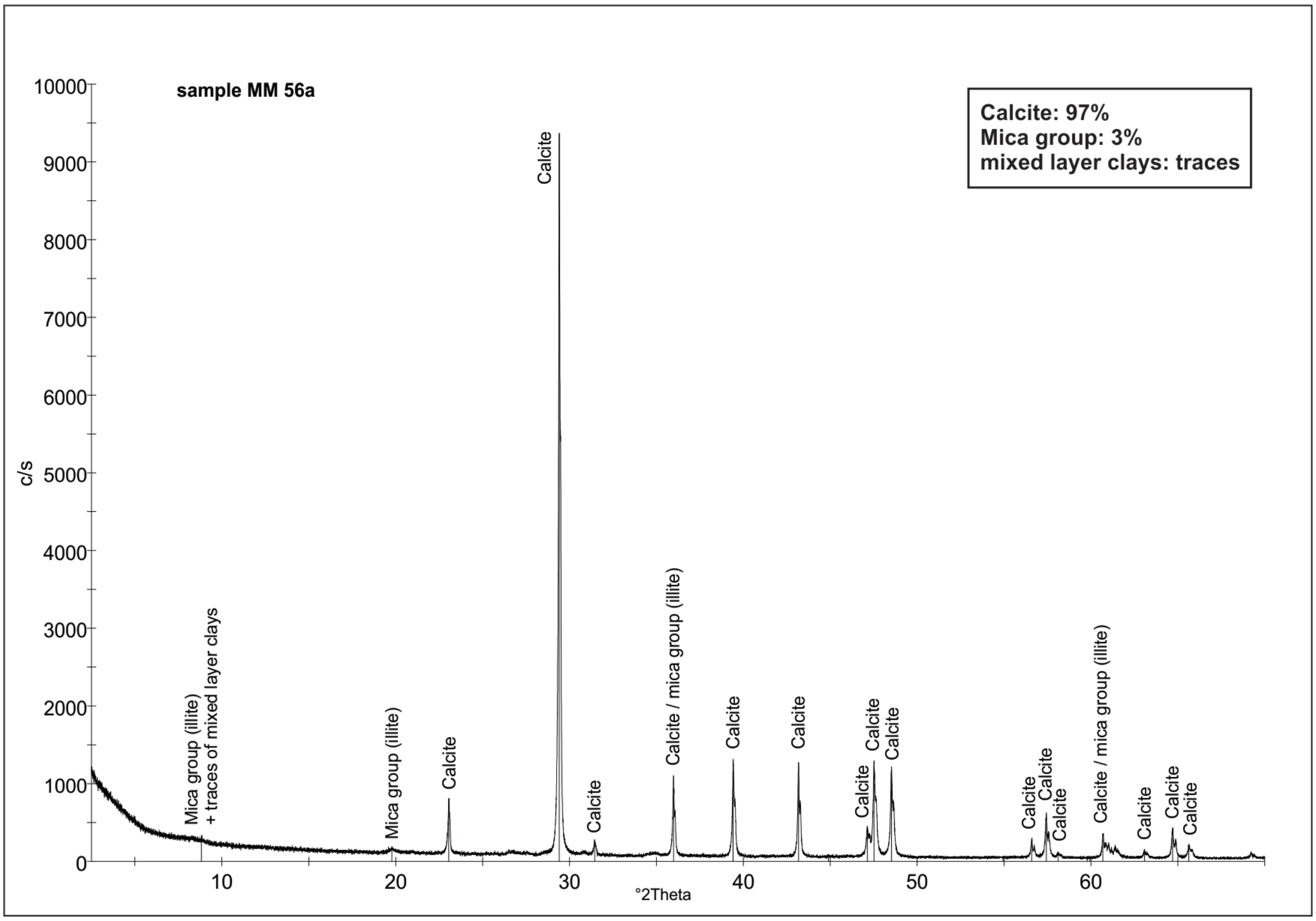

Figure 10. XRD measurement and mineralogical composition of the sample MM 56a.

