Mesozoic deep-water basins of the eastern Southern Alps (NW Slovenia)

By

SPELA GORICAN, ADRIJAN KOSIR, BOSTJAN ROZIC, ANDREJ SMUC, LUKA GALE, DUJE KUKOC, BOGOMIR CELARC, ALENKA EVA CRNE, TEA KOLAR-JURKOVSEK, LADISLAV PLACER & DRAGOMIR SKABERNE

With 37 figures

Field Trip Guide

29th IAS Meeting of Sedimentology
Schladming, Austria

Addresses of the authors:
SPELA GORICAN, ADRIJAN KOSIR, DUJE KUKOC, ALENKA EVA CRNE
Paleontoloski institut Ivana Rakovca ZRC SAZU
Novi trg 2
1000 Ljubljana
Slovenia

BOSTJAN ROZIC, ANDREJ SMUC
Oddelek za geologijo NTF, Univerza v Ljubljani
Privoz 11
1000 Ljubljana
Slovenia

LUKA GALE, BOGOMIR CELARC, TEA KOLAR-JURKOVSEK, LADISLAV PLACER, DRAGOMIR SKABERNE
Geoloski zavod Slovenije
Dimiceva 14
1000 Ljubljana
Slovenia

Journal of Alpine Geology	**54**	**S. 101-143**	**Wien 2012**

Contents

Abstract

The field-trip deals with the eastern part of the Southern Alps where the South Alpine and the Dinaric structures now overlap. In Mesozoic times, this area belonged to the northeastern Adriatic continental margin which was facing the Meliata-Maliac-Vardar Ocean but was also close to the Alpine Tethys.

Several paleogeographic units are differentiated in the area. The Bled Basin occupied the most distal position on the continental margin. This basin was characterized by deep-water sedimentation from the Norian onwards and by a relatively early onset of flysch-type sedimentation in the Valanginian-Hauterivian. The Julian High was a pelagic plateau that formed when the Triassic to Early Jurassic carbonate platform (the Julian Carbonate Platform) was dissected into blocks, subsided and drowned. The Bovec Basin evolved during the Pliensbachian to the Bajocian on a more deeply subsided block of the same platform. The Tolmin Basin existed between the Julian High and the stable Dinaric Carbonate Platform from the Triassic to the end of the Cretaceous.

Based on the stratigraphic record, the Norian to Albian evolution of these sedimentary basins is divided into the following stages:

1) In the Norian and Rhaetian, the lagoonal Dachstein limestone and marginal coral reefs were deposited on the Julian Carbonate Platform. Limestones and dolomites with chert accumulated in the Bled and Tolmin basins. These deeper-water deposits include fault-derived coarse-grained breccias. Until the Pliensbachian, both basins were characterized by resedimented carbonates shed from the coeval Julian Carbonate Platform.
2) The main subsidence phase occurred in the Pliensbachian and is documented by a shift to deeper-marine facies rich in echinoderms and ammonites (incipient Bovec Basin) and the first generation of neptunian dikes on the subsided platform, coarse-grained breccia in the Bled Basin, and a change in composition of resedimented limestones (crinoidal limestones start to prevail) in the Tolmin Basin. The Toarcian was a tectonically quiet period. Clay-rich deposits including Lower Toarcian black shales are preserved in the Bovec and Tolmin basins.
3) The subsequent subsidence phase in the Bajocian caused a further deepening of the entire area. Up until the late Early Tithonian condensed Rosso Ammonitico type limestones accumulated on the Julian High, whereas the surrounding basins were characterized by radiolarian cherts and shales. Carbonate gravity-flow deposits, this time sourced from the Dinaric Carbonate Platform, were common in the Tolmin and Bovec basins, but absent in the Bled Basin.
4) In the Late Tithonian, the Biancone limestone started to accumulate in all paleogeographic units of the area. Berriasian limestone breccias in the Bled Basin provide evidence of an isolated carbonate platform that, after the ophiolite emplacement and uplift, formed in more internal Dinaric units and was later eroded. The overlying Valanginian-Hauterivian turbidites with clastic admixtures document the evolution of the Bled Basin into a typical foreland basin.
5) Around the Aptian-Albian boundary, the Early Cretaceous orogeny was intensified and caused a renewed subsidence (associated with an erosional event) in more external paleogeographic units. Coarse-grained polymictic breccias accumulated in the Tolmin Basin. The second generation of deep breccia-filled neptunian dikes on the Julian High was most probably also related to this tectonic event.

1. Topics and area of the field trip

This field trip focuses on the latest Triassic to Cretaceous sedimentary evolution and paleogeography of the Adriatic continental margin that is now preserved in the Julian Alps in NW Slovenia (Fig. 1).
Like elsewhere on the Adriatic continental margin, a well expressed horst-and-graben topography was created during the latest Triassic to Early Jurassic rifting phase. Remnants of four different deeper-water paleotopographic units are preserved in the field-trip area. Arranged according to their location on the continental margin (from relatively distal to more proximal), these units are: the Bled Basin (Stops 1, 2), the Julian High (Stop 6), the Bovec Basin (Stop 5) and the Tolmin Basin (Stops 3, 4). The most proximal paleogeographic unit was the stable Dinaric Carbonate Platform, which bordered the Tolmin Basin and is now exposed south of the field-trip area.
The following lithologies will be examined during this field trip:

- Shallow-water limestones (Upper Triassic to Lower Jurassic)
- Cherty limestones and dolomites (Upper Triassic)
- Calcareous gravity-flow deposits (from fine-grained low-density intrabasinal turbidites to debris flows, Jurassic and Cretaceous)
- Mixed carbonate-siliciclastic turbidites (Lower Cretaceous)
- Bedded radiolarian cherts (Middle and Upper Jurassic)
- Pelagic cherty limestones (Upper Tithonian to Neocomian Biancone limestone and Upper Cretaceous Scaglia rossa)
- Polyphase neptunian dikes

The field trip aims to discuss the sedimentary evolution of these locally recognized basins in the larger framework of the Adriatic continental margin. The relationship to regional synsedimentary tectonic events is introduced and a brief comparison with neighboring depositional basins of the Dinarides and the Southern Alps is presented. For the described area in NW Slovenia we give an extensive list of references relevant to the local geology. Only a few general papers are cited to give the necessary information on the wider regional framework. For geological maps of Slovenia, the reader is referred to the Basic Geological Map 1:100,000 (available online at the Geological Survey of Slovenia, http://www.geo-zs.si/), and to the compiled and updated version of the Basic Geological Map at scale 1:250,000 (Buser 2009).

2. Introduction

The field-trip area is located in the eastern part of the Southern Alps (Fig. 2) where the South Alpine and the Dinaric structures now overlap. In the Mesozoic and early Tertiary, this area clearly evolved as part of the NW-SE oriented Dinaric system (Placer 1999). Only later, in the Neogene, were the Dinaric structures overprinted by southward-directed Alpine thrusting (Doglioni & Bosellini 1987, Doglioni & Siorpaes 1990, Placer 1999). The nappe system in the research area derived from the continental margin of the Adriatic microplate. In the Middle and Late Jurassic, this part of the margin was facing the Meliata-Maliac remnant basin and the Vardar Ocean, which together formed a single branch of the Neotethys (Schmid et al. 2008), but was also close to the Alpine Tethys (see Fig. 3b).
During the latest Triassic and Early Jurassic, the continental margin experienced a major period of extensional tectonics related to the reorganization of lithospheric plates due to the breakup of Pangea and the formation of the Atlantic Ocean. An array of grabens and horsts was created by episodic differential subsidence

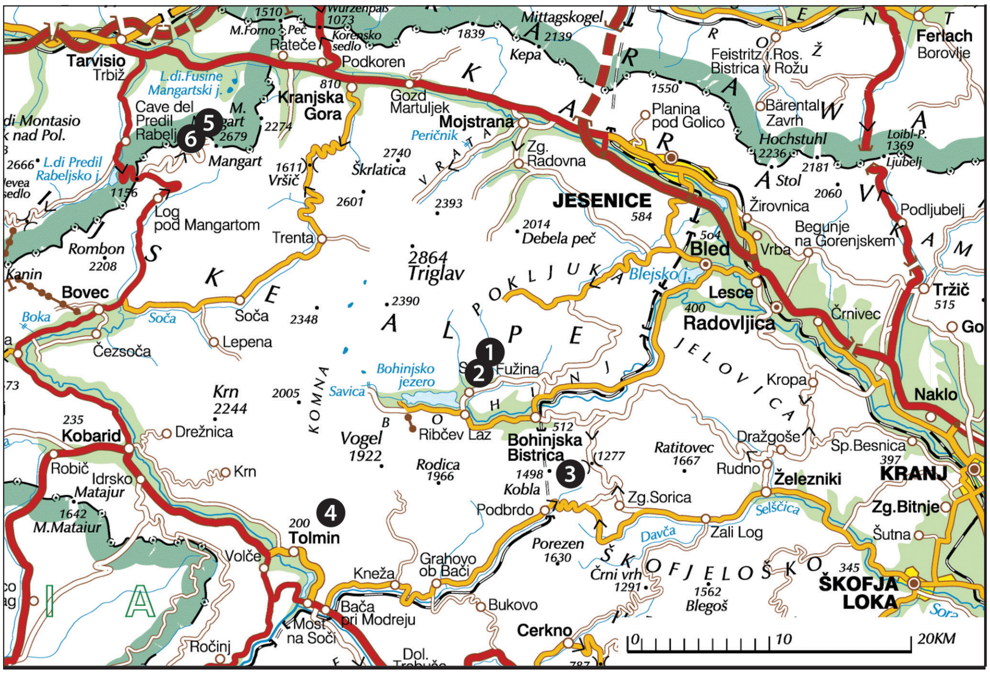


Fig. 1: Road map of NW Slovenia with locations of field-trip sections 1-6.

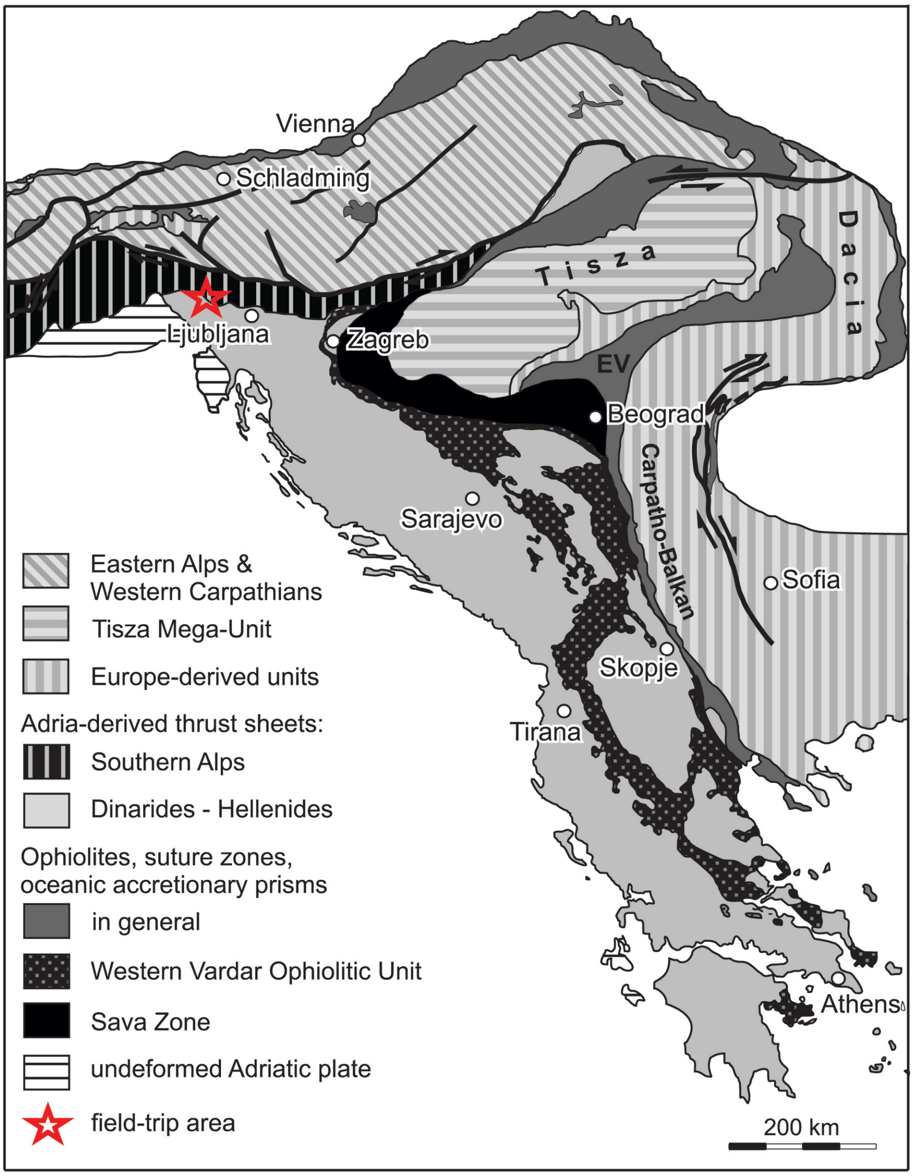


Fig. 2: Major tectonic units of the Alps, Carpathians, Dinarides and Hellenides (simplified after Schmid et al. 2008 and Ustaszewski et al. 2009).

(Bernoulli et al. 1990, Sarti et al. 1992, Bertotti et al. 1993, Berra et al. 2009). The extent of this rifting was regional and has been well documented from the western Mediterranean to the Arabian Peninsula (Schettino & Turco 2011). During the Middle to Late Jurassic, after the final opening of the Alpine Tethys, the region became progressively deeper due to post-rift thermal subsidence. From the Bajocian onwards, the elevated areas were submerged submarine plateaus with condensed pelagic sedimentation and considerable stratigraphic gaps. The surrounding basins subsided to bathyal depths and were mostly characterized by highly siliceous pelagic sediments, occasionally punctuated by calcareous turbidites from adjacent platforms (see Fig. 3a for the present-day location of deep basins and pelagic plateaus).

Structurally, the Southern Alps of NW Slovenia consist of two composite south-verging tectonic units, the Tolmin Nappe and the Julian Nappe; the Julian Nappe overthrusts the Tolmin Nappe (Placer 1999) (Fig. 4). To the north, the Southern Alps are separated from the Austroalpine units by the Periadriatic Line; to the south, the South Alpine front is in direct contact with the Trnovo Nappe of the External Dinarides (Placer 1999).

The Tolmin Nappe (Fig. 4) consists of several thrust sheets composed of Upper Triassic to Upper Cretaceous deep-water successions that are paleogeographically ascribed to the Tolmin Basin. The successions comprise pelagic sediments (thin-bedded micritic limestones, radiolarian cherts and shales) and intervening carbonate gravity-flow deposits (Fig. 5). In the Middle Jurassic and later, the shallow-water carbonate material was sourced exclusively from the stable Dinaric Carbonate Platform, which now occupies a large area of the External Dinarides. The deposition of siliciclastics (flysch) in the Tolmin Basin started in the Campanian-Maastrichtian.

