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Article

Mesozoic stratigraphy of Dinaric successions at the Dinarides – Southern Alps boundary, Sava Folds region, Slovenia

Stratigrafija dinarskih mezozojskih zaporedij na meji med Dinaridi in Južnimi Alpami, območje Posavskih gub, Slovenija

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Ključne besede: trias, jura, kreda, aptijsko-albijske kalpionelide, Dinaridi, Južne Alpe, Posavske gube

Abstract

In central Slovenia, on the border between Southern Alpine derived units and Dinaric units in the northern part of the Sava Folds, detailed field observations and reambulation-type mapping were conducted. The research aimed to clarify the distribution of Mesozoic formations and the palaeogeographical and tectonic position of the studied area.

Based on field observations, lithofacies, microfacies, and biostratigraphic studies (including benthos and planktonic foraminifers, dinocysts, acritarchs, chitinoidellids, calpionellids, green algae, microproblematica, calcareous nannofossils and ascidians), the following successions characterize the northern limb of the Trojane Anticline and the Tuhinj–Motnik Syncline: upper Anisian to lowermost Ladinian platform carbonates (Mendole Formation) are overlain by Ladinian siliciclastic successions including volcanoclastic resediments (Pseudozilian Formation). These either interfinger or are overlain by the Ladinian to lower Carnian platform limestone (Schlern Formation); in the upper part of this formation, the deep–marine siliciclastics and/or carbonates are locally intercalated. Following a significant stratigraphic gap, the lower Tithonian to lower Valanginian pelagic limestone and carbonate resediments (Biancone Formation s.l.) were deposited. The Biancone limestone is covered by upper Aptian–upper Albian (Cenomanian?) marlstone with occasional calcarenite (calciturbidite) interlayers (Lower Flyschoid/Gora Formation). The succession ends with Upper Cretaceous pelagic and resedimented limestones (Volče/Krško Formation).

The age and spatial distribution of these successions often differ from that depicted on the existing geological maps. This succession resembles the Transition Zone between the External and Internal Dinarides. Our study indicates the presence of similar transitional Mesozoic Dinaric successions north of the previously proposed Southern Alpine thrust front.

Izvleček

V severnem delu Posavskih gub osrednje Slovenije, na meji med južnoalpskimi in dinarskimi enotami, je bila izdelana stratigrafska reambulacija z namenom dopolnitve razumevanja paleogeografskega in tektonskega razvoja raziskanega območja.

Na podlagi natančnih in dobro dokumentiranih terenskih opazovanj, litofaciesov, mikrofaciesov in biostratigrafije (vključno z bentoškimi in planktonskimi foraminiferami, dinocistami, akritarhi, hitinolidelidi, kalpionelami, zelenimi algami, različno mikroproblematiko in kalcitnim nanoplanktonom) je bil proučen naslednji razvoj Trojanske antiklinale in Tuhinjsko–Motniške sinklinale: zgornjeanizijski do spodnjeladinijski platformni apnenci (Mendolska formacija), katere prekriva ladinijsko siliciklastično zaporedje s presedimentiranimi vulkaniti (Psevdoziljska formacija), še višje pa ladinijski do spodnjekarnijski platformni apnenci in dolomiti (Schlernska formacija), ki se lahko v zgornjem delu formacije prepletajo z globljemorskimi siliciklastičnimi in/ali apnenčastimi vključki. Po dolgi stratigrafski vrzeli sledijo spodnjetithonijski do spodnjevalanginijski pelagični apnenci z redkejšimi plastmi presedimentiranih apnencev (Biancone formacija s.l.). Biancone apnenec prekriva zaporedje laporovcev in kalkarenitov (kalciturbiditov) zgornjeaptijske do zgornjealbijske (?cenomanijske) starosti (Spodnja flišoidna/Gora formacija). Zaporedje se konča z zgornjekrednimi pelagičnimi in presedimentiranimi apnenci (Volčanski apnenec/Krška formacija). Starosti in prostorsko razširjanje navedenih formacij se pogosto razlikujeta od tistih, prikazanih na obstoječih geoloških kartah.

Ta zaporedja so primerljiva zaporedjem Prehodne cone med Notranjimi in Zunanjimi Dinaridi. V tem prispevku so prvič objavljeni dokazi za obstoj dinarskih razvojev severno od predhodno predlagane Južnoalpske narivne meje. Tovrstne odnose med mezozojskimi paleogeografskimi in recentnimi geotektonskimi enotami je možno razložiti s kompleksnim terciarnim tektonskih razvojem širšega ozemlja.

Introduction

The Southern Alpine Thrust Front (SATF) constitutes the tectonic boundary between the Dinarides and the Southern Alps, and has been studied in western Slovenia, where it is defined by the base of the Tolmin Thrust Sheet in the foothills of the Julian Alps (e.g., Placer, 1998b, 2008; Schmid, 2008, 2020). The Slovenian Basin's (SB) deep-marine Middle Triassic to Cretaceous sedimentary succession, encompassed by this thrust sheet, has been the subject of investigation since the 1970s. The paleogeographic location, while presumed narrow and relatively deep, remains a point of contention amongst scholars (Cousin, 1970, 1973; Caron & Cousin, 1972; Haas, 1995; Buser, 1989, 1996; Rožič, 2005, 2006, 2009, 2016, Rožič et al., 2013, 2014, 2017, 2022, 2024). Its southern and southwestern borders, however, were defined by the Dinaric (Adriatic, Friuli) Carbonate Platform (DCP), situated in what is now the External Dinarides. East of the Quaternary Ljubljana Basin, the exact position of the SATF is still debated (e.g., Placer, 1998b, 2008; Schmid et al., 2020). Prior research indicates that the SATF traverses the central Slovenian Sava Folds region east of Ljubljana. The ambiguity primarily stems from the less-defined stratigraphic subdivision of deeper marine (SB) and shallow marine (DCP) successions within the Sava Folds, which serve as indicators of structural subdivision. The southward migration of deeper marine successions of the SB resulted from Mesozoic paleogeographic and sedimentary conditions on the slopes of the adjacent carbonate platform. This is evident in the Upper Jurassic and Cretaceous deeper marine successions, comparable to those of the SB, deposited over the Triassic and/or Lower Jurassic carbonate platform successions (Aničič et al., 2002; Rižnar, 2006; Poljak, 2017; Reháková & Rožič, 2019; Gerčar et al., 2023). The transition area between the External and Internal Dinarides is defined by this succession (Placer, 1998b, 2008). For brevity, we will refer to this paleogeographic zone as the Dinaric Transition Zone (DTZ). Notably, the Sava Folds contain continuous Ladinian to Late Cretaceous deep-marine sequences within the Sloveni-

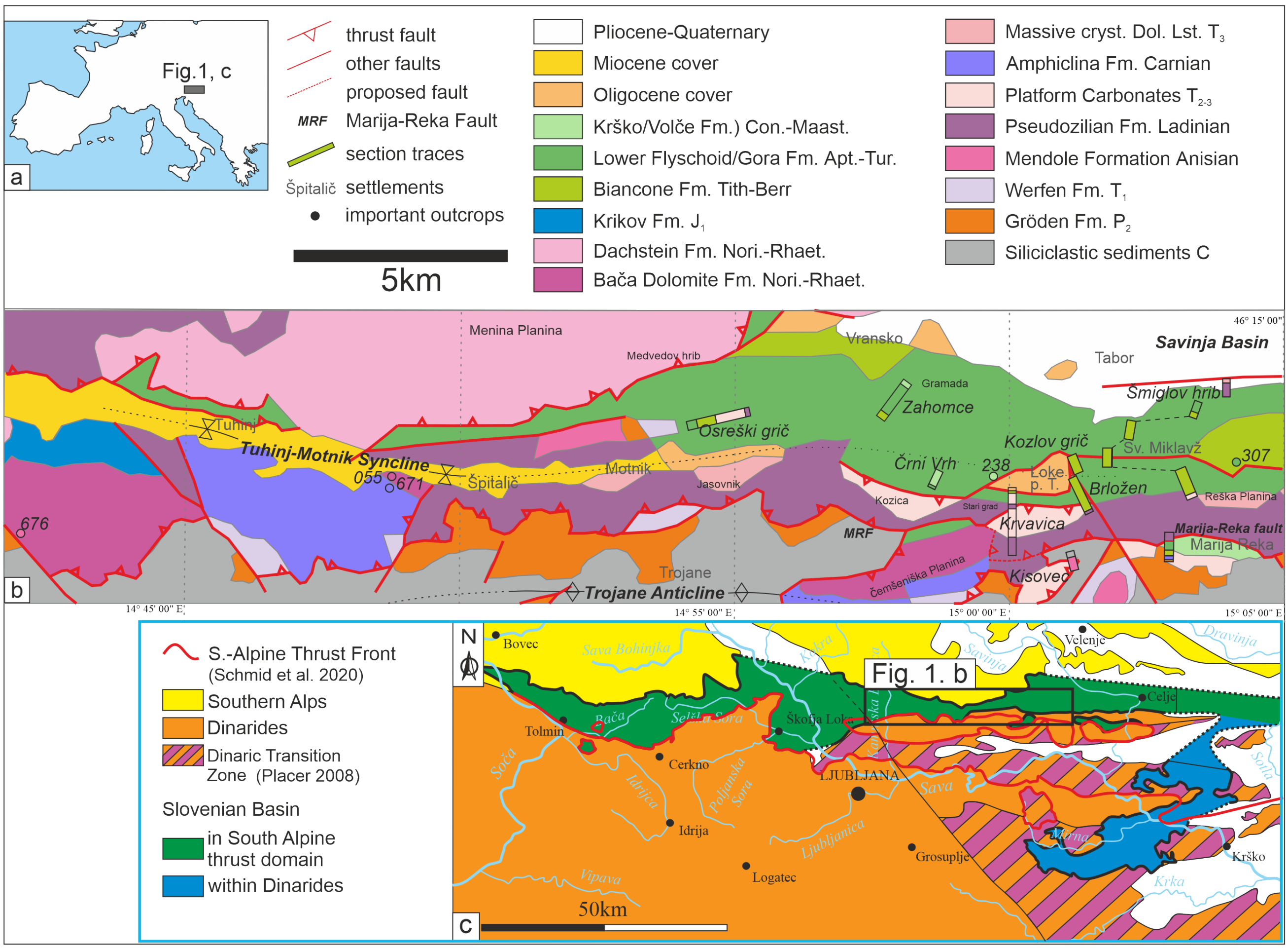


Fig. 1. a) Geographical position of the research area, b) the Trojane Anticline and the Tuhinj-Motnik Syncline of the Sava Folds. Locality of the sections and observation points on the geological map (after Buser, 2010). Modified MRF see dashed line. c) Research area located between the Dinarides and the Southern Alps (map modified after Rožič et al., 2019), the Dinaric Transition Zone marked according to Placer (2008) and the South Alpine Thrust-front according to Schmid et al. (2020).

an Basin, presumably as erosional remnants of a significant thrust-sheet (Buser, 1989, 1996, 2010; Rožič, 2016). Studies from the Mirna River Valley revealed that this succession is characteristic of the southernmost SB (originally nearest to DCP) which comprises coarse Middle Jurassic carbonate breccia megabeds (Ogorelec & Dozet, 1997; Rožič et al., 2019, 2022).

The existence of correlative Jurassic deeper-marine successions in the northern Sava folds has been confirmed recently; this is more precisely on the northern limb of the Trojane Anticline near Celje (Scherman et al., 2023). Alternatively, geological fieldwork conducted in this region indicates the presence of a DTZ succession, structurally consistent with the underlying thrust unit. Consequently, our research plans included expanding our study of Mesozoic successions along the northern branch of the Trojane Anticline and the Tuhinj–Motnik Syncline. The substantial stratigraphic heterogeneity evident in geological maps produced over the last 120 years additionally influenced our area of study (Teller, 1907; Winkler, 1923; Grad, 1969; Lapanje & Šribar, 1973; Buser, 1977, 2010; Premru, 1983a; Placer, 1998b, 2008). This discrepancy can also be attributed to the lack of detailed sedimentological and biostratigraphical research in the area, as only two such studies have been conducted to date. Grad (1969) performed a microfacies analysis of the formations he classified as the Triassic Pseudozilian Formation, finding no fossils other than indeterminate radiolarians. The Upper Cretaceous age of resedimented limestone layers in the study area was determined by Lapanje & Šribar (1973) through foraminiferal analysis of formations near Marija Reka. Their subsequent work in Sveti Miklavž revealed *Clypeina jurassica*, consistent with an Upper Jurassic to Lower Cretaceous age. The accompanying explanatory texts to the geological maps of Buser (1979) and Premru (1983b) only allude to inconsistencies and inaccuracies within these publications without offering a viable resolution. These booklets contain only taxon lists of conodonts, molluscs, benthic and planktonic foraminifers, and nannofossils found in the different formations. This data refers to specific localities or smaller areas, but the exact stratigraphic position is not revealed. We correlated sections of observation points based on sedimentological, biostratigraphical, and palaeoenvironmental data gathered from detailed field observations. We describe nine sections, six of which underwent detailed study, and three more which are included because this data helps to map the sedimentary evolution of the region through the Mesozoic Era. The combination of this study results with previously presented SB succession (Scherman et al., 2023) will serve the basis for ongoing structural geological studies of the region, thereby advancing comprehension of the Dinarides–Southern Alps Border Zone in eastern Slovenia.

Geological setting

The research area is located in Central Slovenia, between Kamnik to the west and Celje to the east, north of the Sava River. It comprises the southern border of the Menina Plateau, the southern end of the Savinja Basin, and the northern Posave Hills (Fig. 1).

According to the tectonic subdivision of Placer (2008), the research area is situated in the northern part of the Sava Folds, namely its northernmost members, the Trojane Anticline and the Tuhinj–Motnik Syncline. It lies on the boundary between the Southern Alps and the Dinarides. Mesozoic successions are partially covered by the sediments of the Pannonian Basin. Important tectonic features in the area are the Sava Fault Zone, Marija Reka Fault, and the Southern Alpine Thrust Front. These faults run west to east across the northern part of the studied area and intersect with each other. The axes of the Sava Folds are also east–west trending. Placer (1998, 2008) distinguished three tectono–stratigraphic units: the Palaeozoic successions named “Palaeozoic Soft Beds”, the Dinaric Transition Zone, and the Slovenian Basin.

The main formations of both the northern Dinarides and the Southern Alpine units are briefly described below. In both tectonic units, the successions start with Carboniferous to Permian siliciclastic sediments. This sequence has been divided into three members, Ca, Cb, and Cc, by Mlakar (1985, 2003). The lowest Ca member is grey to black shale, siltstone, and fine sandstone. Its estimated thickness is 300 m. The Cb member is an upward–coarsening quartz sandstone and an overlying quartz conglomerate with an estimated thickness of 1,100 m. The Cc member is composed of fine–grained shale, with occasional interbeds of sandstone or conglomerate, estimated to be approximately 250 m thick (Novak & Skaberne, 2009). It is followed by the Middle Permian Gröden Formation, a terrigenous fluvial deposit. It is composed of red quartz sandstones and sometimes quartz conglomerates with a thickness of 400 to 900 m (Buser, 1979). The youngest Palaeozoic formation is the bedded dolomite of the Upper Permian “Karavanke Formation”. These few-meter-thick dolomite beds resulted from the marine transgression (Buser, 1989).

In the Trojane Anticline, the Upper Permian carbonates transition to the Lower Triassic Werfen Formation, which consists of limestones and/or dolomites intercalated by clay, siltstone, marl and marly or oolitic limestone. Its relatively rich fossil content suggests that it was deposited in a shallow subtidal – supratidal marine environment (Ramovš et al., 2001). This succession gradually transitions into carbonates, known as the Anisian Platform Carbonates in Slovenian literature, equivalent to the Serla and/or Contrin Formation of the Central Southern Alps (e.g., Gianolla et al., 1998; Celarc et al., 2013). In the southern part of the Sava folds a term Mendole Formation is used for these beds (Poljak, 2017) and we accept it in this paper. It is composed of bedded or massive grey dolomites and limestones, with an approximate thickness of 800 m in the Sava Folds region (Premru, 1983; Aničić, 1991; Dozet & Buser, 2009).

The formations of the Dinaric Transition Zone (DTZ) show transition from a platform to a deeper water basin environment. This area has suffered subsidence during the Middle Triassic, resulting in the intercalation of basinal sediments and the carbonate platform (Rožič et al., 2024). Typically, the Ladinian strata begin with the siliciclastics of the Pseudozilian Formation. It consists of shales, greywackes, sandstones, and resedimented volcanoclastics, sometimes with dark limestone layers. It was first described by Teller (1898) in central Slovenia. In the Southern Alps, it is known as the Wengen Formation (e.g., Gianolla et al., 1998; Skaberne et al., 2024). According to Dozet & Buser (2009), this formation marks the opening of the Slovenian Basin during the Ladinian, but it is also present in DTZ successions (Placer, 2008).

Pseudozilian Formation is overlain by the Ladinian to lower Carnian platform carbonates. A stratigraphic inconsistency marks this formation, as it was previously described as Cordevolian (abandoned early Carnian substage) beds (Buser, 1977, Dozet & Buser, 2009) but was later proven to be largely Ladinian in age (for discussion see Celarc, 2004, 2008). From the eastern Southern Alps corresponding beds are known as the Schlern Formation (Celarc et al., 2013). This name was also conditionally used in Dinarides (Čar, 2010). In Dinarides this formation is known also as Diplopora limestone and/or Saharoid dolomite (due to whitish coarse crystalline texture) (Celarc, 2008). Because Diplopora algae were not found during our research, we decided to use the term Schlern Formation. We note that the topmost part of this formation could also be early Carnian in age in our research area (see below) and would therefore correspond partially to the Cassian Dolomite Formation of the Southern Alps. In this paper, we use the term Schlern Formation in the broad sense for the entire, monotonous upper Ladinian to lower Carnian carbonates lying generally above the Pseudozilian Formation. The characteristic of the Ladinian strata is the gradual progradation of the carbonate platform over the basinal deposits (e.g., Fois, 1983). It was described, for example, from the Julian and Kamnik Alps in Slovenia, although late Anisian–early Ladinian (Celarc et al., 2013) as well as in the Dinarides (Šmuc & Čar 2002; Čar, 2010).

In the southern part of the Sava Folds, these deposits are followed by thick succession of the Upper Triassic and Jurassic shallow-marine carbonates (Poljak, 2017). In the northern Sava folds, including our investigated sections, these carbonates are missing, and the Schlern Formation is covered discordantly by the Upper Jurassic–Lower Cretaceous Biancone Limestone (Aničić et al., 2004; Buser, 2010; Reháková & Rožič, 2019). It is followed by deep marine formations equivalent to the Cretaceous Lower Flyschoid (Gora), Volče Limestone (Krško), and Upper Flyschoid (Veliki trn) formations of the Slovenian Basin (Poljak, 2017; Gerčar et al., 2022).

During the Middle Triassic to Maastrichtian, the Slovenian Basin was an inter–platform basin between the Dinaric (Adriatic) Carbonate Platform to the south and Julian Carbonate Platform (later submarine plateau named Julian High) to the north. The stratigraphy and depositional setting of the SB are well described in the Tolmin nappe system (western Slovenia), in the southern foothills of the Julian Alps (Rožič, 2005, 2009; Rožič & Popit, 2006; Rožič et al., 2009, 2013, 2014, 2017, 2019, 2022; Rožič & Šmuc, 2011; Gale et al., 2012; Goričan et al., 2012a, b). Recently, Rožič et al. (2018, 2019, 2022) described a new occurrence of the SB sequence at Mirna Valley (eastern Slovenia), in the central part of the Sava Folds, south of the investigated area. This succession represents the southern margin of the SB, generally corresponding to that of the Podmelec Nappe, but it contains the thick Middle Jurassic Ponikve Breccia Member, surrounded by prominent gaps. Scherman et al. (2023) have found similar successions along the northern limb of the Trojane Anticline, demonstrating the connection between the western and eastern SB occurrences. In the SB, the deep-water succession starts with the Ladinian–Carnian Pseudozilian–Amphiclina beds. Generally, it is considered that the Pseudozilian Fm. (the composition is the same as that in the DTZ) transitions into the Amphiclina Beds (Skaberne et al., 2024). It means that the Carnian dark pelagic limestone alternates with sandstone and shale. The latter does not contain volcanites and has more carbonate than the Pseudozilian Fm. However, the separation of the Pseudozilian Formation and the Amphiclina Beds is difficult and needs revision (Skaberne et al., 2024). In the Southern Alps, the Amphiclina Beds can be generally correlated with the San Cassiano Formation (Gianolla et al., 1998).

The Triassic ends with the Norian–Rhaetian Bača Dolomite Formation, a dark grey dolomite with chert layers and nodules. The formation is up to 350 m thick and contains chert-dolomite breccia bodies, occasionally several tens of meters thick (Gale, 2010; Oprčkal et al., 2013). Solely in the northernmost outcrops of the SB (proximal to the Julian Carbonate Platform), the late Norian and Rhaetian part is not dolomitized and occurs as hemipelagic and resedimented limestones of the Slatnik Formation (Gale et al., 2012; Rožič et al., 2009, 2013).

The Jurassic of the SB begins with the Hettangian–Pliensbachian Krikov Formation, composed of well-bedded, dark grey, hemipelagic, and resedimented limestones, often featuring chert nodules and layers. Resediments prevail in the northern part of the SB, whereas they become progressively rarer towards the south. In the southernmost parts the lithology is dominated by hemipelagites (Rožič, 2006, 2009). It is followed by the Toarcian Perbla Formation, which consists of laminated marlstones, mudstones, subordinate micritic limestones, black chert, and limestones with chert (Cousin, 1973; Buser & Dozet, 2009; Rožič, 2009; Rožič et al., 2019, 2022). It is overlain by the Aalenian–lower Tithonian Tolmin Formation, consisting of two pelagic members. The Lower Member consists of thin-bedded, silicified, dark limestones and chert, which in the Bajocian passes into the Upper Member, composed of radiolarite and subordinate shale (Rožič, 2009; Goričan et al., 2012). Close to the boundary of the two members and on top of the Upper Member, resedimented limestones (mainly in the form of calciturbidites) are interstratified. In the southernmost part of the SB, the older resedimented limestones became abundant, thicker, and coarser and were described as the Bajocian–Bathonian (?Callovian) Ponikve Breccia Member of the Tolmin Formation. This member was produced by large–scale debris–flows and subordinate calciturbiditic currents and is usually following and followed by a stratigraphic gap. The Ponikve Breccia contains Late Triassic to Middle Jurassic platform carbonate lithoclasts and platform–derived components, including fossils, ooids, and oncoids (Rožič, 2019, 2022; Scherman et al., 2023).

The following formation is the Tithonian–Berriasian Biancone Limestone Formation (e.g., Rožič & Reháková, 2024). These thin-layered white to yellow and occasionally red pelagic carbonates are very rarely interrupted by resedimented limestone layers. It is followed by the Aptian–Turonian Lower Flyschoid Formation (sensu Cousin, 1981), which often begins with a basal breccia layer and transitions upwards into alternating marlstone, mudstone (sometimes even shale), and calciturbiditic beds. The measured thickness in the western Slovenian Basin is up to 300 m (Schlagintweit et al., 2024; Gerčar, 2024). We note that the upper (upper Cenomanian-Turonian) part of this formation is dominated by reddish marly limestone and was mapped in the western SB as a separate unit (Buser, 1986). It is overlain by the Coniacian–lower Maastrichtian Volče Limestone Formation, a thin–layered or laminated creamy–white micritic limestone (e.g., Ogorelec et al., 1976; Premru, 1983). It is characterized by varying time intervals, from upper Cenomanian to the lower Maastrichtian, and thicknesses (50–200 m) depending on the area (e.g., Ogorelec et al., 1976; Rižnar, 2006; Poljak, 2017; Gerčar et al., 2022). In the Slovenian Basin, the succession overlain by the Maastrichtian Upper Flyschoid Formation, composed predominantly of marlstone and marked by different resedimented layers containing carbonates and thin sandstone beds. The maximal thickness is 400 m. We note that in the southern Sava Folds, different names were used for the Cretaceous formations that generally correspond to those described above. In stratigraphic order, these are the Gora, Krško, and Veliki trn formations (Poljak, 2017). The Mesozoic formations are covered discordantly by the Cenozoic ones and are preserved in the cores of the Tuhinj–Motnik and Laško synclines. The deposition of the Oligocene Pseudosocka (Trbovlje) Formation began in the early Oligocene (Kiscellian) with conglomerates that show upward gradation, followed by coal deposits, which are covered by sandstones, claystones, and other siliciclastic sediments. Andesite, dacite, and their rhyolitic tuffs are interbedding from the middle Kiscellian. (Placer, 1998a; Aničić et al., 2002). Deposition in the Miocene begins with the Laško Formation, characterized by conglomerates covered by Lithotamnium Limestone, followed by a marlstone with varying sand and limestone content (Buser, 1979; Premru, 1983; Aničić et al., 2002).

Materials and methods

Our fieldwork aimed to determine the distribution and relationship of the lithostratigraphic units. Except for a few small (10–20 m) quarries, natural cliffs and road cuts most of the observation points (shortly sites) represent only a few meters of rock outcrops, although some roadcuts offered more continuous observations. Selected from a few hundred sites, 119 of them are discussed in this work. From there, rock samples were collected. Strike and dip data, site numbers, field sketches, field images, notes, and tags with GPS coordinates were documented using the Field MOVE field mapping software. High–quality field photos were taken using a Panasonic DMC–FZ200 camera.

The numbering of the samples corresponds to the site number, and within a site, different samples were also given a letter code. The samples were examined and compared in the laboratory using a magnifying glass (loupe). Finally, 5 × 5 cm–sized thin–sections were made from 64 samples for microfacies and microfossil analyses made by Á Görög. The preservation of the microfossils varies from well to weak due to the post–depositional alterations (e.g., silicification, dolomitization) of the rocks. Petrological analysis was carried out on two samples (614 and 326) by Sándor Józsa (Eötvös University, pers. Communication). Calcareous nannofossils analysis was performed on eight samples where thin–sections did not contain age–determining microfossils. For this study, two smear slides per sample were prepared in the Laboratory of the Hantken Foundation, using standard techniques (samples from sites 238, 299, 301–303, 307, 326, 330, and 549). Except for 301–302 and 326, each yielded a poor nannofossil assemblage, allowing investigation only with the polarizing light microscope. Frequent silicification altered the optical properties of the crystal-units, making determination difficult. For the radiolaria study, 5 samples from sites 629, 632, 636, 643, and 644 were dissolved in diluted HF, following the standard laboratory procedures of Pessagno and Newport (1972), and the same samples in 75 % acetic acid, following methods of Karaminia (2004), but residues yielded no fossils. Samples from site 614 were prepared using the standard palynological processing techniques described by Wood et al. (1996). Two smear–slides were made from each, but none contained fossils.

The thin–sections and smear–slides were studied using an Olympus BH2–BHS microscope, and photomicrographs were taken with a Canon EOS 200D camera of the Hantken Foundation. Additionally, two composite photomicrographs were created using a Zeiss Axioskop 40 microscope with an AxioCam MRc5 (Zeiss) camera at 1x zoom and the AxioVision AxioVs40 V4.8.2.0 software at the MTA–ELTE Geological, Geophysical, and Space Sciences Research Group, Hungarian Academy of Sciences, at Eötvös University.

As the results of the microfacies analysis, the following categories were determined (see Fig. 2). Carbonate–texture system of Dunham (1962) and Folk (1962) are in column 1 and 2. Frequently occurring allochems, observed alterations and visible post depositional fabrics are colour coded in column 3, 4 and 5. In column 6 the relevant fossils are marked with letters. The detailed legend for all microfacies analysis is placed at Figure 2.

During the microfossil analyses, we first provide the occurrence and semiquantitative abundance of different fossil groups such as calcareous nannofossils, calcareous dinocysts (or c–dinocysts) and calcitarchs, calcimicrobes, microproblematica, green algae, terrestrial plants, Calpionella, Radiolaria, benthic Foraminifera, planktonic Foraminifera, Porifera, Stromatoporoidea, Vermes, Gastropoda, fragments of Bivalvia shell, elongated calcite particles ("filaments"), Ostracoda, Bryozoa, Echinodermata and Tunicata. Then, the semiquantitative abundance of the classified taxa (genus and species) of calcareous nannofossils, c–dinocysts, calcitarchs, calcimicrobes, microproblematica, green algae, Calpionella, benthic and planktonic Foraminifera, Porifera, Stromatoporoidea, Vermes and Tunicata are listed. The stratigraphic range and biozones of the most important taxa are indicated in charts (Tables 1–5) and along the lithological columns of the sections. In the text, fossils are listed in order of their frequency. The order of the images of the microfossils belonging to a section follows the systematic order, and within that, the succession of the samples from oldest to youngest. The selected synonymy, taxonomy, stratigraphic range, and ecological requirement of the most important microfossils are enumerated in Appendix 2.

The results of all these investigations helped B. Scherman to give the stratigraphic position of the separated sites and arrange them into sections. The map coordinates of the sites and site numbers, with the determined formation names, are listed in Appendix 3.

Results

Description of the studied sites

In previous studies (Scherman et al., 2023), we have observed Slovenian Basin–type successions along the northern limb of the Trojane Anticline. To understand the contact with the north–lying units, their age and paleogeographic origin had to be determined.

Based on field observations, lithofacies, microfacies, and biostratigraphical studies, several stratigraphical columns could be compiled which can contain hiatus in observation. These can be composed of several sites or sub-sections, which are shifted along the strike of the rock units (see for example Sveti Miklavž section on Fig. 1). In other cases, the section contains tectonic units which belong to different stratigraphical columns (e.g., Marija Reka section the following sections have been compiled and named after nearby mountains, hills, and villages.