Paragondolella excelsa appear most likely in the younger neptunian dike infilling as their FAD is younger as late Pelsonian – earliest Illyrian. In contrast, the younger neptunian dike infilling contains only two older species with *Paragondolella bulgarica* and *Gladigondolella budurovi*. The conodont assemblage *Gladigondolella tethydis*, *Paragondolella excelsa*, *Paragondolella szaboi*, and *Paragondolella trammeri* indicates a late Illyrian (to Fassanian) age. In the younger fissure generation brachiopods also appear beside clasts of volcanic material and green-grey clayey sediments. In these neptunian dikes the occurrence of volcanic grains and sediments is much more common as in the overlying light red limestones. This indicates decreasing volcanic activity after the formation of the neptunian dikes. Redeposition of the various breccia levels postdate the main volcanic activity and the formation of the second horst-and-graben system. A similar conclusion was reached by MRDAK et al. (2024a) more to the north in the area of Durmitor Mt.

4.3. Clay mineralogy

The analysed sample MM 56a (Fig. 4) was taken from green, carbonaceous, fine-grained, marly, soft sediments in a light red neptunian dike infilling of late Illyrian age. Lithologically, these sediments resemble incorporated volcanic ashes in these neptunian dikes.

The XRD image (Fig. 10) shows no sharp peaks for the clay minerals, but a broad band of scattering, resulting in weak signals. The sample consists predominantly of calcite and only traces of clay minerals of the mica group (mainly Illite) including traces of mixed layer clay minerals could be determined. Strong diagenetic alteration of this sediment prevents the assignment of this material to a volcanic ash origin. Only the occurrence of traces of mixed layer clay minerals give a hint for a volcanic provenance.

4.4. Conodont Colour Alteration (CAI)

The diagenetic overprint of the studied sedimentary succession was estimated using the Conodont Colour Alteration Index (CAI) method (for details see EPSTEIN et al., 1977; REJEBIAN et al., 1987), calibrated with other temperature sensitive methods (NÖTH, 1991; KÖNIGSHOF, 1992; RANTITSCH et al., 2020). Characteristic conodonts of the studied sections and their Conodont Colour Alteration Index (CAI) values are shown in Figure 11. All conodonts are from the late Pelsonian to the late Illyrian, that is from the two generations of neptunian dikes and the drowning sequence of the Bulog Group show relative homogeneous CAI values of CAI 1.0, which correspond to a diagenetic overprint at 50 – 90 °C (EPSTEIN et al., 1977; BURNETT et al., 1994). This indicates a burial of less then 2 kilometres, meaning that it would correspond to the known thicknesses of the Upper Triassic to Palaeogene overlying sequences in the central East Bosnian – Durmitor mega-unit according to DIMITRIJEVIĆ (1997).