The structure of the Julian Nappe (Fig. 4) is more complicated and has not been satisfactorily reconstructed yet. In addition to structural elements, the differences in the stratigraphic record clearly document the existence of several tectonic/paleogeographic units. Triassic to Lower Jurassic platform limestones predominate over the entire area but the overlying pelagic successions may vary

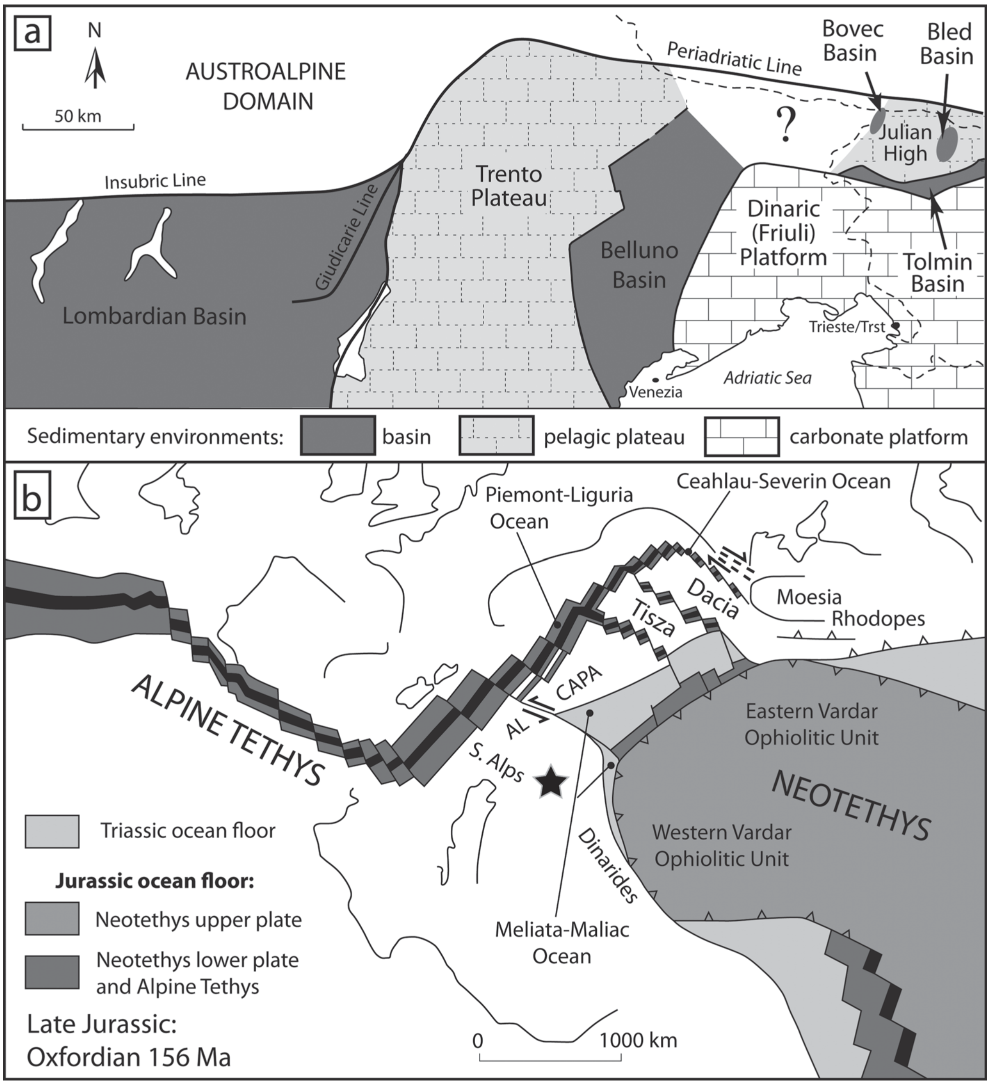


Fig. 3a: Present-day position of paleogeographic units in NW Slovenia and NE Italy (according to Winterer & Bosellini 1981. Smuc 2005).
Fig. 3b: Paleogeographic reconstruction for the Oxfordian (after Schmid et al. 2008) with the location of the Julian Alps marked (star symbol).

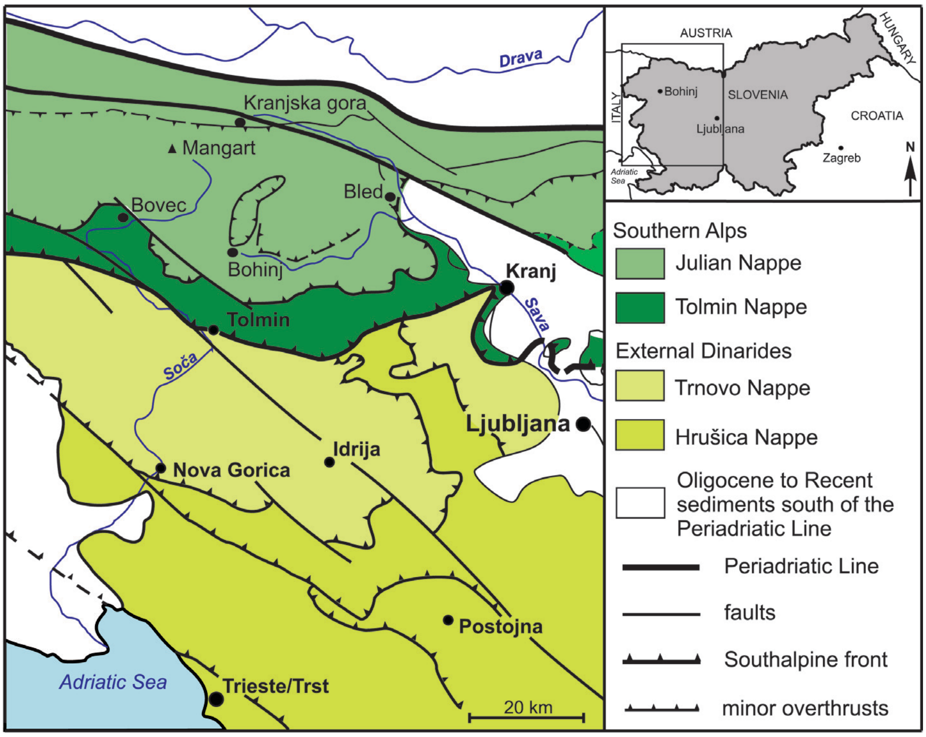


Fig. 4: Simplified structural map of NW Slovenia (after Placer 1999).

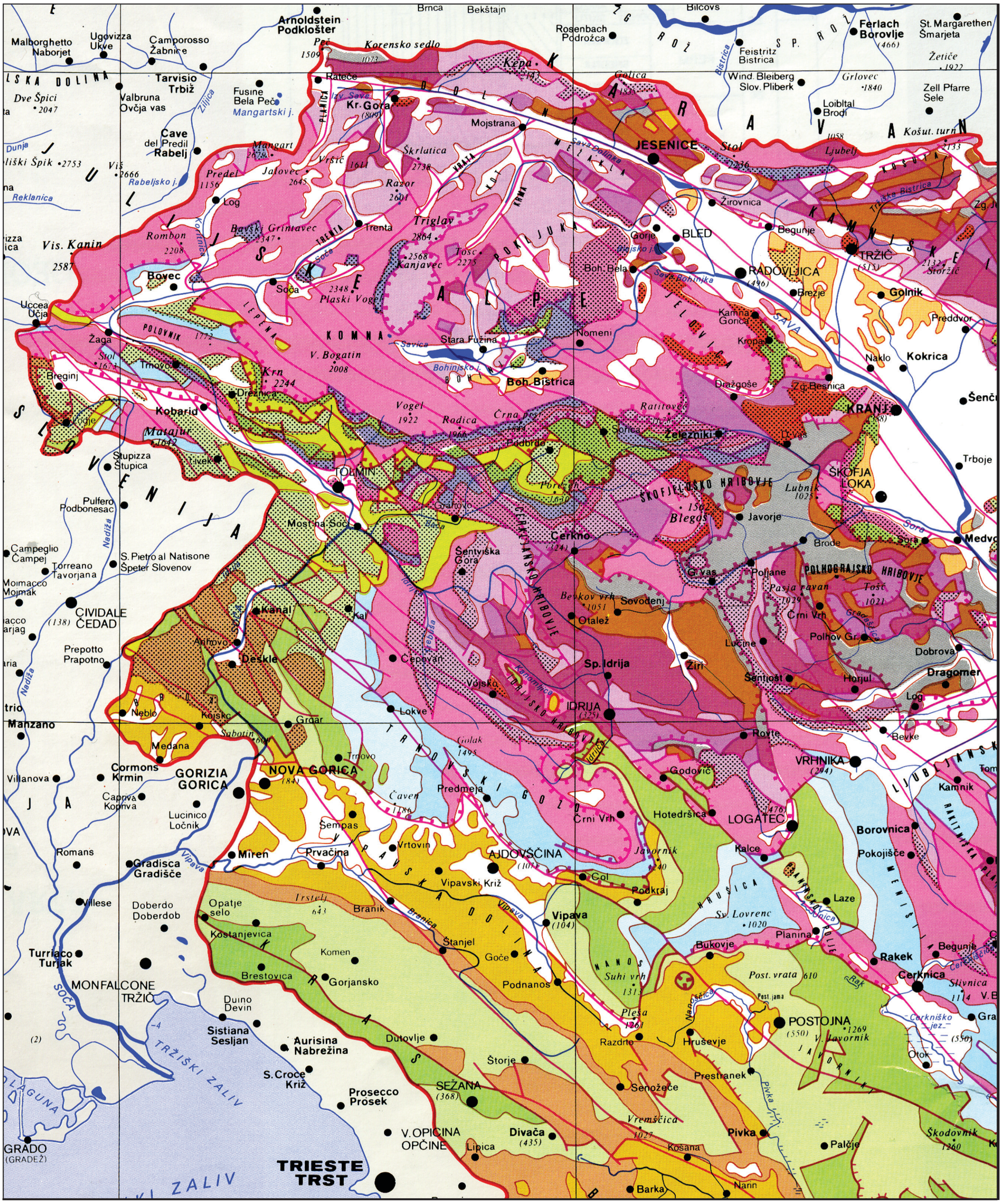


Fig. 5: Geological map 1:500,000 of NW Slovenia (after BUSER & DRAKSLER 1993).

significantly in thickness and facies types. In terms of paleotopography (best pronounced during the Middle and Late Jurassic), these deep-water deposits are attributed to three separate units: the Bovec Basin, the Julian High, and the Bled Basin. Since the structure within the Julian Nappe is relatively complex, and because the exposures of Jurassic and Cretaceous sediments are scarce and laterally discontinuous (see Fig. 5), the exact location of different sedimentary basins in the regional paleogeography is difficult to ascertain. The Bovec Basin was presumably part of the Tolmin Basin but may have belonged to the Belluno Basin of the Southern Alps. The Julian High was an isolated intrabasinal plateau characterized by condensed pelagic sedimentation and, locally, deep breccia-filled neptunian dikes. This succession ends with a Campanian-Maastrichtian flysch that is approximately coeval to the flysch of the Tolmin Basin. On the other hand, the succession of the Bled Basin shows clear affinities with more internal Dinaric units. The Lower Cretaceous mixed carbonate-siliciclastic turbidites suggest a correlation with the Bosnian Flysch, which is extensively exposed only in the central Dinarides. In Slovenia, the Lower Cretaceous deposits of the Bled Basin are the oldest known sediments related to Dinaric orogeny and represent the most internal zone preserved in a wider area. The nearest outcrops of Lower Cretaceous flysch-type deposits are known about 200 km southeastwards at Mt. Ivanscica in northern Croatia.

In the field trip we will focus on sedimentary evolution of the deeper-water basins from the latest Triassic to the mid-Cretaceous (Albian) to encompass the interval from the initial rifting to the early stages of orogeny.

3. Field-trip description

3.1. The Bled Basin

General description

The remnants of this basin are exposed in the surroundings of Bohinj and on the Pokljuka Plateau in the eastern Julian Alps (Fig. 5). Cousin (1981) introduced the paleogeographical term Bled Basin because he noticed significant differences in the stratigraphy of this area compared with other deep-water successions in the Julian Alps. The most notable difference is the age of flysch deposits. The flysch-type sedimentation in the Bled Basin started in the Early Cretaceous, but significantly later, in the Campanian to Maastrichtian, in the other basins of the Julian Alps. This comparison led Cousin to correlate flysch deposits of the Bled Basin with the Bosnian Flysch in the Central Dinarides and, thus, to assume a relatively internal position of this paleogeographic unit.

The general stratigraphy of the Bled Basin (Fig. 6) is summarized from previous works (Härtel 1920, Budkovic 1978, Buser et al. 1979, Cousin 1981, Kolar-Jurkovsek et al. 1983, Buser 1986, 1987, Kukoc et al. 2012). The Norian and Rhaetian deposits are mostly relatively thick-bedded limestones with chert nodules (Zatrnik limestone of Cousin 1981). Locally, reef limestone occurs. The Lower Jurassic succession is characterized by bedded, often cherty limestones with echinoderms (Hierlatz facies) that laterally and vertically pass into massive oolitic limestone. The uppermost part consists of coarse-grained carbonate breccia that also includes chert nodules. Cousin (1981) informally named this interval the Ribnica breccia. The following lithostratigraphic unit comprises Middle and Upper Jurassic bedded radiolarian cherts and shales. In the upper part, cherts and shales alternate with marly limestone and are overlain by approximately 50 m of laminated limestone, which passes into typical Upper Tithonian Biancone limestone. The Biancone limestone is overlain by carbonate gravity-flow deposits of the Bohinj Formation. The overlying succession starts with siliceous limestone with

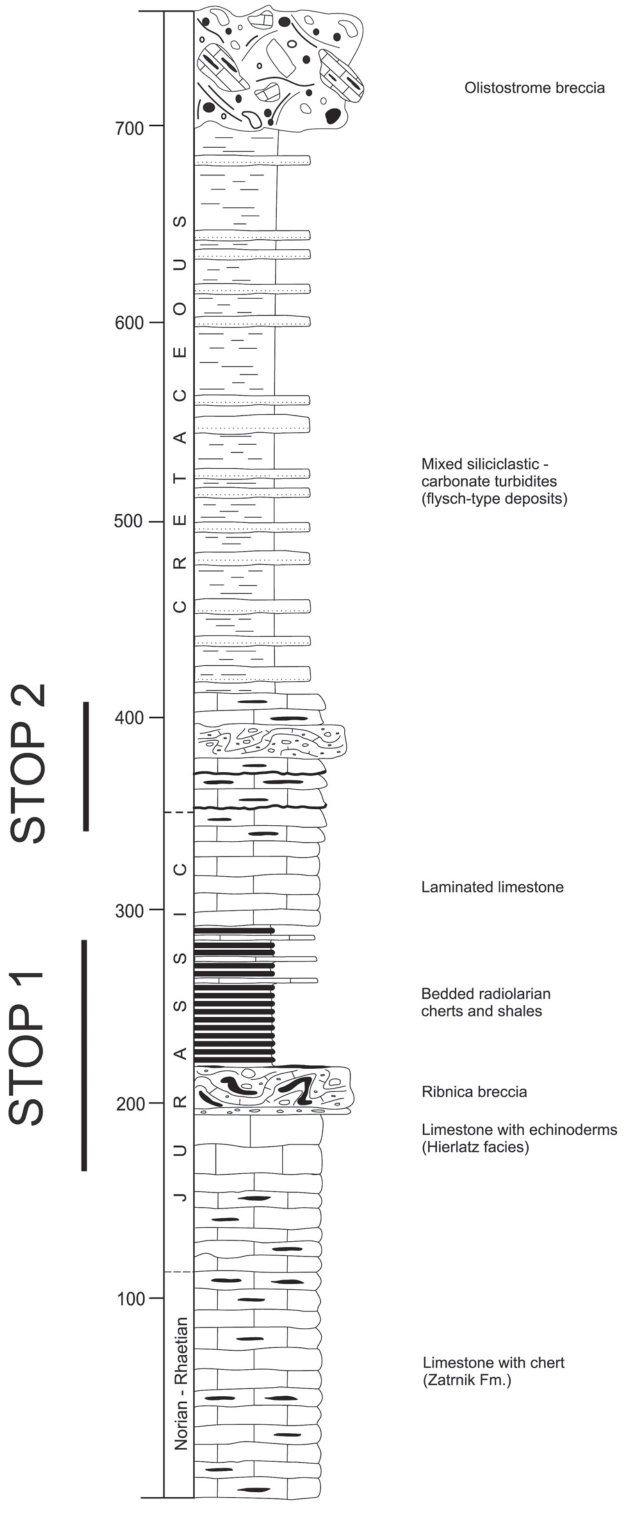


Fig. 6: General stratigraphy of the Bled Basin. The stratigraphic position of Stops 1 and 2 is indicated.