We are presenting our observations in composite sections in an order moving northwards from the Palaeozoic core of the Trojane Anticline (Fig. 1) Krvavica section, Marija Reka section, Brložen and Kozlov grič sections, Sv. Miklavž section (composed of four sub-sections), Šmiglov hrib section, Osreški grič section, Zahomce section, and finally, the Črni vrh section. The latter three are positioned north–west from the Krvavica section. In addition, four single observation sites were selected and analysed. These are listed in chronological order from oldest to youngest.

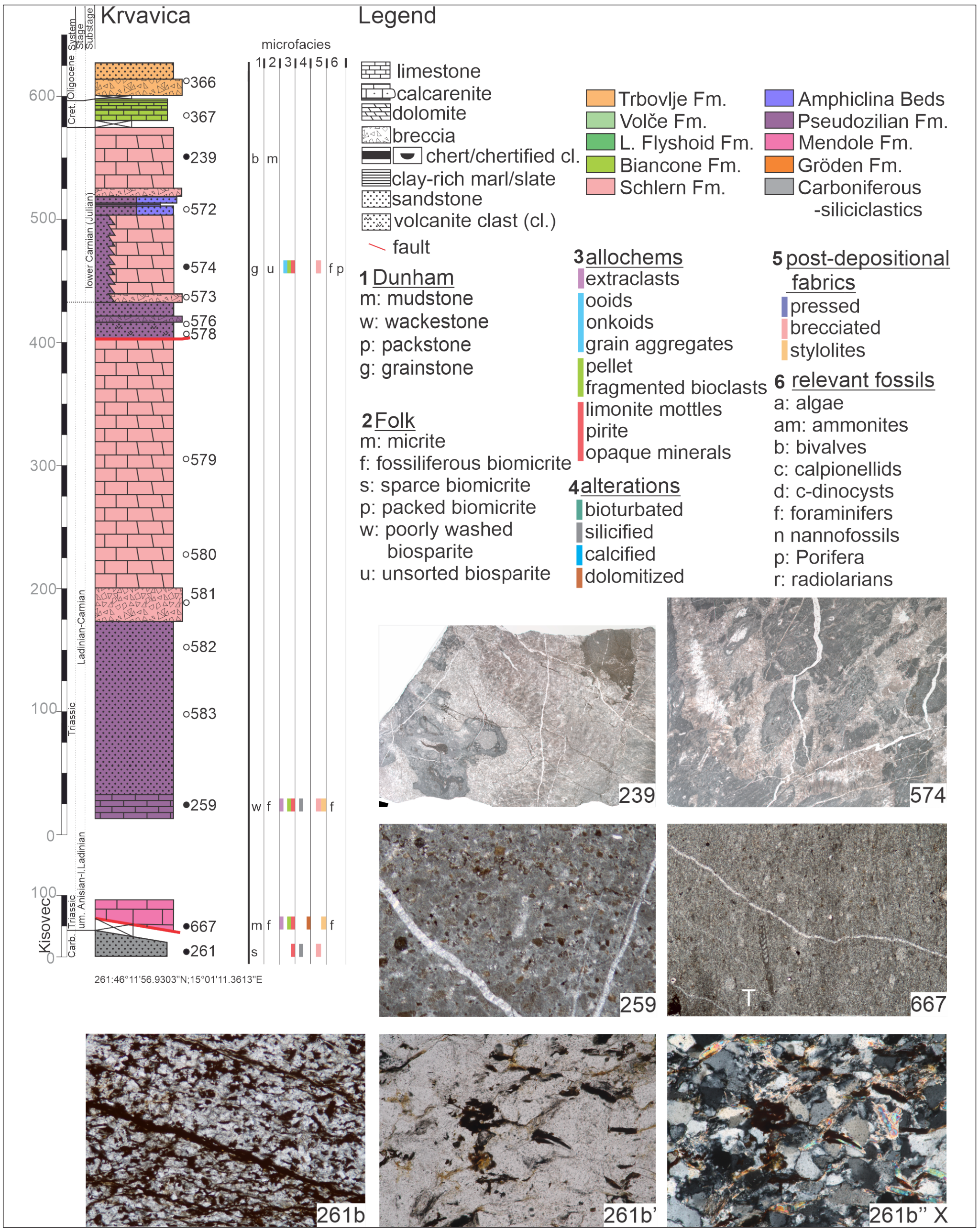


Fig. 2. Stratigraphic column of the Kisovec Hill and Krvavica Mt. sections with the indication of the chronostratigraphic assignments and GPS coordinates (below). Note the lithology and the formations marked by colors (see legend); the studied sites shown with a circle, sites with samples taken for analyses marked with black-filled circles; the results of the microfacies analysis (see legend); photomicrographs of the thin sections made from samples with sample number (right lower corner). See the text and Appendix 1 for the details of the microfacies and microfossil analysis. All of these apply to the stratigraphic column and microfacies images presented in each section of the current paper. Fossils: T: *Turriglomina mesotriassica* (Koehn-Zaninetti) site 667; Calcimicrobe bundstone, sites 574 and 239. The width of the microphotographs is 3mm (sites 261b, 667, and 259); 6 mm (sites 574 and 239), and 0.6 mm (sites 261b' and 261"). X: crossed polarized light. Abbreviations: Carb. (Carboniferous); Cret. (Cretaceous); um. (upper-middle); cl. (clast).

Fig. 3. Lithofacies of the Kisovec Hill and Krvavica Mt. sections. **a** variegated siliciclastic sediments of the Trbovlje Fm., **b** carbonate breccia bed, Schlern Fm., **c** gravitational breccia forming the base of the Schlern Fm., **d** volcanic clasts in the Pseudozilian Fm., **e** Fine-grained sandstone of the Pseudozilian Fm., **f** black pelagic limestone of the Pseudozilian Fm., **g** bedded part of the Mendole Formation, **h** slates of the Carboniferous siliciclastic sediments, **i** massive carbonate body of the Mendole Formation. The letters in the upper right corner are abbreviations for the cardinal directions. Numbers in the lower right corner are site numbers.

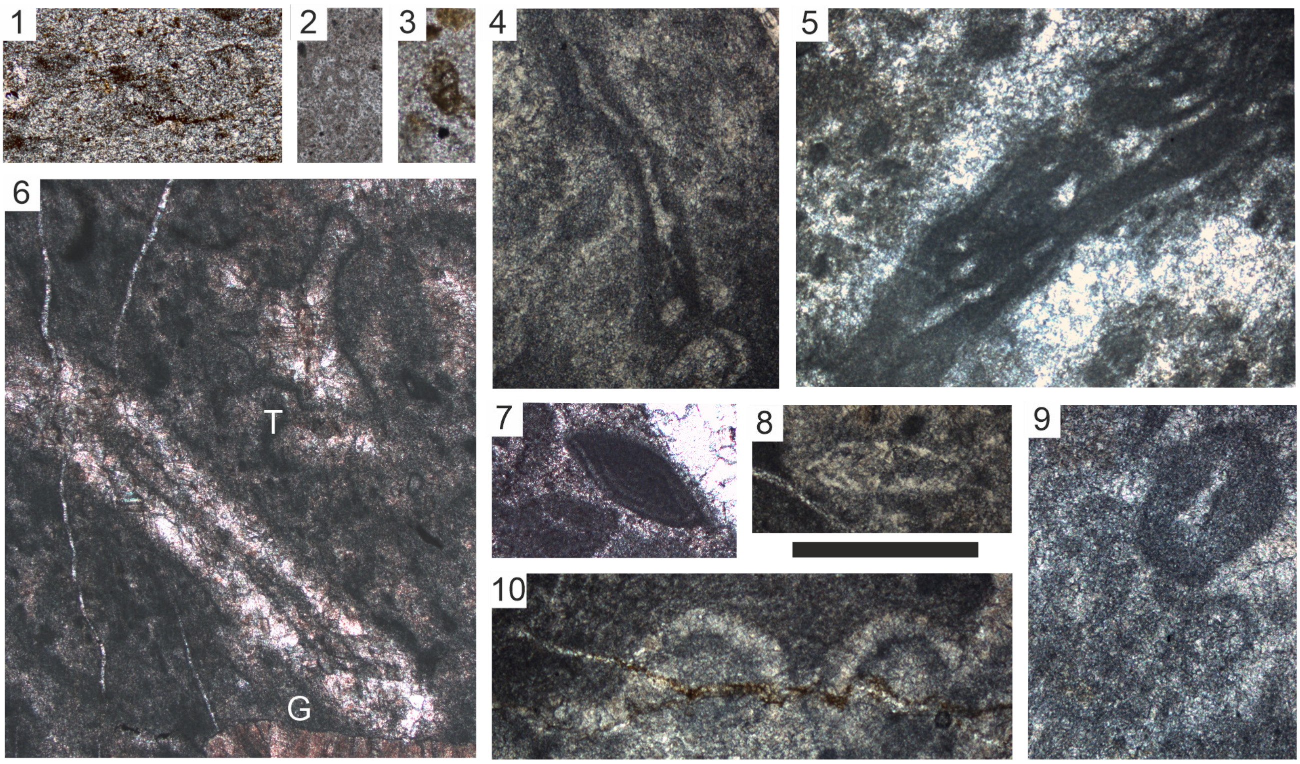


Fig. 4. Microfossils of the Kisovec Hill (1-2) and Krvavica Mt. (4-10) sections. **1-2** sample 667: **1** *Paratriasina* sp., **2** Textularidae sp., **3** Textularidae sp., sample 259a, **4-10** sample 574, **4** „*Tubiphytes*" (sensu Senowbari-Daryan) sp., **5** *Palaeonubecularia gregaria* (Wendt), **6** *Nodobacularia vujisici* Urošević & Gaździcki (N) and *Thaumatoporella parvovesiculifera* (Raineri) (T), **7** *Ophthalmidium* sp., **8** *Howchinella woodwardii* (Howchin), **9** *Angulodiscus minutus* (Koehn-Zaninetti), **10** *Salzburgia ?variabilis* Senowbari-Daryan & Schäfer. The scale bar is 200 μm.

Kisovec Hill and Krvavica Mt. sections (Figs. 1–4; Tables 1–2; Appendices 1–2)

Kisovec Hill is located 2 km south of the village Loke pri Taboru. On the eastern side of Kisovec Hill, at site 261, the lowermost part of the section builds up from continental, dark, purplish–brown Carboniferous shale. Based on the petrological analysis, the foliated shale dominantly consists of well–sorted angular quartz grains. Besides them, a few micas and opaque minerals are also present.

Above it, a nearly 20 m high outcrop (site 667) of medium–grey limestone succession appears. The contact between the two formations has not been explored, but based on the literature (e.g., Rainer et al., 2016), an erosional disconformity may exist between them while former maps interpreted a thrust contact (Buser, 1977, 2010). In the lower part, the limestone is massive and thick-bedded (up to 1,8 m), upwards, the beds become thinner at the top, the layers are only 5–10 cm thick. The texture of the rock is mudstone/wackestone, fossiliferous biomicrite, with scattered opaque minerals and partly dolomitized. There are a few intraclast, pellets, benthic foraminifers, ostracods, and fragments of *Thaumatoporella parvovesiculifera*. Among the foraminifers, the upper Anisian–lower Ladinian *Turriglomina mesotriassica,* the uppermost Anisian––Carnian *Paratriasina* sp, and a few textulariids could be recognized. These fossils date the rock to the latest Anisian–early Ladinian interval. The macro– and microfacies of the rock indicate a carbonate platform environment. Most likely, these rocks can be classified as the Mendole Formation.

The Krvavica Mt. section is located 1 km east of Čemšeniška–Planina and 1.5 km south of the village of Loke pri Taboru. This composite section comprises observations made on Kisovec Hill, just south of Krvavica Mt., and extends through Krvavica Mt. The beds dip to the north, the order of sites in the description is from south to north. It begins with observations at site 261, featuring Carboniferous shales, and it is followed by carbonate platform sediments observed at site 667. Site 259 is projected from approximately 1 km east, resembling the limestone member of the Pseudozilian.

Towards the north of the previous sites, southeast of Krvavica Mt. (site 259), dark grey, well–bedded, partly silicified limestone succession can be observed. The texture of the rock is wackestone, fossiliferous biomicrite, with common angular intraclasts and pellets. Fossils are represented only by a few specimens of benthic foraminifers, such as textulariids and nodosariids. Based on the mac-

Table 1. Stratigraphic range of the algae, green algae, porifera, vermes and tunicata in the studied sites.

System	Triassic						Jurassic											Cretaceous							
Taxa / Stage	Lower Triassic	Anisian	Ladinian	Carnian	Norian	Rhaetian	Hettangian	Sinemurian	Pliensbachian	Toarcian	Aalenian	Bajocian	Bathonian	Callovian	Oxfordian	Kimmeridgian	Tithonian	Berriasian	Valanginian	Hauterivian	Barremian	Aptian	Albian	Cenomanian	Turonian
C-dynocyst & Calcitarch																									
Cadosina disiuncta																							—		
Calcisphaerula innominata																							—	—	→
Calcisphaerula ? innominata lata																							—	—	→
Colomisphaera alpina																	—	—	—	—					
Colomisphaera carpathica																	—	—	—						
Colomisphaera fortis																	—	—	—						
Colomisphaera lapidosa															—	—	—	—	—						
Crustocadosina semiradiata																—	—	—	—	—	—	—	—		
Pithonella sphaerica																							—	—	→
Pithonella lamellata																							—	—	—
Stomiosphaera moluccana																—	—	—	—						
Stomiosphaerina proxima																		—							
Calcimicroba																									
Rivularia lobatum															—	—	—	—	—	—	—	—	—		
Microproblematica																									
Crescentiella morronensis															—	—	—	—							
"Tubiphytes" ? sensu Senowbari-Daryan, 2013			—	—	—	—																			
Gemeridella minuta				—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
Lithocodium aggregatum															?		—								
Muranella parvissima				—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Thaumatoporella parvovesiculifera			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Green algae																									
Aloisalthella sulcata																—	—	—							
Salpingoporella ? sellii																—	—	—							
Tethysicodium elliotti																	—								
Porifera																									
Cladocoropis mirabilis															?	—	—	—	— ?						
Salzburgia variabilis						—																			
Vermes																									
Carpathiella triangulata															—	—	—	—	—	—	—	—	—	—	→
Tunicata																									
Didemnoides moreti			—	—	—	—									—	—	—	—	—	—	—	—	—		

roscopic appearance and the microfacies, the rock most probably belongs to the Ladinian Pseudozilian Formation.

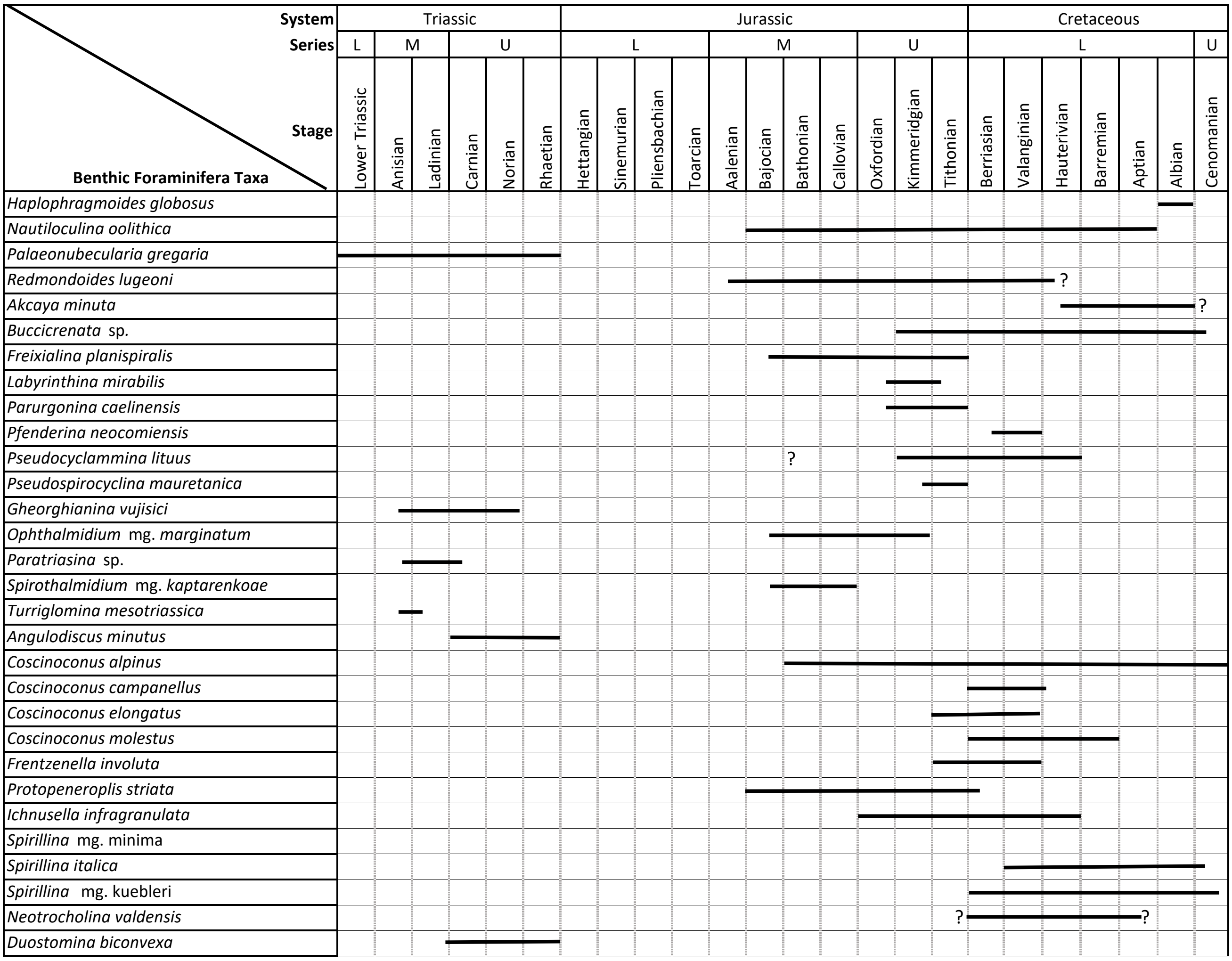
On the southern flank of Krvavica Mt., the classic greywacke development of the Pseudozilian Formation can be studied in several natural outcrops and road cuts (e.g., sites 583 and 582). The estimated thickness is about 150 m. This siliciclastic succession is cut by ~25 m thick, light grey monomictic breccia horizon (site 581). The clasts are composed of carbonate, and the matrix is a brick–red clay, occasionally with light grey calcite cement. Above it in succession, at more than 200 meters (sites 580 and 579), the massive platform carbonate succession of the Ladinian–Carnian Schlern Formation can be traced. The rocks are greyish–white limestones–dolostones.

Above this (sites 578, 576), the Pseudozilian Formation reappears at a thickness of about 30 m. Here, the Pseudozilian Formation is composed of greywacke with volcanoclastic intercalations; upwards, the grain size decreases. At this point our mapping observations indicate a tectonic contact between them, a thrust fault can be projected from the west to the section. Alternatively, this could also represent interfingering of basinal and platform succession, which presumably is the case further north.

At site 573, a thinner, approximately 5–7 m thick breccia horizon occurs, like the one at site 581. Above it, the beds of the Schlern Formation occur again. At site 574, the texture of the rock is pelloidal grainstone, unsorted biosparite with ooids, oncoids, benthic foraminifers, and fragments of the sponge cf. *Salzburgia variabilis*, the microproblematica *Thaumatoporella parvovesiculifera,* and the Dasycladacean algae. Among the foraminifers, the platform–dwelling *Angulodiscus minutus*, *Palaeonubecularia gregaria, Gheorghianina vujisici,* and *Howchinella woodwardii* could be identified. Based on the cooccurrence of the *A. minutus* and *G. vujisici,* the age of the rock is early Carnian–Norian.

More to the north (at site 572), the massive carbonate is overlain by medium–dark grey aleuritic shale. On the field, only debris was observed that

Table 2. Stratigraphic range of the benthic foraminifers in the studied sites.



we attributed to the topmost part of the Pseudozilian Formation. Additionally, the geomorphology of the area shows peaks composed of carbonates and intervening saddles formed by clastic rocks, found in scree. Breccia horizons are observed on the bottom of the carbonate bodies. This geometry can be interpreted as the interfingering of the harder limestone beds of the Schlern Formation and the softer siliciclastic Pseudozilian Formation. These phenomena also indicate that the sediments of this interval in the Krvavica Mt. section were deposited in somewhat deeper water than those of the previous ones. The Schlern Formation begins with a breccia horizon, indicating episodical carbonate progradation over the deeper water successions. Another interpretation for the alternation of the Pseudozilian and Schlern Formation would be tectonic stacking. However, these middle carbonate bodies do not continue down the valley, as observed at Krvavica Mt. or the northernmost platform, thus the repetition is at least partly sedimentary in origin.

The appearance of the third monomictic breccia bed (above site 572) and the massive, light grey limestone with a microbial bioherm (site 239) suggest shallowing. The texture is microbial boundstone, with voids filling with radial fibrous cement. This carbonate can belong to the latest prograding toe of the Schlern Formation.

The following outcrop (site 367) is situated on the northern side of Krvavica Mt., where thin-layered (2–4 cm) ochre, cream-white limestone with interlayered clay films and marl crop out. Based on the macroscopic fabric analogy, this could be the Upper Jurassic–Lowermost Cretaceous Biancone Formation with an estimated thickness of 20 m.

On the uppermost part of the section (site 366), variegated grey–ochre siliciclastic sediment crops out. In the lower part, the rock is a fine-grained unsorted breccia composed of rounded and angular clasts (up to 5 cm) derived from older formations, primarily carbonates and shales, as well as cemented sandstones. Upwards, the amount and the size of the clasts decrease, and the sandstone is less cemented. With facies analogy and according to the older maps, this was categorized as the Oligocene Trbovlje Formation.

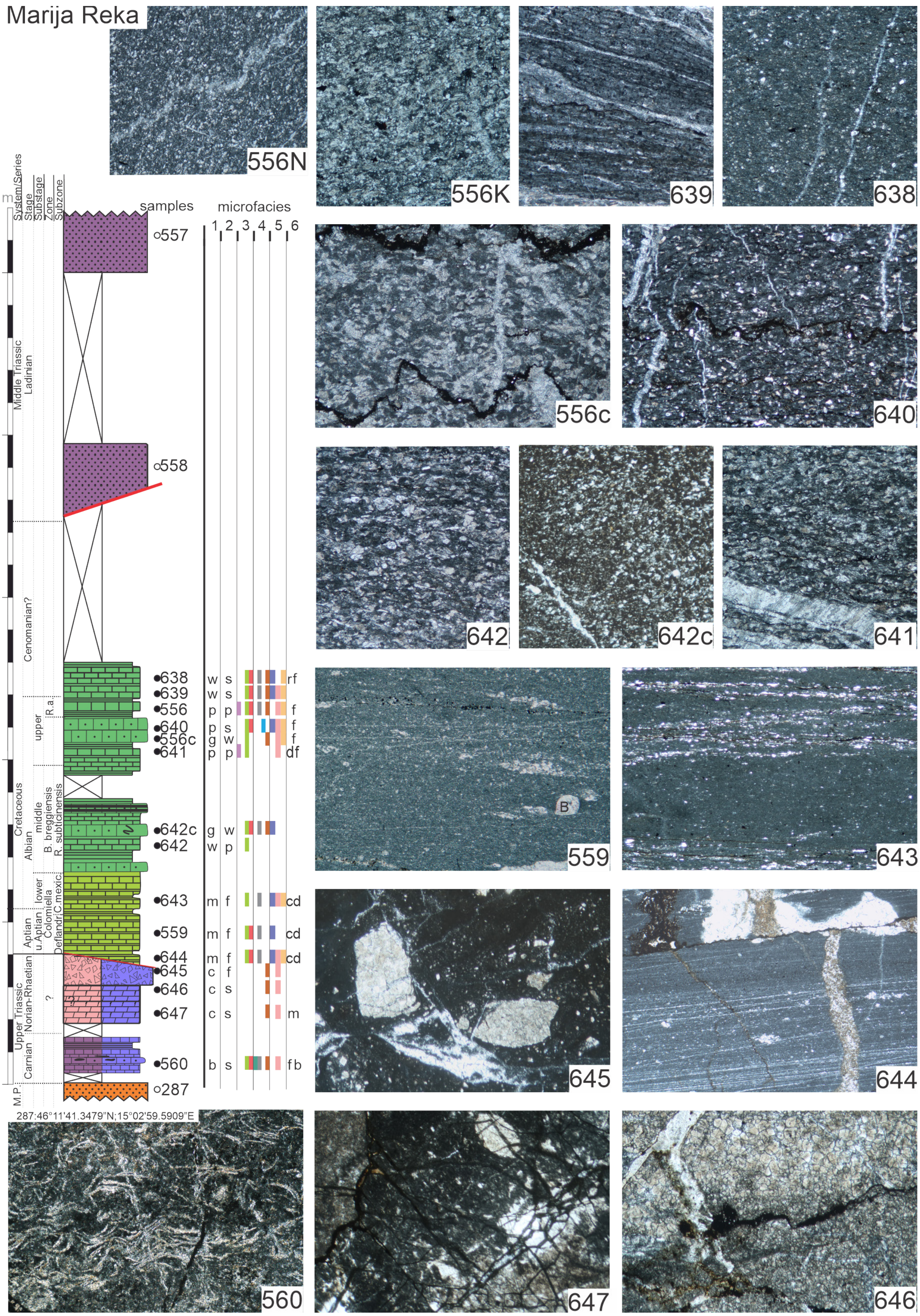


Fig. 5. Stratigraphic column and microfacies of the Marija Reka section. For the legend, see Fig. 2. The width of the photomicrographs is as follows: sites 560, 647, and 646 – 6 mm; sites 645-643, 559, 556c, and 640 – 3 mm; sites 642, 642c, 641, 638, 639, 556K, and 556N – 2 mm. Abbreviations: M.P. (Upper Permian); u. (upper); Deflandr. (*Deflandronella*); C.mexic. (*Colomiella mexicana*); B. breggiensis (*Biticinella breggiensis*); R. (*Rotalipora*); R.a. (*Rotalipora appeninica*) B. (*Bullopora rostrata*).

Fig. 6. Lithofacies and structural features of the Marija Reka section. For the legend, see Fig. 3. **a** calcarenite bodies and thin-layered marl with limestone alternating within the Lower Flyschoid Fm., **b** layers and axial plane foliation within the Pseudozilian Fm., **c** folded chert layers inside a calcarenite body, Lower Flyschoid Fm., **d** thick calcarenite beds between thinly layered marlstone of the Lower Flyschoid Fm., **e** Thin-layered limestone folded in asymmetric folds with steeply NW-plunging fold hinges with stereogram within the Biancone Fm., **f** dark chert layers in calcarenite body within Lower Flyschoid Fm. **g** map view of early joints, veins, and faults and their relation to NW-dipping bedding inside Ladinian-Carnian limestone (Pseudozilian Fm. or Amphiclina Beds), **h** brecciated dolomite, probably Amphiclina Beds.