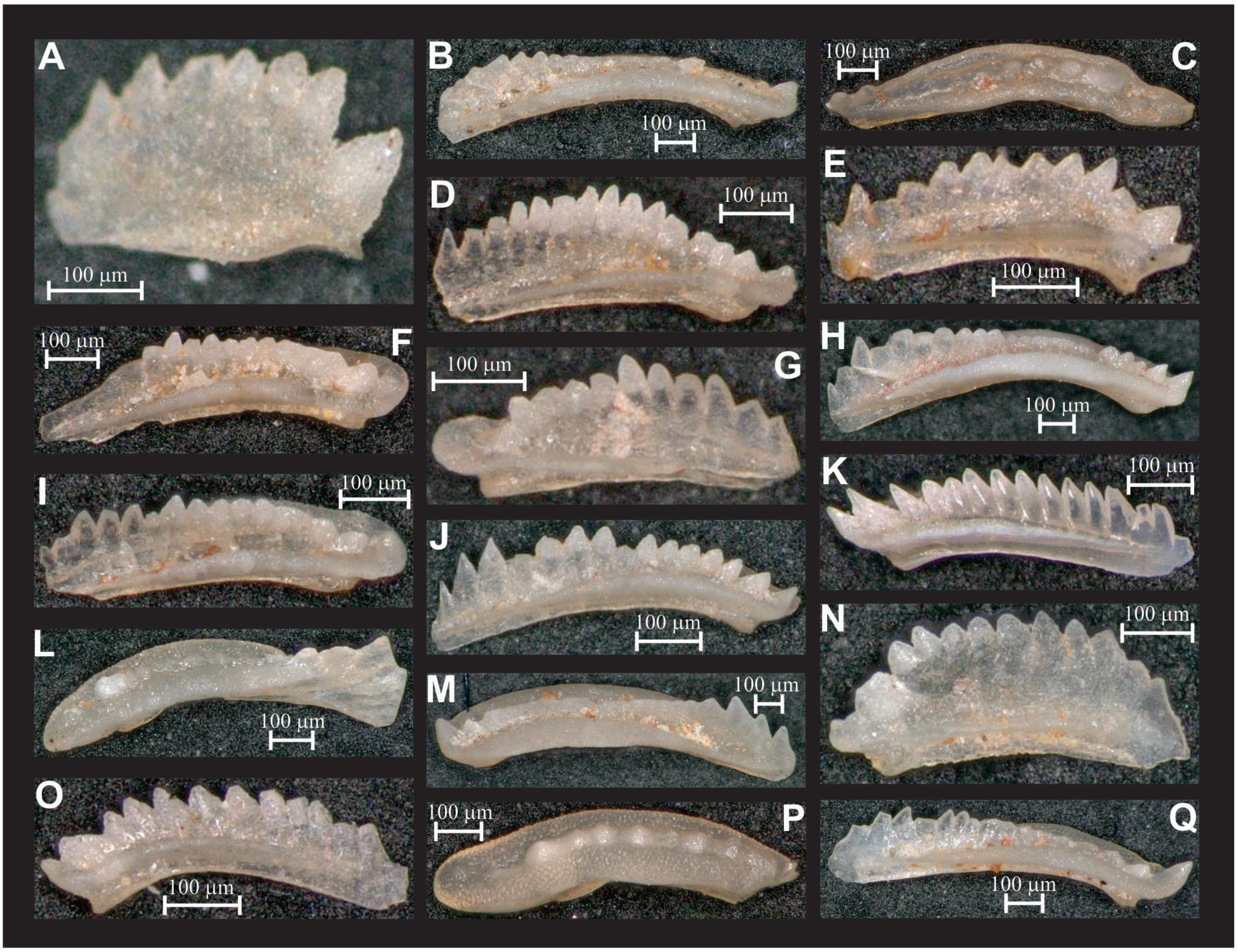

Figure 11. Photos of some characteristic conodonts of the Seljani section, showing all homogeneous CAI-values of CAI 1.0. Instead of using the white background as normally obligatory to show the CAI-values a black background was used in this case. Photographing the conodonts with CAI 1.0 on white background would result in practically poor visibility and would hamper the determination capability of the conodonts. **a** *Nicoraella kockeli* (TATGE), sample MM 55; **b** *Neogondolella cornuta* BUDUROV & STEFANOV, sample MM 55; **c** *Gladigondolella budurovi* KOVÁCS & KOZUR, sample MM 56; **d** *Paragondolella szaboi* (KOVÁCS), sample MM 56; **e** *Paragondolella trammeri* (KOZUR), sample MM 56; **f** *Paragondolella bulgarica* BUDUROV & STEFANOV, sample MM 56; **g** *Paragondolella excelsa* (MOSHER), sample MM 56; **h** *Paragondolella bifurcata* BUDUROV & STEFANOV, sample MM 57; **i** *Paragondolella hanbulogi* SUDAR & BUDUROV, sample MM 56; **j** *Paragondolella eotrammeri* (KRYSTYN), sample MM 59; **k** *Paragondolella trammeri* (KOZUR), sample MM 61; **l** *Gladigondolella tethydis* (HUCKRIEDE), sample MM 56; **m** *Neogondolella cornuta* BUDUROV & STEFANOV, sample MM 62; **n** *Paragondolella excelsa* (MOSHER), sample MM 62; **o** *Paragondolella trammeri* (KOZUR), sample MM 60; **p** *Gladigondolella tethydis* (HUCKRIEDE), sample MM 61; **q** *Neogondolella cornuta* BUDUROV & STEFANOV, sample MM 62.

5. DISCUSSION

5.1. Depositional environment

After formation of the Ravni Carbonate Ramp (Fig. 12a) late Pelsonian tectonic motions resulted in a horst-and-graben topography indicated by neptunian dikes filled with red marly mud of the same age.