a significant proportion of marl and then passes into mixed siliciclastic-carbonate turbidites, referred to as flysch by previous authors. In places, olistostrome breccia containing blocks (a few m^3 in size) of the Biancone limestone occurs (Buser 1986). The matrix of the breccia is siliciclastic and composed predominantly of quartz but also includes lithic grains, hornblende and plagioclase. Buser (1986) estimated

Fig. 7: Geographic location of Stops 1 and 2.

the entire flysch sequence to be approximately 400 m thick. The flysch-type deposits near Bohinj have been dated with nannoplankton as Valanginian - Hauterivian (Buser et al. 1979). These mixed calcareous-siliciclastic turbidites have a very limited areal extent and their present location in the Julian Alps appears quite “exotic“. Facies and time-equivalent lithostratigraphic units are the Vranduk Formation of the Bosnian Flysch (Mikes et al. 2008 and references therein), the Ostrc Formation in NW Croatia (Babic & Zupanic 1978, Luzar-Oberiter et al. 2009), and the Rossfeld Formation in the Northern Calcareous Alps (e.g., Faupl & Wagreich 2000, Missoni & Gawlick 2011).

Stop 1: The Ribnica Valley

Pliensbachian to Tithonian
Guided by Duje Kukoc

General description

The Lower Jurassic Ribnica breccia and the overlying Middle to Upper Jurassic radiolarian cherts (Fig. 8) are best exposed at the first waterfall in the Ribnica Valley (N 46° 18.190', E 13° 54.821', Fig. 7). The lowermost part of the section is composed of calcarenite with more than 50% echinoderms and rare foraminifers (Fig. 9a). The calcarenite is followed by a 0.5 m thick layer of greenish marly limestone and a 20 cm thick layer of reddish filament-bearing limestone, which also contains echinoderms and foraminifers (Fig. 9b).

The Ribnica breccia consists of several beds. The first is 1 m thick and contains limestone clasts up to 40 cm in size, but no chert. The overlying bed is thinner (0.5 m) and the limestone clasts are smaller. The upper part of the Ribnica breccia is an approximately 5 m thick chaotic bed containing large limestone and chert clasts, and also irregularly shaped folded layers of chert up to 1 m in size. The upper bedding plane is in places silicified and covered by a 10 cm thick horizon of gray marl. The topmost breccia bed is similar to the one below; it is 0.5 m thick and contains a high amount of chert (app. 50%) in the form of folded nodules and layers (Fig. 9e, f).

The most common microfacies of the breccia clasts is bioclastic wackestone-packstone with abundant echinoderms and foraminifers (e.g., *Involutina liassica* (Jones)). Ammonite and gastropod shells also occur (Fig. 9d). Some clasts are wackestones with radiolarians and sponge spicules. Glauconite grains are rare but present throughout the Ribnica breccia.

The overlying succession is dominated by radiolarian cherts. It starts with a 6 m thick slumped interval of dark-green bedded chert. The shale interlayers constitute less than 10% of the sequence. The transition to the overlying bedded cherts is not exposed; presumably mostly shales occur in this covered interval. The upper part of the succession consists of dark-brownish-red bedded cherts and shales. The content of shale in this part of the succession is high and reaches up to 60%. Individual chert beds are 3

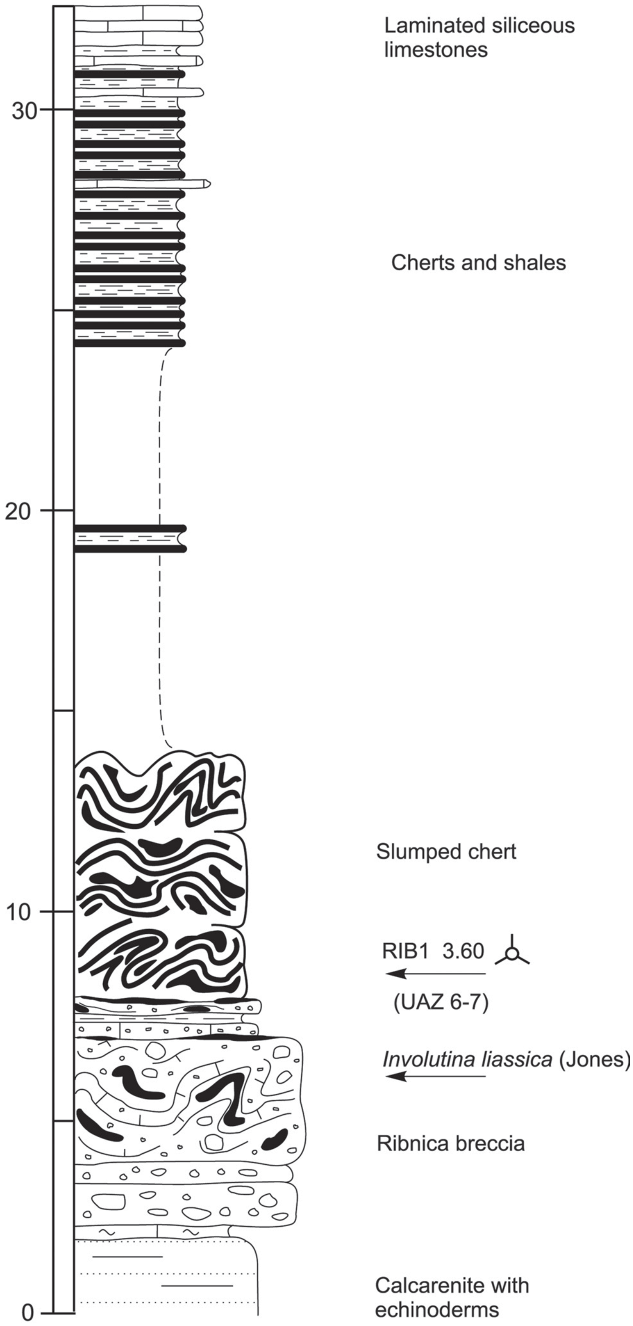


Fig. 8: Jurassic stratigraphy in the Ribnica Valley (Stop 1).

to 5 cm thick and generally laminated. In places, normal grading and channel structures (Fig. 9g) clearly indicate that the chert beds were deposited as low-density turbidites. In the upper part of the section carbonate content increases again. Gray laminated siliceous-limestone beds, up to 10 cm thick, are intercalated in the dark-gray shale. The content of shale decreases upsection and the succession ends with thin-bedded laminated siliceous radiolarian-bearing limestones. The entire thickness of the laminated limestones is estimated to 50 m but is not visible at this outcrop.

Age

In the breccia clasts, the diagnostic foraminifer *Involutina liassica* (JONES) indicates an Early Jurassic age. The maximum range of this species is from the Upper Norian

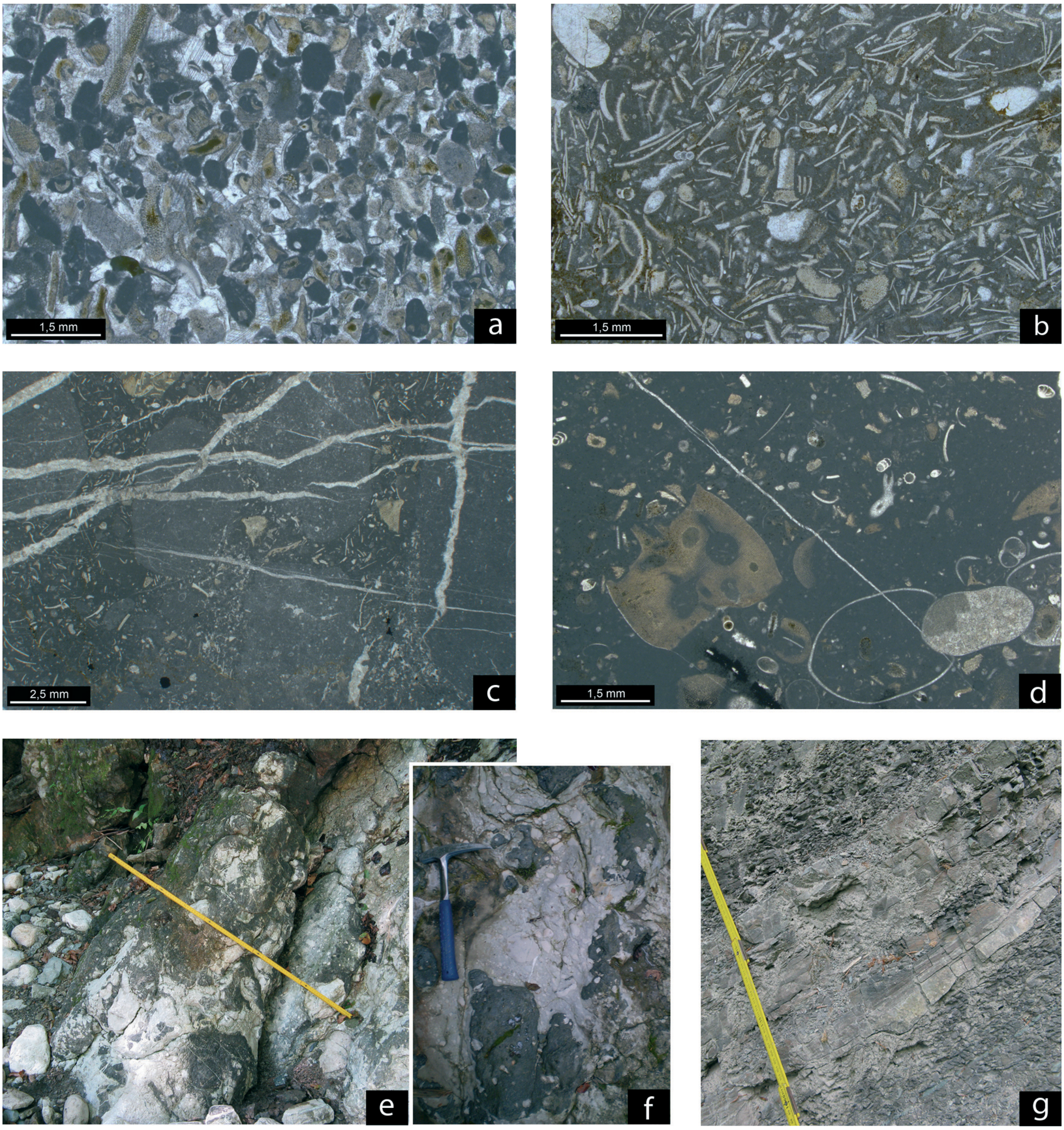


Fig. 9: Microfacies and field photographs from the section at Stop 1: a) calcarenite with echinoderms and peloids (Hierlatz facies) at the base of the section; b) reddish limestone with filaments, echinoderms and rare foraminifers beneath the Ribnica breccia; c) lower part of the Ribnica breccia with mudstone clasts in the matrix composed of the same material as the microfacies in Fig. 9b; d) clast from the upper part of the Ribnica breccia: wackestone with echinoderms, foraminifers and an ammonite shell; e, f) field photograph of the uppermost part of the Ribnica breccia; g) bedded chert and shale from the upper part of the section, the thickest chert bed displays a channelized base and parallel lamination on the top.

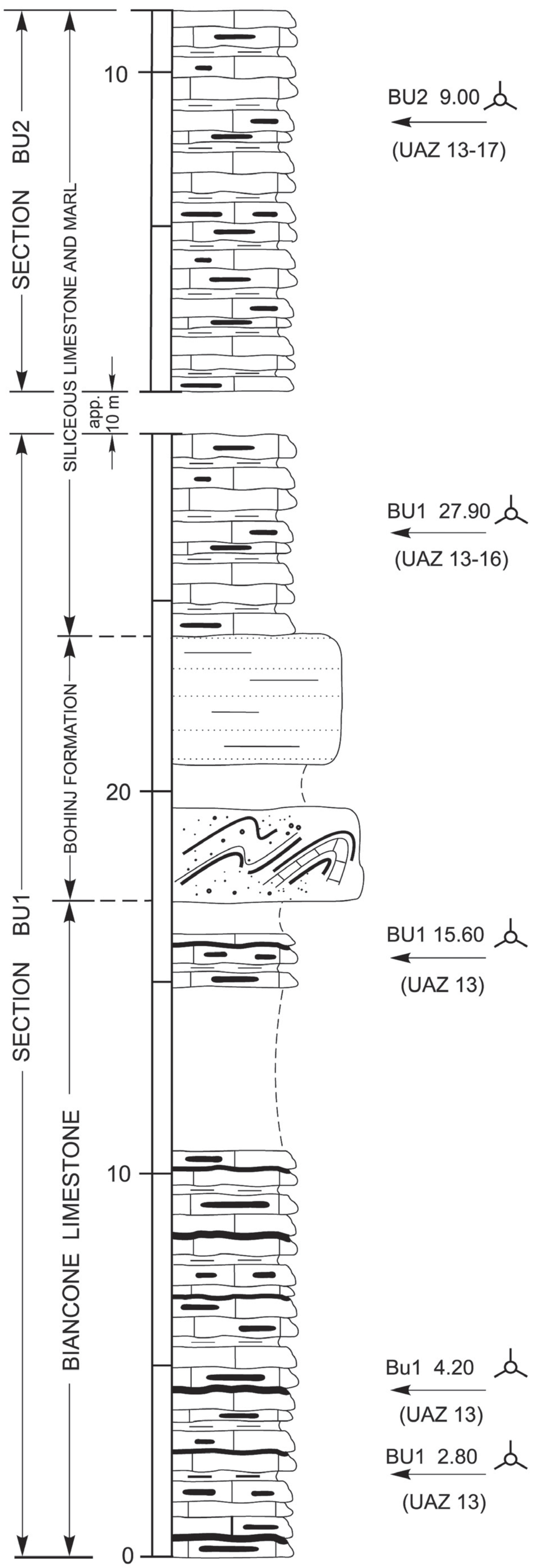


Fig. 10: Tithonian-Berriasian stratigraphy along the road to Uskovnica (Stop 2).

to the lowermost Toarcian (Bassoullet 1997). Based on regional stratigraphic correlations, the Pliensbachian is the most probable age of the Ribnica breccia. The slumped cherts above the breccias yielded a middle Bathonian to early Callovian radiolarian assemblage (UA Zones 6-7 of Baumgartner et al. 1995b). These two age constraints suggest that a significant stratigraphic gap occurs between the Ribnica breccia and the overlying radiolarian cherts. The age of the upper part of the succession is yet to be determined.