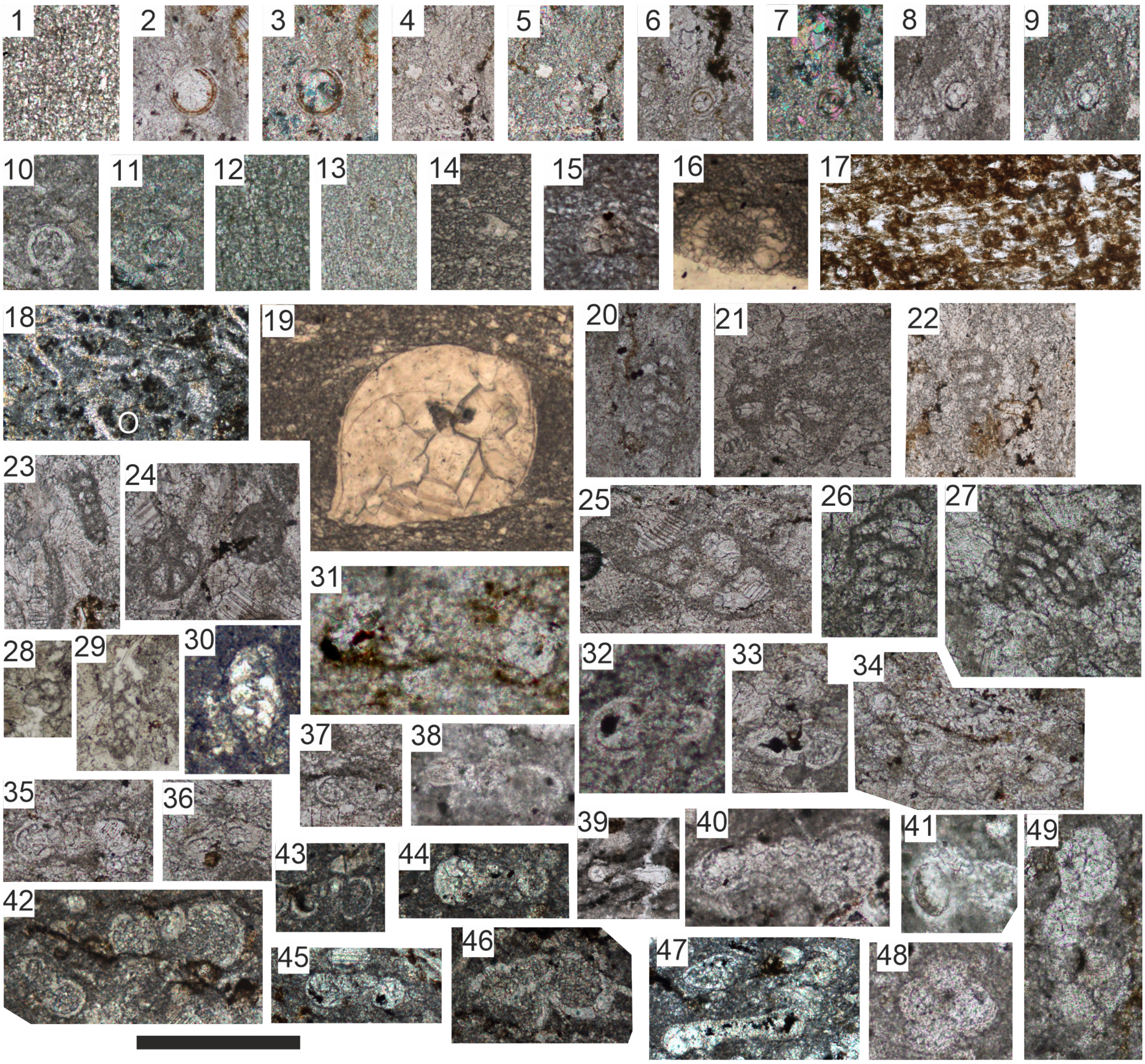


Fig. 7. Microfossils of the Marija Reka succession: **1** *Cadosina disiuncta* Knauer, sample 559, **2-5** sample 642: **2-3** *Pithonella sphaerica* (Kaufmann), (**3**: crossed Nicols), **4-5** *Pithonella* sp. A with three layered wall (**5**: crossed Nicols), **6-9** sample 241: **6-7** *Calcisphaerula? innominata lata* Adams, Khalili and Said, (**7**: crossed Nicols), **8-9** *Praecalcigonellum* sp., **10-11** sample 556N: **10-11** *Calcisphaerula innominata* Bonet, (**11**: crossed Nicols), **12***Parachitinoidella cuvillieri* Trejo, sample 559, **13** *Colomiella recta* Bonet, sample 643, **14-17** sample 559: **14-15** *Gemeridella minuta* Borza & Misik, **16** *Didemnoides moreti* (Durand Delga), **17** *Dasycladacea indet*., sample 642c, **18** oberhauserellid (o) and thin Bivalve valves coated by isopachous rims on both sides, sample 560, **19** *Bullopora rostrata* Quenstedt, sample 559, **20-23** sample 642: **20** *Ammobaculoides* sp., **21** *Voloshinoides* sp., **22** *Vercorsella* sp., **23** *Novolesia* sp., **24-25** sample 641: **24** *Nezzazatinella* sp. and *Haplophragmoides globosus* Lozo, **25** *Verneuilina* sp. **26-27** sample 556c: **26** cf. *Novolesia* sp., **27** cf. *Akcaya minuta* (Hofker), sample 640, **28-30** sample 556K: **28** Verneuilinidae sp., **29** *Bolivinopsis* sp., **30** Bolivinidae? sp., **31** *Coscinoconus* sp., sample 638, **32-34** sample 642: **32** *Biticinella breggiensis* (Gandolfi), **33** *Thalmanninella balernaensis* (Gandolfi), **34** *Ticinella raynaudi* Sigal and *Thalmanninella praebalernaensis* (Sigal), **35-37** sample 641: **35** *Ticinella primula* Luterbacher (Plummer), **36** *Ticinella madecassiana* Sigal**, 37** *Ticinella raynaudi* Sigal, **38-41** sample 640: **38-39** *Clavihedbergella simplex* (Morrow), (Gandolfi), **40** *Ticinella praeticinensis* Sigal, **41** *Ticinella roberti* (Gandolfi), **42-47** sample 556K: **42** *Laeviella bentonensis* (Morrow) and *Microhedbergella rischi* (Moullade), **43** *M. rischi* (Moullade), **44-45** *Muricohedbergella planispira* (Tappan), **46** *Muricohedbergella delrioensis* (Carsey), **47** *P. buxtorfi* (Gandolfi) and *Spirillina* sp., **48-49** sample 556N: **48** *Favusella washitensis* (Carsey), **49** *Pseudothalmanninella subticinensis* (Gandolfi). The scale bar is 500 µm at figures 1-31 and 200 µm at figures 32-49.

The Marija Reka section (Figs. 1, 5–7; Tables 1–4; Appendices 1–2)

The Marija Reka section is located on the eastern side of Štrebenkel Mt., starting 450 m south of the farm Urankar. Our observations were conducted along a 600 m-long stretch of road. The approximate thickness of the section is 270 m. The bedding is dipping to the north, the order of sites in the description is from south to north. In most studied Mesozoic beds, silicification, secondary dolomitization, and other post-depositional fabrics (e.g., micro-breccia, stylolites) could be recognized.

The section begins with the Permian terrestrial, red clastic Gröden Formation, which outcrops at site 287. At site 560, the succession is approximately 15 m thick, composed of grey, well-bedded micritic limestone and laminated marlstone. The limestone layers, with thicknesses ranging from 5 to 20 cm, are occasionally silicified. A poorly preserved ammonoid with ceratitid sutures was found. The rock is boundstone, packed biomicrite with thin-shelled, pelagic bivalves, primarily their debris. Polycrystalline neomorphic rims grow out syntaxially from both sides of the valves. There are a few recrystallized foraminifera (oberhauserellid?). The rock is brecciated, and the fractures are filled with red-black striped calcite crystals. The rock could belong to the deep-water Ladinian Pseudozilian Formation or Carnian Amphiclina Beds because it is the only formation from when Triassic ammonites and "Bositra" lumachella are known (Ramovš, 1981, 1986, 1997, 1998a; Gale et al., 2017; Rožič et al., 2024).

After a gap brecciated grey and white crystalline, fossil-free dolomites crop out (sites 647, 646, and 645). This approximately 20 m thick dolomite succession may most likely belong to the Amphiclina Beds or Pseudozilian Formation. However, the Ladinian to early Carnian Schlern Formation cannot be excluded. In the next ~25 m, these beds are followed by tectonically folded thin-bedded Biancone-type, light grey–ochre, mottled, cherty limestone, often with thin marly intercalations (sites 644, 559, and 643).

The texture of the rock is mudstone, fossiliferous biomicrite with large amounts of scattered pyrite and other opaque minerals. Due to subsequent silicification, the preservation of the fossils is poor. The bioclasts are radiolarians and a few calpionellids. Additionally, c-dinocysts and calcitarchs such as *Cadosina disiuncta, Crustocadosina semiradiata,* and ascidia *Didemnoides moreti* could be identified, as well as the microproblematica *Gemeridella minuta*. At site 559, the presence of *Parachitinoidella cuvillieri*, characterized by dark microgranular lorica, indicates the late Aptian *Colomiella* Zone, *Deflandronella* Subzone (Trejo, 1975). Higher in the section (site 643), with the appearance of the calcite–hyaline-walled *Colomiella recta,* the existence of the uppermost Aptian–lowermost Albian *Colomiella* Zone, *C. mexicana* Subzone (Trejo, 1975) could be demonstrated. Besides them, a few specimens of *Spirillina italica* and the attached *Bullopora* sp. could be identified. The presence of calpionellids and c-dinocysts, and the almost complete absence of foraminifers imply an oligotrophic hemipelagic/pelagic palaeoenvironment, with occasionally dysoxic conditions.

Further to the north, about 10 m away, a lithological change can be observed. In the dark grey silicified marl succession, grey calcarenite beds occur (e.g., sites 642, 642c, and 641). Chert layers and nodules are commonly intercalated in the latter. At site 642, the texture of the marl is wackestone, packed biomicrite with planktonic and benthic foraminifers and c-dinocysts. The planktonic foraminifers are represented by *Ticinella raynaudi, T.* spp*., Clavihedbergella simplex, Biticinella breggiensis,* and *Thalmanninella praebalernaensis*. Based on the co-occurrence of the two latter species, this bed belongs to the uppermost middle Albian *B. breggiensis* Zone *R. subticinensis* Subzone. The benthic foraminifera assemblage consists of agglutinated forms such as *Ammobaculoides* sp., *Novolesia* sp., *Voloshinoides* sp., and *Vercorsella* sp. Pithonellids are common, especially *Pithonella sphaerica*, but a few specimens of the three-layer-walled *P. lamellata* also occur. The very fine-grained calcarenite bed at site 642c is a poorly washed grainstone with common fragments of Bivalvia shells and a few agglutinated benthic foraminifera (textulariids). A thallus of Dasycladales indet. also could be recognized. Higher up, after a gap, at site 641, the macroscopic appearance and texture of the rock are very similar to those at site 642 but richer in fossils. Especially c-dinocysts are common, namely *Pithonella sphaerica* and *Calcisphaerula*? *innominata lata*. A few specimens of the calcitarch *Praecalcigonellum* sp. could also be identified. The planktonic foraminifera fauna consists of ticinellids; the following species can be classified as *T. raynaudi, T. primula,* and *T. madecassiana*. Among benthic foraminifers, only agglutinated occur, mainly textulariids indet., additionally *Akaya minuta*, *Haplophragmoides globosus, Nezzazatinella* sp., *Belorussiella* sp., and *Verneuilina* sp. appear. *Calcisphaerula*? *innominata lata* is known from the late Albian thus, this bed can be dated to this age.

Above, in the next 15 m (sites 556c, 640, 556), the calcarenitic limestone beds become gradually thinner and more frequent, and the rock between them is more argillaceous and finely laminated. At site 556c, the microfacies study indicates fine-grained calcarenites with grainstone and poorly washed biosparite texture. In the relatively diverse foraminiferal fauna, the agglutinated forms dominate, such as *Akcaya minuta, Novolesia* sp. *Verneuilina* sp., *Verneuilinidae* sp*., Nezzazatinella* sp*., Trochammina* sp., and textulariids indet. Besides them, a few specimens of calcareous-hyaline Lenticulina spp. and nodosarid sp. could also be recognized. Among the planktonic forms, only the *Ticinella primula* could be classified, indicating that this bed is not younger than the late Albian.

Table 3. Stratigraphic range of the planktic foraminifers in the studied sites.

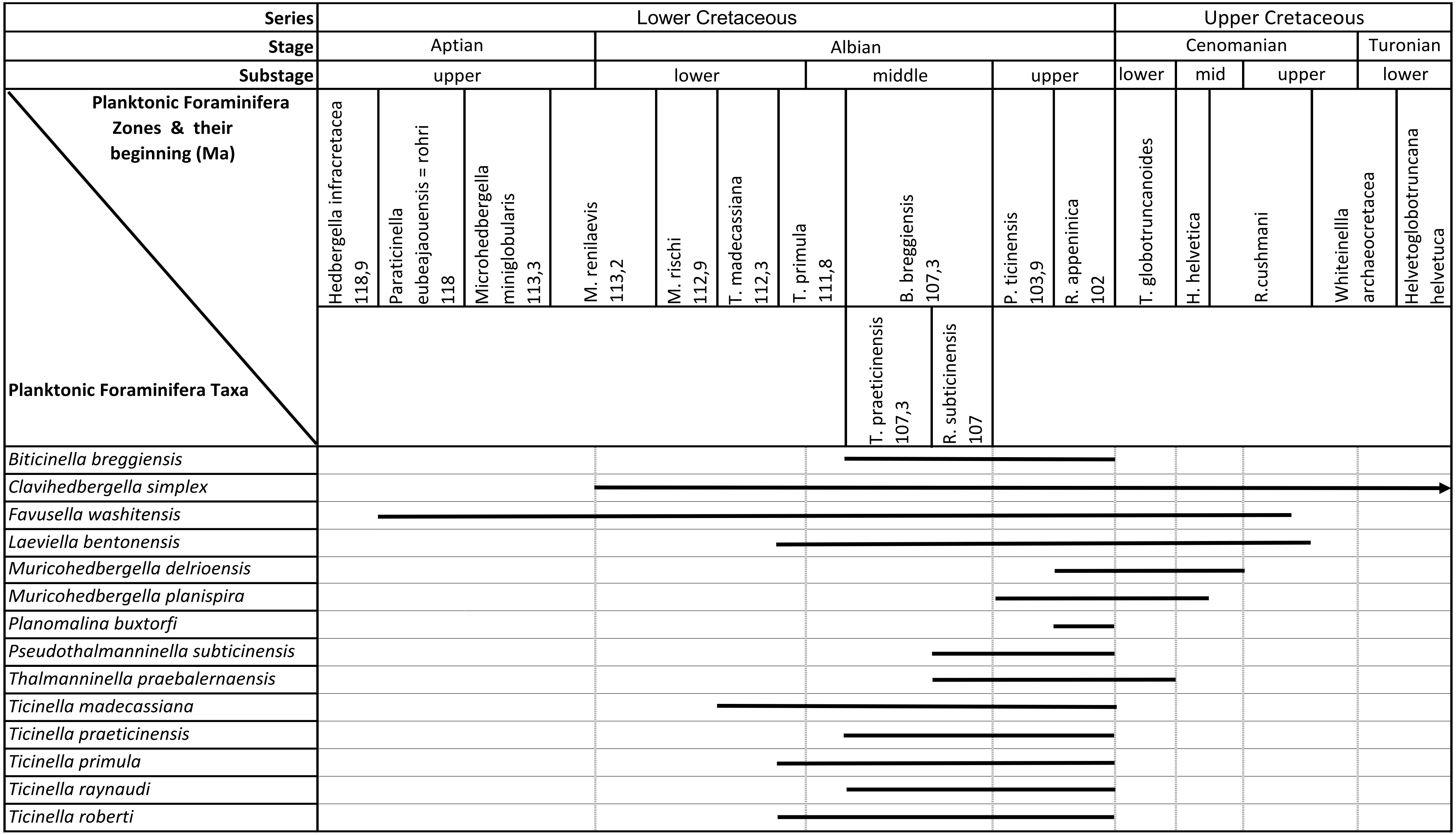


Table 4. Stratigraphic range of the calpionellids in the studied sites.

Taxa \ Stage	System	Jurassic	Lower Cretaceous					
	Stage	Tithonian	Berriasian	Valanginian	Hauterivian	Barremian	Aptian	Albian
Calpionella alpina		—	—					
Calpionellopsis oblonga			—	—				
Calpionellopsis simplex			—	—				
Chitinoidella boneti		—						
Chitinoidella elongata		—						
Colomiella recta							—	—
Crassicolaria intermedia		—	—	—				
Lorenziella hungarica			—	—				
Parachitinoidella cuvillieri							—	—
Praetintinnopella andrusovi		—						
Tintinnopsella carpathica		—	—	—				
Tintinnopsella remanei		—	—	—				

At sites 640 and 556, the texture of the marl layers is packestone. The fossil and mud content varies even within a single rock sample; thus, the type of biomicrite can be sparse, packed, or poorly washed. The opaque minerals are common. The bioclasts are mainly planktonic foraminifers. At site 640, the following planktonic foraminifera could be identified: *Ticinella raynaudi, Clavihedbergella simplex, T. roberti, T. praeticinensis,* and *Pseudothalmanninella subticinensis*. Besides them, only a few specimens of *Valvulina* sp. and textulariids occur. Based on species and the stratigraphic position, the age of this bed is late Albian. At site 556, diverse planktonic and benthic foraminifera assemblage appear containing the following taxa: *Muricohedbergella delrioensis, M. planispira, Planomalina buxtorfi, Pseudothalmanninella subticinensis, Thalmanninella praebalernaensis, Ticinella madecassiana, T. praeticinensis, T. primula, Biticinella breggiensis, Favusella washitensis, Laeviella bentonensis,* and *T.* sp. also the agglutinated benthic forms such as *Bolivinopsis* sp., *Ammobaculoides* sp., *Nezzazatinella* sp. *Verneuilinidae* sp., *Akcaya minuta,* and ?Bolivinidae sp. The following c-dinocysts occur: *Calcisphaerula innominata, Calcisphaerula*? *innominata lata,* and *Pithonella sphaerica*. Since *Muricohedbergella delrioensis* and *Planomalina buxtorfi* appeared at the beginning of the *Rotalipora appeninica* Zone and *Biticinella breggiensis*, *Ticinella madecassiana* and *T. praeticinensis* became extinct at the end of this zone, this bed deposited during the uppermost Albian *R. appeninica* Zone.

In the next 12 m, at sites 639 and 638, the calcarenitic limestone beds range from a few cm to 10 cm in thickness, interspersed with marl and shale clay layers. The texture of the limestone is wackestone, sparse biomicrite. The planktonic foraminifers and the c-dinocysts are missing. Besides the very rare aragonitic involutinid foraminifers, such as platform-dwelling *Coscinoconus* sp. and *Frentzenella* sp., only a few calcified radiolarians occur. Since both genera became extinct at the end of the Cenomanian, these beds cannot be younger than this age. This entire upper Aptian (? Cenomanian) succession can be classified as the Lower Flyschoid Formation.

Further north, no rock outcrops were found in the next 75 m of the Marija Reka section, while at site 558, the resedimented volcaniclastics of the Triassic Pseudozilian Formation are present. Further along the section, the dark greenish-grey Triassic formation is easily traceable, and there is a good outcrop north of the farm Urbanek (site 557) ending the section. The Pseudozilian Formation, however, continues towards the Sv. Miklavž composite section (Buser, 1977). This northern part of the section is separated from the southern one, by a major thrust fault which corresponds to the Marija Reka Fault. This fault extends both to the west and east from Krvavica Mt. to Mrzlica Mt. (Grad, 1969; Buser, 1977, 1979; Placer, 1998b, 2008) (Fig. 1). The southern segment of the section represents a separate lithostratigraphic column, which could be truncated by a fault (Fig. 5).

The Brložen section (Figs. 1, 8–10; Tables 1–2, 4; Appendices 1–2)

The Brložen section is located 2 km south of the village Loke on the eastern side of Brložen Mt. It is compiled from almost continuous outcrops interrupted by short, covered segments. The beds are always dipping to the north, gently or very steeply, the order of sites in the description is from south to north.

The succession starts in the volcanoclastic-rich Pseudozilian Formation at outcrop 254. After a short gap in outcrops and stratigraphy, the outcropping succession continues with a significantly younger 60 cm thick brecciated limestone bed with medium grey clasts in an ochre matrix at site 555. The texture of the rock is wackestone, with finely fragmented bioclasts of unknown origin and very rare calpionellids. The lorica of the *Chitinoidella boneti* could be identified, indicating the lowermost upper Tithonian Chitinoidellids Zone, *Boneti* Subzone (sensu Benzaggagh, 2020).

Above it, roughly 30 m higher, the succession continues with alternating marlstones and limestones (sites 625 and 626). The brownish–grey marl is a thin laminated shale. The limestone is mostly just a few centimeters thick, but occasionally, m-thick beds can be observed. The thin-layered limestone beds are fine-grained and vary in colour from light grey to yellow and sometimes pink. The thick layers are coarse-grained calcarenites. The find grade limestones are radiolarian wackestone, sparse, or packed biomicrite. Besides the calcified radiolarians, a few calpionellid, benthic foraminifers, and ostracods occur. The existence of *Calpionella alpina, Chitinoidella boneti, Ch. elongata*, and *Crassicolaria intermedia* indicates the lower upper Tithonian *Crassicolaria* Zone or A Zone, Chitinoidellids/Primitive Calpionellids Subzone or A0 Subzone (sensu Benzaggagh, 2020) or *T. remanei* Zone (sensu Reháková, 2000). Within the foraminifers, *Vercorsella* sp., *Spirillina* mg. *kübleri*, and *Lenticulina* sp. could be recognized. Due to the tectonic influences, the appearance of folds and post-depositional fabrics are common.

After an approximately 20 m thick covered interval, a more than 130 m thick continuous section is exposed. It starts with brecciated limestone (site 627), which is overlain by a relatively homogenous succession consisting of well-bedded grey, pink, and ochre limestones with common grey calcarenite intercalations and occasionally cherty layers and nodules. The limestone beds are 1–10 cm thick and intercalated with clay films or upwards finely layered several cm to dm thick marls (from sites 628 to 251). In the last 20 m, the bedding thickens up to roughly 1 m. At the end of the succession (sites 251, 593 and 634), similar thick brecciated limestone beds occur. In some places (sites 253 and 252), the folding of the thinly layered limestone could be observed. The texture of these limestones is wackestone with varying amounts of fossils, from fossiliferous biomicrite to packed biomicrite. Limonitic mottles and opaque minerals are dispersed in the calcareous matrix. Finely fragmented bioclasts, followed by radiolarians, echinoderm skeletons, and c-dinocysts are the most common components. Besides them, a few calpionellids, benthic and planktonic foraminifers (hedbergellids indet.), and ostracods also could be recognized.

At site 628a, based on the existence of *Praetintinnopsella andrusovi, Calpionella alpina*, and *Tintinnopsella carpathica,* this bed also belongs to the lower upper Tithonian *Crassicolaria* Zone, Chitinoidellids/Primitive Calpionellids Subzone. Among the foraminifers, only a few specimens of *Spirillina* mg. *kuebleri* appear. A relatively large fragment of *Rivularia lissaviensis* is present, indicating that the platform was not far away, as its fragile skeleton would not have been able to withstand prolonged transport.

Higher up in the section (sites 628), besides the relatively common *Colomisphaera carpathica* and *C. fortis,* a few specimens of *Crassicolaria intermedia* and *Tintinnopsella remanei* show that this layer belongs to the *Tintinnopsella Intermedia* Subzone (A1) within the *Crassicolaria* Zone. In the micritic limestone layers of the upper part of the Brložen section (from site 630 to 252), the index fossil content is relatively homogeneous, consisting of c-dinocysts such as *Colomisphaera carpathica, C. alpina,* and *Crustocadosina semiradiata;* calpionellids such as *Tintinnopsella carpathica* and *Calpionella alpina*. Additionally, a few specimens of spirillinids, namely *Spirillina* mg. *kuebleri* and *S.* mg. *minima,* occur. These fossils also suggest the upper Tithonian *Tintinnopsella Intermedia* Subzone.

In the succession, the multiple calcarenite layers appear, for example, at sites 628, 253, 629, 630, 631, 632, and 633. Their thickness ranges from 30 to 70 cm.

At site 630, the thickness of the calcarenite bed varies between 70–200 cm, most probably due to syn-sedimentary or early diagenetic faulting. These calcarenite beds yield fossils primarily of platform origin, including benthic foraminifers, calcimicrobes, microproblematica, green algae, mollusk shell fragments, and sponges. Among the hemipelagic elements, only *Colomisphaera alpina* could be recognized.

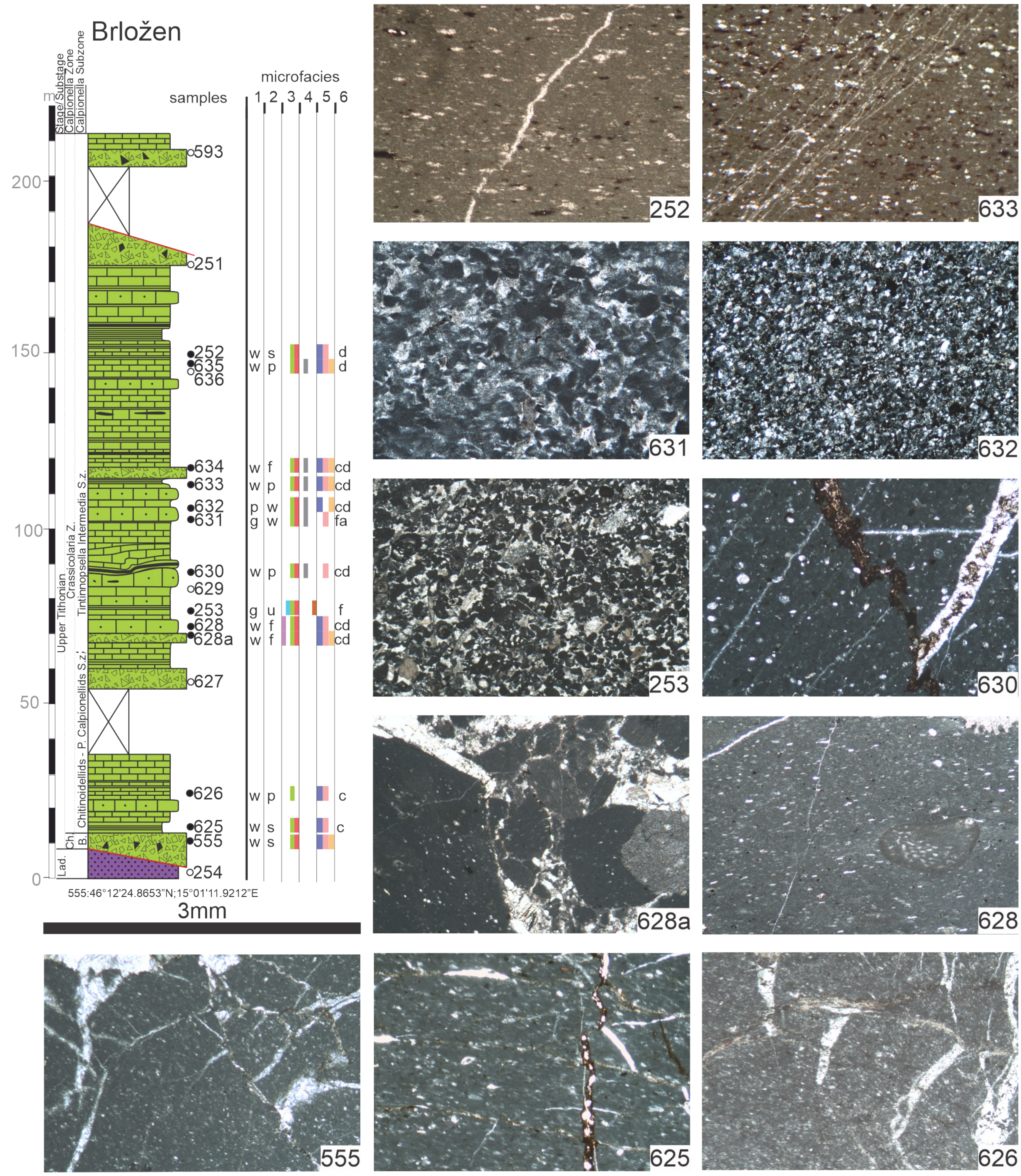


Fig. 8. Stratigraphic column and microfacies of the Brložen section. For the legend, see Fig. 2. The scale bar is 3 mm. Abbreviations: Lad. (Ladinian); Ch. (*Chitinoidella*); B. (*Boneti*); Z. (Zone); P. (Primitive); S.z. (Subzone).

The sample from site 253 contains a diverse fossil assemblage, dominating the agglutinated foraminifers such as *Redmondoides lugeoni, Nautiloculina oolithica, Buccicrenata* sp., *Pseudogaudryina* sp., *Valvulina* sp., *Dobrogeina* sp., and textulariids indet. Involutinids are relatively common, namely *Protopeneroplis striata, Coscinoconus alpinus*, and *Trocholina* cf. *conica*. Besides them, *Mohlerina basiliensis, Neotrocholina valdensis, Lenticulina* spp., and *Istruloculina* sp. could be identified. The microproblematicum *Thaumatoporella parvovesiculifera*, as well as the green algae *Aloisalthella sulcata* (formerly *Clypeina jurassica*) and other Dasycladales sp., also occur. This fossil assemblage indicates the late Tithonian age.

Higher up in the section, in the calcarenite beds (sites 631 and 632), a few pelagic-hemipelagic elements, such as *Colomisphaera alpina, Calpionella alpina*, and *Spirillina* mg. *kuebleri,* could be identified. Their assemblages are poorer in the

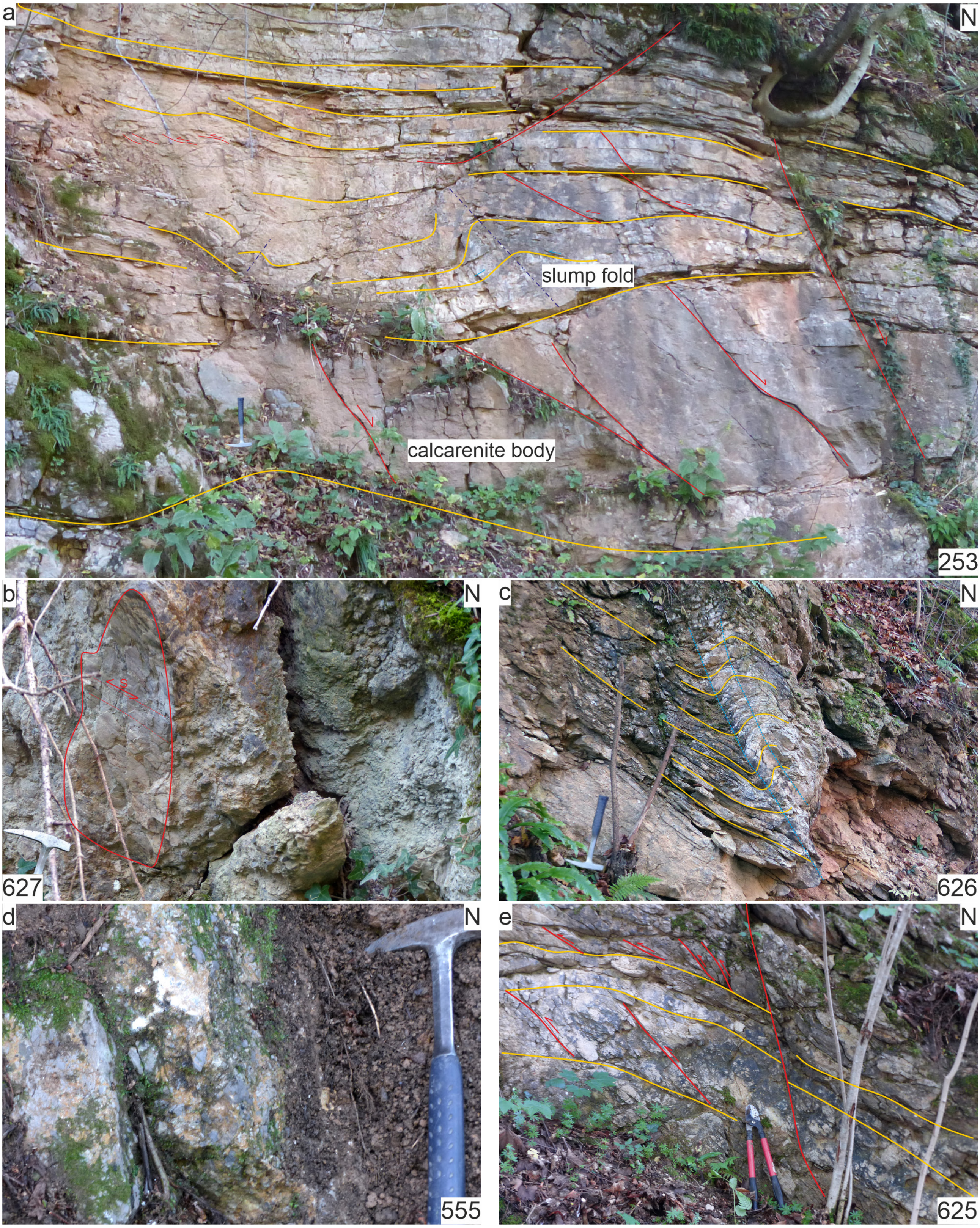


Fig. 9. Lithofacies and structural features of the Brložen section. For the legend, see Fig. 3. **a** calcarenite body with alternating thickness covered with layered limestone slumpfolds is covered with the following strata; thrust joints taper to the bedding, and faults sometimes are covered with following beds inside the resedimented limestones, Biancone Fm., **b** breccia body and sinistral strike-slip fault surface, **c** over calcarenite bed the thin-layered limestone is folded into close folds with oblique fold axial plane, **d** Brecciated limestone on the southern contact of Biancone Fm with Pseudozilian Fm., **e** small thrust joints indicate top-to-S direction these joints only appear to connect clay films between layers, Biancone Fm.