5.1.1. Late Pelsonian neptunian dike infilling

The Seljani area is only mildly folded and not too many faults can be observed. Therefore, it is most likely that BEŠIĆ (1949a, b) collected his well-preserved and rich brachiopod faunas at least in the strike of the described section, but the ammonoids from an older level. In contrast to the infilling of the neptunian dikes the overlying drowning sequence contain no brachiopods. As stated by WENDT (1973) the environment in neptunian dikes is different compared to the environment on the sea bottom. The determined brachiopod fauna by BEŠIĆ (1949a) is quite similar to widespread brachiopod faunas determined in the broader Western Tethys Realm, as in the Bulog Limestones around Sarajevo (BITTNER, 1892, 1902; KITTL, 1904; Mt. Trebević), or the Northern Calcareous Alps (BITTNER, 1890). In addition, the microfacies of the older neptunian infilling (Fig. 9b, c) indicate deposition on a horst at a relative shallow-water depth (position a in Fig. 12e). The recrystallized Ravni Formation components indicate karstification, i.e. they derive from an uplifted horst above the sea-level (Fig. 12e). As in the overlying Bulog Limestones, this microfacies with “thin-shelled“ bivalves and hardground clasts is not preserved, it can be concluded that bottom currents transported all the sediment from this elevated position into adjacent depressions.

5.1.2. Late Pelsonian to middle Illyrian Bulog Limestone

The first bed of the Bulog Limestone representing the drowning sequence of the Ravni Carbonate Ramp (Fig. 12b) is characterized by strong stratigraphic condensation as indicated by a mixed late

Pelsonian to earliest Illyrian conodont and ammonoid fauna (Fig. 4), but with only a few, poorly preserved brachiopods. Such strongly condensed red nodular limestones with mixed faunal content appear very often in the drowning sequence of the shallow-water Ravni Carbonate Ramp (equivalent to the Steinalm Carbonate Ramp) elsewhere in the Western Tethyan Realm (HAUER, 1884, 1888, 1892; ASSERETO, 1971; KRYSTYN et al., 1971). Such stratigraphic condensation is quite typical for deposition of red nodular limestones on a morphological high, where currents transport the fine-grained material into adjacent basins (WENDT, 2017). That is in contrast to typical sedimentologal features described for deposition on an elevated and relative shallow high (JENKYNS, 1971; FÜRSICH, 1978; WENDT, 1973; BÖHM, 1992; FLÜGEL, 2004). The typical features for extreme condensation such as a relatively thick hardground formation, hardground clasts, appearance of phosporites, stromatolithic Fe/Mn-crusts etc. are missing (FLÜGEL, 2004 and references therein). In contrast, the radiolarian-rich microfacies with intense corrosion of ammonoid shells indicates deposition in relatively deep-water, that is near to the aragonite compensation depth (see FLÜGEL, 2004 for details). As the age of the basal Bulog Limestone bed is only slightly younger than the neptunian dike infilling below, a extreme rapid subsidence of the block can be concluded (from position a to position b in Fig. 12e). Stratigraphic condensation prevailed until the middle/late Illyrian boundary (Fig. 12c).

5.1.3. Late Illyrian neptunian dike infilling

These neptunian dikes, which cross-cut the older Bulog Limestone, the Ravni Formation with the older neptunian dikes (Fig. 12d), contain "filament-rich" wackestones with volcanic clasts (Fig. 9e, f), beside a late Illyrian conodont fauna, and greenish-grey clays (Fig. 9d) with traces of mixed layer clay minerals (Fig. 10). While in the underlying Bulog Limestone no traces of volcanic activity could be recognized, we attribute the creation of the second generation of neptunian dikes to the onset of volcanic activity subsequently followed by the creation of a second horst-and-graben topography (Fig. 12f). The microfacies of the younger neptunian dike infilling (Fig. 9e, f) indicate formation of this calcareous mud again on a deep swell in relative shallow-water, meaning that this mud was transported from newly formed swells into the deep-water depositional environment of the footwall block. Reworked clasts of the Ravni Formation are absent in these infillings.

5.1.4. The Late Illyrian to ?Fassanian Bulog Limestone

Around the middle/late Illyrian, the depositional environment changed as indicated by the intercalated oligomictic breccias (Fig. 7g, h) in a marly-silicous matrix with broken thin-shelled bivalves (Fig. 7d–f). These breccias can be compared to the younger Komarani Formation (SUDAR et al., 2023b), which was also recently described from the East Bosnian – Durmitor mega-unit (MRDAK et al., 2024a). Breccia components are coated by hardgrounds, and their microfacies characteristics (Fig. 7d–f) are similar to the microfacies of younger neptunian dike infillings. In the matrix, only a few volcanic clasts appear. Reworked material from the Ravni Formation is missing in these oligomictic breccias. While most of the components are characterized by intensive coatings, they originated from a deep swell at a relative shallow-water depth. In contrast, the more greyish marly siliceous matrix indicates deposition in a basinal environment. The basin received reworked material from the adjacent high (Fig. 12f).