Stop 2: Along the road from Srednja vas to Uskovnica
Tithonian and Lower Cretaceous
Guided by Duje Kukoc

General description

An approximately 40 m thick section of pelagic limestones, including carbonate gravity-flow deposits (Fig. 10), is well exposed northeast of the Bohinj Lake, along the road from Srednja Vas to Uskovnica (N 46° 17.992', E 13° 55.069', H = 785 m, Fig. 7).

This section is subdivided into three lithostratigraphic units: 1) the Biancone limestone; 2) carbonate gravity-flow deposits (the Bohinj Formation); and 3) siliceous limestone with marl. The section combines two partial sections (marked BU1 and BU2 in Fig. 10), and the contact between them is tectonized. The missing part is estimated to be 10 m.

The Biancone limestone is characterized by thin- to medium-bedded light-gray to white limestone with individual beds up to 20 cm thick. Up to 5 cm thick discontinuous beds of dark-gray chert and irregularly shaped chert nodules are common. Intercalations of marl are also present. The predominant microfacies are radiolarian-rich wackestone and packstone (Fig. 11a). Parallel lamination is present in some layers. In places, normally graded calcarenites occur as several centimeters thick intercalations in micrite beds and contain up to 5 mm large clasts in the basal part (Fig. 11b).

The second lithostratigraphic unit has recently been described as the Bohinj Formation (Kukoc et al. 2012). At the type locality, the Bohinj Formation consists of 3 m of carbonate breccia and 4 m of calcarenite. Slump folds are present in the breccia. The calcarenite is massive and shows no internal folding or bedding.

The third lithostratigraphic unit is reddish siliceous limestone similar to the Biancone limestone, from which it differs by its higher proportion of marl and the red color. At this section, the transition into the overlying flysch-type deposits is covered.

Composition of the breccia and calcarenite

The breccia consists primarily of matrix-supported angular to subangular shallow-water carbonate clasts. The largest clasts are up to 2 cm in diameter. The matrix is radiolarian-rich lime mudstone with sponge spicules and scarce calpionellids. Most of the limestone clasts are bioclastic grainstones and bioclastic-peloidal packstones (Fig. 11f, k). Clasts of algal wackestone and oncoid packstone are also present but rare. The skeletal grains in

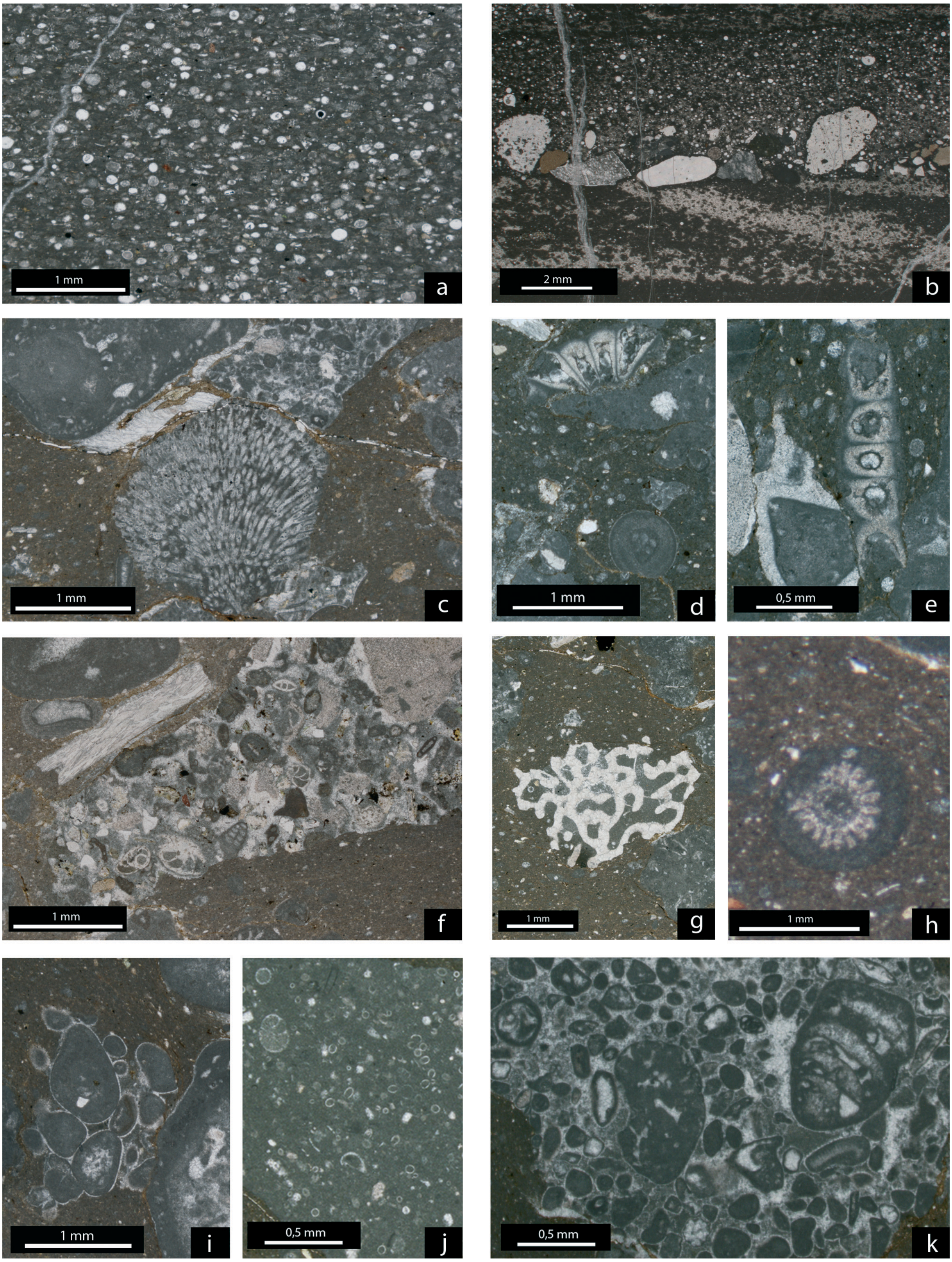


Fig. 11: Microfacies at Stop 2: a) pelagic Biancone limestone, radiolarian packstone; b) graded layer in Biancone limestone with grains of chert at the base and accumulation of radiolarian skeletons above; silicified parts (lighter area) are visible below and above; c) bioclast of *Cayeuxia* in mud-supported breccia and clasts of bioclastic packstone with textulariids; d) isolated *Clypeina jurassica* Favre and an isolated ooid in matrix-supported breccia; e) bioclast of *Clypeina jurassica* Favre; f) bioclastic packstone with foraminifers and echinoderm fragments; g) bioclast of calcareous sponge; h) matrix with coated echinoid spine; i) clast of oolite weakly cemented with a thin fringe of early cement, pore spaces are filled with the breccia matrix; j) clast of pelagic wackestone containing abundant calpionellids; k) clast of bioclastic-peloidal packstone with benthic foraminifers.

these clasts are miliolid and textulariid foraminifers, echinoderm fragments and algal fragments. The dasyclad algae *Clypeina jurassica* Favre, characteristic of the upper Kimmeridgian to lowest Berriasian, is found both in the clasts of algal wackestone and in the form of isolated fragments (Fig. 11d, e). Intraclasts of pelagic calpionellid wackestone are also present (Fig. 11j). *Calpionella alpina* Lorenz, ranging from the late Tithonian to earliest Valanginian has been recognized. In addition to common remains of *Clypeina jurassica* Favre, the green algae *Cayeuxia*, and fragments of sponges (Fig. 11g, h), bryozoans, echinoderms and thick-shelled bivalves are identified as single bioclasts. Well-developed concentric and radial ooids and oncoids are present as isolated grains (Fig. 11i, h); rare chert grains also occur. Calcarenite is predominantly composed of shallow-water skeletal fragments and lithoclasts similar to those found in the breccia. Grains of chert and glauconite are present but are less abundant than carbonate components.

The microfacies analysis reveals that the main source area of the resedimented limestone was a penecontemporaneous carbonate platform. Limestone clasts and isolated grains from the outer platform prevail, but lagoonal facies (algal wackestone) is also present.

Age

Radiolarians from the pelagic Biancone limestone below the Bohinj Formation indicate a latest Tithonian to earliest Berriasian age (UA Zone 13 of Baumgartner et al. 1995b), and those above may range into the early Valanginian (UA Zones 13-16). The radiolarian dating is in accordance with the ages suggested by *Clypeina jurassica* and calpionellids from the breccia clasts.

Significance for local paleogeography

The Bohinj Formation provides evidence of a carbonate platform that must have been located more internally but is now not preserved. This inferred platform (named the Bohinj Carbonate Platform by Kukoc et al. 2012) may have developed on top of a nappe stack which formed during the early emplacement of the internal Dinaric units onto the continental margin (Fig. 12). The platform correlates regionally with genetically similar isolated carbonate platforms of the Alpine - Dinaride - Carpathian orogenic system, e.g., with the Plassen Carbonate Platform in the Northern Calcareous Alps (Gawlick & Schlagintweit 2006) and the Kurbnesh Carbonate Platform in Albania (Schlagintweit et al. 2008).

3.2. The Tolmin Basin

General description

Among the three basins of the eastern Southern Alps, the Tolmin Basin is characterized by the largest extent of outcrops and the most complete stratigraphic record. Several well-preserved Mesozoic successions provide evidence for the longest basinal history, a relatively complex intrabasinal variability, and an indisputable paleogeographic position between the Dinaric Carbonate Platform and the Julian High.

The successions of the Tolmin Basin are exposed in the southern foothills of the Julian Alps in NW Slovenia. Structurally, they form the Tolmin Nappe that is generally subdivided into three second-order nappes (Fig. 13). From bottom to top, these are the Podmelec Nappe, the Rut Nappe and the Kobla Nappe (Buser 1986, 1987). In terms of paleogeography, the stratigraphic successions of these nappes correspond to different parts of the Tolmin Basin. Different proximal to distal successions are now juxtaposed primarily because of the Neogene N-S shortening. Facies variations in the W-E direction have also been observed; these variations reflect the original NW-SE basin orientation, which was amplified by older, i.e., Paleogene, thrusting towards the southwest (Rozic 2009). The Triassic to Cretaceous rocks of the Tolmin Nappe exhibit a considerable thermal overprint which occurred in post-Late Cretaceous to pre-mid Oligocene times (Rainer et al. 2009). Vitrinite reflectance and illite crystallinity studies have demonstrated that these rocks were subject to deep diagenesis and, in the area NE of Cerkno (see Fig. 13), reached the anchizone (Rainer et al. 2002, 2009).

In the Mezozoic, the Tolmin Basin was a deep-water paleogeographic domain located between the Dinaric Carbonate Platform in the south and the Julian Carbonate Platform in the north. During the Early Jurassic, the Julian Carbonate Platform was dissected, subsided and progressively drowned making a pelagic plateau known as the Julian High (Buser 1989, 1996, Jurkovsek et al. 1990, Smuc 2005, Smuc & Rozic 2010). Except for the marginal parts, the Dinaric Carbonate Platform (also named Friuli or Adriatic or Adriatic-Dinaric Carbonate

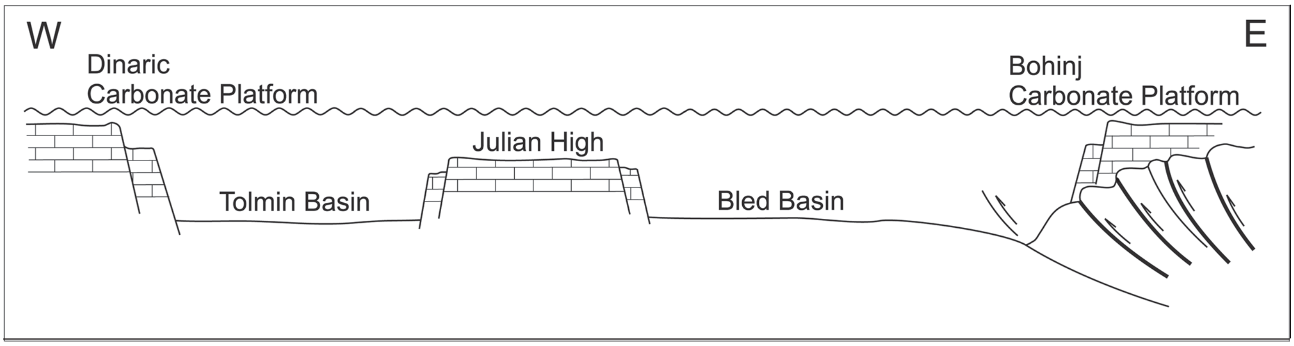


Fig. 12: Schematic cross-section of paleogeographic units in western Slovenia in the Berriasian (from Kukoc et al. 2012).

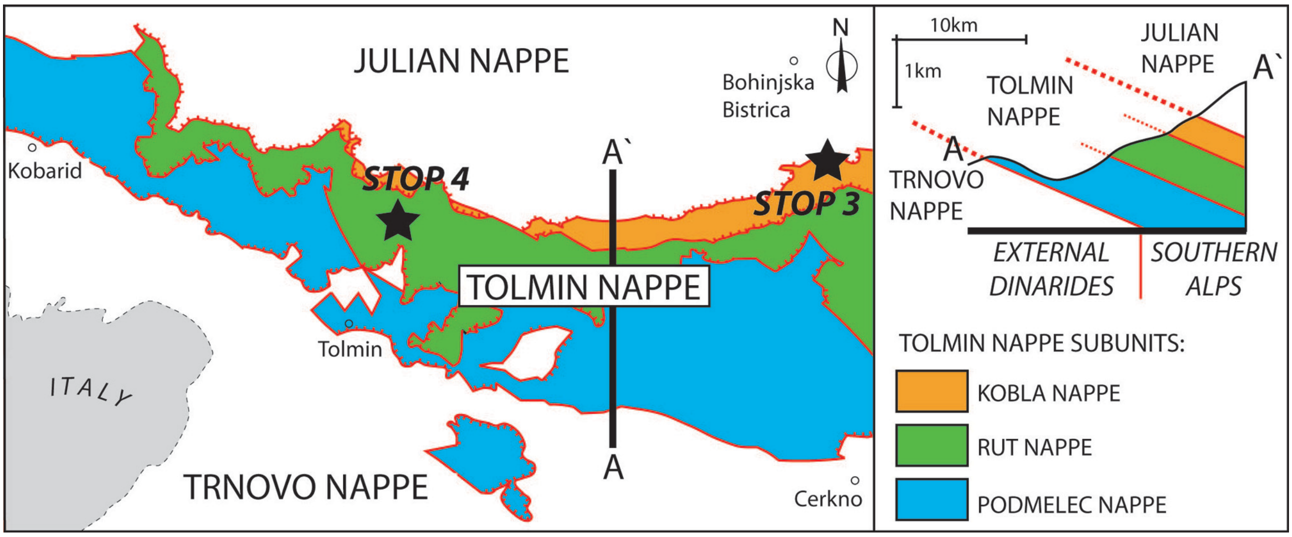


Fig. 13: Structural map of the area between Kobarid and Cerkno with the locations of Stops 3 and 4.