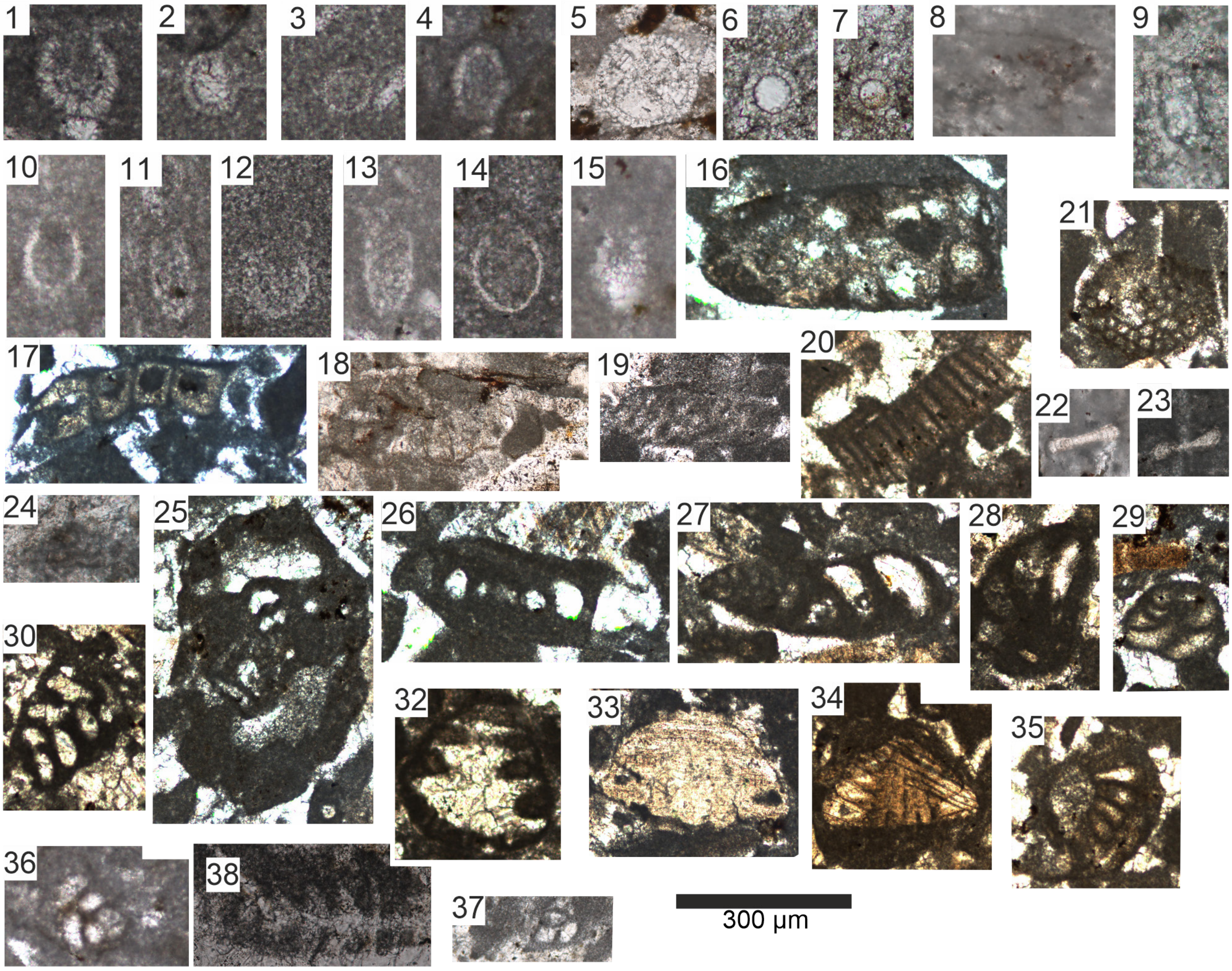


Fig. 10. Microfossils of the Brložen section. **1-3** sample 628: **1-2** *Colomisphaera carpathica* (Borza), **3** *Colomisphaera fortis* Řehánek, **4** *Crustocadosina semiradiata* (Wanner), sample 630, **5** *Colomisphaera alpina* (Leischner), sample 632, **6-7** *C. carpathica* Borza, sample 635, **8** *Chitinoidella elongata* Pop, sample 625, **9** *Chitinoidella boneti* Doben, sample 626, **10-11** *Praetintinnopsella andrusovi* Borza**,** sample 628c, **12-13** sample 628: **12** *Tintinnopsella remanei* Borza, **13** *Crassicolaria intermedia* Duran Delga, **14** *Calpionella alpina* Lorenz, sample 630, **15** Charophyta gyrogonite, sample 628, **16-17** sample 253: **16** Dasycladales sp., **17** *Aloisalthella sulcata* Alth, **18-19** sample 631: **18** ?*Suppiluliumaella* sp., **19** ?*Linoporella* sp., **20-21** *Thaumatoporella parvovesiculifera* (Raineri), sample 253, **22-23** sample 625, **22** *Spirillina minima* Schako, B, **23** *Spirillina* mg. *kuebleri* Danitch, **24** Vercorsella sp., sample 626, **25-35** sample 253: **25** Buccicrenata sp., **26** *Nautiloculina oolithica Mohler,* **27** *Paleogaudryina* sp., **28** *Freixialina planispiralis* Ramalho, **29** *Dobrogelina* sp., **30** *Redmondoides lugeoni* (Septfontaine), **32** *Coscinoconus alpinus* Leupold, **33** *Trocholina* cf. *conica* (Schlumberger), **34** *Neotrocholina valdensis* (Reichel), **35** *Protopeneroplis striata* Weynschenk, **36***Textularia* sp., sample 630, **37-38** sample 631: **37** *Valvulina* sp., **38** *Coscinoconus elongatus* Leupold. The scale bar is 300 µm.

number of species, but among the foraminifers, *Coscinoconus elongatus* and nodosarids, and among the green algae, ?*Linoporella* sp. and ?*Suppiluliumaella* sp. appear as newer taxa. Based on the stratigraphic range of the aforementioned taxa, the age of these calcarenite beds is late Tithonian. The approximately 200 m thick Biancone succession of the Brložen section is late Tithonian in age.

The Kozlov grič section (Figs. 1, 11–14; Tables 1–2, 4; Appendices 1–2)

The Kozlov grič section is located 750 m south of the village Loke and west of Kozlov grič (Kozlov Hill). The nearly 70 m section consists of almost continuous outcrops. Because of the southerly dip, the order of sites in the description is from north to south.

In the northernmost part of the section (site 610), a dark grey brecciated silicified limestone layer is present, which probably resulted from syn-sedimentary brecciation. It is overlain by ~17-m-thick (up to site 613) fine-grained grey marls in which limestone layers occasionally appear (e.g., sites 611 and 612). The composition of the breccia clasts is wackestone and packed biomicrite which contains radiolarians. The radiolarians have been deformed and lie in an oriented manner due to pressure. Fragmented calcareous bioclasts and opaque minerals are also common (Fig. 11). At site 612, the limestone intercalation is wackestone, composed of packed biomicrite with fragmented calcareous bioclasts of unknown origin and filaments.

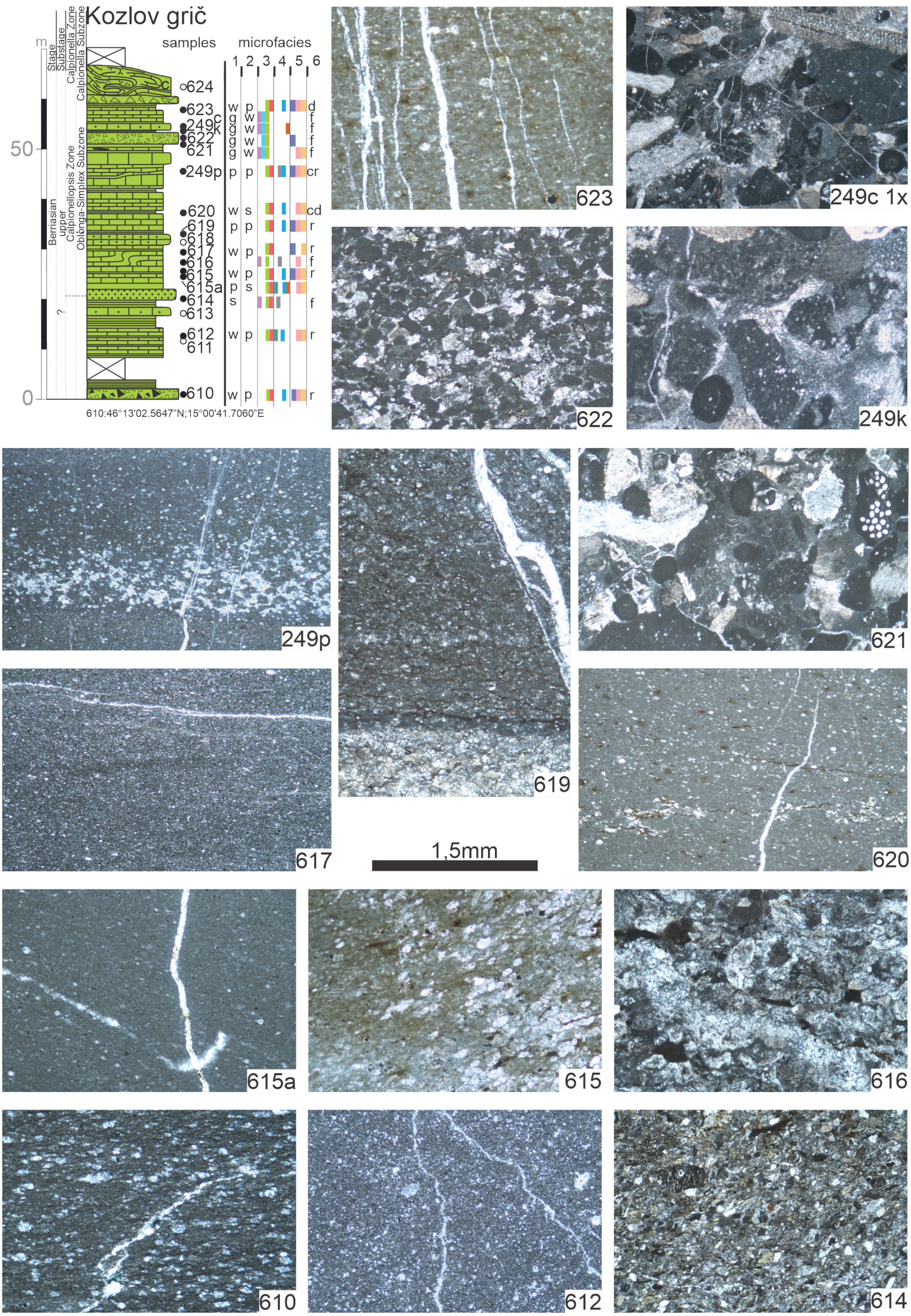


Fig. 11. Stratigraphic column and microfacies of the Kozlov grič section. For the legend, see Fig. 2. The scale bar is 1.5 mm, except for 249c 1×, where it is 3 mm.

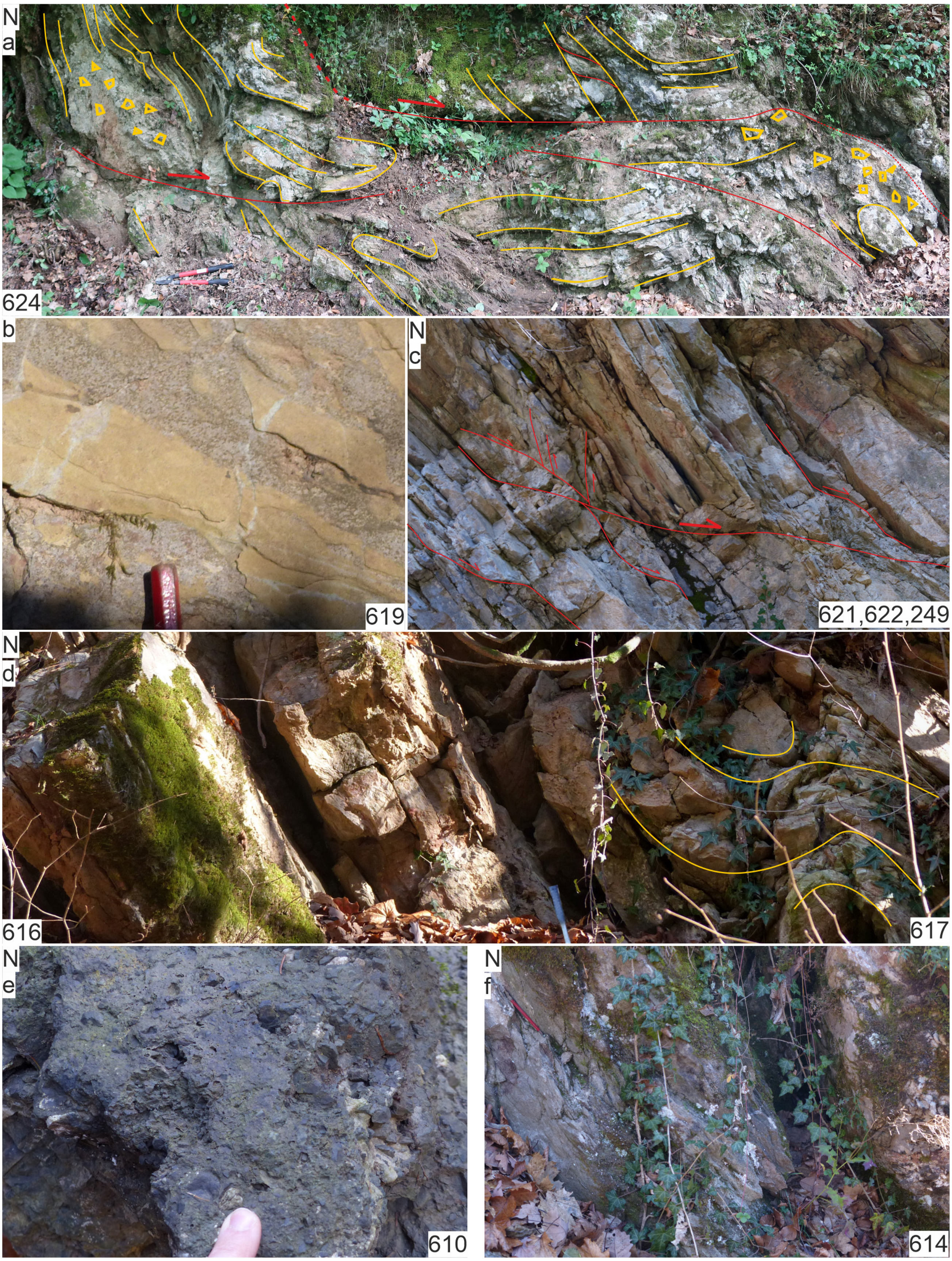


Fig. 12. Lithofacies and structural features of the Kozlov grič section. For the legend, see Fig. 3. **a** breccia bodies and thin layered limestone with marl chaotically folded in a slump fold, Biancone Formation, **b** thin films of clay-rich sediment over the coarse limestone layers, Biancone Fm., **c** limestone layers and calcarenite bodies cut through by pretilt thrust fault pairs that run into the clay richer interlayers, Biancone Fm., **d**: limestone layers and calcarenite beds sandwich almost isoclinally folded layers another sump fold in Biancone Fm. E: Dark chert breccia on the northernmost outcrop in Biancone Fm. F: Coarse sandstone flysch-like layer containing basic volcanic material between limestone beds, Biancone Fm.

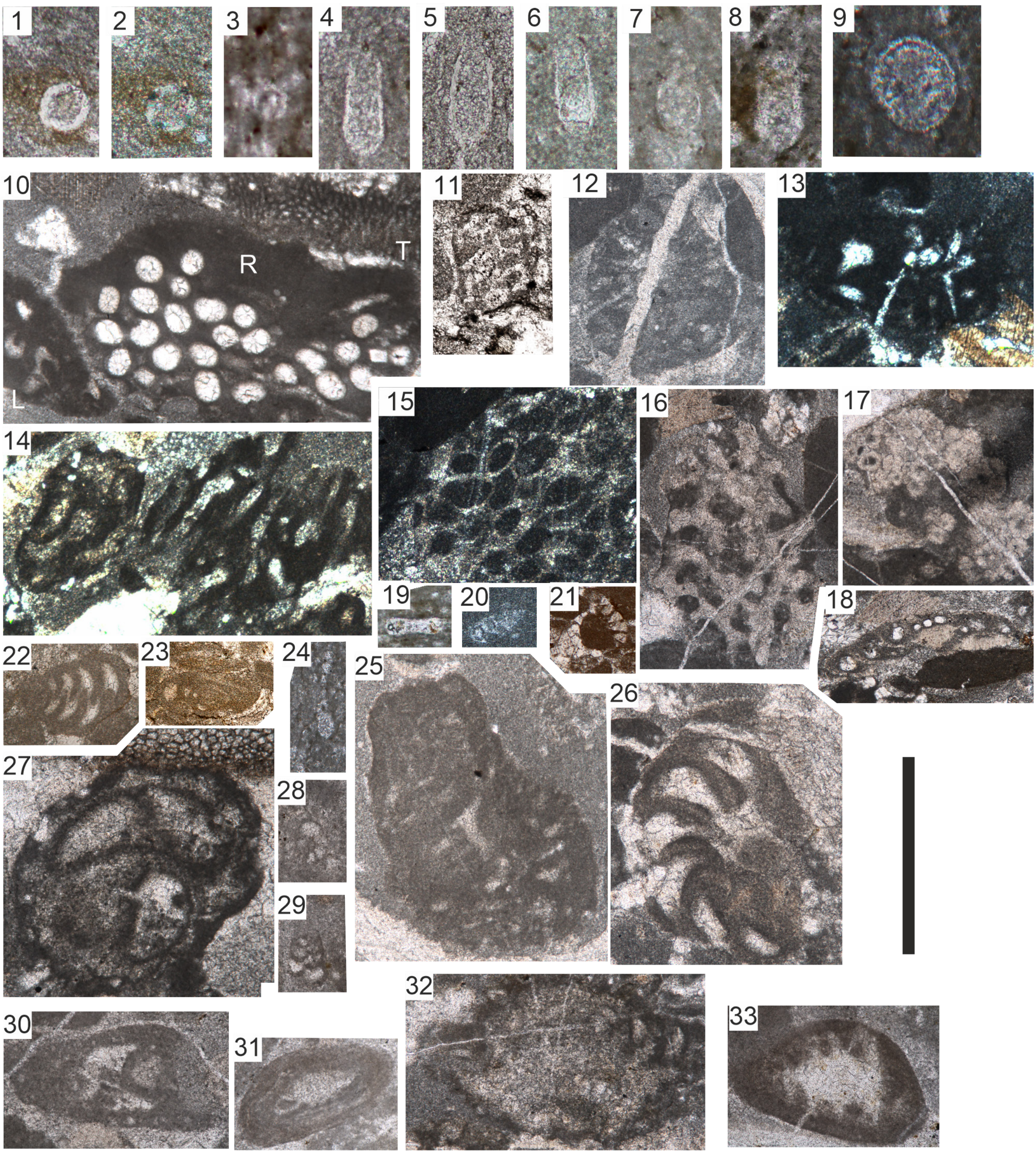


Fig. 13. Microfossils of the Kozlov grič section. **1-2** *Stomiosphaera moluccana* Wanner (**2**: crossed Nicols), sample 620, **3** *Colomisphaera lapidosa* (Vogler), sample 623, **4-7** sample 620: **4-5***Calpionellopsis oblonga* (Cadisch), **6** *Tintinnopsella carpathica* (Murgeanu & Filipescu), **7** *transitional form of Lorenziella plicata Remane and Lorenziella hungarica Knauer & Nagy and,* **8-9** sample 249p: **8** *Calpionellopsis* simplex (Colom), **9** *Stomiosphaerina proxima* Řehánek, **10** *Rivularia lobatum* (Yabe & Toyoma) (R), *Lithocodium aggregatum* Elliott (L) and *Thaumatoporella parvovesiculifera* (Raineri) (T), sample 621, **11** ?*Teutloporella* sp., sample 622, **12-14** sample 249k: **12** Dasycladales (?*Triploporella*) sp., **13** *Clypeina* sp., **14** *Isnella* aff. *misiki* Senowbari-Daryan sensu Schlagintweit & Gawlick, **15-17** sample 249c: **15** microproblematicum tubes with calcareous micritic wall, **16** *Cladocoropis mirabilis* Felix, **17** *Muranella parvissima* (Dragastan), **18** *Mohlerina basiliensis* (Mohler), sample 616, **19** *Spirillina italica* Dieni & Massari, sample 623, **20** silicified textulariids, sample 621, **21-23** sample 622: **21** *Protopeneroplis* sp., **22** *Redmondoides lugeoni* (Septfontaine), **23** *Istriloculina* sp., **24** silicified *Spirillina* sp., sample 249p, **25-26** sample 249k: **25** *Labyrinthina*? sp. A, **26** *Pfenderina neocomiensis* (Pfender), **27-33** sample 249c: **27** Lituolidae indet., **28** *Trochammina* sp., **29** textulariid sp. **30** *Everticyclammina* sp., **31** *Coscinoconus molestus* (Gorbachik), **32** *Frentzenella involuta* (Mantsurova) **33** *Coscinoconus campanellus* (Arnaud-Vanneau et al.). The scale bar is 200 µm at figures 1-9 and 1000 µm at figures 10-33.

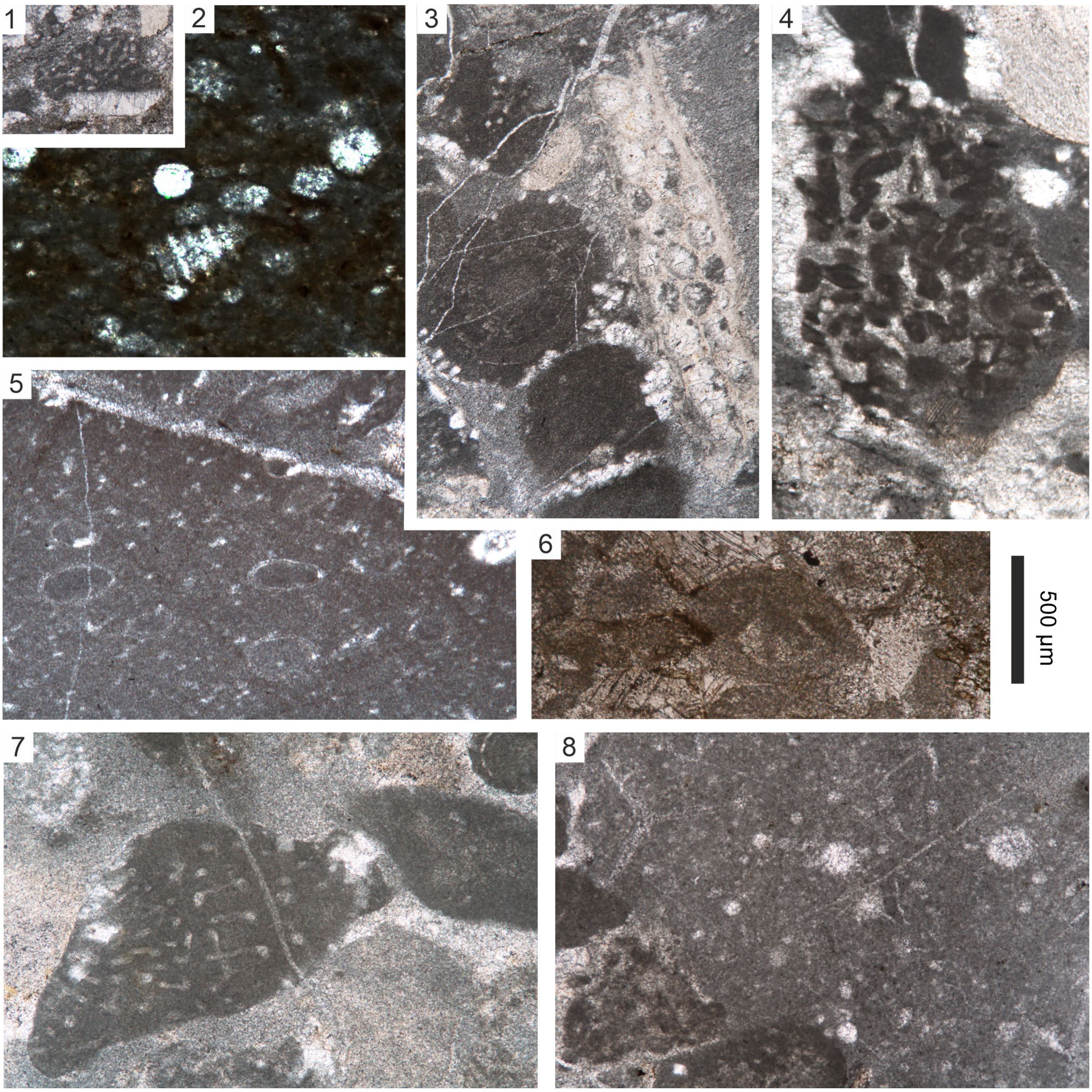


Fig. 14. Microfossils of the Kozlov grič section. **1** Stromatoporoidea sp., sample 616, **2** well-preserved radiolarians, sample 249p, **3-5** sample 621: 3 grainstone with the skeleton of Bryozoa, radial ooid with peloid nucleus, peloid, the latter show the trace of microborer (microbe or fungi), **4** extraclasts, peloidal grainstone with miliolinid foraminifera, **5** extraclasts, wackestone with ostracods, and fine calcitic fragments, **6** *Carpathiella triangulata* Misík, Sotak & Ziegler, sample 622, **7-8** sample 249c: 7 fragment of Porifera skeleton, **8** extraclasts, radiolarian wackestone. The scale bar is 500 µm.

Over the first calcarenite layer (site 613), the marl succession is followed by an approximately 2 m-thick sandstone bed (site 614). The grey sandstone is composed of a silicified matrix and contains various metamorphosed heavy minerals, as well as volcanic and sedimentary rocks. Among the minerals, chrome-spinel with a chlorite coating and secondary opaque minerals, such as ilmenite and magnetite, are the most common. The majority of the rock grains are chlorite, showing a metamorphic appearance; basalt with an equigranular fabric is metamorphosed and calcified; and dolerite, which contains plagioclase mesh and in between pyroxene altered into chlorite. These minerals and rock fragments indicate an ophiolitic provenance of this bed. (petrology by Józsa, personal com., see correlations in the Discussion chapter) There are only a few sedimentary rock fragments, including micritic limestone with poorly preserved benthic foraminifers such as the upper Tithonian–lowermost Aptian *Neotrocholina valdensis*, nodosarid sp., and foraminifera indet.

Above the sand layer, in the next 10 m (sites 615–619), the limestone content dominates and is separated by just thin clay films. A 30 cm thick medium grey calcarenite bed occurs at site 616.

Rip-up mudclasts were observed at site 619. The light grey-ochre mottled limestones, with tiny terracotta mottles (sites 615a, 615, 617, and 619), are radiolarian wackestone/packestone, packed biomicrite. Besides the limonite mottles, other opaque minerals are also common. The arrangement of the fossils (radiolarian and calcareous fragments) often shows gradation (Fig. 11.). Apart from the calcified radiolarians, only a few sponge spicules and fragments of Echinodermata and thin mollusca shells appeared. The 60 cm thick calcarenite bed (site 616) is a partly silicified grainstone, packed biomicrite with high amounts of opaque minerals. The fossil assemblage consists of Echinodermata, benthic foraminifera, and Stromatoporoidea. Among the foraminifers, *Mohlerina basiliensis*, *Redmondoides lugeoni*, *Lenticulina* sp., nodosarid sp., and *Valvulina* sp. could be identified. The co-occurrence of these species suggests the Kimmeridgian–Valanginian interval. The microfacies indicates that the northern part of the section (up to site 619) was deposited in a pelagic, toe-of-slope environment. This explains the appearance of the layers (at site 617) folded into a slump fold.