5.2. Age of the ammonoid fauna

5.2.1. Ammonites from the basal drowning sequence

The determined ammonites *Balatonites* sp., *Philippites* ? sp., and *Proarcestes* sp. from the lower condensed red nodular limestone contain taxa, which normally are typical for the Pelsonian. It should be noted that specimens assigned to the genus *Balatonites* show most resemblance to *Balatonites ottonis* (BUCH) in being strongly ornamented, whereas the one tentatively assigned to *Philippites* also shows a resemblance to *Nicomedites barbarossae* (ARTHABER) being lateraly compressed and having a high, subtriangular whorl section. This would imply that the ammonoid fauna in this level could also be of Bithynian age, since *Nicomedites* is still unknown from the Pelsonian, and some authors consider that *Balatonites ottonis* (BUCH) could also indicate a Bithynian age (e.g. VÖRÖS, 2003; SIEGEL et al., 2022). However, a preserved part of the suture line in the specimen Figure 8 (b4), i.e. its first lateral saddle is identical to *Philippites*, and is compressed due to fossilization. The subtriangular whorl section is more or less a characteristic of all Beyrichitidae, to which both *Nicomedites* and *Philippites* belong. On the other hand, the appearance of *Balatonites* cf. *ottonis* (BUCH) in the Balaton highland together with *Balatonites balatonicus* (MOJSISOVICS) and other Pelsonian forms as reported by VÖRÖS (2003), excludes it from being used as a zonal marker. This does not contradict the proposal of SIEGEL et al. (2022) for the Germanic basin, but also raises a question of whether this fauna could also belong to the Pelsonian. In conclusion, the sparse fauna from this level is considered to be Pelsonian, but redeposition of a much older fauna represented by dissolved and corroded specimens cannot be excluded, although it is not likely because of the underlying shallow-water Ravni Formation.

5.2.2. Pelsonian ammonites from BEŠIĆ (1949b)

BEŠIĆ (1949b) also determined and described an ammonoid fauna from the Seljani region, but south of the studied section presented here (at the locality of Radonjića Vrt and Komarnički Brod). What he mentioned is that the locality is situated on a hiking trail between the Komarnica river and the villages of Rudinice and Seljani (Fig. 2b). At that time, the artifical Piva Lake did not exist in the area, but according to his description, it can be assumed that it is in the area between the river Komarnica and the village of Rudinice, and it is most probably now flooded. BEŠIĆ (1949b) mentioned another locality with ammonoids, also not indicated on the map, but probably situated somewhere in the vicinity of Sinjac. However, he stated that these ammonoids are not found within the red Bulog limestones, but in the grey, in parts dolomitized marly limestones.

According to BEŠIĆ (1949b) the section starts near the river (now a lake) with sandy limestones of the upper Werfen Formation followed by grey dolomitized massive limestones. Up-section this is followed by a grey, marly limestone, belonging to what can only be assumed to be a formation not described in detail in this area. This part of the section contains the quite well-preserved ammonoid fauna described by BEŠIĆ (1949b). The presence of *Proteusites* in one and *Acrochordiceras* genera in the other assemblage, should both indicate a Pelsonian age. Above this level with the ammonites, grey dolomitized (in fact recrystallized) limestones with brachiopods follow (BEŠIĆ, 1949a), which derive from neptunian dikes in the upper Ravni Formation (Dedovići Member).

However, this ammonoid fauna does not derive from the Bulog Formation or an age-equivalent limestone, i.e. the drowning sequence of the Ravni Carbonate Ramp. This ammonoid fauna from BEŠIĆ (1949b) derives from an open-marine level between the lower Utrine Member of the Ravni Formation and the upper Dedovići Member of the Ravni Formation. This stratigraphic level indicates the first deepening trend due to the opening of the Neo-Tethys Ocean to the east and is known from the Northern Calcareous Alps, termed there the Annaberg Formation (GAWLICK et al., 2021 and references therein). Sequences analogous to the Annaberg Formation in the Northern Calcareous Alps have not been previously known from the Dinarides, but the existence of such an open-marine level in the Ravni Formation is known from the area south of Sarajevo (Trebević Mt.) (SUDAR, 1986). Revision of the Hallstatt Limestone sections in Trebević Mt. results in the correlation of the Trebević Member of the Ravni Formation and the Annaberg Formation in the Northern Calcareous Alps (SUDAR et al., 2025 and references therein), deposited around the Bithynian/Pelsonian boundary. A similar lithology was also found in the Budva unit, *sensu lato*, by ĐAKOVIĆ et al. (2018).