Platform) was less affected by tectonic subsidence and remained the most stable shallow-water carbonate system in the Mediterranean Tethys throughout the Jurassic and Cretaceous (e.g., Vlahovic et al. 2005 and references therein).

The Tolmin Basin originated in the Middle Triassic when a uniform carbonate platform (the Slovenian Carbonate Platform, Buser 1989) was disintegrated due to the rifting related with the opening of the Meliata-Maliac Ocean. The Ladinian is marked by alternating siliciclastic and carbonate (hemi)pelagic sedimentation with intercalations of volcaniclastics. A similar depositional style, but without volcaniclastics, continued into the Carnian (Buser 1989, 1996, Buser et al. 2007, 2008). The Norian/Rheatian is marked by pure carbonate sediments that are dolomitized to the Baca Dolomite Formation (bedded dolomite with chert nodules). In just the northern part of the basin, the uppermost Norian and Rhaetian is preserved as alternating hemipelagic/resedimented limestone succession and was recently defined as the Slatnik Formation (Rozic et al. 2009, Gale 2010). Replacement chert nodules are common in all lithologies. Early Jurassic rifting events of the Alpine Tethys are reflected in a progressive deepening of the Tolmin Basin. During Hettangian to Pliensbachian period the Krikov Formation originated (Cousin 1973, 1981) that is often marked by thick limestone breccias in the basal part. The Krikov Formation is composed of alternating resedimented and hemipelagic limestones that show great lateral variations. The northern part of the basin reveals the predominance of resedimented carbonates, whereas the southern part is dominated by hemipelagic sediments (Rozic 2006, 2009). Such facies distribution implies that the north-lying Julian Carbonate Platform was the main source area of the redeposited carbonate material. Further, the demise of shallow-water sedimentation on this platform at the end of the Pliensbachian (Smuc 2005) is directly reflected in the sharp upper boundary of the Krikov Formation (Rozic 2009). The Toarcian is marked by marl-dominated Perbla Formation, a succession typical of this stage in the Alpine Realm (Cousin 1973, Rozic 2009, Rozic & Smuc 2011), while the Middle and Upper Jurassic is characterized by pelagic siliceous limestones and radiolarian cherts (Cousin 1973, 1981, Buser 1989) that were recently defined as the Tolmin Formation (Rozic 2009). In the southern part of the basin resedimented limestones occur sporadically and wedge out towards the north. Such facies distribution indicates a south-lying Dinaric Carbonate Platform as a source area of Middle and Upper Jurassic redeposited shallow-water material (Rozic & Popit 2006, Rozic 2009). The Jurassic succession ends with the upper Tithonian to Neocomian Biancone limestone (Cousin 1981). Local and regional stratigraphic correlations of the Jurassic deposits are presented in Figs. 14 and 15.

The Early Cretaceous (Valanginian to Aptian) is missing in the Tolmin Basin due to a prominent erosional event. The Lower flyschoid formation (Caron & Cousin 1972, Cousin 1981, Buser 1986, 1989) starts around the Aptian-Albian boundary with a thick limestone breccia which unconformably overlies mostly the Biancone limestone, but can be locally in direct contact with the Toarcian Perbla Formation. Above the basal breccia, the Lower flyschoid formation is characterized by shales and marls with intercalations of calcareous turbidites. In marginal areas, adjacent to the Dinaric Carbonate Platform, there is less marl and the succession is almost entirely composed of calcareous turbidites (Samiee 1999, Rozic 2005). In the upper, i.e. Turonian, part of the formation, red marls and pelagic limestones with globotruncanids are characteristic. The Coniacian to Campanian is marked by the Volce Limestone, which consists of thin-bedded calcareous turbidites and pelagic limestones with globotruncanids (Ogorelec et al. 1976, Buser 1989). Replacement chert nodules and layers are abundant in the Volce Limestone. The succession of the Tolmin Basin ends with the uppermost Campanian-Maastrichtian coarse-grained calcareous breccias that upsection pass into mixed calcareous-siliciclastic flysch-type deposits (Caron & Cousin 1972, Cousin 1981, Buser 1989).

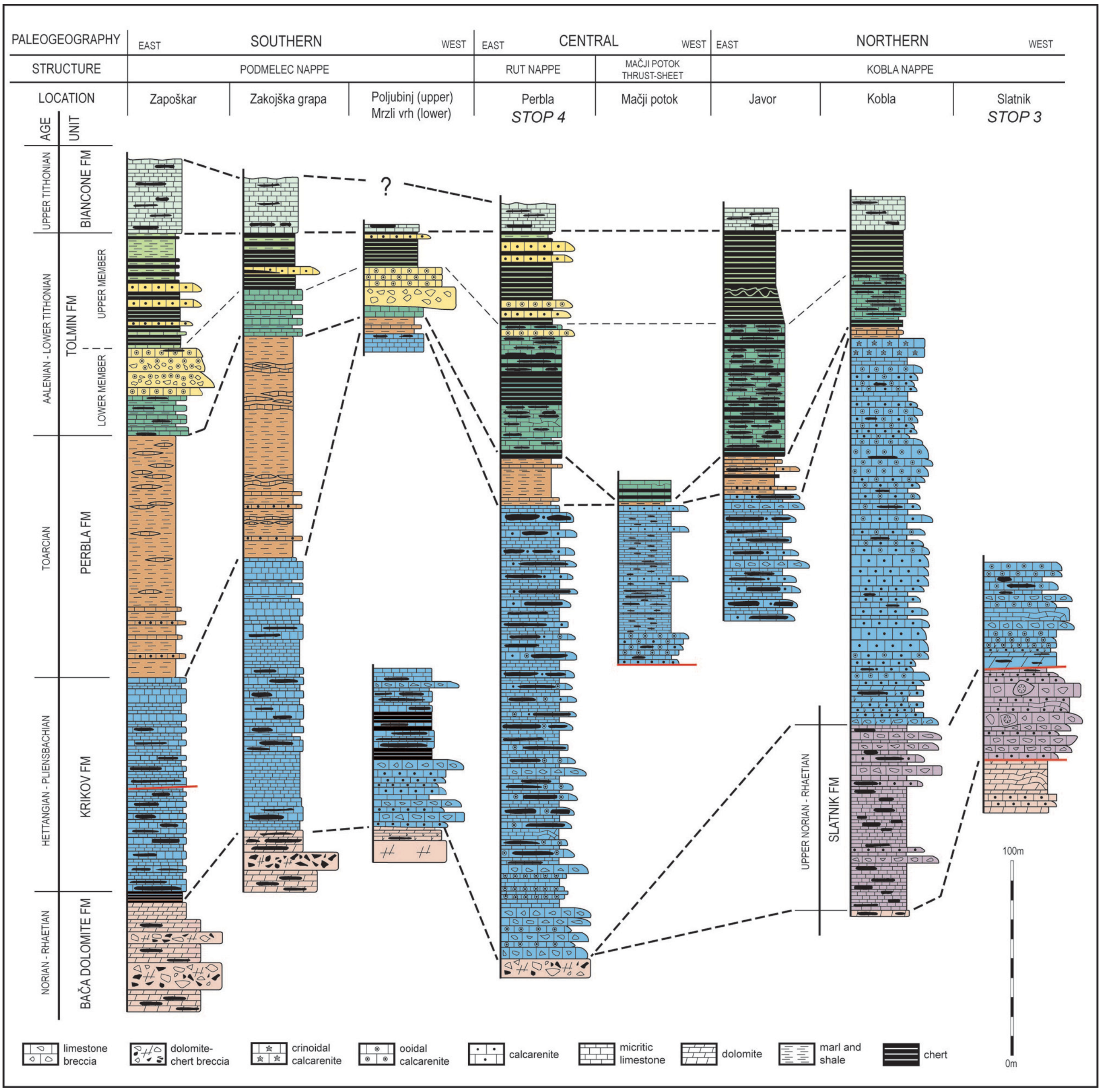


Fig. 14: Stratigraphic correlation of uppermost Triassic to lowermost Cretaceous formations of the Tolmin Basin (after ROZIC 2006, updated).

A note on the history of the name Tolmin Basin: In the past, several names were introduced for the basinal facies belt located in the foothills of the Julian Alps. The facies belt, where Mezozoic successions are common, well-exposed and most studied, is 50 kilometers long and up to 20 kilometers wide, extending W-E between Tolmin and Cerkno (see Fig. 5). For all basinal successions that crop out in the eastern Southern Alps, AUBOUIN (1963) introduced the term Julian Basin. After a more detailed study, COUSIN (1970) defined the Slovenian Basin for the successions in the foothills of the Julian Alps. The same term Slovenian Basin (or Trough) was used by BUSER (1989, 1996) who claimed that the basinal successions extend from the Tolmin area much further to the east through the whole central and eastern Slovenia (also see OGORELEC & DOZET 1997, BUSER et al. 2007, 2008). Subsequently, the term Slovenian Basin became widely accepted and is still used in the Slovenian literature. In his later work, COUSIN (1981) extended the definition of the Slovenian Basin to all Jurassic deeper-water paleogeographic domains of the Julian Alps (including the Bovec Basin and the Bled Basin), whereas the basinal facies belt previously described as the Slovenian Basin was considered a sub-basin and re-named the Tolmin Basin. Here we use the term Tolmin Basin sensu COUSIN (1981). Nevertheless, we believe the term Slovenian Basin should remain confined to the Middle Triassic to Cretaceous basinal successions that are found as a laterally continuous facies belt in the foothills of the Julian Alps, but are also traceable eastwards. According to this definition, the term Tolmin Basin corresponds to the

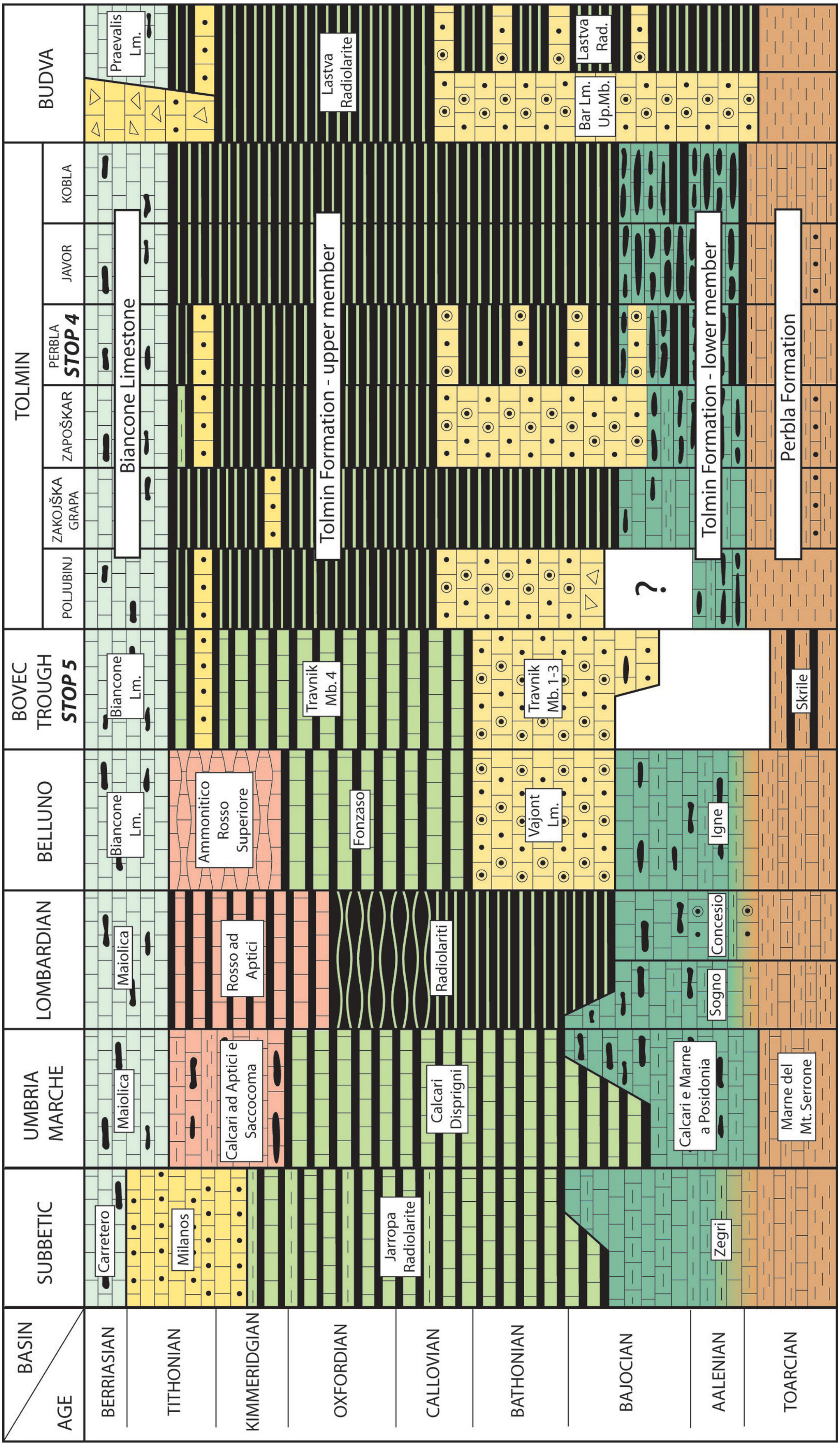


Fig. 15: Correlation of the Tolmin Basin with other basins of the western Tethys (from Rozic 2009); same legend as in Fig. 14.

westernmost part of the Slovenian Basin, but the Bovec and Bled basins are considered separate basinal areas.

Stop 3: Slatnik

Norian and Rhaetian
Guided by Luka Gale

General description

The Mt. Slatnik section (Figs. 16, 17) is accessible along an old mountain path crossing the southern flank of Mt. Slatnik (N 46° 02.756', E 14° 29.932', 1597 m a.s.l.). The section is located in the Kobla Nappe, the northernmost subunit of the Tolmin Nappe (Fig. 13). The section displays the most proximal development of the Tolmin Basin with respect to the north-lying Julian Carbonate Platform. Along the path, the following formations are exposed: the Baca Dolomite, the Slatnik Formation and the Krikov Formation. The section provides some key evidence of the evolution of the Tolmin Basin during the Norian-Rhaetian period.

The Baca Dolomite

The Baca Dolomite is usually denoted as Norian-Rhaetian bedded dolostone with chert (Fig. 18a) (Buser 1979, Buser 1986, Buser et al. 2008, Gale 2010). The Mt. Slatnik section is unique for its non-dolomitized parts in which primary sedimentary structures are preserved (Fig. 18d). The total exposure of the Baca Dolomite is 257 m (Fig. 17). The section starts with slump breccias with intraclasts and chert clasts (Fig. 17, Interval A). The breccias are followed by medium-thick amalgamated, partly bioturbated beds of dolostone with parallel lamination and chert nodules; slump breccias are rare (Interval B). The following 10 m are composed of thin-bedded cherty limestone and light-brown dolostone, arranged in up to 1 m thick sedimentary cycles (Interval C; Fig. 18c). Texturally these are thin-shelled bivalve wackestone/floatstone to packstone/rudstone (Fig. 18g), or very fine-grained peloidal

Fig. 16: Geographic location of Stop 3.

and fine-grained peloidal-bioclastic packstone. The light-brown color of the dolostone comes from a large amount of pyrite. Very fine plant detritus and detritial quartz are present. Higher up, the pyrite content decreases and the beds become thicker (Interval D). Rare mudstone or wackestone beds are preserved in the lower part. Dolostone beds are mostly medium-thick, with partly visible parallel and cross lamination. Chert is common in this and in the next interval where amalgamated limestones predominate (Interval E). Very fine-grained peloidal and fine-grained peloidal-bioclastic packstone (Fig. 18i) shows normal and inverse grading, parallel, cross and convolute lamination, geopetal structures and load casts (Fig. 18d). A new package of slump breccias follows (Interval F; Fig. 18b). It is succeeded by medium-thick dolostone beds with subordinate laminated wackestone to packstone (Interval G; Fig. 18h), dolostone with chert nodules (Interval H) and then by a succession of dolostone without chert (Interval I). In the last interval, limestone predominates again (Interval J). Amalgamated wackestone to packstone shows grading, parallel, cross and convolute lamination. The uppermost part of this interval consists of some mudstone layers. The Baca Dolomite is separated from the overlying Slatnik Formation by a minor fault.