From site 620 to site 623, in the thin-bedded fine-grained limestone succession, the calcarenite intercalations become more common and thicker, reaching a maximum thickness of 1 m. It can be observed in a small quarry (sites 249 p, c, k, 621-623). Here, the steeply dipping layers are cut by faults that are formed on low angles compared to the bedding planes (Fig. 12).

The limestone layers are similar in macroscopic appearance to the previous ones, i.e., ochre-grey mottled with terracotta patches (sites 620, 249p, and 623). Their texture is also wackestone-packstone, packed biomicrite with common opaque minerals. The main difference is that in addition to the radiolarians, calpionellids and c-dinocysts are also present, although in smaller numbers.

At sites 620 and 249p, the co-occurrence of *Calpionellopsis oblonga, Tintinnopsella carpathica, C. simplex, Lorenziella plicata-hungarica, Stomiosphaera moluccana,* and *S. proxima* indicate the upper Berriasian substage, *Calpionellopsis* Zone, *Oblonga-Simplex* (D2) Subzone or *Oblonga* Subzone (sensu Allemann et al., 1971). In the upper most studied micritic layer (site 623), only the upper Oxfordian–lower Valanginian *Colomisphaera lapidosa* occurs. Besides these planktonic forms, only a few ostracods and benthic foraminifers, such as *Spirillina italica* and textulariid sp., could be identified.

At site 249c, the texture of the fine to medium-grained calcarenite layers (sites 621, 622, 249k, c) is grainstone, poorly washed biosparite. The intraclasts and extraclasts are common. Each studied sample contained ooids, oncoids, and pellets. Among the bioclasts, the fragments of echinoderms and the benthic foraminifers are the most frequent. Besides them, the remnants of platform-dwelling organisms, such as microproblematica, green algae, Porifera, Stromatoporoides, Vermes, and Bryozoa, form diverse fossil associations. The Foraminifera fauna is dominated by agglutinated species, such as *Redmondoides lugeoni, Trochammina* sp., textulariid spp., and larger foraminifers like *Pfenderina neocomiensis, Everticyclammina* sp., *Labyrinthina*? sp., and Lituolidae indet. Involutinids are relatively diverse, represented by *Coscinoconus molestus, C. alpinus, C. campanellus, Frentzenella involuta,* and *Protopeneroplis* sp. Besides them, specimens of *Mohlerina basiliensis, Neotrocholina valdensis,* and *Istriloculina* sp. also could be identified. The fragments of microproblematica are frequent, such as ?*Crescentiella morronensis*, *Lithocodium aggregatum, Thaumatoporella parvovesiculifera, Isnella* aff. *misiki, Muranella parvissima,* and tubes with calcareous micritic walls. The algae are represented by *Rivularia lobatum, Clypeina* sp., ?*Teutloporella* sp., ?*Triploporella* sp., and Dasycladales sp. The Porifera *Cladocoropis mirabilis* and Vermes *Carpathiella triangulata* could be recognized. These fossils are characteristic of shallow, photic-zone marine environments. The most common extraclasts are the radiolarian wackestone grains. In the semi-consolidated state, the basin sediment was torn up and crumpled by the moving debris. The microfossil assemblages are typical of the Tithonian—Valanginian interval. The *Pfenderina neocomiensis, Coscinoconus campanellus,* and *Frentzenella involuta* narrow down the succession's age to the late Berriasian–Valanginian. The clasts of peloidal grainstone with miliolinid foraminifers or wackestone with ostracods (site 621) may originate from a different environment of the same age as the platform or even from an older formation.

Over the previously described calcarenite layers, limestone and marl succession returns below site 624, where a chaotically folded unit with disrupted carbonate breccia bodies follows. The bedding of the layers turns from steeply dipping to the south into sub-horizontal. The breccia bodies and the slump folds are then cut through by a low-angle fault with top to-the-north movement. (Fig. 12a)

Summing up, similarly to the Brložen section, the Kozlov grič section built-up from the Biancone Limestone, deposited in a proximal hemipelagic toe of slope–slope environment during the late Berriasian, *Calpionellopsis* Zone, *Oblonga-Simplex* (D2) Subzone or *Oblonga* Subzone. The succession is a radiolarian micritic limestone with intercalated calcarenite layers that become more common, thicker, and more proximal upwards.

The Sveti Miklavž section (Fig. 1, 15–19; Tables 1–2, 5; Appendices 1–2)

The composite Sveti Miklavž (or Sv. Miklavž) section was created based on field observations and detailed studies of sites around the former settlement of Sveti Miklavž (46°6′37″N 14°44′39″E). It covers an area of ~3.5 km wide in an E–W direction and ~1.5 km long in an N–S direction. In this studied area, the bedding dip direction is alternating between north and south, dipping steeply to sub-vertical or moderately to gently. These facts make the compilation of a continuous succession impossible and the estimations of thickness and correlation difficult.

The section begins at the south, on the western side of Kukel Mt. (site 352), where layers of the light grey Triassic Platform Limestone are exposed. Above it (sites 346, 347, 349, 554a, b), along a NE–SW section, the ochre-coloured carbonate layers can be followed with a thickness of more than 200 m. The succession consists of limestone beds (site 554a) of variable thickness (5–50 cm), with calcarenite beds (e.g., site 347, 554b) and thin-bedded marl or marly limestone intercalations (e.g., site 349). At site 554a, the texture of the limestone is radiolarian wackestone, sparse

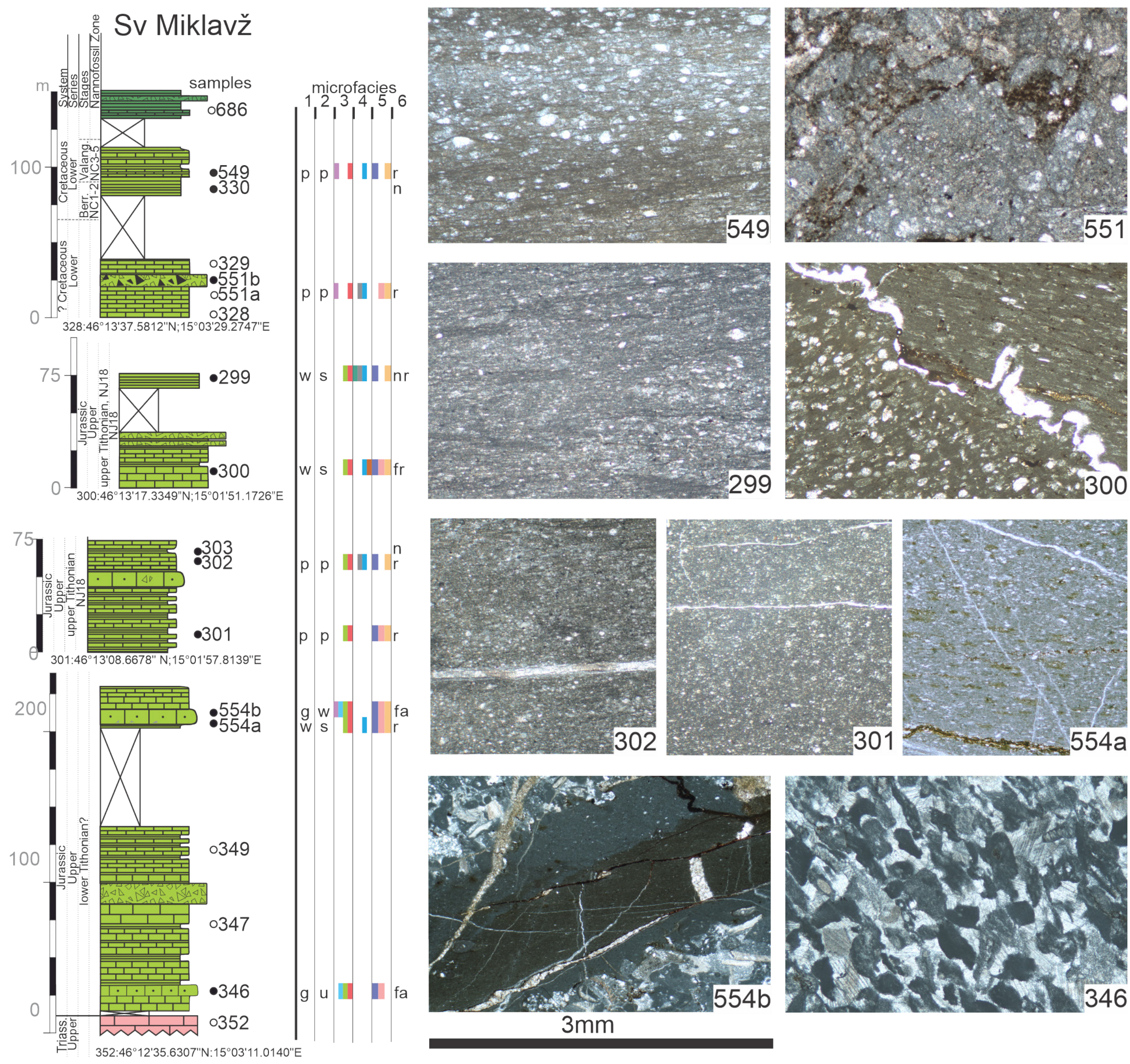


Fig. 15. Stratigraphic column and microfacies of the Sveti Miklavž section. For the legend, see Fig. 2. The scale bar is 3 mm, except for 554b, where it is 6 mm. Abbreviations: Triass. (Triassic); Berr. (Berriasian); Valang. (Valanginian).

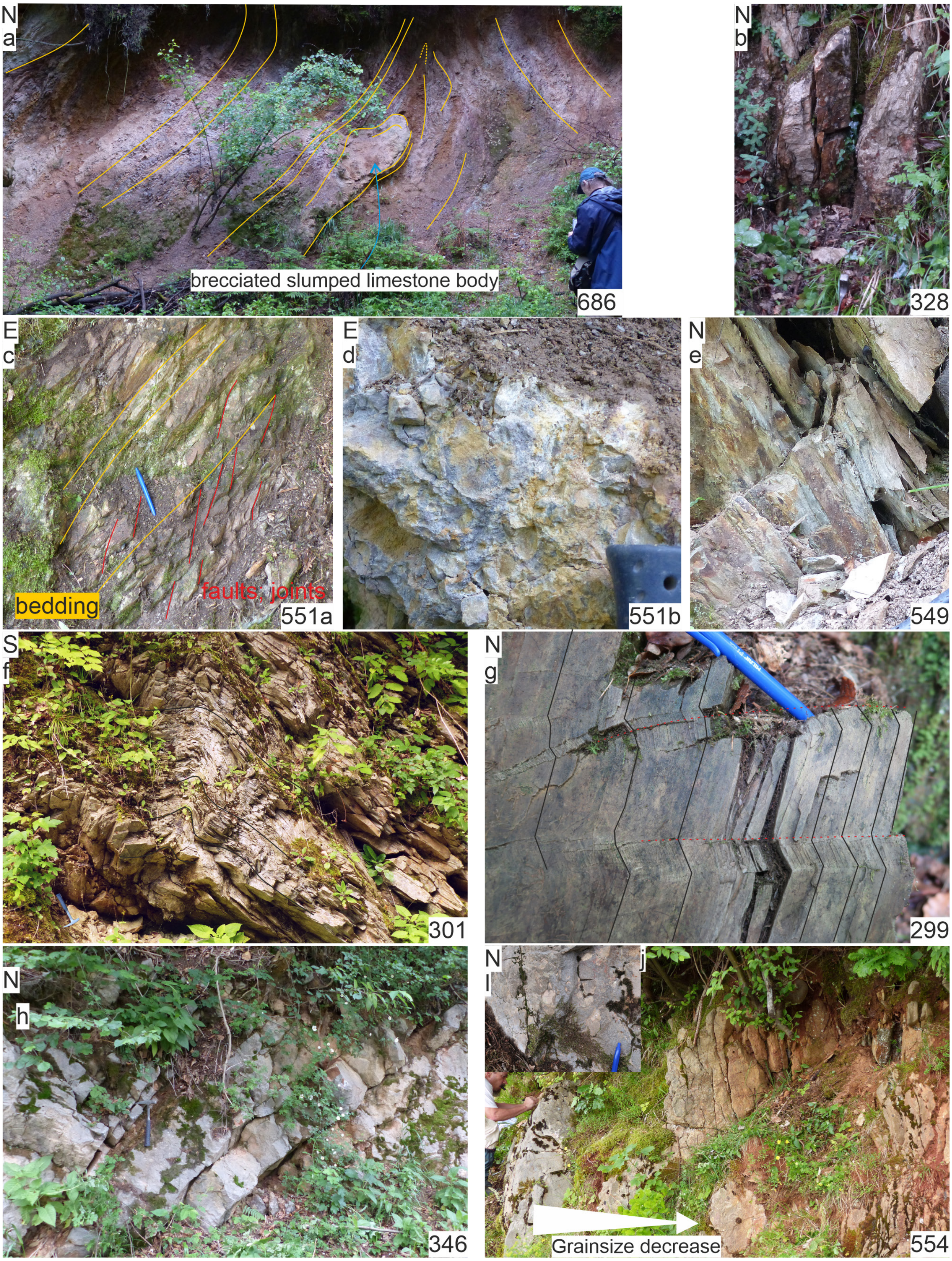


Fig. 16. Lithofacies and structural features of the Sveti Miklavž section. For the legend, see Fig. 3. **a** calcarenitic body slump folded in marl, Lower Flyschoid Fm., **b** *bedded chert between pelagic limestone layers,* Biancone Fm., **c** *chertified pelagic limestone,* Biancone Fm., **d** *lime*-stone breccia, Biancone Fm., **e** thin-laminated marl, *Biancone* Fm., **f** close detachment folds in thin layered limey marlstone, Biancone Fm., **g** kink-folds in the thin laminated silicified marl, Biancone Fm., **h** *t*hick-bedded resedimented limestones at the base of *the* Biancone Fm., **i** fine-grained mud-clasts inside *a* calcarenite body of *the* Biancone Fm., **j** *c*alcarenite with mud-clasts following bedded limestone of the Biancone Fm.

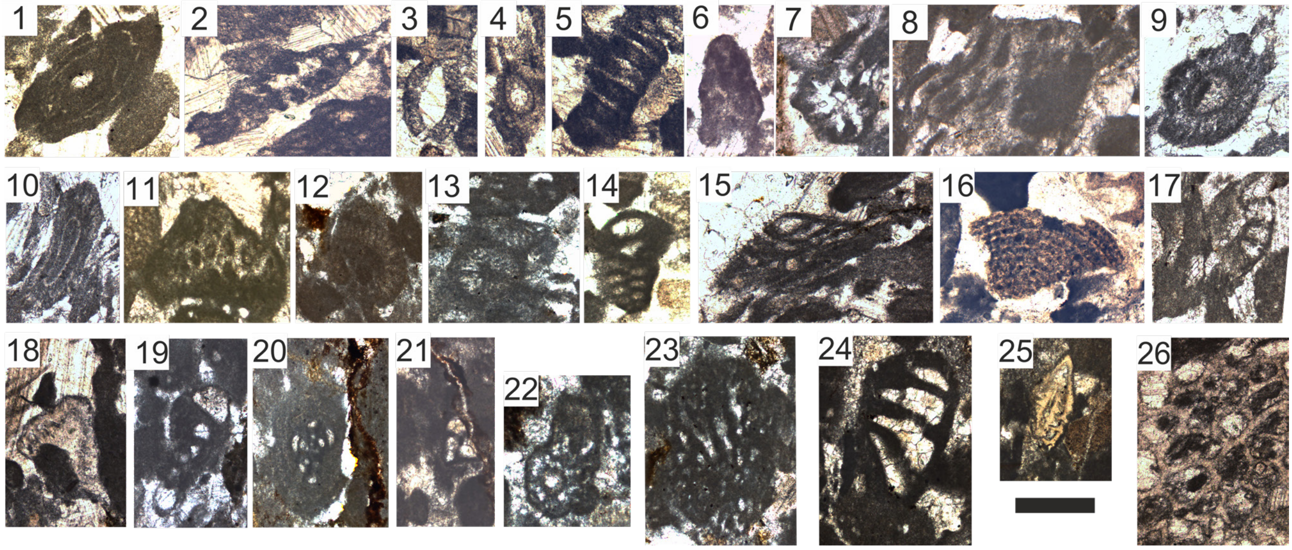


Fig. 17. Microfossils of the Sveti Miklavž section. **1-10** sample 346: **1** *Crescentiella morronensis* (Crescenti), **2** *Acicularia* sp., **3-4** Charophyte gyrogonites, **5** *Anisoporella* sp., **6** *Cylindroporella* sp., **7** *Clypeina* sp., **8** *Salpingoporella* sp., **9-10** *Linoporella* sp., **11-13** sample 554b: **11** *Salpingoporella* sp., **12** *Salpingoporella*? *sellii* (Crescenti), **13** *Tethysicodium elliotti* (Dragastan), **14-19** sample 346: **14** textulariid sp., **15** larger agglutinated indet., **16** *Pseudospirocyclina mauretanica* Hottinger, **17** *Protopeneroplis* sp., **18** *Ichnusella infragranulata* (Noth), **19** *Spirothalmidium* mg. *kaptarenkoae* Danitch, **20-26** sample 554b: **20** *Glomospira* sp. in ooids, **21** *Valvulina* sp., **22** *Labyrinthina mirabilis* Weynschenk, **23** *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano, **24** pfenderinid? sp., **25** *Lenticulina* sp., **26** Bryozoa, sample 554b. The scale bar is 200 μm.

biomicrite with fragmented bioclasts of undeterminable origin, and dispersed limonite mottles. The studied calcarenite layers (sites 346 and 554b) are unsorted or poorly washed biosparite, with extra- and intraclasts, ooids, pellets, and limonite mottles. The most common bioclasts are benthic foraminifers, green algae, microproblematica, and fragments of echinoderms. Both calcarenite layers yielded the following taxa: *Mohlerina basiliensis*, *Crescentiella morronensis*, *Thaumatoporella parvovesiculifera*, and *Salpingoporella* sp. A. In the lower layer (site 346), besides the fossils listed above, *Lithocodium aggregatum*, *Acicularia* sp., Charophyte gyrogonite, Dasycladales sp. indet., *Anisoporella* sp., *Clypeina* sp., *Cylindroporella* sp., *Linoporella* sp., textulariids, *Pseudospirocyclina mauretanica, Ophthalmidium* mg. *marginatum*, *Spirothalmidium* mg. *kaptarenkoae*, *Coscinoconus alpinus*, *Protopeneroplis striata*, *Protopeneroplis* sp., *Ichnusella infragranulata* also occur. While in the upper layer (site 554b) among the green algae *Aloisalthella sulcata*, *Salpingoporella*? *sellii*, *Tethysicodium elliotti* could be identified. Here, in the foraminifera association, *Glomospira* sp., *Redmondoides lugeoni*, *Valvulina* sp., *Labyrinthina mirabilis*, *Parurgonina caelinensis*, pfenderinid sp., and *Lenticulina* sp. also appear. Based on the stratigraphic distribution of these taxa, especially the co-occurrence of *Tethysicodium elliotti* and *Labyrinthina mirabilis,* the age of these layers is early Tithonian. It is worth noting that *Spirothalmidium* mg. *kaptarenkoae* appears to have existed during the Tithonian period. The microfacies and fossil association of the succession suggest that these layers were deposited in a hemipelagic basin, where grains produced in the photic zone of a shallow marine environment were supplied. The occurrence of the Charophyte gyrogonites indicates a freshwater inflow. Each studied sample exhibits post-depositional fabrics caused by increased pressure due to burial.

The next outcrop-sequence has a thickness of approximately 75 m and consists of sites 301-303, which are situated in a nearly northeast–southwest direction. The rock is ochre-coloured and thin-layered almost throughout, with only one thicker (~10 m) calcarenite bed appearing. In the older part (site 301), marl and shale layers are dominant, while upward, the limestones become more abundant. The texture of the limestone (sites 301, 302) is radiolarian packstone, packed biomicrite, with fragments of calcareous bioclast of unknown origin, dispersed opaque minerals, and a few specimens of textulariid benthic foraminifera. Nannofossils could not be identified in these samples. The sample from site 303 yielded a moderately preserved, relatively diverse association of a few nannofossil specimens. The genus *Cyclagelosphaera* is the most common, represented by *C. brezae* and *C. deflandrei*. Besides them, *Rotelapillus crenulatus, Hexalithus noeliae, Conusphaera mexicana, Retecapsa schizobrachiata, Truncatoscaphus intermedius, Stradnerlithus* sp., ?*Lithraphidites* sp. and ?*Acadialithus* sp. also occur. Based on the stratigraphic range of these nannofossils, the age of the rock is late Tithonian, NJ18 Nannofossil Zone.

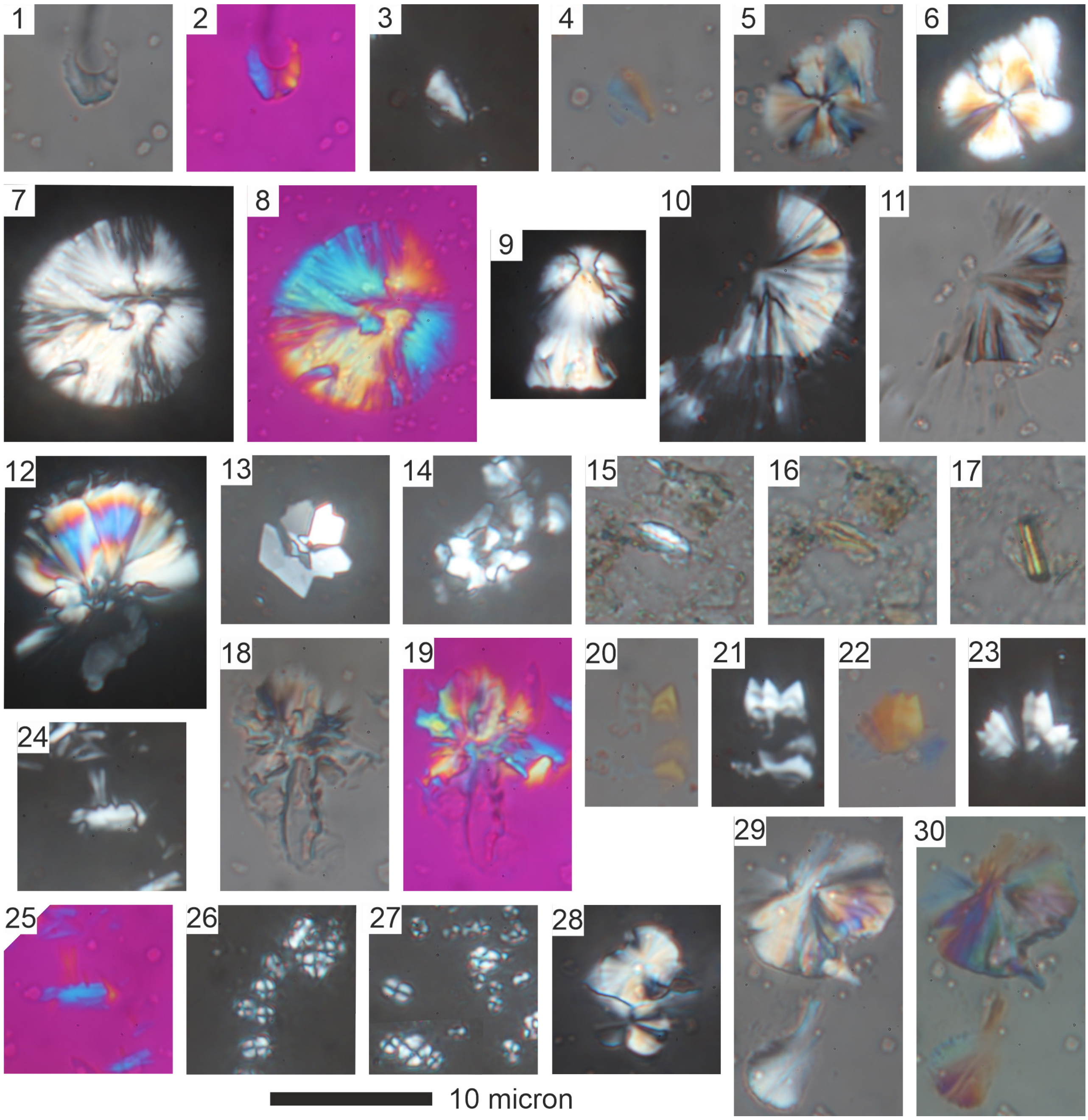


Fig. 18. Upper Tithonian nannofossils from the Sveti Miklavž section. **1-25** sample 303: **1-2** ?*Acadialithus* sp., **3-4** *Conusphaera mexicana* Trejo, **5-9** *Cyclagelosphaera brezae* Applegate & Bergen, **10-12** *C. deflandrei* (Manivit) Roth, **13-14** *Hexalithus noeliae* Loeblich & Tappan, **15-16** ?*Lithraphidites* sp., **17** *Truncatoscaphus intermedius* Perch-Nielsen, **18-19** *Retecapsa schizobrachiata* (Gartner) Grün in Grün & Allemann, **20-23** *Rotelapillus crenulatus* (Stover) Perch-Nielsen, **24-25** *Stradnerlithus* sp., **26-30** sample 299: **26-27** *Conusphaera maledicto* Varol & Bowman, **28-30** *Cyclagelosphaera brezae* Applegate & Bergen. The scale bar is 10 µm. Fossils under plane-polarised light are: 1, 3, 5, 10, 15, 17-18, 20, 22, 30; under cross-polarized light are: 4, 6, 7, 9, 11-14, 16, 21, 23-24, 26-28, 31, under cross-polarized light and gypsum plate are: 2, 4, 8, 19, 25.

Further north, the next succession starts with site 300. Above, the grey-ochre-coloured, fine-grained, thin-bedded limestones are replaced by thicker (varies from 40 cm up to 2 m) breccia layers. The texture of the limestone is radiolarian wackestone-packstone, sparse-packed biomicrite with dispersed opaque minerals and a few fragments of echinoderms and benthic foraminifera. Despite the dolomitization, *Neotrocholina valdensis* could be identified, dating the rock to the late Tithonian to early Aptian interval. *Neotrocholina* is platform-dwelling foraminifera (e.g., Rigaud et al., 2018), its appearance in this pelagic-hemipelagic limestone indicates a nearby platform environment. The sample exhibits post-depositional fabrics resulting from pressure. After the nearly 50 m thick gap, at site 299, grey-ochre mottled, thin-layered marl and shale appear. The texture of the marl is wackestone, sparse biomicrite with tiny fragmented bioclasts and several calcified radiolarians. From the smear slides of the sample, *Conusphaera maledicto* and *Cyclagelosphaera brezae* could be classified. The co-occurrence of

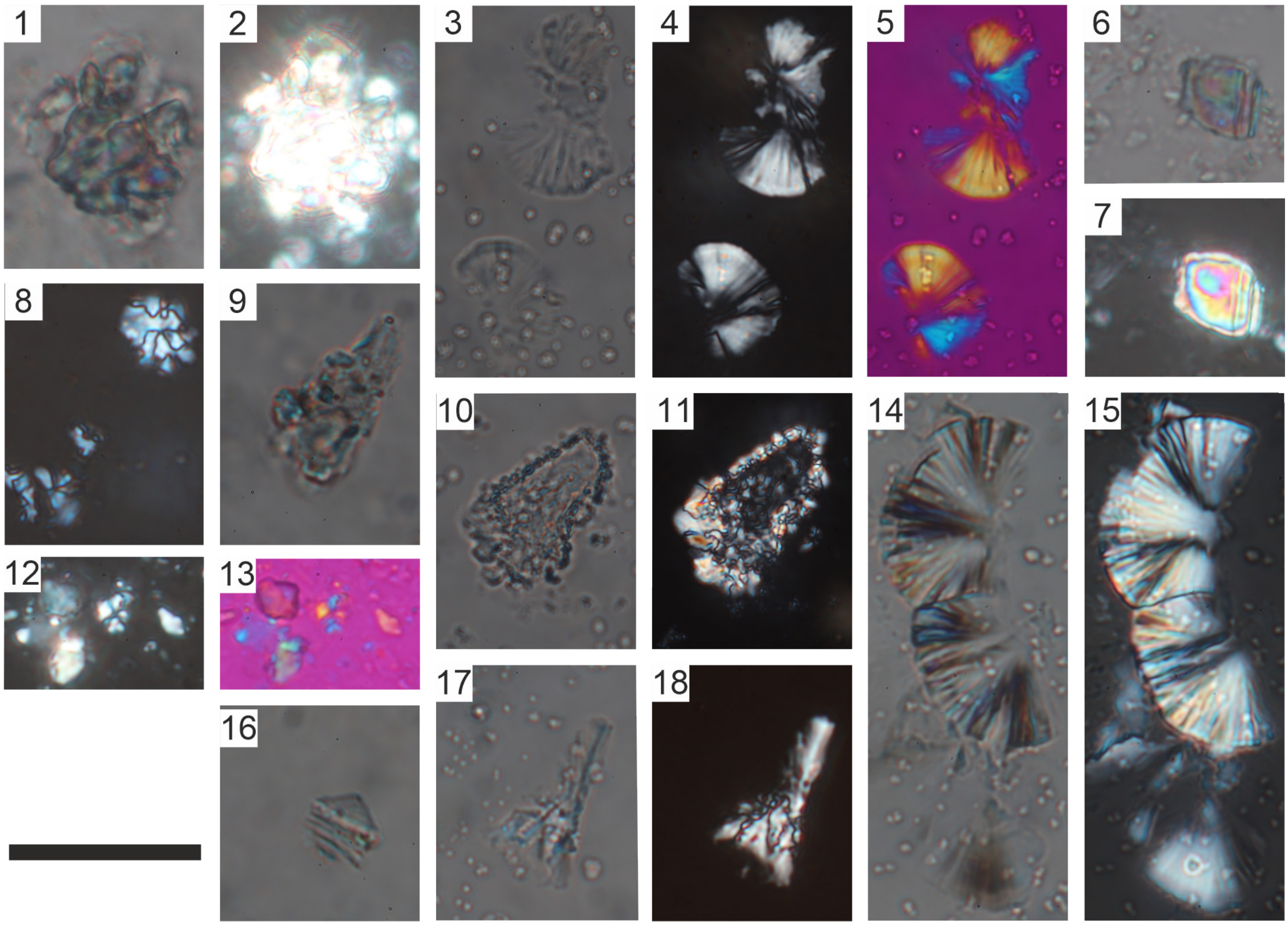


Fig. 19. Lower Cretaceous (Berriasian – Hauterivian) nannofossils from the Sveti Miklavž section. **1-13** sample 330: **1-2** *Assipetra* sp., **3-5** *Cyclagelosphaera brezae* Applegate & Bergen, **6-7** *Nannoconus* gr. *circularis* Deres & Achéritéguy, **8** *Nannoconus* sp., **9** *Nannoconus colomii* (de Lapparent) Kamptner, **10-11** *Nannoconus kamptneri* Brönnimann, **12-13** *Palaeomicula maltica* (Worsley) Varol & Jakubowski, **14-18** sample 549: **14-15** *Cyclagelosphaera deflandrei* (Manivit) Roth, **16** *Conusphaera* sp., **17-18** *Staurolithites pseudocarinolithus* (Applegate & Bergen) Young & Bown. The scale bar is 10 μm. Fossils under plane-polarised light are: 1, 3, 6, 9-10, 14, 16-17; under cross-polarized light are: 2, 4, 7-8, 11-12, 15, 18; under cross-polarized light: and gypsum plate are: 5, 13.