5.2.3. Ammonites from the higher Bulog Limestone sequence

In the upper part of the Bulog Formation, above the breccia layers, a second ammonoid-bearing level was detected. Within this level, only poorly and fragmentary preserved specimens could be collected. The determined fauna with *Parasturia* cf. *emmrichi*, *Monophyllites* cf. *wengensis* and *Flexoptychites* sp. can only be assigned to a late Illyrian – Fassanian age, since these ammonites are all long-ranging taxa. However, *Parasturia emmrichi* is in the Western Tethys Realm found from the *Aplococeras avisianum* Zone to the *Nevadites secedensis* Zone (MANFRIN et al., 2005; VÖRÖS, 2018), which makes this interval tentatively comparable with the Kovčezi section ammonoids, recently published by ĐAKOVIĆ et al. (2025). Also, from the sedimentological point of view, this ammonoid fauna in the Seljani section appears in a comparable level above the breccias of the Komarani Formation as in the Kovčezi section (MRDAK et al., 2024a).

5.3. Reconstruction of Pelsonian – Illyrian geodynamic evolution

The uppermost shallow-marine limestones of the Ravni Carbonate Ramp with open-marine influence represent the last sedimentary rocks deposited in an epicontinental sea (GAWLICK & MISSONI, 2019 and references therein), i.e. they represent the uppermost part of deposition in the graben shortly before the continental break-up (Fig. 12a), related to the opening of the Neo-Tethys Ocean around the Pelsonian/Illyrian boundary (GAWLICK et al., 2008; OZSVÁRT et al., 2012; DJERIĆ et al., 2024 and references therein). The drowning of the Ravni Carbonate Ramp (and the equivalent Steinalm Carbonate Ramp) is time-equivalent everywhere in the Western Tethys Realm (SCHLAGER & SCHÖLLNBERGER, 1974; KOVÁCS et al., 2010, 2014; SUDAR et al., 2013; GAWLICK et al., 2021; KARÁDI et al., 2022; MRDAK et al., 2024a). This drowning is characterized by the overregional demise of shallow-water carbonate production and formation of the break-up unconformity, in the form of horst-and-graben structures (Fig. 12). In the frame of the formation of the late Pelsonian horst-and-graben structure due to extension, some horsts uplifted and karstified while others sink into a deeper-water position (SUDAR et al., 2013). In such cases it can be expected that the subsidence of such horsts is rather high, but this was never proven or documented. In Seljani, the late Pelsonian neptunian dike infillings are characterized by a “filament-rich“ microfacies typical of relatively shallow deep-swells (most probably some few 10s of metres water depth; BÖHM, 1992; WENDT, 2017) where bottom currents transport the fine-grained material into adjacent basins. In contrast, the drowning sequence, presented by the first condensed layer with ammonoids of the Bulog Formation (Fig. 12b), also of late Pelsonian age, is characterized by a deep-water microfacies (most probably more than 100 m water depth; GAWLICK et al., 2012). This proves a very rapid subsidence during the short time span of the late Pelsonian (Fig. 12e). During early/middle Illyrian times condensed deposition prevailed (Fig. 12c). Around the middle/late Illyrian boundary a second pulse of tectonics create a second generation of neptunian dikes (Fig. 12d), which crosscut the older generation. A new horst-and-graben system formed and the former horsts were flooded and condensed red nodular limestones with hardgrounds deposited. Reworked material from these flooded horsts was transported gravitationally into the deeper environments forming mass-transport deposits. Whereas near to the escarpments thick breccia bodies were deposited (compare SUDAR et al., 2023b; MRDAK et al., 2024a). In a more distal position, breccias of reduced thickness were desposited in channels (Fig. 12f). Up-section, the amount of intercalated breccias decreased and a second condensed layer with ammonoids was deposited. The whole Bulog Limestone succession is siliceous and rich in recrystallized radiolarians. Above the second ammonoid-bearing horizon, the Bulog Limestone is characterized by an increasing amount of silica and finally overlain by reddish radiolarites of Ladinian age.