The Slatnik Formation

The Slatnik Formation represents the non-dolomitized uppermost part of the Baca Dolomite known solely in the Kobla Nappe (Rozic et al. 2009, Kolar-Jurkovsek 2011). The 52 m thick succession consists of resedimented limestones and sporadic hemipelagic limestones. The progradational trend, from predominantly mudstone-wackestone (Intervals L, M) to packstone and fine-grained rudstone (Interval N; Fig. 18j) and finally to limestone breccias with large boulders (up to several meters in size) of reef limestone (Interval O; Figs. 18e, 18f) can be followed through the first half of the formation. Crinoids appear in large amounts for the first time in Interval N. Numerous channel structures indicate development of the sediment by-pass zone. The rest of the Slatnik Formation exhibits retrogradation (Intervals O, P) and an abrupt change to platy micritic limestones at the very top (Interval R).

The Krikov Formation

The contact between the Slatnik Formation and the Krikov Formation is faulted. The Krikov Formation is exposed for 28 m and completely dolomitized in the lowermost part (probably a fault-related alteration). Higher in the section it consists of resedimented limestones, predominantly graded calcarenites composed of ooids, peloids and bioclasts, mainly crinoids (Fig. 18k).

Age: Conodont data are quite scarce in the Mt. Slatnik section. *Norigondolella steinbergensis*, *Epigondolella* ex gr. *E. abneptis*, *E. bidentata* and *E. postera* were found in the Baca Dolomite. Most samples from the Slatnik Formation were taken from very fine-grained packstones and at least a short-term resedimentation cannot be totally excluded. However, clearly resedimented older conodont elements from the upper part of the Slatnik Formation were easily recognized due to their fragmented nature and dif-

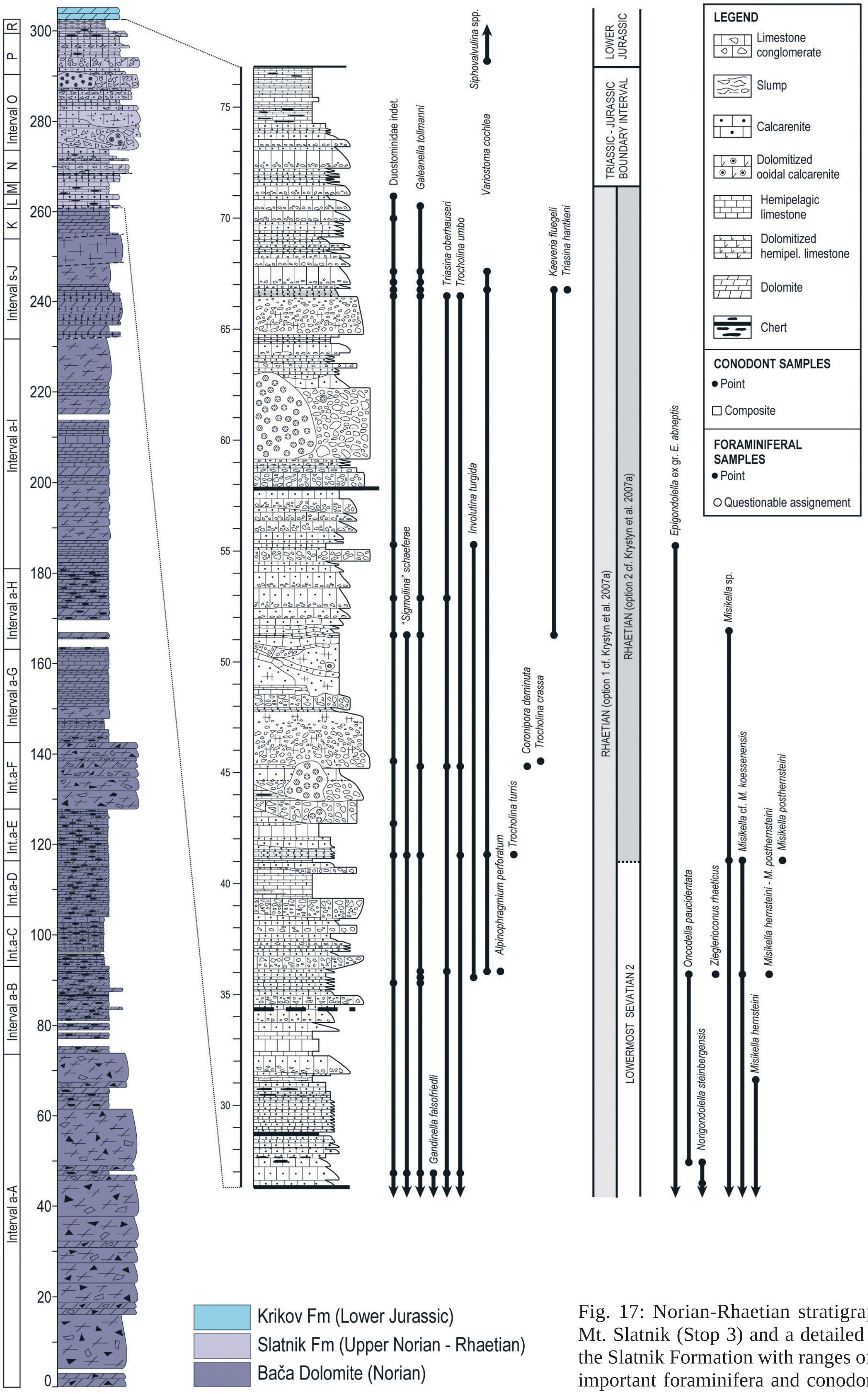


Fig. 17: Norian-Rhaetian stratigraphy at Mt. Slatnik (Stop 3) and a detailed log of the Slatnik Formation with ranges of some important foraminifera and conodonts.

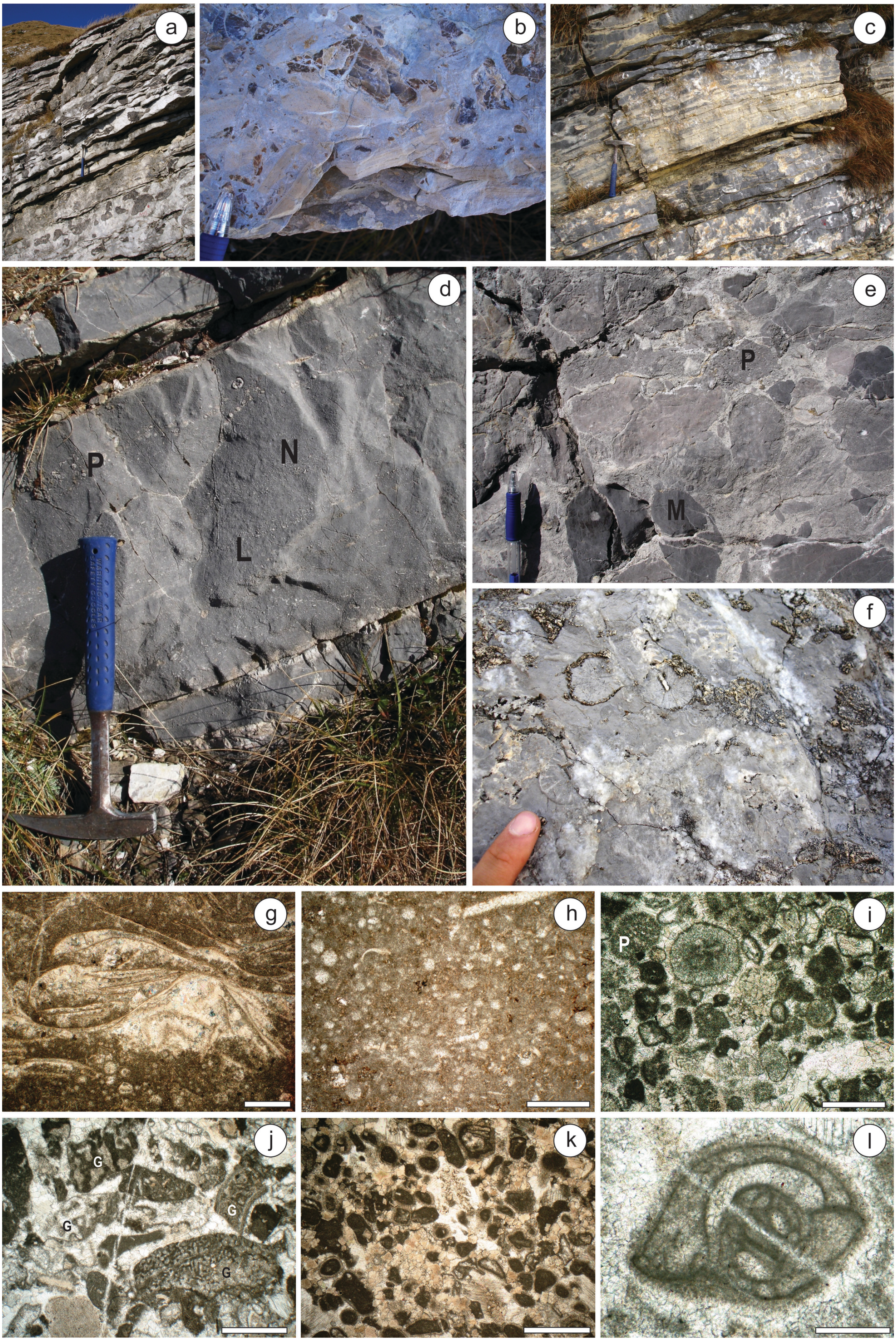

a
b
c
d
P
N
L
e
P
M
f
g
h
i
P
j
G
G
G
G
k
l

Fig. 18: Macroscopic and microscopic features of the Mt. Slatnik section: a) a typical appearance of the Baca Dolomite (bedded dolomite with chert); b) dolomite slump breccia with dolomite intraclasts and chert clasts (Baca Dolomite, Interval F in Fig. 15); c) light brown dolostone interchanging with thin-bedded, resedimented limestone (Baca Dolomite, Interval C in Fig. 15); d) partial Bouma sequences in non-dolomitized beds of the Baca Dolomite (L- parallel lamination, N- normal grading, P- more buoyant particles settled later); e) polymictic limestone breccia of the Slatnik Formation, Interval O (P- packstone, M- mudstone); f) partly silicified corals in limestone breccia (Slatnik Formation, Interval O); g) hemipelagic limestone with pelagic bivalves and radiolarians (Baca Dolomite, Interval C), scale bar 1 mm; h) radiolarian packstone (Baca Dolomite, Interval G), scale bar 0.5 mm; i) spheroidal-bioclastic-peloidal packstone with winnowed matrix (P- *Parafavreina* sp.) (Baca Dolomite, Interval E), scale bar 0.5 mm; j) coarse-grained bioclastic grainstone (G- fragments of reef-forming organisms) (Slatnik Formation, Interval L), scale bar 1 mm; k) partly dolomitized intraclastic-ooidal packstone (Krikov Formation), scale bar 1 mm; l) *Galeanella tollmanni*, scale bar 0.2 mm.

ferent color. It is important to note, that *Misikella posthernsteini* was found in the residue of micritic, hemipelagic limestone, ten meters above *Misikella hernsteini*. The transitional form between the two species was found in between these levels. The Norian-Rhaetian boundary can thus be set between 5 m (with a transitional form between *M. hernsteini* and *M. posthernsteini*) and 10 m of the formation (with *M. posthernsteini*) (Fig. 17). In contrast, highly abundant resedimented limestones provide relatively rich assemblages of benthic foraminifera. The assemblages contain over 30 genera and over 50 species, derived mostly from the reef and back-reef area of the adjacent Julian Carbonate Platform. Stratigraphically important species are: *Galeanella tollmanni* (Fig. 18l) and *"Sigmoilina" schaeferae* (supporting Norian-Rhaetian age for the Baca Dolomite and the Slatnik Formation), *Involutina turgida* (its First Occurrence closely coincides with the conodont-dated Norian-Rhaetian boundary), *Trocholina turris* and *Triasina hantkeni* (supporting the Rhaetian age of the upper Slatnik Formation), and Duostominidae (the family became extinct at the end of the Triassic and duostominids are a good proxy for the Triassic-Jurassic boundary where conodont data are absent).

Norian-Rhaetian evolution of the Tolmin Basin

The observed succession was deposited on the basin plain, lower and upper slope (Rozic et al. 2009, Gale 2010). Intensive slumping in the lower and middle parts of the Baca Dolomite (Intervals A and F) indicates periods of tectonic activity. Corresponding breccia levels have been found throughout the Tolmin Nappe (also see Fig. 14). An increased terrigenous input (detritial quartz, plant remains), and a decrease in the carbonate input (thinning of resedimented limestone beds) in Interval C are attributed to the 3rd order sea-level fall separating the two tectonic events. Based on the correlation with the Dolomites (Gianolla et al. 1998) and the Transdanubian Range (Haas & Budai 1999), the fall is set at the boundary between the Lower and the Middle Norian. Above the second interval of slump breccias, the rest of the Baca Dolomite records a slow progradation of carbonate platform into the basin during the Norian sea-level highstand (for a correlation, see Gianolla et al. 1998, Haas & Budai 1999, Gawlick & Böhm 2000, Berra et al. 2010). A sudden shift to a fast progradation near the Norian-Rhaetian boundary is taken to mark the 2nd order sea-level fall. The sequence boundary is set above the thickest breccia bed of Interval O. The change to retrogradation took place at the beginning of the sea-level rise. The paucity of fossils in the platy limestones at the top of the Slatnik Formation is probably related to the biocalcification crisis at the Triassic-Jurassic boundary (e.g., Crne et al. 2011 and references therein), coupled with the beginning of the transgression (Rozic et al. 2009).

Stop 4: From Perbla to Tolminske Ravne

Hettangian to Albian

Guided by Bostjan Rozic

General description

The section is exposed along the road between the villages of Perbla (N 46°13.066', E 13° 45.733', Fig. 19) and Tolminske Ravne on the northern limb of a large anticline that characterizes the middle structural unit (the Rut Nappe) in this area (Figs. 13, 20). The succession (Fig. 20) is characteristic of the central part of the Tolmin Basin (for a correlation with other sections, see Fig. 14). The uppermost Norian to Albian deposits are divided into the following formations:

A) the Hettangian-Pliensbachian Krikov Formation overlies the Baca Dolomite and starts with a thick interval of basal limestone breccia that passes into alternating calciturbidites and hemipelagic limestone;

B) the Toarcian Perbla Formation dominated by laminated dark marl;

C) the Aalenian to Lower Tithonian Tolmin Formation composed of thin-bedded siliceous limestones and rare chert beds in the lower part, and radiolarian cherts in the upper part; some calciturbiditic interbeds are present in the middle and uppermost parts of the formation;

D) the Upper Tithonian to Berriasian Biancone-type pelagic limestone; and

E) Aptian/Albian to Turonian Lower flyschoid formation which starts with a thick interval of basal limestone breccia and passes upwards into marls, shales and calcareous turbidites. Where the road reaches the Tolminske Ravne village, Quaternary tillites occur.