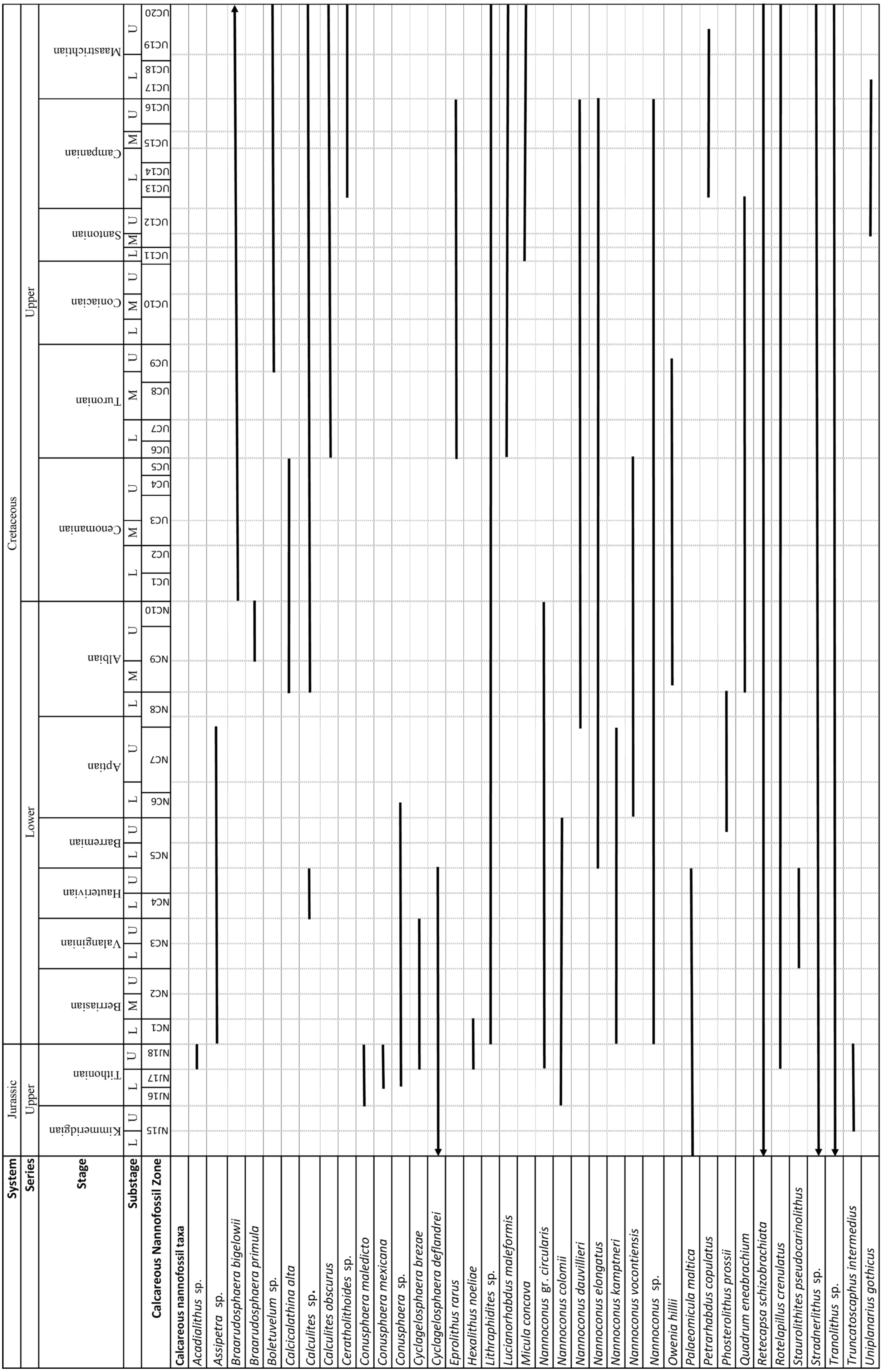
these nannoliths indicates the late Tithonian NJ18 nannofossil zone, and it coincides with the age of the site 300. Based on these, the entire succession is also upper Tithonian (NJ18 Zone).

The next succession was composed based on sites 328, 551a, b, and 329, and above a ~45 m gap on sites 330 and 549. At the lower three sites, the lithology is grey-ochre thin-bedded, silicified limestone with dispersed mm-sized brick-red dots. At site 551b, an about 50 cm thick grey breccia horizon occurs. In the thin section, the rock is microbreccia, the clasts are composed of radiolarian packstone or packed biomicrite with common opaque minerals. Only terrestrial plant remains appeared as fossils, indicating the proximity to the mainland. The upper part of the succession (site 330) starts with grey-ochre thin-layered marl and shale. The genus *Nannoconus* dominates the nannofossil association. The following taxa could be determined: *Nannoconus kamptneri, N.* gr. *kamptneri, N. colomii, N.* gr. *circularis, N.* sp. Besides them, specimens of *Cyclagelosphaera brezae, Palaeomicula maltica,* and *Assipetra* sp. occur. The co-occurrence of these taxa suggests the earliest Berriasian–latest Valanginian (NC1–NC3 zones) interval. Upwards (site 549), the rocks are more calcareous and thin-bedded. Here, the texture of the limestone is radiolarian packstone, packed biomicrite, with a few fragments of terrestrial plants and sponge spicules. The very poor and predominantly fragmented nannofossil assemblage consists of *Nannoconus* sp., *Conusphaera* sp., *Cyclagelosphaera deflandrei*, and *Staurolithites pseudocarinolithus,* indicating an age of Valanginian–Hauterivian (NC3– lower NC5 zones).

More than 100 m north of site 330, at site 686, a few meters-thick layer of purplish-red, shaley marl is exposed. Limestone layers and a 1–2 m thick sedimentary breccia body are intercalated in the marl.

In summary, the layers of the Biancone Formation could be identified in the Sv. Miklavž section, except the northernmost site 686, whose layers are classified as the Lower Flyschoid Formation based on lithology. The age range of the Biancone Formation was determined using calcareous nannofossils, spanning from the earliest Berriasian–latest Valanginian and Valanginian–Hauterivian.

Table 5. Stratigraphic range of the calcareous nannofossils in the studied sites.



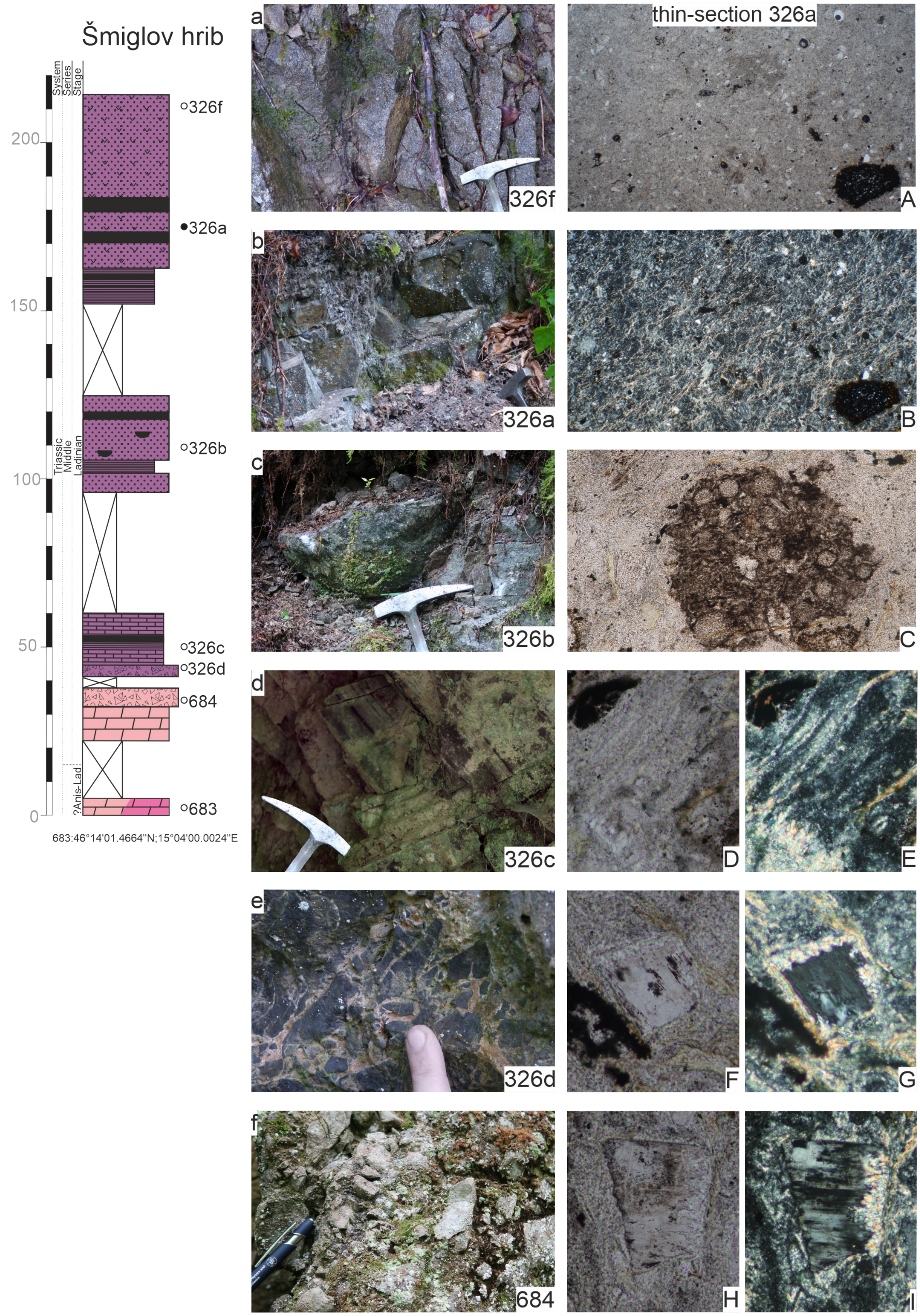


Fig. 20. Stratigraphic column and lithofacies of the Šmiglov hrib section, and microfacies of the sample 326a. **a, b, c** Pseudozilian Formation volcanoclastics in sandstone, **d,** Pseudozilian Formation slate and marl, **e** Pseudozilian Formation limestone breccia, **f** Schlern Formation dolomite breccia. For the legend, see Figs. 2-3. **A-B** fine sandstone with tiny glass shards and fragments of terrestrial plants (bottom right corner), **B** with crossed Nicols, **C** radiolarian packstone grain, **D-E** pumice grain, **E** with crossed Nicols, **F-G** Potassium feldspar (sanidine) with sericite rim, **G** with crossed Nicols, **H-I** plagioclase altered by sericite, **I** with crossed Nicols. The widths of the photomicrographs are: A-B – 3 mm; C – 1,5 mm; D-I – 0,2 mm. Abbreviations: Anis-Lad. (Anisian-Ladinian).

The Šmiglov Hrib section (Figs. 1, 20; Appendix 1)

The north–south Šmiglov hrib section starts 250 m south of Grajska vas village. The bedding is dipping to the south throughout. The succession is continuous but might be overturned in this case the description starts from the youngest formation.

In the northernmost part (site 683), the massive white to light grey fine-grained dolomite is covered by white, grey dolomite breccia (site 684) with a calculated thickness of 40 m. Based on the lithology, these beds presumably belong to the Schlern Dolomite or the Mendole Formation. After a small gap, a several-meter thick, silicified limestone breccia appears (site 326d). The cement is composed of red calcite, and the dark grey carbonate clasts are 3–7 cm in diameter. Above (site 326c), it is followed by a 20 m thick, medium-grey, well-bedded pelagic limestone. Some layers are silicified in a few meters thickness.

After a 30 m gap, alternating dark purple-grey fine-medium-grained sandstones and siltstones are cropping out in a 30 m thick succession (site 326b) while shale was observed in scree. Half-spherical, 30-40 cm large, silicified blocks occur in some places (Fig. 20), and higher up the section, strongly silicified beds appear. After another gap, a 12 m thick, well-bedded, dark greenish-grey, chertified siltstone succession occurs.

This succession is capped by an approximately 65 m thick, medium to coarse grey sandstone with white pumice clasts (1–2 mm) (site 326a, f). The silica content is changing, and the highest volcanic content is located at the top of the site 326f. In the thin-sections from site 326a, components of acidic magmatic origin are the most common, such as glass shards, pumice fragments, resorbed quartz grains, alkali feldspars (sanidine), plagioclases, biotite, and zircon. The presence of sericite and calcite indicates the influence of metamorphism. (S. Józsa personal comment). Besides the mineral constituents, carbonized fragments of terrestrial plants and fragments of benthic foraminifera (*Lenticulina* sp., Foraminifera indet.) could also be recognized. These rock-forming particles refer to a rhyolite tuff that fell into a shallow sea relatively close to the shore.

Based on the results of this study and the principle of superposition, we can classify these rocks as the Schlern Formation (each sub site of 326) and the Ladinian Pseudozilian Formation.

The Osreški grič section (Figs. 1, 21)

The east–west oriented Osreški grič section is situated on the north slope of Osreški Hill and has a westward dip in this area.

The section begins (at site 690b) with a massive shallow marine carbonate, followed by an almost 150 m thick succession of dark grey weathered shales of the Pseudozilian Formation. Its stratigraphic position and lithological features led to the assumption that it is the Ladinian Schlern Dolomite. Below the middle part of the succession (site 690), approximately 15 m thick, well-bedded (7–12 cm thick layers) black pelagic limestone interlayers occur. These beds probably indicate a minor drowning of the platform. About 20 m above the pelagic limestone, a several-meter-thick dolomite breccia interlayer interrupts the monotonous platform depositional sequence again.

These Middle Triassic carbonates are overlain by the 70–90 m thick, characteristic Upper Jurassic–Lower Cretaceous Biancone Formation. In the ochre-grey, thin-layered (2–8 cm) carbonate succession (site 689d), redeposited beds ranging from calcarenite to breccia appear occasionally. The frequency of these resedimented layers and the thickness of the marls increase (up to 10 m) upwards.

In the uppermost 60–80 m of the section, Lower Flyschoid Formation is observed. The lithology changes, becoming more argillaceous. Medium grey, thin-bedded marls, marly limestones with clay intercalation, argillaceous marls, and fine-grained calcarenite and breccia beds alternate frequently. The submarine erosion has created uneven surfaces and channels (site 689c) between the breccia and the underlying marl and limestone layers. Additionally, marly-limestone beds with bed-parallel chert nodules (site 689b) and 30–50 cm silicified blocks in argillaceous marl (site 689a) occur.

The contact of Biancone and Lower Flyschoid is additionally observed at site 315, on the opposite side of the valley. Here, the main outcrop is of Biancone sl., and the systematic appearance of the calcarenite layers is truncating the thin-layered limestone and marl beds.

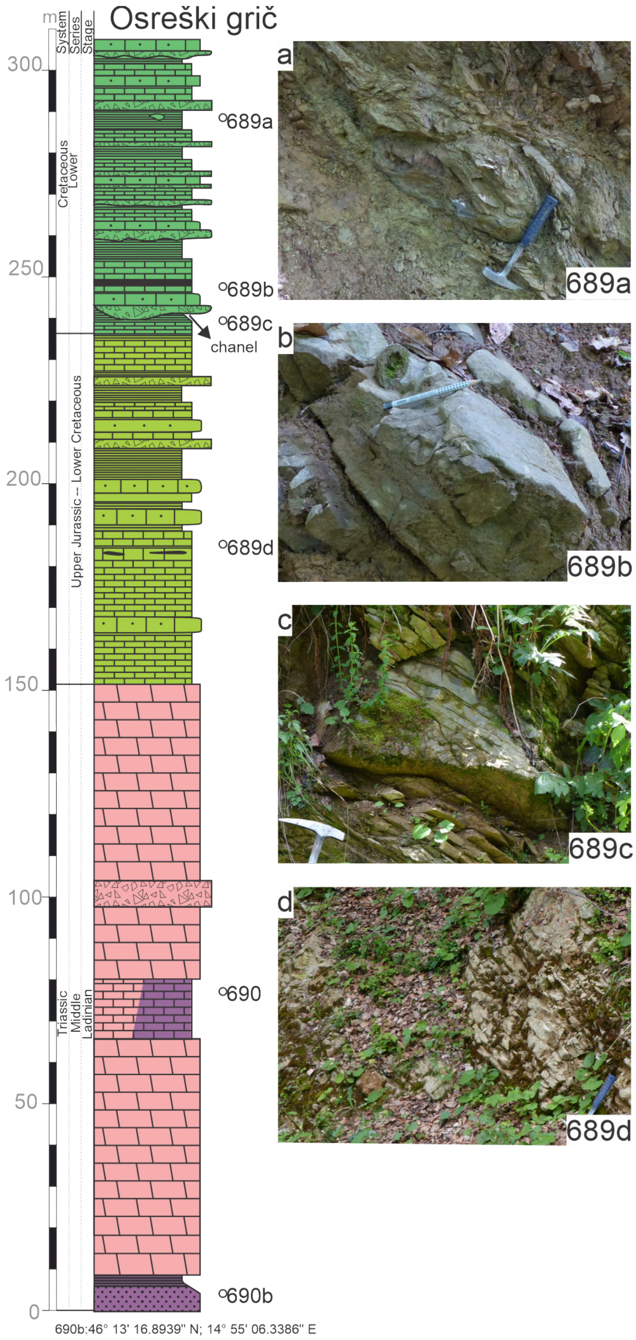


Fig. 21. Stratigraphic column and lithofacies of the Osreški grič section. **a** Lower Flyschoid Formation silicified carbonate body **b** Lower Flyschoid calcarenite with chert layer **c** Lower Flyschoid formation channel and erosional bottom **d** Biancone Formation. For the legend, see Fig. 2.

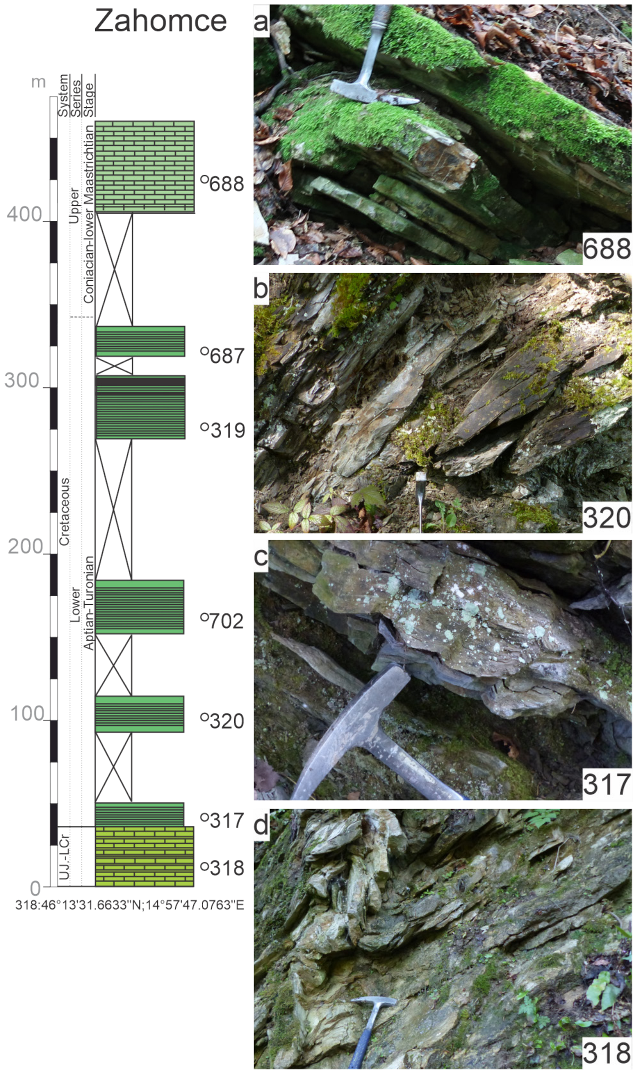


Fig. 22. Stratigraphic column and lithofacies of the Zahomce section. **a** Volče Limestone Formation, **b**, **c** Lower Flyschoid Formation, **d** Biancone Formation folded isoclinally. For the legend, see Fig. 2. Abbreviations: UJ-LCr. (Upper Jurassic – Lower Cretaceous).

The Zahomce section (Figs. 1, 22; Appendix 1)

The south–north Zahomce section runs north from the scattered settlement of Zahomce to Grmada Hill. The strike of the bedding is E–W, although the dip angle changes from shallow to steeply dipping. The dip direction is mostly to the north, but at sites 317 and 320, it is to the south. The section is composed of smaller observed segments. The total thickness was calculated considering the missing section parts.

At the lowermost part of the section (site 318), an ochre-grey folded (anticline) limestone is visible. This thin-bedded limestone is considered the Upper Jurassic–lowermost Cretaceous Biancone Formation.

It is overlain by approximately 10 m thick, grey, finely laminated marl layers (site 317). Black shales with a couple of 10-m thicknesses appear in several places (sites 320, 702, 319, 687) up the section. Sporadically, some 10 cm thick layers of fine-grained calcarenite limestone occur (e.g., site 320). Based on lithological features and stratigraphic position, these beds belong to the Lower Flyschoid Formation with an estimated thickness of 300 m. At the northern end of the section (site 688), ochre – light grey pelagic limestone with chert nodules, the Scaglia-type Upper Cretaceous Volče limestone crops out for 50–60 m.

The Črni Vrh (Zahomce) section (Figs. 1, 23)

The Črni Vrh section is located 1.5 km west of the village of Loke. It runs from the saddle north of Kozica through Črni vrh. The observations of multiple sites are projected into a north–south directed section. The bedding dips gently to the north throughout. The section starts at site 235, which is topographically lower positioned, and thus, it is projected into the section from the north from a 200 m distance. The rock is thin-bedded dark grey marl and slaty marlstone. The same formation is observed at site 706a in the south. The thickness of this marly succession exceeds 50 m and likely continues downwards. Based on the lithology, it can be identified as the Lower Flyschoid Formation.

It is overlain by a ~10 m thick, medium-grey monomict limestone breccia bed. Upwards, the succession consists of cream-white, ochre, thin (2–5 cm) layered pelagic limestones with grey, 2 to 10 m thick allodapic limestone (calcarenite) intercalations (sites 706b and 234).

On the west side of Črni Vrh (site 705, projected 100 m westward), in a thickness of ~20 m, the pelagic limestone mentioned above alternates with beds of calcareous microbreccia or fine-grained calcirudit, ranging in thickness from 10 to 25 cm. The grey calcareous micritic matrix of the resedimented limestones contains dark grey, red, and ochre clasts. The clasts are moderately sorted and subrounded in shape. Based on the lithology (Ogorelec et al., 1976), this approximately 60 m thick rock formation most probably belongs to the Volče Limestone.

Other important sites (Figs. 1, 24–26; Tables 1, 2, 5; Appendices 1–2)

Four sites (sites 676, 671, 307, and 238) could not be fitted into the sections, but they provided new and relevant data for recent and further studies.

Site 676 (46° 12' 07.7225" N, 14° 41' 51.5503" E) is located 500 m west of the Velink Hill, on the small mountain road from Vaserno towards Gradišče. A medium-grey, well-bedded limestone outcrops here, with a thickness of ~2 m. The texture of the rock is dolomitized packstone/wackestone, fossiliferous micrite with pellets, microbial grains, and opaque minerals. The fossil assemblage consists of Echinodermata fragments, benthic foraminifers, ostracods, and microproblematica. The following taxa could be identified as*Thaumatoporella parvovesiculifera*, textulariids, *Turriglomina mesotriassica,* and *Paratriasina* sp. The co-occurrence of the latter foraminiferal taxa indicates the latest Anisian–earliest Ladinian age. Based on the macroscopic and microscopic characteristics of these beds, including fossils, this formation is identical to that in the Kisovec Hill section (site 667) near Krvavica, namely the Mendole Formation.

Site 671 (46° 12' 44.2990" N, 14° 48' 45.4369" E) is near the main road from Špitalič to Tuhinj, southeast of a large quarry (site 055), exposing Bača Dolomite Buser (2010). From the main road a forestry road heads into a small valley where 18–20 m thick layers of dark grey limestone are exposed with a dip angle greater than 70°. The texture of the rock is peloidal-bioclastic wackestone, poorly washed biosparite with benthic foraminifers, Vermes tubes, fragments of Echinodermata, and

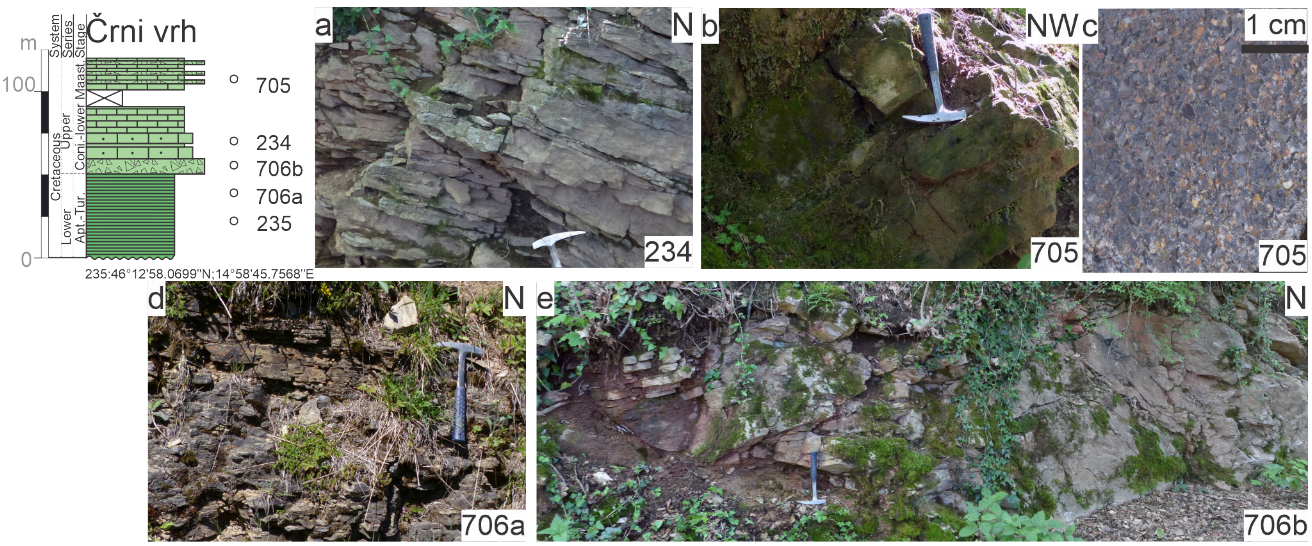


Fig. 23. Stratigraphic column and lithofacies of the Črni vrh section. **a, b, e** Volče Limestone Formation **c** the cut and polished surface of the sample from site 705. **d** Lower Flyschoid Formation. For the legend, see Fig. 2. Abbreviations: Apt.-Tur. (Aptian – Turonian); Coni. – lower Maast. (Coniacian – lower Maastrichtian).