The water depth of the late Anisian basin can be estimated only by the sedimentological (microfacies) characteristics and the overlying sedimentary rocks. As already stated by BEŠIĆ (1949b) the Bulog Limestone succession and the overlying basinal sedimentary rocks are overlain by limestones and dolomites of the Wetterstein Carbonate Platform with a variable thickness of 50 to 100 metres. MIRKOVIĆ (1980) assumed a thickness of up to 200 m for the whole Ladinian in the wider region, referring to the entire sequence from the radiolarites to the Wetterstein Carbonate Platform, during that time seen as part of the Ladinian. It can be concluded, that the lower thicknesses of the Wetterstein Carbonate Platform sedimentary rocks reflect deposition on top of the shallower

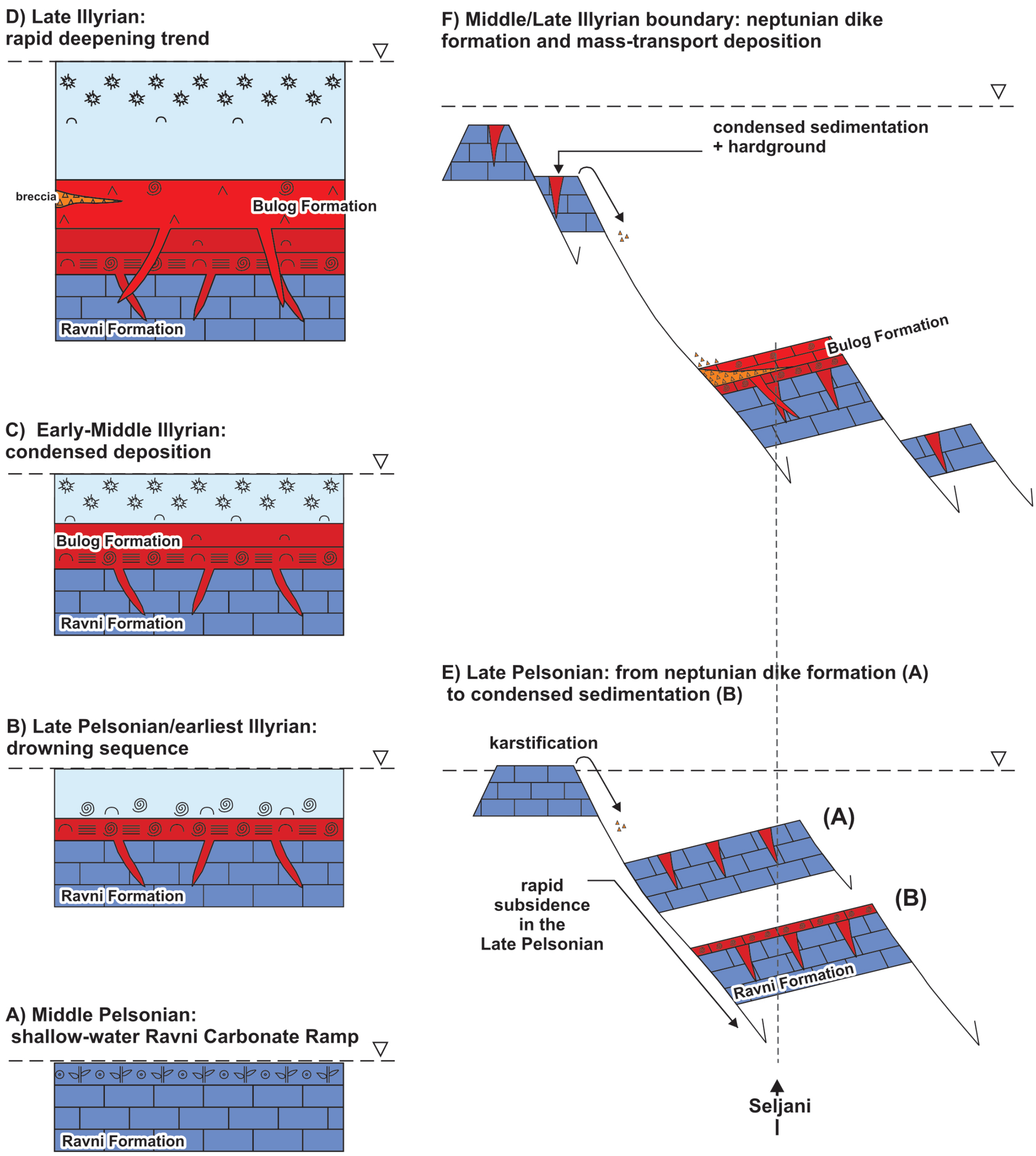

Figure 12. Reconstruction of the depositional environment and geodynamic evolution in the timespan middle Pelsonian to the late Illyrian (?Fassanian) and the position of the Seljani studied section. **a** Deposition of the Middle Pelsonian shallow-water limestone of the uppermost Ravni Formation with dasycladalean-rich beds containing crinoids in its uppermost part indicating an increasing open-marine influence; **b** Late Pelsonian to earliest Illyrian drowning sequence of the Ravni Carbonate Ramp. The formation of the neptunian dikes filled with late Pelsonian Bulog Limestone predates the deposition of the siliceous condensed ammonid-bearing red limestone, indicating tectonic motions; **c** Early – Middle Illyrian deposition of relatively condensed dark-red siliceous Bulog Limestones during a period of relative tectonic quiesence; **d** Late Illyrian period of rapid deepening and tectonic motions. A younger generation of neptunian dikes crosscut the older lithologies, subsequently followed by deposition of red nodular limestones with intercalated breccia channels and volcanic clasts. The topmost part of the Bulog Limestone also contains an ammonoid-bearing horizon; **e** Recontruction of the late Pelsonian formation of a horst-and-graben system. Neptunian dikes were formed during this phase of extension. Parts of the dismembered Ravni Carbonate Ramp were uplifted and karstified while other parts underwent rapid subsidence (A) and took a deep swell position (B) in a graben during late Pelsonian times; **f** Around the middle/late Illyrian boundary, a second phase of extension created a second horst-and-graben topography, with the formation of neptunian dikes. The elevated horst flooded. From the newly formed escarpments mass-transport deposits accumulated in the grabens and half-grabens.