The Krikov Formation

The contact with the underlying Norian-Rhaetian Baca Dolomite is erosional. The Krikov Formation (Fig. 20) starts with a 50 m thick interval dominated by thick-bedded breccia and subordinate calcarenite (Fig. 21a). The breccia is deposited in channels and at the base is intensively

Fig. 19: Geographic location of Stop 4.

dolomitized.

Clasts in the breccia are:

1) grainstone with pellets, peloids, ooids, intraclasts and bioclasts, predominantly echinoderms and benthic foraminifera;
2) peloidal-intraclastic packstone/grainstone;
3) wackestone (mudchips) with calcified radiolarians and sponge spicules (Fig. 22a); and
4) bioclasts, mostly codiaceans and calcisponges.

The breccia matrix is calcarenite, equal to the surrounding calcarenite beds. Calcarenite is graded and horizontally laminated, texturally grainstone or rarely packstone composed of ooids, peloids, intraclasts and bioclasts, mostly echinoderms and codiaceans, together with brachiopods, benthic foraminifera (lenticulinas and biserial textularians) and bryozoans (Fig. 22b). With grading the ooids become rarer, whereas pellets and small intraclasts become more abundant. The upper part of the formation is 200 meters thick and characterized by alternating calcarenite and micrite (Fig. 21b,c). Calcarenite is graded, horizontally and wavy laminated and usually intensively silicified (Fig. 22c). At first, the composition closely resembles the calcarenite from the basal interval. Upwards, the ooids become rarer, whereas echinoderms, intraclasts and lithoclasts (similar to those from the base of the formation) become progressively abundant (Fig. 22d). Thin-bedded hemipelagic wackestone is composed predominantly of pellets, calcified radiolarians, sponge spicules, and thin-shelled bivalves. Replacement chert nodules are common. Parallel and wavy laminations occur rarely.

Age: Hettangian to Pliensbachian age was determined with benthic foraminifera by Cousin (1973, 1981) and Buser (1986), and confirmed by Rozic (2006).

Depositional environment: The limestone breccia and calcarenite at the base were formed by high-density turbidity currents and rarely two-component flows, i.e. a debrite overlain by a turbidite. Such facies association is characteristic of a lower slope environment. Clasts in the breccia indicate the erosion of platform carbonates, whereas the matrix reveals that the deposition originated from high-energy ooidal shoals. The basal breccia-dominated interval presumably reflects the accelerated rifting-related subsidence of the basin margins. The upper part of the formation is characterized by hemipelagic carbonate sedimentation occasionally interrupted by calciturbiditic events. The facies association is characteristic of sedimentation on the proximal basin plain. Firstly, calciturbidites originated on ooidal shoals. Upwards, a change in composition (with ehinoderms replacing ooids) indicates a deepening of the source area. The re-occurrence of platform lithoclasts implies a tectonic disintegration and subsidence of the adjacent platform margin.

Lateral variations: The Krikov Formation shows considerable lateral variation (Fig. 14). The succession seen at Stop 4 (especially its upper part) is characteristic of the central part of the basin. In the northern part of the basin (Kobla Nappe), calcarenites are dominant. The succession is marked by thick- to medium-bedded graded peloidal/ooidal grainstone and subordinate packstone. Breccia with basinal intraclasts and grainstone matrix is common at the base. The composition of resedimented limestones changes abruptly at the top of the formation where grainstone, rich in echinoderms and diverse platform clasts, prevails. Hemipelagic limestone is rare in this part of the basin. Contrary to this, in the southern part of the basin (Podmelec Nappe) the formation consists exclusively of hemipelagic limestone and distal turbidites deposited by low-density currents. The transition from the underlying Baca Dolomite is often gradual or marked by a few meters thick interval of thin-bedded vitreous black chert. In the southwestern margin of the basin (westernmost Podmelec Nappe) the breccias re-occur at the base of the formation. Clasts correspond to those from the basal breccia in the central basin (Stop 4), but the grainstone matrix lacks ooids and is dominated by echinoderms.

The Perbla Formation

The contact with the Krikov Formation is sharp (Fig. 21d). The formation is 24 m thick and characterized by dark-gray, parallelly laminated marl and subordinate calcareous shale. In the first meter, the calcareous shale is black and intensively impregnated with manganese. Thin interbeds of black chert and dark-gray wackestone with pellets, calcified radiolarians, and rarely sponge spicules, lagenid foraminifers, ostracods, and thin-shelled bivalves are rare. A similar composition is observed in marl but the clayey component is more abundant and often concentrated in laminae or dissolution seams. In the lower part of the formation, two beds of pebbly marl are interbedded. Pebbles (up to 10 cm) form 10% of these beds, are well-rounded and composed of the wackestone described above, whereas the matrix corresponds to the surrounding marl.

Age: Fossils are scarce in the Perbla Formation. The occurrence of the foraminifer *Agerina martana* FARINACCI in the lower part of the formation in the Zaposkar and Javor sections (see Fig. 14) indicates a Pliensbachian to Toarcian age (CHIOCCHINI 1994). Preliminary results for palinomorphs have provided dinoflagellate cyst *Luehndea spinosa*, a marker species for the Pliensbachian/Early Toarcian (GÖTZ, personal comm.). Enrichments with manganese in the lower part of the formation, characteristic of the early Toarcian OAE (JENKYNS 1988, JENKYNS et al.

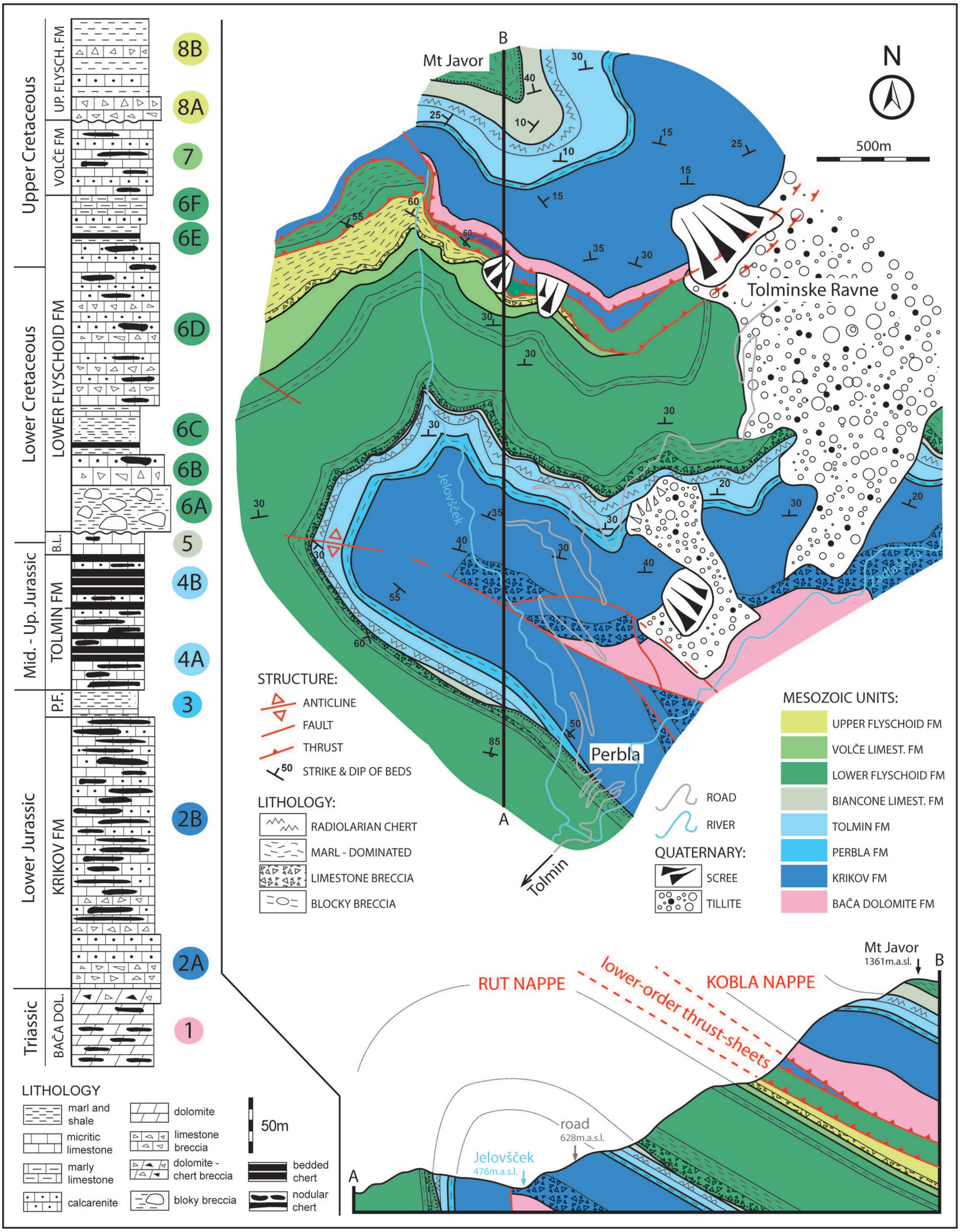


Fig. 20: Stratigraphic log of the section at Stop 4 (left) with a geological map and a cross-section (right).

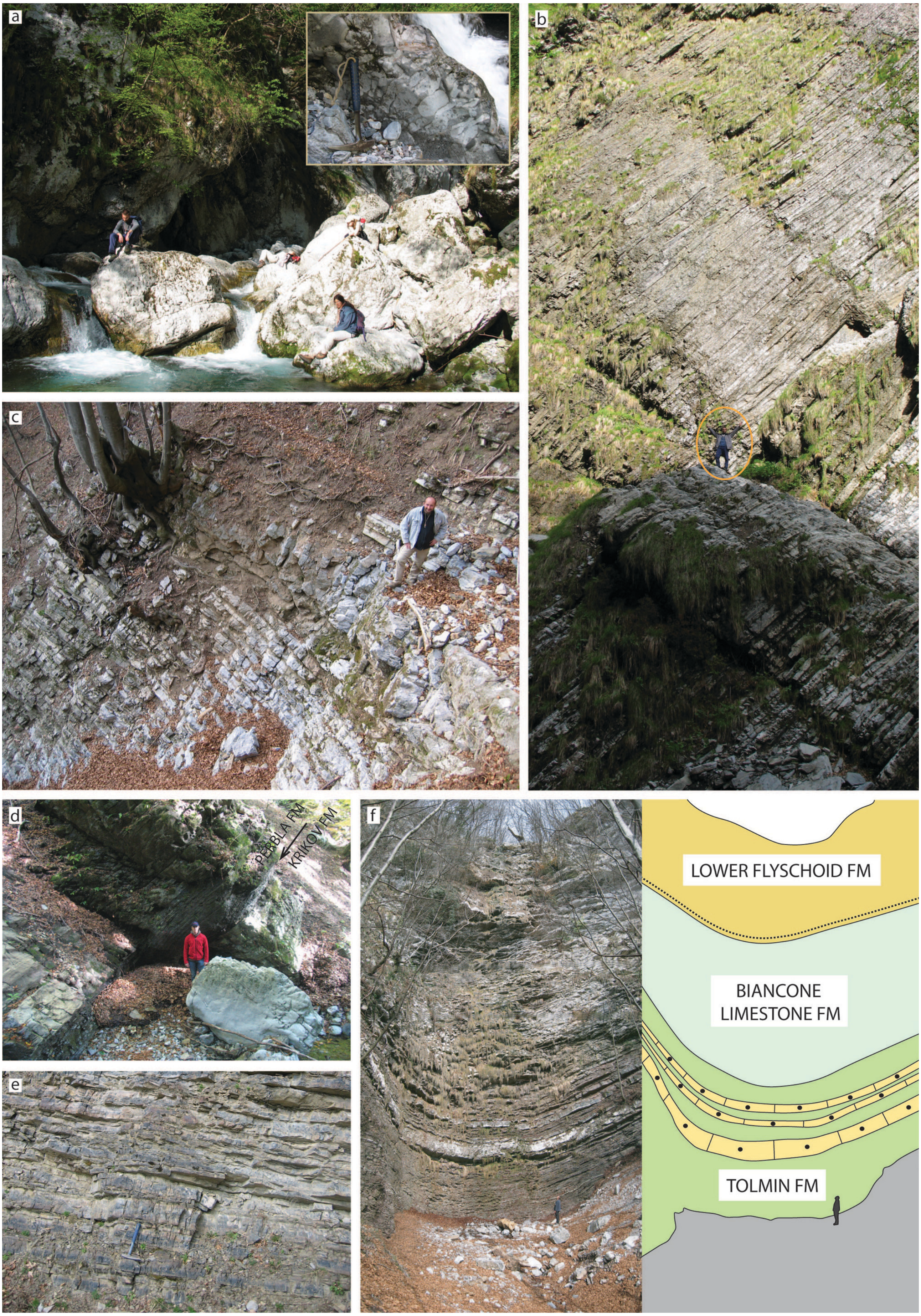

a
b
c
d
PERBLA FM
KRIKOV FM
e
f
LOWER FLYSCHOID FM
BIANCONE LIMESTONE FM
TOLMIN FM

Fig 21: Photographs of outcrops in the Perbla area: a) students resting on outcrops of the basal, thick-bedded limestone breccia of the Krikov Formation in the Zadlascica Canyon (a closer look at breccia in the upper-right corner); b) cliffs in the Krikov Formation in the Zadlascica Canyon; c) a geologist standing on the uppermost calcarenite bed intercalated in thin-bedded hemipelagic limestone at the top of the Krikov Formation; d) the sharp boundary between the limestone-dominated Krikov Formation and the marl-dominated Perbla Formation; e) lower member of the Tolmin Formation: thin-bedded, dark-gray siliceous limestone; f) a large outcrop in the Jelovscek Stream side-gorge near the road between Perbla and Tolminske Ravne with three formations. Radiolarian cherts and upper resedimented limestones of the Tolmin Formation pass with a sharp contact into the pelagic Biancone limestone that is with erosional contact overlain by basal limestone breccia of the Lower flyschoid formation.

1991) are another important stratigraphic marker.

Depositional environment: The Perbla Formation is dominated by basinal sediments that record a high input of terrigenous material. As suggested by the manganese impregnations and geochemical analyses (Oven et al. 2007), the lower part of the formation could have been deposited during the Toarcian OAE. The parallel lamination and occurrence of silt-sized grains in calcareous shale and marl point to deep-water bottom currents. Pebbly marls originated from the redeposition of basinal sediments by debris flows.

Lateral variation: The composition of the Perbla Formation is uniform throughout the basin, whereas the thickness varies significantly (Fig. 14). The formation is thickest in the southeastern part of the basin, where it reaches 130 meters. The formation thins out towards the basin margins and reaches 9 m at the southwestern margins and 2 m in the northeastern part of the basin. The thinnest known interval of just 0.6 m was recently reported from a small thrust-sheet located between the Rut and Kobla nappes (Svetlicic et al. 2011). In north-western and south-eastern parts of the basin calciturbidites (calcarenite) also occur. These are crinoidal grainstones that usually grade into packstones composed almost exclusivelly of thin-shelled bivalves (for details, see Rozic & Smuc 2011).