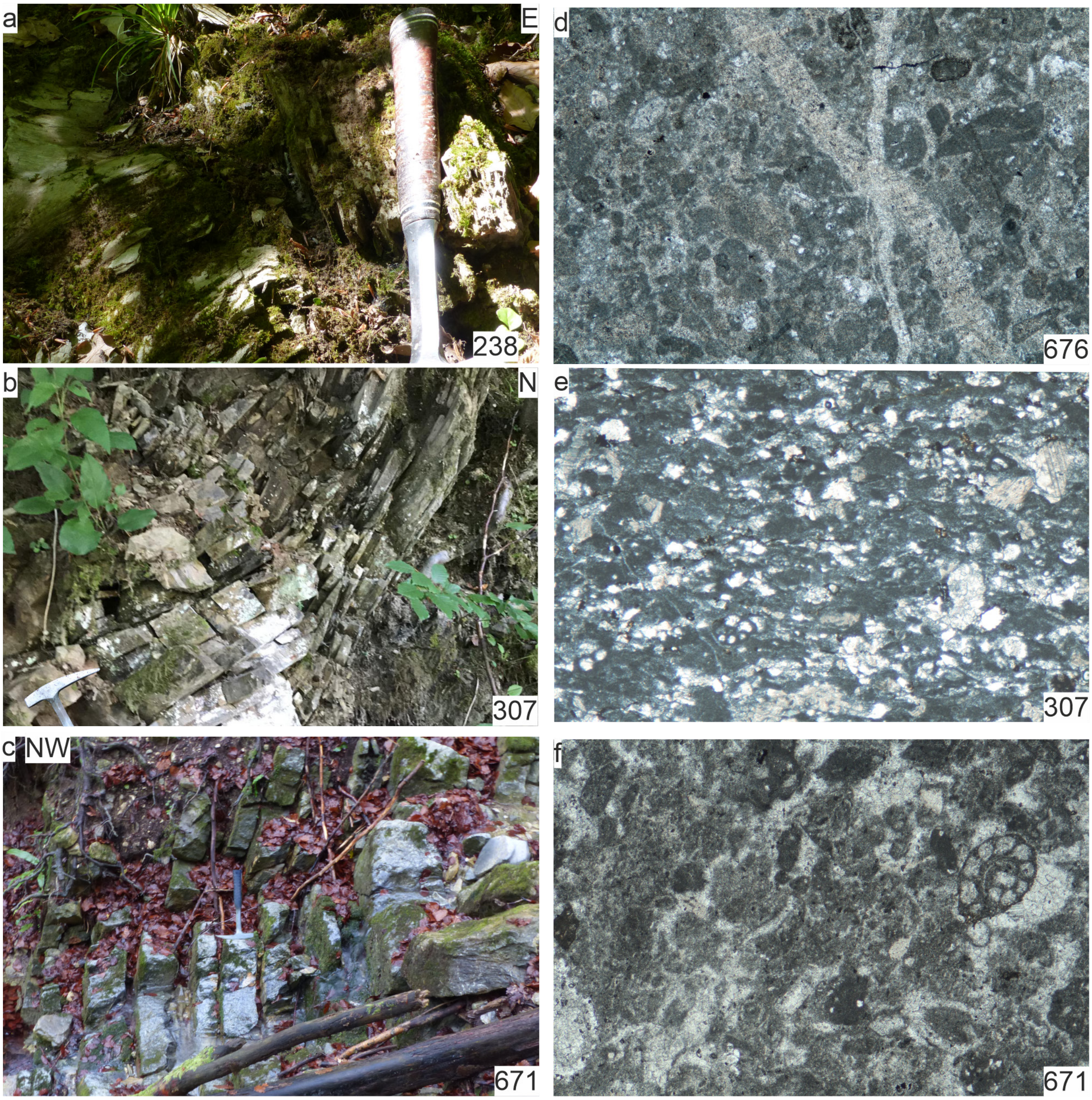


Fig 24. Lithofacies and microfacies of sites. For the legend, see Fig. 3. **a** site 238 =Volče Limestone Formation, **b** and **e** site 307 = Lower Flyschoid Formation; **c** and **f** 671 = Amphiclina Beds; and **d** site 676= Mendole Formation. The width of the photomicrographs is 3 mm.

Bivalvia. Among the foraminifers, the specimens of aragonitic Duostominidae and Oberhauserellidae are the most common. From these groups, the *Duostomina* sp. and the Lower Triassic–Rhaetian *D. convexa* could be identified. Miliolinids are represented by *Agathammina* sp. and miliolinids sp., while the agglutinated ones are by *Ammobaculites* sp. and *Palaeonubecularia gregaria*. A few *Lenticulina* sp. also occur. The microfacies and the fossils indicate a shallow marine environment. Based on the literature (Gale et al., 2017), these rocks can be attributed to the upper part of the Carnian Amphiclina Beds or the transition of this formation to the Bača Dolomite (site 055).

Site 307 (46° 13' 03.4793" N, 15° 04' 09.5071" E) is located in the broader Sv Miklavž area, on the road from the valley of Reka Creek towards Marija Reka, approximately 250 m east of Strnik Hill. The approximately 6 m wide outcrop features thin-bedded (3–15 cm) medium-dark grey calcarenite with thin clay intercalations, some layers contain dark grey cherty nodules. The texture of the rock is peloidic bioclastic grainstone, poorly washed biosparite with benthic foraminifers, and fragments of the Echinodermata. Among the foraminifers, the agglutinated forms such as *Arenobulimina* sp., *Belorussiella* sp., *Nezzazata* sp., *Vercorsella* sp., and textulariid sp. and the

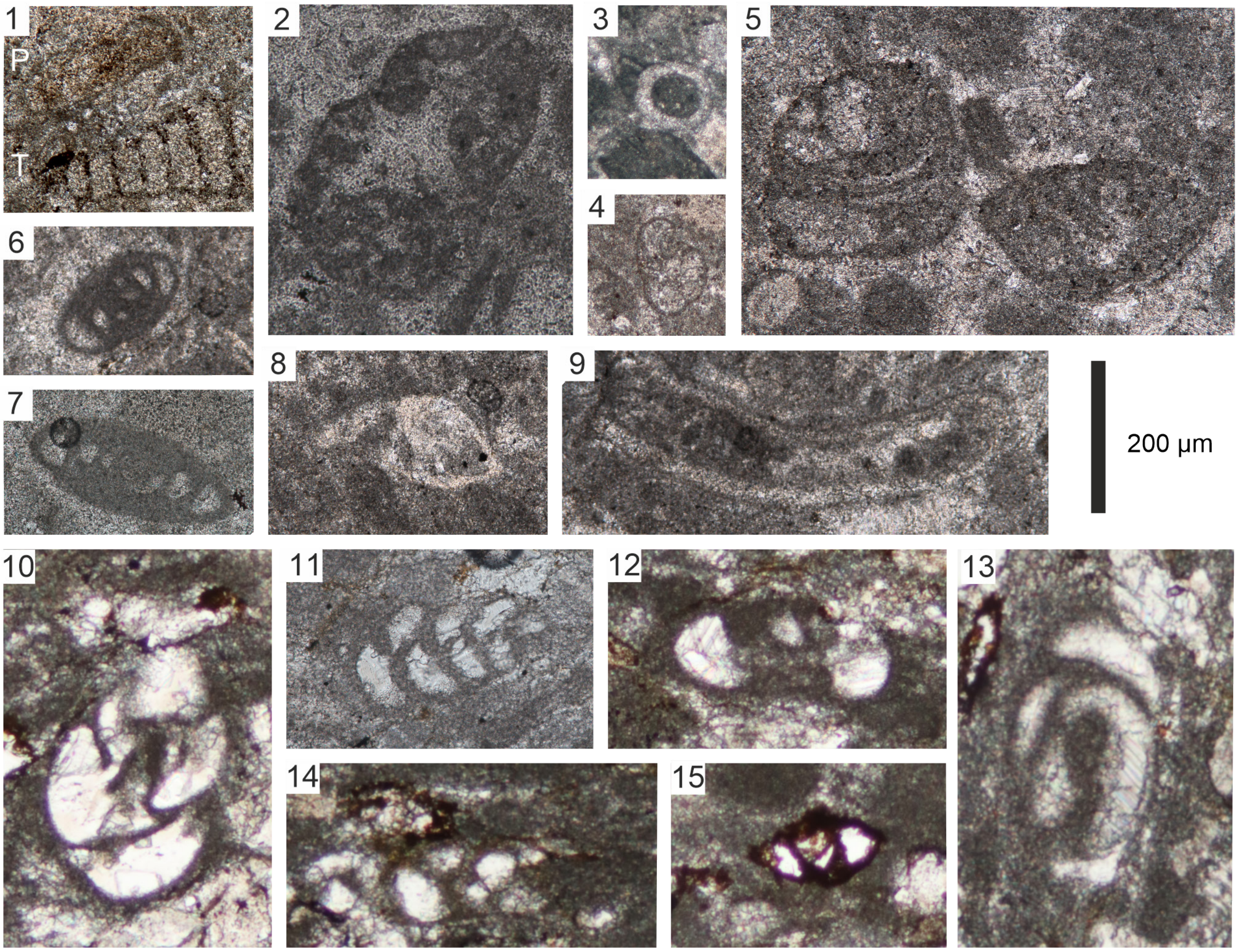


Fig. 25. Microfossils of the sites 676, 671 and 307. **1** *Paratriasina* sp. (P) and *Turriglomina mesotriassica* (Koehn-Zaninetti) (T), sample 676, **2-9** sample 671, **2** *Ammobaculites* sp., **3** *Palaeonubecularia* gregaria (Wendt) on a Vermes tube., **4** *Oberhauserella* sp., **5** *Duostomina biconvexa* Kristan-Tollmann, **6** *Agathammina* sp., **7** *Ophthalmidium* sp., **8** *Lenticulina* sp., **9** Vermes tube, **10-15** sample 307, **10** *Arenobulimina* sp., **11** *Belorussiella* sp., **12** *Nezzazata* sp., **13** *Pseudotriloculina* sp. **14** *Decussoloculina* sp., **15** *Istriloculina* sp. The scale bar is 200 µm.

miliolinids such as *Decussoloculina* sp., *Istriloculina* sp., *Pseudotriloculina* sp., and Miliolina indet. are dominated. A few specimens of nodosariids also occur. The co-occurrence of these genera indicates a late Early Cretaceous (Aptian–Albian) age. In the poor nannofossil association, the *Nannoconus* (*N. vocontiensis, N. elongatus,* and *N.* cf. *dauvillieri)* is the most common taxon. Besides them, *Tranolithus* sp., *Owenia hillii*, *Calcicalathina alta*, *Braarudosphaera primula*, *Quadrum eneabrachium,* and *Phosterolithus prossii* also occur, suggesting a late Albian age (mid NC9–NC10 zones). It is consistent with the age assigned by foraminifera. It means that the platform, from which the calcarenite layers with foraminifera originate is coeval (late Albian) with the deeper marine interlayered marls containing nannofossils. This rock is related to the Lower Flyschoid Formation.

Site 238 (46° 12' 53.4832" N, 14° 59' 42.5620" E) is in a roadcut on the road from Loke village towards Črni Vrh, approximately 370 m west of the village Loke, at the second hairpin turn uphill. The rock is brownish-grey, thin-bedded, or laminated calcareous marl. Due to the nature of the rock, it was not possible to make thin-sections, so smear-slides were made for nannofossil examination. The poor and partly silicified nannofossil assemblage provided the following taxa: *Braarudosphaera bigelowii, Micula concava, Lucianorhabdus* aff. *arborius, L. maleformis, Petrarhabdus copulates, Boletuvelum* sp., *Calculites* sp., *C. obscurus, Ceratholithoides* sp., ?*Cylindralithus* sp., *Eprolithus rarus,* and *Uniplanarius gothicus*. These forms indicate the Campanian age, namely the (UC13–UC16) zone, and thus, the rock can be classified as the Volče Limestone Formation.

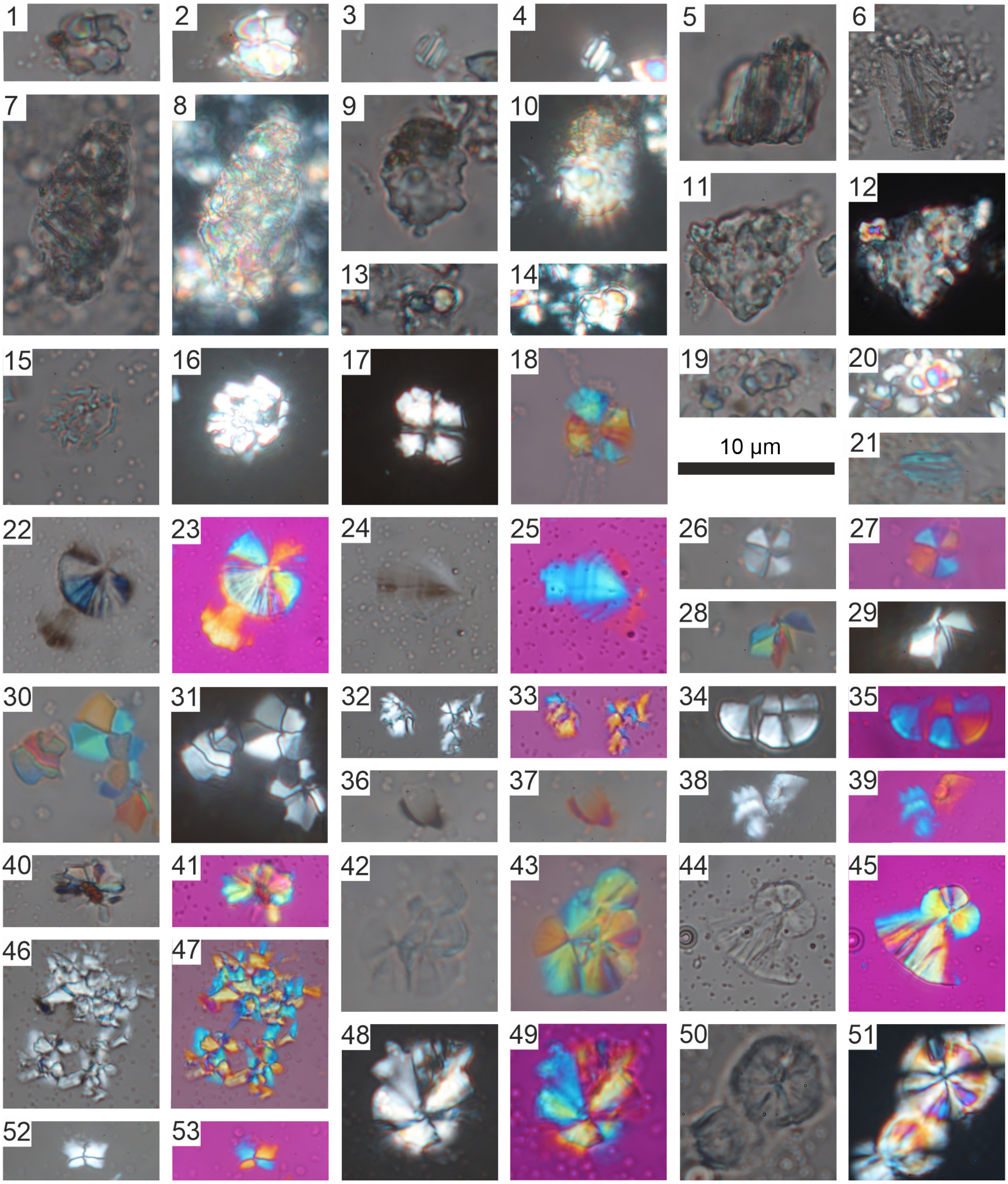


Fig. 26. Cretaceous nannofossils of the sites 307 and 238. **1-20** sample 307: **1-2** *Braarudosphaera primula* Black, **3-6** *Calcicalathina alta* Perch-Nielsen, **7-8** *Nannoconus* cf. *dauvillieri* Deflandre & Deflandre-Rigaud, **9-10** *Nannoconus elongatus* Brönnimann, **11-12** *Nannoconus vocontiensis* Deres & Achéritéguy, **13-14** *Owenia hillii* Crux, **15-16** *Phosterolithus prossii* (Herrle & Mutterlose) Aguado, reworked?, **17-18** *Quadrum eneabrachium* Varol, **19-20** *Tranolithus* sp., **21-40** sample 238: **21** *Lucianorhabdus maleformis* Reinhardt, **22-25** *Boletuvelum* sp., **26-31** *Braarudosphaera bigelowii* (Gran & Braarud), **32-33** *Calculites* sp., **34-35** *Calculites obscurus* (Deflandre) Prins & Sissingh in Sissingh, **36-37** *Ceratholithoides* sp., **38-39** ?*Cylindralithus* sp., **40-41** *Eprolithus rarus* Varol, **42-45** *Lucianorhabdus* aff. *arborius* Wind & Wise in Wise & Wind, **46-47** *Micula concava* (Stradner *in* Martini & Stradner) Verbeek, **48-51** *Petrarhabdus copulatus* (Deflandre) Wind & Wise in Wise, **52-53** *Uniplanarius gothicus* (Deflandre) Hattner & Wise, in Wind & Wise. The scale bar is 10 µm. Fossils under plane-polarised light are 1, 3, 5-7, 9, 11, 13, 15, 19, 21, 22, 24, 26, 28, 30, 36, 42, 44, 50; under cross-polarized light are: 2, 4, 8, 10, 12, 14, 16-17, 20, 29, 31, 32, 34, 38, 40, 46, 48, 51, 52, under cross-polarized light: and gypsum plate are: 18, 23, 25, 27, 33, 35, 37, 39, 41, 43, 45, 47, 49, 53.

Discussion

Based on our study, we present the distribution of formations observed in the area, highlighting new occurrences and biostratigraphical data (Fig.27). For details, see the chapter "Description of the Studied Sites."

The oldest formations, including terrestrial **Carboniferous shale** and the **Middle Permian Gröden Sandstone,** are outcropping at the southernmost points of the studied area, at Kisovec Hill and Marija Reka sections. The formations were identified based on their litho- and microfacies.

After a large gap, the Mesozoic series starts with the so-called **Mendole Formation**. This formation was detected at the westernmost observation point (site 676) and Kisovec Hill (site 667) (Fig.27). Site 676 had different classifications, Lower Triassic basinal carbonate (Premru, 1983a) and Bača Dolomite (Buser, 2010). This paper presents the first microfacies description of this formation at Kisovec Hill. Previous geological maps (Buser, 1977, 2010; Premru, 1983a) described this succession as Middle-Upper Triassic Platform Carbonates. The litho- and microfacies, as well as the foraminiferal fauna of these two sites, are very similar despite their relatively large distance (more than 22 km) and patchy occurrence. The foraminifera fauna (*Turriglomina mesotriassica* and *Paratriasina* sp.) indicates the latest Anisian–early Ladinian interval. At the base of the Šmiglov hrib section, the light-grey dolomite (site 683) may also belong to this formation or to the Ladinian–lower Carnian Schlern Dolomite. Previously, Grad (1969) interpreted this part as Pseudozilian Fm. which was reinterpreted as Jurassic (Buser, 1977) and later, to Cretaceous Lower Flyschoid Formation (Buser, 2010), as indicated by the map (Fig. 1).

The next two formations, namely the Ladinian siliciclastic-volcanoclastic **Pseudozilian** and platform carbonate **Schlern** formations, interfinger in the middle-upper part of Krvavica (Fig. 2, 27) and probably also in the Osreški grič section (Pseudozilian Fm: 690b and 690?; Schlern Fm. sites 690?). In the latter section, previously only the Pseudozilian (Premru, 1983a) or Lower Flyschoid formations were mapped (Buser, 2010;). While, in the Šmiglov hrib section, the Pseudozilian Formation (sites 326 d, c, b, a, f) overlies the Mendole Formation or Schlern Fm. (sites 683 and 684) with a thickness of nearly 200 m (Fig. 20). It means that the entire Šmiglov hrib sequence is Triassic, not Cretaceous as previously thought (Buser, 2010).

The Pseudozilian Formation was identified based on its lithofacies and microfacies, as only a few non-age-indicating benthic foraminifera were found in the Krvavica section. From the Krvavica section in the west to the northern Marija Reka section and further east, the Pseudozilian Formation has been confirmed at the base of the Brložen section (Fig. 8, site 254, Buser, 1977; Premru, 1983a), in several individual sites. It is found in the northern part of the Marija Reka section (Fig. 5, sites 558 and 557), where it lies structurally above the Cretaceous formations. This tectonic contact was postulated by previous authors to be the Marija Reka Fault. Its western continuation is south of the Krvavica Mt. (Grad, 1969, Lapanje & Šribar 1973; Buser, 1977).

The **Schlern Formation** was identified with the help of its lithofacies and microfacies as well as the shallow-water microfossil assemblage of the Krvavica section (Fig. 2, site 574). The age-determining benthic foraminifers, such as *Angulodiscus minutus* and *Gheorghianina vujisici,* suggest lower Carnian–Norian age. It also occurs at the base of the Sveti Miklavž section at the Reška Planina. The map indicates a narrow strike of platform carbonate just east of the section (Fig. 1b) and our new data confirms this. It is important to mention, that the platform carbonate does not form a continuous belt between Pseudozilian and the Biancone formations; it is missing in some cases, for example from the Brložen section.

In the upper part of the Krvavica section (sites 573, 574, and 572), the **Schlern Formation** interfingers with the dark grey pelagic marlstone (only detected from scree), the uppermost **Pseudozilian Formation** or the Amphiclina Beds. At the lower part of the Marija Reka section (site 560), the pelagic limestone with thin-shelled bivalves and ammonite and the fossil-free dolomite above it (sites 647, 646, and 645) most probably belong to this formation or the Amphiclina Beds. It should be noted that dolomite may be part of the Schlern Dolomite or the Norian-Rhaetian Bača Dolomite, so the section could belong either to DTZ or SB succession. At site 671 (at the western part of the studied area), dark grey limestone with rich and diverse Upper Triassic shallow-water fossil assemblage (benthic Foraminifers, Vermes, and Bivalvia) crops out. This rock can be attributed to the upper part of the Carnian **Amphiclina Beds.** Although in general the lithostratigraphic attribution of the Ladinian to Carnian mixed siliciclastic, volcanoclastic and carbonate succession is difficult in this case the continuation of this section to the overlying Bača Dolomite at site 055 may support their classification to the SB succession (Buser, 2010; Placer, 2008).

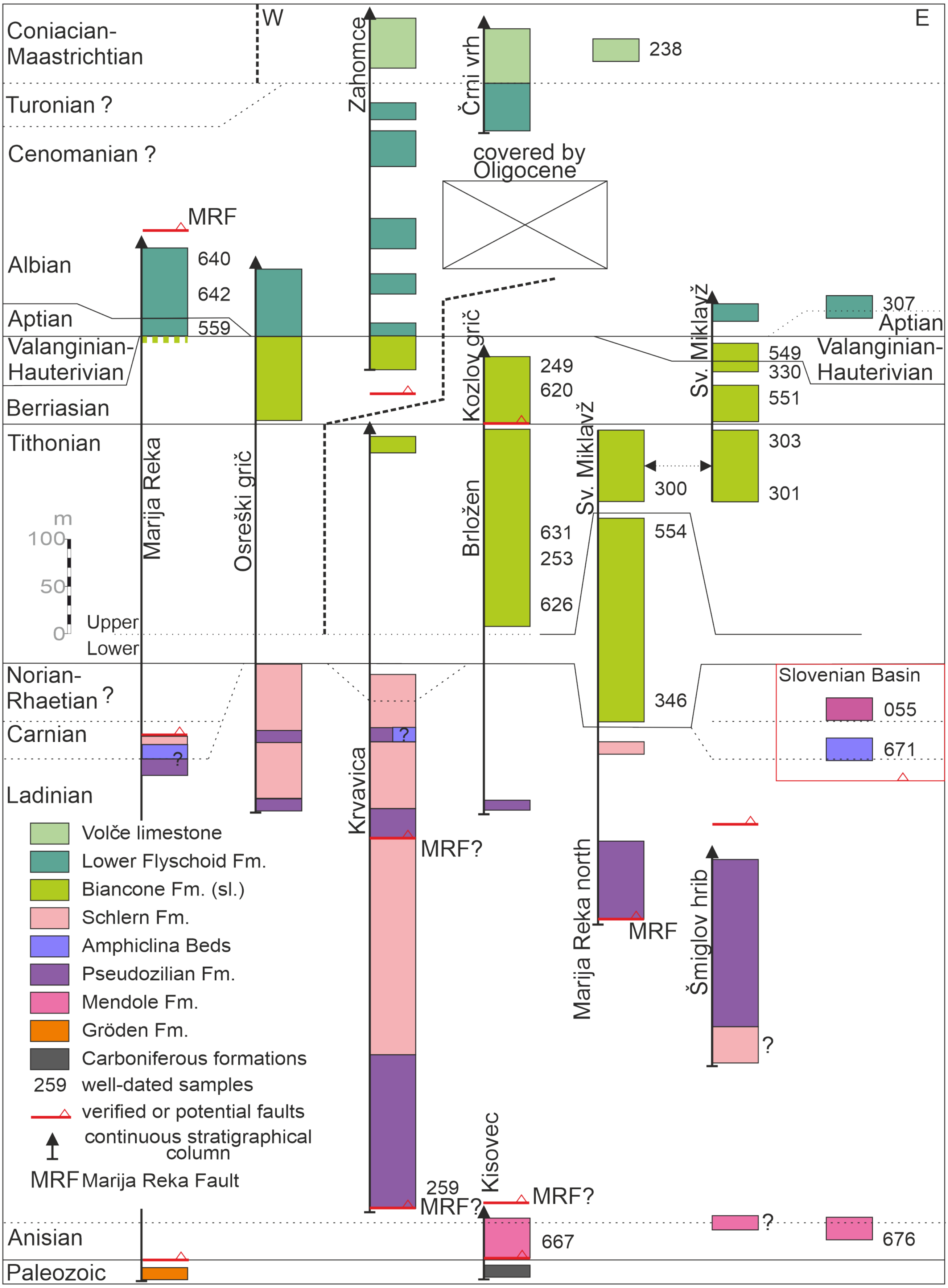


Fig. 27. Correlation of the formations in the discussed composite sections. All of the successions belong to the DTZ, except for the outcrops at 671 and 055, which belong to the SB. Detailed sections are presented in chapter Description of the Studied Sites. Site numbers are shown where age data has been determined in this study. Formation ages at other sections are based on literature. Question mark (?) indicates uncertainties in the determined formation or fault-line. Sections are in a west-east order except the Marija Reka section, which is split by the MRF, for their placement see (Fig. 1) thick dashed line is separating successions visually.

Age distribution of the Biancone Formation

After a major sedimentary gap, the Upper Jurassic–Lower Cretaceous Biancone Limestone appears. The macroscopic appearance of the formation compared to the so far studied sections of the central SB in western Slovenia (Rožič & Rehákova, 2024) and the studied area does not match entirely. In the studied sites, chert layers or nodules are almost never found. Their colour is light grey to ochre, mottled and spackled with ochre. In addition, calcarenite interbeds are common in the studied sites, whereas they are almost absent in the SB.

Thus, all rocks with lithofacies resembling this one were classified as the Biancone Formation sensu lato (Fig.27). This thin-bedded micritic limestone, often with marl, shale, and calcarenite intercalations, appears in most sections, except the Marija Reka (where the age of the rock is younger despite the facies), Šmiglov hrib, and Črni Vrh sections. Its thickness varies roughly between 20 m (Kvravica section) and 200 m (Brložen section). The tectonic repetition of layers within a section was not detected. A few age-indicator chitinoidellids, calpionellids, c-dinocysts, calcitarch, and microproblematica occasionally appear in the thin-sections. The ages of four sites (sites 303, 299, 330, and 549 in the Sveti Miklavž section) are based on nannofossils. In the calcarenite layers, mainly the benthic foraminifers and green algae serve as age-diagnostic taxa.

The oldest biostratigraphic data from the Biancone Formation originate from the two calcarenite beds (site 346 and 554b) in the lower part of the ~200 m thick Sveti Miklavž section. The rocks yielded relatively diverse microfossil assemblages dominated by benthic foraminifera and Dasycladales. *Clypeina jurassica* (=*Aloisalthella sulcata*) was also likely identified from this location by Lapanje & Šribar (1973, pl. 2, fig. 1). Based on the co-occurrence of *Tethysicodium elliotti* and *Labyrinthina mirabilis,* the age of these beds is early Tithonian. The oldest known occurrence of the Biancone Limestone in the Southern Alpine–Dinaric Realm dates back to the late Tithonian (e.g., Goričan et al., 2012; Rožič et al., 2014; Rožič & Reháková, 2024). We note that fossils redeposited from the platform can be older than the sediment in which they were buried in a hemipelagic environment. However, this possibility is ruled out by the taphonomic nature of the fossils (e.g., even the most fragile skeletons are preserved, lithoclasts are missing). We assume that these layers correspond to the first sediments after the Early to Middle Jurassic sedimentary gap, which is dated to the late Kimmeridgian–lower Tithonian (Buser, 1986; Rožič et al., 2014). In the western outcrops of the SB, the oldest part of the Biancone Formation is coeval with the uppermost part of the Tolmin Formation. There in the Kimmeridgian–early Tithonian part of the formation, calcarenites are described within the radiolarites (Rožič, 2009; Goričan et al., 2012 a). Those calcarenites have a similar composition to those observed at the Sv Miklavž section.

Upward, the age of the two nearly 75 m thick subsections is late Tithonian, NJ18 Nannofossil Zone based on the co–occurrence of *Cyclagelosphaera brezae, Hexalithus noeliae,* and *Conusphaera mexicana* (Fig. 15, in sites 303 and 299). The appearance of the upper Tithonian–lower Aptian benthic foraminifera, *Neotrocholina valangiana* (site 300), coincides with it (Fig. 27).

The Biancone Limestone of the Brložen section is also late Tithonian in age. With the help of chitinoidellids and calpionellids, it was possible to divide succession into calpionellid zones and subzones. The appearance of the *Chitinoidella boneti* and the absence of other calpionellids verify the lowermost upper Tithonian *Chitinoidellids* Zone, the *Boneti* Subzone (sensu Benzaggagh, 2020) in the lowermost bed of the section (site 555). It is worth mentioning that this is the oldest calpionellid zone demonstrated from the DTZ succession of the Mt. Rudnica, located within the Sava Folds (Reháková & Rožič, 2019). The next 60 m of the section belongs to the lower upper Tithonian *Crassicolaria* Zone or A Zone, Chitinoidellids/Primitive Calpionellids Subzone or A0 Subzone (sensu Benzaggagh, 2020) or *T. remanei* Zone (sensu Reháková, 2000), based on the occurrence of *Calpionella alpina, Chitinoidella boneti, Ch. elongata*, and *Crassicolaria intermedia, Praetintinnopsella andrusovi, Tintinnopsella carpathica* (sites 625, 626 and 628a). This calpionellids zone was also identified by Rožič & Reháková (2024) from the western SB.