swells, whereas the greater thickness reflects deposition in a basinal position. Together with the decompacted thicknesses of the late Anisian to Ladinian basinal sedimentary rocks (≈30 m-thick), the water depth of the deep swells hardly exceed 200 metres. A similar conclusion of a water depth of 200 (-300) metres for similar basins was reached for the late Anisian – Ladinian basinal deposits in the High Karst unit by GAWLICK et al. (2012). Above an unconformity, the carbonates of the Wetterstein Carbonate Platform (in contrast to MIRKOVIĆ, 1980) were overlain by limestones of the Dachstein Carbonate

Platform. This unconformity is marked by bauxite lenses (MIRKOVIĆ, 1980), which most probably mark the Middle – Late Carnian stratigraphic gap (MRDAK et al., 2023), before the onset of the Dachstein Carbonate Platform, with a thickness of up to 700 m (MIRKOVIĆ, 1980). BEŠIĆ (1949b) contributed by the discovery of *Megalodon* sp., an open lagoonal depositional environment indicator, during the Norian in the region near the Seljani section. This Middle – Late Triassic sedimentary sequence also disproves the existence of a deep-water intraplatform basin (Bosnian trough/basin) between the East Bosnian – Durmitor mega-unit and the Pre-Karst unit.

6. CONCLUSION

The Bulog Limestone evolution and the two generations of neptunian dike infillings in the Ravni Formation, reflect two phases of tectonic extension and a stepwise deepening of the depositional environment. The first event in the late Pelsonian is related to the onset of the opening of the Neo-Tethys and a rapid subsidence of some blocks from shallow-water depths to a relative deep-water environment of at least 100 m water depth during late Pelsonian times is documented here for the first time. The second deepening event starting around the middle/late Illyrian boundary, and can be correlated with the onset of intense volcanic activity. A second generation of neptunian dikes and a second horst-and-graben structure was created.

The late Anisian to Ladinian depositional history is elsewhere in the East Bosnian – Durmitor mega-unit and adjacent areas characterized by the deposition of deep-water sedimentary rocks and cannot be used for any palaeogeographic reconstuctions of the existence of deep-water intraplatform basins. During this time span practically no shallow-water carbonate production existed, and in the entire Dinarides from the open (distal) shelf (Hallstatt shelf) to the east to the Budva unit to the west, specific deep-water sedimentary rocks were deposited.

The Gordian knot of the controversial discussion about the tectonic position of the tectonic outlier with the studied section at Seljani and a possible affiliation to an existing long-lasting intraplatform basin (Kuči unit, Zone Bosniaque/Zone Serbe in parts) is now open.

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