In the upper part of the Brložen section (from site 628), *Tintinnopsella carpathica*, *Calpionella alpina, Crassicolaria intermedia,* and *Tintinnopsella remanei* indicate the middle upper Tithonian Tintinnopsella Intermedia Subzone (A1) of the *Crassicolaria* Zone. The calcareous dinoflagellate cysts, such as Colomisphaera carpathica and C. fortis, C. alpina, and Crustocadosina semiradiata, which appear together with the calpionellids, reinforce this age. The microfossil association of the calcarenite bed (site 253), including *Redmondoides lugeoni, Nautiloculina oolithica, Mohlerina basiliensis, Protopeneroplis striata, Neotrocholi-*

na valdensis, Coscinoconus alpinus, *Trocholina* cf. *conica*, *Thaumatoporella parvovesiculifera*, *Aloisalthella sulcata* suggests also a late Tithonian age.

We could not confirm the presence of the uppermost Tithonian and lower–middle Berriasian calpionellid zones in the studied area due to the lack of calpionellids or other age-indicator fossils. We should not assume a lack of sediment in succession but rather explain the lack of finding them by the rarity of calpionellids and the post-diagenetic alteration of the rocks. One possible occurrence of these layers is at Osreški grič (~80 m, site 689d), Krvavica (~25 m, site 367), and Zahomce (~30 m, site 318) sections; however, these sections have not been studied in detail to date. Another possible occurrence of these layers could be the bottom of the Kozlov grič section and the uppermost sub-section of the Sveti Miklavž section.

The lowermost 20 m of the marl succession of the Kozlov grič section did not yield age-determining fossils.

From two micritic layers (sites 620 and 249p) the upper Berriasian, *Calpionellopsis* Zone, *Oblonga-Simplex* (D2) Subzone or *Oblonga* Subzone (sensu Allemann et al., 1971) could be proven based on the *Calpionellopsis oblonga, Tintinnopsella carpathica, C. simplex, Lorenziella plicata-hungarica, Stomiosphaera moluccana,* and *S. proxima*. Higher up (site 623), the appearance of the upper Oxfordian–lower Valanginian *Colomisphaera lapidosa* also supports this age. The microfossil assemblages of the calcarenite beds (sites 616, 621, 622, 249k, c) are diverse, consisting of platform-dweller forms such as benthic foraminifers, Echinodermata, green algae, microproblematica, algae, Porifera, Stromatoporoides, Vermes, and Bryozoa. In the larger foraminifers- and involutinid-dominated foraminifera fauna, the co-occurrence of *Pfenderina neocomiensis, Coscinoconus campanellus,* and *Frentzenella involuta* suggests the late Berriasian–Valanginian age. It is consistent with the late Berriasian age obtained from the calpionellids.

The sample examined from the Sveti Miklavž section (site 551b) did not contain age-indicating fossils. Upwards (site 330), after a gap, the lowermost Cretaceous nannofossils assemblage was found containing *Nannoconus kamptneri, Nannoconus gr. kamptneri, N. colomii, N.* gr. *circularis, N.* sp., *Cyclagelosphaera brezae, Palaeomicula maltica*, and *Assipetra* sp. These taxa indicate the lower Berriasian–upper Valanginian (NC1–NC3 zones). Higher up in the section (site 549), the Valanginian–Hauterivian age (NC3–lower NC5 zones) is plausible based on the nannofossils, such as *Cyclagelosphaera deflandrei* and *Staurolithites pseudocarinolithus*. These latter ages are slightly younger than the late Berriasian (Calpionellopsis Zone, Oblonga Subzone) age established based on previous calpionellid studies (Reháková & Rožič, 2019; Rožič & Reháková, 2024). However, it is worth noting that at the upper boundary of the sections examined in these older studies, the much younger Lower Flyschoid Formation was deposited with disconformity.

Summing up, the stratigraphic range of the Biancone Limestone sensu lato in the studied area is early Tithonian–earliest (?) Valanginian. It means that we have identified layers of this pelagic formation in the Sveti Miklavž section that are slightly older and slightly younger than the generally accepted late Tithonian–late Berriasian age in the SB (e.g., Cousin, 1981; Rožič & Reháková, 2024) as well as DTZ successions (Reháková & Rožič, 2019). It is important to emphasise that classical SB has radiolarites of the Tolmin Formation and above the Biancone Limestone overlain by a sharp contact (Rožič & Reháková, 2024). Whereas in areas closer to DCP, the succession below the typical calpionellid-bearing Biancone limestone is also rich in calcareous content. These are characterized by limestones rich in chert nodules and beds. (Rožič et al., 2014). Similar succession rich in the Upper Jurassic (hemi) pelagic carbonate is reported also from the Bovec Trough from the NW Julian Alps (Šmuc, 2005; Šmuc & Goričan, 2005). In the same area, the Valanginian–Hauterivian nannofossil associations and the upper Valanginian–lower Hauterivian radiolarian zone (UAZ 17–18 of Baumgartner et al., 1995) were mentioned in this formation (Buser, 1979; Goričan & Šmuc, 2004; Šmuc, 2005). Similarly, in the NW Dinarides, the pelagic limestone ranges from the Tithonian to the end of the Hauterivian (e.g., Cadet, 1978; Lužar–Oberiter et al., 2012).

The depositional environment of the Biancone Limestone formation in the studied sites may have been a pelagic-hemipelagic basin above the CCD. Debris from the nearby platform was periodically transported into this basin. Only in the Kozlov grič section were extraclasts of ophiolitic origin found in the calcarenite layers. In the oldest part of the formation (site 346, Sveti Miklavž section, Fig. 15), the Charophyte gyrogonites, while in the youngest part (sites 551b, 549, Sveti Miklavž section), the remnants of terrestrial plants indicate a freshwater influence.

The geographical distribution of the Biancone Limestone formation is much larger within the northern Trojane anticline than what is depicted on the latest geological map of the area (Buser, 2010). Additionally, without exception, these layers were formerly classified as Lower Flyschoid Formation. In contrast, the occurrence of the Biancone Limestone, as indicated in the easternmost part of the area (site 307), is now attributed to the Lower Flyschoid Formation based on our investigations.

Sandstone bed in the Biancone Formation

In the lowermost 20 m of the marl succession of the Kozlov grič section a nearly 2 m-thick grey, cherty sandstone bed (site 614) occurs. In addition to few fossils, rock fragments and heavy mineral grains typical of sandstones originating from the ophiolite series are present. Sandstone beds in a marl succession with similar composition are known from several gravity-flow dominated successions. Examples include the Berriasian–lowermost Albian Rossfeld Formation of the Eastern Alps (Pober & Faupl, 1988), the Valanginian Studor formation of the Bled Basin (Slovenia, Kukoc et al. 2012), the Oštrc formation in Croatia (Lužar-Oberiter et al., 2012), and the late Berriasian–Hautrivian Bersek Marl in the Gerecse Mountains, Hungary (Császár & Árgyelán, 1994; Árgyelán, 1996). It has been demonstrated that the material of the rock fragments originates from the Dinaric Ophiolite Belt (e.g., Pober & Faupl, 1988; Császár & Árgyelán, 1994; Kukoč et al., 2012; Lužar-Oberiter et al., 2012; Goričan et al., 2018). This work presents the first discovery of these lithofacies within the Biancone Formation of the Sava Folds. Because of the isolated occurrence of this sandstone bed, the palaeogeographic position of the northern Sava Fold area was far from the ophiolite source.

Lower Flyschoid Formation and Volče Limestone Formation

In the studied area, from west to east, we were able to identify the Lower Flyschoid Formation in the following sections: Osreški grič section (sites 689 d, c, a, 80 m), Zahomce section (sites 318, 317, and 320) Črni Vrh section (sites 235 and 706a), Sveti Miklavž section (site 686), Marija Reka section (sites 644, 559, 643, 642, 642c, 641, 556c, 640, 556, 639, 638) and site 307 (Fig.27). In the Osreški grič, Zahomce, and Sveti Miklavž sections, it overlies the Biancone Limestone with disconformity. The Marija Reka section is exceptionally deposited directly on the Triassic strata, which might indicate a tectonic contact in this area.

The identification of the formation was based on the typical lithofacies, except for the Marija Reka section and site 307, where microfacies analysis and nannofossil examination were also performed on the samples. The succession consists of the dense alternation of dark grey or purplish-red thin-bedded marly-limestone, marl or shaley argillaceous marl, with dark-grey calcarenite, breccia and chert layers, or limestone with chert nodules. Upwards, the alternation of different rock lithofacies becomes more frequent, and the marl content increases. The texture of the marly layers is dominantly wackestone, packed biomicrite with planktonic and benthic foraminifers and c-dinocysts. Calcarenite beds have a grainstone, poorly washed biosparite texture and contain mainly benthic foraminifera as fossils.

In the Marija Reka section, the ~25 m sequence overlying the Triassic formations differs from those described above. The rock is light grey, ochre-mottled, cherty limestone with marly intercalations. The texture is mudstone, fossiliferous biomicrite with scattered opaque minerals and poorly preserved radiolarians, c-dinocysts, chitinoidellids, calpionellids, calcitarchs, and benthic foraminifers. The appearance (site 559) of Parachitinoidella cuvillieri indicates a late Aptian age within the *Colomiella* Zone and *Deflandronella* Subzone (Trejo, 1975). Upward (site 643), the occurrence of *Colomiella recta* suggests the younger subzone of the *Colomiella* Zone, the uppermost Aptian–lowermost Albian, *C. mexicana* Subzone (Trejo, 1975). The lithofacies, microfacies, and fossil groups of the rock are very similar to those of the Biancone Formation; however, the age is significantly younger, as indicated by the presence of calpionellids and chitinoidellids, which is also confirmed by the occurrence of *Cadosina disiuncta*. It is important to note that this is the first confirmation of the existence of the upper Aptian layers of the Lower Flyschoid Formation, which several previous authors assumed based on foraminifers (Caron & Cousin, 1972; Caron in Cousin, 1981; Samiee, 1999; Brajkovič et al., 2022; Schlagintweit et al., 2024) or radiolarians (Rožič et al., 2014).

Above this pelagic limestone macroscopically resembling the Biancone s.s Formation, the classic development of the Lower Flyschoid Formation appears in the Marija Reka section. The uppermost middle Albian *R. subticinensis* Subzone of the *B. breggiensis* Zone is indicated by the co-occurrence of the *Biticinella breggiensis* and *Thalmanninella praebalernaensis*. Upwards (from site 641), the existence of the *Calcisphaerula*? *innominata lata* and *Ticinella primula* suggest that layers were deposited in the late Albian. From site 556, the succession belongs to the uppermost Albian *R. appeninica*

Zone, based on the concomitance of *Muricohedbergella delrioensis, Planomalina buxtorfi, Biticinella breggiensis*, *Ticinella madecassiana,* and *T. praeticinensis*. The benthic foraminifera fauna of the calcarenite beds consist predominantly of agglutinated forms, but no orbitolinids were found. Based on the involutinids (*Coscinoconus* sp. and *Frentzenella* sp.) recovered from the uppermost 10 m of the Marija Reka section, the succession cannot be older than Cenomanian.

According to previous geological maps (Buser, 2010), the rocks at the southern part of the Marija Reka section were classified as the Upper Cretaceous Volče Limestone but were previously mapped as Lower Flyschoid or equivalent Cretaceous formations (Lapanje & Šribar, 1973; Buser, 1977). This 90 m thick sequence is likely to belong to the Lower Flyschoid Formation. Their figured orbitolinid fragments (pl. 1, fig. 2; pl. 2, fig. 2) cannot be assigned to a species. Their specimen identified as *Globotuncana* sp. (pl. 1, fig. 1) is likely a rotaliporid and can be attributed to the Albian–Cenomanian genus *Thalmaninella*. Buser (1977) similarly marked the area as Upper Cretaceous limestones, this corresponds with the age of the Lower Flyschoid Formation.

In the eastern observation point (site 307) of the studied area, the benthic foraminifera fauna of the calcarenitic bed indicates an Aptian–Albian age. At the same time, in the marl layer, the appearance of *Braarudosphaera primula* within the nannofossil association narrows down the age of the formation to the late Albian.

The age of the Lower Flyschoid Formation in the studied area is late Aptian–latest Albian (early Cenomanian?).

By comparing the new data with the classification of the latest geological map (Buser, 2010), the following can be established. The Lower Flyschoid Formation occurs at its greatest thickness (300 m) in the Zahomce section, it overlies the Biancone Limestone and is overlain by the Volče Limestone. (see below). The situation is similar in the Osreški grič section (where it is 80 m thick), where the Biancone is underlying, and in the Črni Vrh sections (here 50 m thick), where the Volče Limestone is overlying the formation. While the map of Buser (2010) indicates the Lower Flyschoid Formation throughout the entire area of the Sveti Miklavž section, it is only present at the very top of the section with a thickness of a few meters. As mentioned above, the map indicates the Biancone Formation at site 307. The largest difference was observed in the Marija Reka section, where it appears to be 100 m thick. It was mapped as Triassic Platform Carbonates and the surrounding Cretaceous formations were classified as the Krško beds of late Cenomanian Turonian age (Lapanje & Šribar, 1973; Buser, 2010).

Based on its lithofacies, the Coniacian–lower Maastrichtian Volče Formation is identified in three locations within the studied area: at the top of the Zahomce (site 688) and Črni vrh (sites 706b, 234, 705) sections, as well as east of these sections, at site 238. The nearly 60 m Scaglia-type succession consists of alternating thin-bedded ochre – light grey pelagic limestones and calcarenite, calcirudite, or microbreccia. The thickness of the latter beds can reach 10 meters at the bottom of the sequence, becoming thinner upwards. A nannofossil study was carried out from the marl sample of site 238. The co-occurrence of *Petrarhabdus copulates* and *Eprolithus rarus* refers to the Campanian age (UC13–UC16 zones). However, further detailed studies should be done on this formation to consolidate its stratigraphic frame.

The youngest formation in the studied area is the Oligocene siliciclastic Trbovlje Formation. It was identified only at the uppermost part of the Krvavica section (site 366) and near site 238 based on its lithofacies, namely sandstone, siltstone, conglomerate and breccia. This more than 20 m thick succession covers the Biancone, Lower Flyschoid and Volče Formations and is built up of variegated grey–ochre breccia, siltstone and sandstone beds. Its appearance in the investigated area agrees with the geographical distribution marked on previous maps (Grad, 1969; Buser, 1977, 2010; Premru, 1983).

Summary of the lithostratigraphic results

From the studied sections we reconstructed several lithostratigraphic columns which are marked by arrowhead lines on Fig. 27. Sometimes the successions are probably cut by minor faults like in the Marija Reka section. The continuity of sections into a single column is not always certain, partly because of the presence of structural complications. Although probable tectonic disturbances (folding and/or faulting) are present in the Brložen and Kozlov grič sections, they are considered to form one lithostratigraphic column. Their ages are complementary, Tithonian and Berriasian, respectively. The composite Sv. Miklavž section forms a single stratigraphic column although an overlap can exist in the Tithonian part (Fig. 27). The northern part of the Marija Reka section is the base of the stratigraphy at this succession although the Pseudozilian was not surveyed in detail. At its southern end the Šmiglov hrib section is separated by a fault and the opposite bedding dip from the Sv. Miklavž section and it is in contact with the Oligocene rocks to the north (Fig. 1). Although a tectonic contact between the Kisovec Hill and Krvavica sections is possible, they can also form a continuous stratigraphical column because the two sections apparently form a youngening succession without repetition or gap. The Črni vrh section can be the continuation of the Krvavica section, although they are shifted along strike and the Oligocene covers the transition (Fig. 1, 27).

All these constructed successions share the same formations, although thickness variations can occur (Fig. 27). They all have a similar Triassic succession with basinal and platform development. Their age can be Ladinian to early Carnian, with a supposed continuation into higher Late Triassic in the Krvavica section. These are followed by the Biancone Formation, with a large hiatus. The pelagic limestone start earliest in the Tithonian. Another specialty is the Aptian thin-layered limestone at the Marija Reka section which is considered as the lower Flyschoid Formation according to its age, but with macroscopic appearance similar to the Biancone Fm. The Lower Flyschoid Formation is unequivocally present, while the Volče Limestone could have been eroded during the Cenozoic from some sections.

All these led to the conclusion that sections described in this paper belong to the palaeogeographic and tectonic unit determined by Placer (1998b, 2008) as the DTZ (Dinaric Transition Zone). From all locations presented in this paper only at one (sites 055 and 671) we could clearly confirm that the formations belong to the SB succession as suggested previously (Buser, 2010; Placer, 1998b, 2008). Other SB successions were identified in the area situated south from the supposed Marija Reka Fault, like on the Čemšeniška Planina (Fig. 1, Scherman et al. 2023). All the studied new sections and stratigraphical columns lie north of this important fault expect for the Marija Reka section itself. The position of the Krvavica section is not clear, could be south or north from the western branch of the MRF or this latter dissects in two the section itself. This shows that the Dinaric successions reappear north of the Slovenian Basin succession, involving the nappe position of this latter, as indicated by previous studies (Placer, 1998b, 2008; Buser 2010, Rozic et al 2019; Fig. 1b).

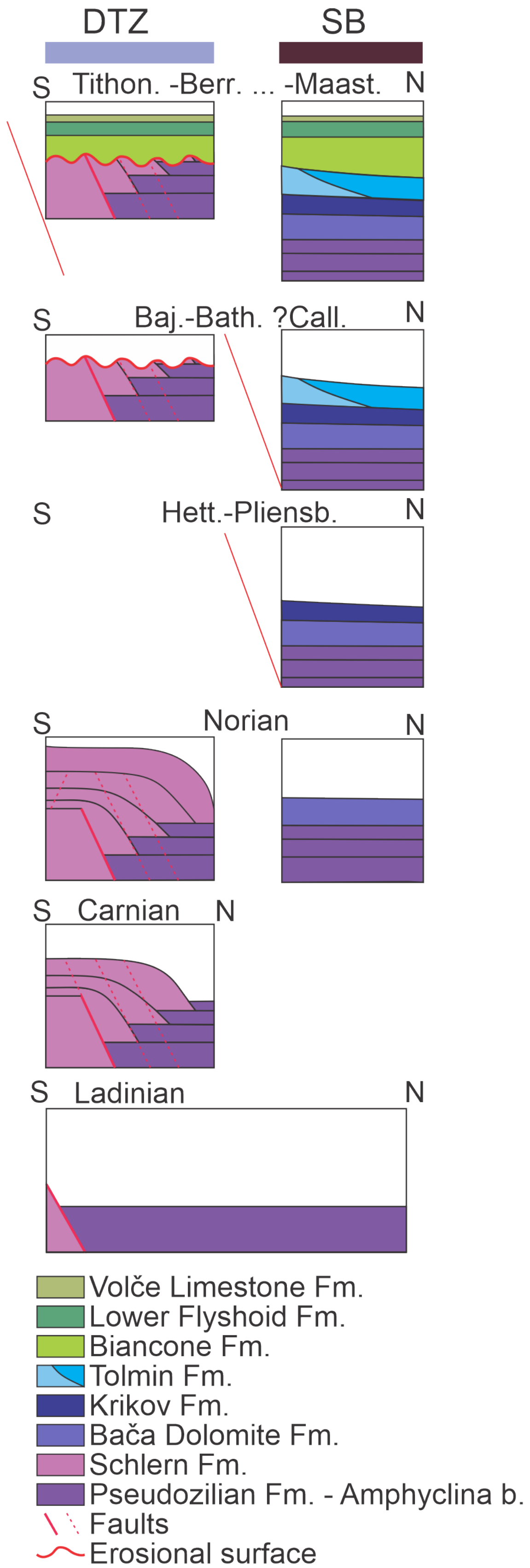


Fig. 28. Comparison of the Mesozoic evolution of the Dinaric Transitional Zone (DTZ) and Slovenian Basin (SB) during the Ladinian – Maastrichtian interval. Abbreviations: Hett.: Hettangian; Pliensb.: Pliensbachian; Baj.: Bajocian; Bath.: Bathonian; Call.: Callovian; Tihon.: Tithonian; Berr.: Berriasian; Maast.: Maastrichtian.

Evolution of the Slovenian Basin and Dinaric Transition Zone

In this paper we presented new stratigraphic and sedimentological findings from the DTZ successions of the northern Sava folds. Combined with previously published studiees of the basinal successions from the same area (Scherman et al., 2023), the paleogeographic evolution of this segment of the Greater Adria margin (Schmid et al. 2020) can be better constrained. The history of the SB and the DTZ began during the Ladinian with the fragmentation of the unified Anisian Mendole Formation (e.g., Rožič et al., 2017). During the Ladinian and early Carnian, a siliciclastic and volcaniclastic deep-marine Pseudozilian formation was deposited in both paleogeographic units. After the main tectonic/volcanic period, the platform prograded above the entire DTZ area, whereas SB remained deep-marine until the end of Cretaceous. A fault-controlled margin of the platform is postulated but not confirmed within the study area (Fig. 28: Ladinian). Namely, solely the two end-member successions are observed here: the DTZ with late Ladinian-early Carnian platform carbonates (Schlern Formation) and the SB with a Carnian deep marine clastic and carbonate sequence (Amphiclyina beds). For this reason, a large thrust displacement is most probable between SB and DTZ successions which covers the gradual palaeogeographical and sedimentologic transitions between these two distinct palaeogeographical domains. At the Krvavica section, we observed the alternation of the platform and deep-water sediments. It could be interpreted as a platform-edge carbonate lobes prograding into the basin. Interestingly, the authors of the earliest works (Teller, 1907; Winkler, 1923) on the Trojane Anticline and the Tuhinj-Motnik Syncline already recognized this sedimentological phenomenon. However, as described before, the interpretation of structurally repeated boundaries between the Pseudozilian and Schlern formations would also be possible, considering the tectonic setting. Further detailed studies of this area should clarify the question. (Fig. 2. Fig. 28: Carnian).

Above the Schlern formation, the long stratigraphic gap marks the DTZ succession and is covered by the already deep marine Biancone Limestone Formation. This gap cannot be univocally explained, but in the neighbouring SB sedimentation continued and the Upper Triassic and Lower Jurassic shows rather distal basinal formations (Fig. 28). These are in sharp contrast to the overlying Middle Jurassic Ponikve breccia member of the Tolmin Formation (Scherman et al., 2023). In the wider area, this limestone megabreccia was recently recognized along the entire margin of the SB, assigned to the Bajocian–Bathonian and is interpreted to have originated during a major collapse of the Dinaric Carbonate Platform margin. Clasts in this breccia belong to the basin, slope as well as Upper Triassic and Lower Jurassic platform-margin carbonates. The collapse of the platform margin led to the first major post–Triassic retread of the platform margin (Rožič et al., 2019, 2022) and could also contribute to the origin of the described gap in the DTZ successions. The Middle Jurassic extensional deformation might have resulted in rift shoulder uplift, and this process could be associated with denudation and/or non-deposition during and just after the Mid-Jurassic extension. The denudation could erase the trace of the latest Triassic to Early Jurassic evolution of this segment of the margin.

Over a minor gap in the southernmost SB and a significant gap in the DTZ successions, a generally uniform sedimentation pattern was established in both paleogeographic entities. However, important differences still occur and are best recorded in the Biancone Limestone formation (Fig. 27: Tithonian). The formation is relatively thin (ranging up to several tens of meters) and composed almost entirely of pelagic limestone, near the Krvavica Section at the northern slope of Čemšeniška Planina (Scherman et al., 2023), but the thickness in DTZ (e.g. Brložen section) can exceed 100 m, and the succession spans a longer time interval. In contrast to the SB, in the study area the Biancone contains quite frequent resedimented limestones due to proximity of active Dinaric Carbonate Platform. Our results provide two other important pieces of information.

The onset of the Biancone Limestone Formation in the DTZ could be a combination of a substantial depression of the CCD (Weissert 1979) and probably a renewed tectonic subsidence, likely of post-rift character (Bertotti et al., 1993; Berra & Carminati 2010). Alternatively, the Tithonian subsidence can be a reflection of the subduction to obduction process along the eastern active Adriatic margin (Picotti & Cobianchi 2017). This tectonic pulse was so far poorly detected in mesoscale structures. In the form of latest Jurassic neptunian dykes From the Dinaric region, in the Julian Alps and the Alpine passive margin (e.g., Šmuc 2005; Črne et al., 2007; Whitmarsch & Manatschal, 2012; Rožič et al., 2018), slumps in the Biancone limestone in other localities (Rožič & Reháková, 2024) and origination of the Bohinj Breccia in the Bled Basin (Kukoč et al., 2012; Goričan et al., 2018).

In the studied Brložen section, syn-sedimentary normal faults were recognized, which caused slope instability associated with slump folds.

The second important information comes from the intercalated sandstone bed of the Kozlov grič section. The documented ophiolitic detritus was deposited in the early Cretaceous foreland basin situated on the thinned Greater Adria margin in front of the advancing obducted Neotethyan ophiolite sheets (Internal Dinarides) (Tari, 1994; Kukoč et al., 2012; Lužar-Oberiter et al., 2012; Goričan et al., 2018). In such a scenario, the studied paleogeographic domains were situated on the forebulge side of the foreland basin where slope instability occurred but was rarely reached by gravity mass flow deposits which derived from the ophiolite. A similar geodynamic-sedimentological situation was proposed for the northern Transdanubian Range segment of the foreland basin (Fodor et al., 2013; Sztanó et al., 2018).

The distinction between the SB and DTZ structural units is based on differences between the stratigraphic units and the overall absence of the Norian–lower Tithonian sediments in the described succession. Our results also indicate that the SB sediments marked in the Trojane Anticline and the Tuhinj-Motnik Syncline on the map of Placer (2008) largely belong to the DTZ palaeogeographic domain and not to the SB. In addition to stratigraphical complexities, the post-Mesozoic deformations largely rearranged the original palaeogeographical situation (Scherman et al., 2023). This calls for a reinterpretation or a redefinition of the Southern Alpine thrust front in this part of Slovenia, as both tectonic interpretations and stratigraphical and palaeogeographical observations should be considered in its definition.

Summary

In the Trojane Anticline and the Tuhinj-Motnik Syncline, located in the northern part of the Sava Folds, revision of selected parts of the Mesozoic successions was conducted. The formations were identified based on their stratigraphic position, litho- and microfacies, and biostratigraphic data.

The paper presents the lithofacies of nearly 120 selected observation sites, of which microfacies analysis and paleontological investigation were performed on ~70. Each litho- and microfacies type as well as all 141 identified microfossil taxa, is shown.

Biostratigraphy is mainly based on benthic (32 species) and planktonic foraminifera (14 species), calpionellids (12 species), and calcareous nannofossils (31 species). We also considered age-indicating forms belonging to other fossil groups, such as c-dinocysts (13 species), calcimicroba (1 species), microproblematica (6 species), Dasycladales (3 species), Porifera (2 species) and Vermes (1 species) (Tables 1–5). The following biozones could be identified in the formations: the calpionellids zones: Chitinoidellids Zone, *Boneti* Subzone, *Crassicolaria* Zone, Chitinoidellids/Primitive Calpionellids and *Tintinnopsella Intermedia* Subzones (from upper Tithonian to lower Valanginian), *Calpionellopsis* Zone, *Oblonga-Simplex* Subzone (upper Berriasian) and *Colomiella* Zone *Deflandronella* and *C. mexicana* subzones (upper Aptian–lower Albian); planktonic foraminifera zones as from *B. breggiensis* Zone *R. subticinensis* Subzone (uppermost middle Albian) to *R. appeninica* Zone (the uppermost Albian); and nannofossil zones: NJ18 (the upper Tithonian), NC1–NC3 (Berriasian–latest Valanginian), NC3– lower NC5 (Valanginian–Hauterivian), NC9–NC10 (upper Albian) and UC13–UC16 (Campanian).

For the palaeoecological interpretation, in addition to the fossil groups listed above, we also utilized semi-quantitative data from charophytes, terrestrial plants, radiolarians, stromatoporoids, gastropods, bivalves, ostracods, bryozoans, echinoderms, and the results of the microfacies analysis (Appendices 1–2).

The Mesozoic successions of the studied area belong to the Dinaric Transition Zone (DTZ), which is underlain by Palaeozoic clastics and Late Permian to Anisian carbonates. However, in the studied area, the Upper Permian and Lower Triassic strata were not recorded. In the Ladinian deep marine volcaniclastites siliciclastics and carbonates were followed by the re-established carbonate platform towards the Upper Triassic. The Ladinian and Carnian heterogenous sequences of deep-marine successions are under- and overlain by several generations of re-established carbonate platform successions. A long stratigraphic gap was followed by end-Jurassic to Cretaceous basinal formations comparable to those of the Slovenian Basin deposited. These include the lower Tithonian–lower Valangian Biancone Limestone s.l., the upper Aptian–upper Albian (Cenomanian?) Lower Flyschoid Formation and the Upper Cretaceous Volče Formation, which closes the sequence. Cretaceous formations correspond to Gora, Krško and Veliki trn formations from the southern Sava Folds.

The present-day geographic distribution of studied stratigraphic units differ from those shown on the existing geological maps. We found that either the spatial extent of units or their litho-

and/or chronostratigraphic definitions of older geological maps have to be updated. Our observations also indicate that vast areas of the northern Trojane Anticline and the Tuhinj–Motnik Syncline composed of the stratigraphic successions of the Dinaric Transition Zone. This indicates that this Dinaric transitional unit is present even north of the previously proposed Southern Alpine thrust front. They appear in this structural position due to north-dipping thrust faults. In consequence in the Sava Folds region, the lower structural boundary of the typical SB successions cannot be considered a clear marker for the Southern Alpine thrust front, which is in a strong contrast to the western Slovenian structural geometry.

Further systematic lithostratigraphic and structural geological studies are necessary to refine the existing geological maps, understand the structural evolution, and redefine the Southern Alpine thrust front.

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