The Tolmin Formation

The boundary with the Perbla Formation is gradual and defined at the point where cherts start to predominate. The formation is divided into two members. The lower member is 74 m thick and begins with a 5 m thick interval of thin-bedded, dark-violet, and upsection dark-green chert that alternates with marl. In the following 7 m, the marly intervals are thicker (up to 90 cm) and alternate with thin-bedded, dark-gray limestone with chert nodules. Upwards, marl intercalations become rare and limestone beds occasionally thicker. Between 19 and 25 m slumps are present. The limestone is dark-grey, bioturbated, parallelly and wavy laminated (Fig. 21e). The prevailing microfacies is wackestone composed predominantly of calcified radiolarians (Fig. 22e). Other grains are sponge spicules, thin-shelled bivalves, small lagenid foraminifers, ostracods, echinoderm fragments, and pellets. Chert nodules are present throughout the member. The silicification is especially intense in the middle part where horizons of thin-bedded, black chert are common. Chert nodules and beds are strongly altered and usually only radiolarians are recognizable. The upper member is 57 m thick and composed of thin-bedded, parallelly and rarely wavy laminated radiolarian chert. The color changes from greenish-gray at the base to violet-red towards the top of the member (Fig. 21f). Shale intercalations are rare but become progressively abundant in the uppermost 3 m of the member. Within pelagic beds, two intervals of resedimented limestones are distinguished. The lower interval consists of thin- to medium-bedded, graded, parallel and rarely cross-laminated calcarenite that occurs around the boundary between the two members. It is composed of ooids, peloids, shallow-water intraclasts, basinal clasts, and fossils, predominantly echinoderms (Fig. 22f). Other fossils are bivalve, brachiopod, and ostracod shells, gastropods, bryozoan fragments, and benthic foraminifers. The upper resedimented interval occurs at the top of the formation and consists of thin- to medium-bedded, graded and parallel laminated calcarenite (Fig. 21f), composed predominantly of (shallow-water) intraclasts, peloids, basinal clasts, fossils, and very rare ooids (Fig. 22g). The most abundant fossils are echinoderms. Others are bivalves and brachiopods, fragments of calcareous sponges, and benthic foraminifers. Rare aptychi and *Saccocoma* fragments are observed in the uppermost beds. Finer calcarenite exhibits a similar texture, structure, and composition as the corresponding beds of the lower interval. All resedimented limestones are partially replaced by chert nodules.

Age: The lower boundary of the Tolmin Formation is not dated. It is placed only by lithological correlation with other basins of the Western Tethys at the Toarcian/Aalenian boundary. The upper member has recently been dated with radiolarians and nannoplankton (Gorican et al. 2012). The base of the upper member is assigned to the upper Bajocian (UA Zone 4 of Baumgartner et al. 1995b). The top of the formation is placed at Lower/Upper Tithonian boundary (UA Zone 12). The lower resedimented limestone starts at the boundary between the two members; the directly overlying chert beds in more proximal areas (see the Poljubinj section in Fig. 14) are middle Callovian - early Oxfordian in age (UA Zone 8). The upper resedimented limestones are assigned to the late Kimmeridgian to early Tithonian. The age of these limestone interbeds is further constrained with benthic foraminifers and dasycladalean algae (Rozic 2009).

Depositional environment: The transitional lower boundary of the Tolmin Formation records a progressive decrease in terrigenous input to the basin simultaneously with the onset of first siliceous and soon after more calcareous pelagic sedimentation. Laminations in these beds and in the overlying radiolarian cherts indicate low-density turbidity currents. Vertical color changes reflect the changing degree of bottom-water oxygenation during

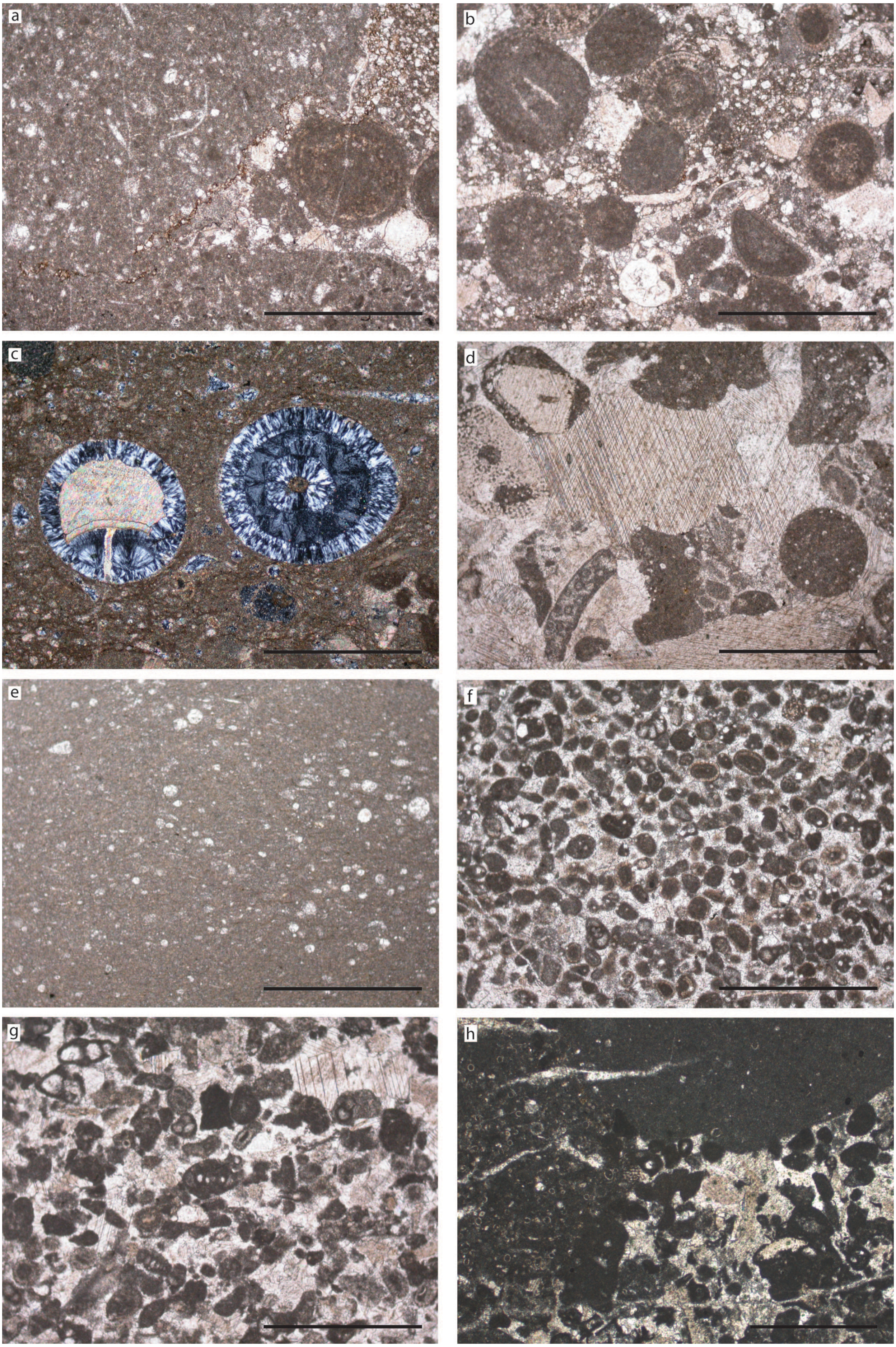

a
b
c
d
e
f
g
h

Fig. 22: Microfacies characteristics (scale bars 1 mm): a) Basal limestone breccia of the Krikov Formation: wackestone basinal clasts with calcified radiolarians, sponge spicules and thin-shelled bivalves; b) calcarenite from the lower part of the Krikov Formation: packstone with ooids, peloids, intraclasts and fossils, mainly echinoderms and benthic foraminifera; c) calcarenite from the lower part of the Krikov Formation: silicification of the ooids (cross-polarized light); d) calcarenite from the upper part of the Krikov Formation: grainstone with echinoderms, intraclasts, lithoclasts and peloids; e) hemipelagic limestone of the lower member of the Tolmin Formation: wackestone with calcified radiolarians; f) lower resedimented limestones of the Tolmin Formation: grainstone with ooids, peloids, intraclasts and fossils, mainly echinoderms and benthic foraminifera; g) upper resedimented limestones of the Tolmin Formation: grainstone with intraclasts and fossils, predominantly echinoderms and benthic foraminifera; h) basal limestone breccia of the Lower flyschoid formation: rudstone composed mainly of intraclasts and echinoderms, and two larger clasts with calpionellids.

deposition. The uppermost part of the Tolmin Formation records an increase in terrigenous input, presumably related to a more warm and humid climate in the Late Jurassic. Sedimentary structures in resedimented limestones indicate deposition by turbidity currents. Facies association is characteristic of a basin plain sedimentary environment. Abundant ooids and peloids in the lower resedimented limestones indicate that the source area was ooidal shoals. The upper resedimented limestones also originated at an open carbonate shelf but, in contrast, the end Jurassic shelf provided mainly intraclasts and fossils (echinoderms).

Lateral variations: The background sediments are similarly developed throughout the Tolmin Basin, but in the southern part of the basin, marl intercalations are locally common. Apart from the central part of the basin, resedimented limestones also occur in the southern part of the Tolmin Basin (Fig. 14). The lower resedimented limestones form locally an up to 25 m thick interval of amalgamated coarse-grained beds. Graded limestone breccia occurs additionaly and contains the following clasts: 1) deep-water intraclasts (mud-chips); 2) shallow-water clasts with abundant ooids/peloids; and 3) chert clasts. The upper resedimented interval is very similar in the southern and central parts of the basin.

The Biancone limestone

The boundary with the Tolmin Formation is sharp (Fig. 21f). The Jurassic succession ends with thin-bedded light-gray micritic Biancone limestone. The formation is up to 16 m thick but laterally wedges out because its upper boundary is erosional. It consists of mudstone to wackestone with calcified radiolarians, calpionellids and rare aptychi. Replacement chert nodules occur sporadically.

Age: A Late Tithonian to Berriasian age was determined with nannoplankton and calpionellids (Rozic 2009) and is also constrained with radiolarians at the top of the underlying Tolmin Formation (Gorican et al. 2012).

Depositional environment: The uniform composition of this formation indicates pelagic sedimentation in a basin-plain sedimentary environment.

Lateral variation: Throughout the basin, the formation is uniform in composition but its thickness varies significantly (from 0 to 40 meters). Most of the Biancone limestone was removed due to mid-Cretaceous erosion (see below). In the northwestern part of the basin at Mt. Javor (in the Kobla Nappe just above the Tolminske Ravne village), the pelagic Neocomian limestones were described as the Javor Formation (Cousin 1973). They contain more marl than the typical Biancone limestone, are reddish in color and possibly range into the Valanginian.

The Lower flyschoid formation

The boundary with the underlying formations is sharp and marked by a highly irregular erosional surface. The formation is up to 280 meters thick. In the area around Perbla, the formation is subdivided into six members (6A-6E in Fig. 20). In the southern limb of the anticline (seen on the way to Stop 4), the formation starts with a breccia with large blocks (up to a few tens of meters in size) of Carnian reef limestone embedded in a marly matrix. This breccia is up to 40 meters thick and was deposited in a large erosional channel that cuts downwards to the Toarcian Perbla Formation. At Stop 4, the formation starts with 30 m of basal limestone breccia and calcarenite. The breccia beds are up to several meters thick and graded. Clasts in breccia are very diverse platform carbonates (fenestral bindstone, ooidal grainstone, coralline framestone etc.), pelagic carbonates (mainly clasts of the Biancone limestone; Fig. 22h) and cherts. Calcarenite (that also forms matrix in the breccia), is graded, horizontally laminated and composed of intraclasts and bioclasts, mainly benthic foraminifers, echinoderms, calcisponges and bivalve shells (Fig. 22h). Upwards, a 50 m thick shale/marl dominated interval starts. It gradually passes into a 150 m thick interval dominated by calcarenite. The calcarenite is medium-bedded and shows a similar composition and structure to that at the base of the formation. Beds of micritic limestone are intercalated. The 5th member (6E in Fig. 20) of the formation is 20 m thick and composed of black to dark-red marl and shale with rare thin interbeds of manganese impregnated chert. Upwards, it passes into the last member that is 30 m thick and starts with dark-gray graded calcarenite that passes into red or rarely green pelagic limestone with globotruncanas. All limestones in this formation contain replacement chert nodules.

Age: The formation is dated with nannoplankton, planktonic and benthic foraminifers (Caron & Cousin 1972, Cousin 1973, 1981, Buser 1986, Samiee 1999, Rozic 2005). The lower three members are ?Aptian to middle Albian in age. The fourth member is probably late Albian to Cenomanian, whereas the uppermost two members presumably span the latest Cenomanian and the Turonian.

Depositional environment: The breccia with blocks of Carnian reef limestone was deposited in an erosional channel by a debris flow. At first, based on the analysis of corals, this breccia was considered to be part of the Carnian succession characterized by coral pach reefs (Turnsek 1985, Turnsek et al. 1987). Later, the nannoplankton analysis of the marly matrix revealed a middle Cretaceous age of this gravitational event (Buser, personal comm.). We note, however, that the breccia with Carnian blocks is so far only known from the Perbla locality. The limestone breccias and calcarenites at Stop 4 were deposited by debris flows and high-density turbidity currents. Member 6B indicates deposition in marginal parts of the basin characterized by stratigraphic gaps, highly irregular erosional surfaces and coarse-grained lithologies. Member 6C records a sharp distalization of the sedimentary environment from a slope to basin-plain setting dominated by shales and marls. The subsequent gradual increase in the amount of resedimented limestone in member 6D is attributed to the re-establishment of carbonate production on the margin of the Dinaric Carbonate Platform. The base of member 6E, enriched in manganese, probably records the OAE at the Cenomanian/Turonian boundary, whereas the rest of the formation is characterized by pelagic carbonate sedimentation.

Lateral variation: In the major part of the basin the formation is composed of shale, marl and chert interbedded with distal calciturbidites. Generally, the formation begins with basal limestone breccia that is a few meters thick (Caron & Cousin 1972, Cousin 1981, Buser 1986). In the southwestern margin of the basin, the formation has a similar composition as members 6D and 6E in the Perbla-Tolminske Ravne section. It is also considered to be only upper Albian to Turonian in age. The gap between the underlying formations is greater and limestone breccias are more abundant. These facts indicate a sedimentation in a more marginal, i.e. a lower slope, sedimentary environment (Rozic 2005).

Jurassic to Early Cretaceous evolution of the Tolmin Basin

This chapter is summarized from the following publications: Rozic (2006, 2009), Rozic & Popit (2006) and Rozic & Smuc (2011) for the Jurassic, Rozic (2005) for the Cretaceous.

The limestone breccia at the base of the Krikov Formation records an accelerated subsidence of the basin around the Triassic/Jurassic transition. Intensified tectonic activity is regional and in the Southern Alps leads to the disintegration of the vast Dolomia Principale Platform (e.g., Winterer & Bosellini 1981). The distribution of facies associations in the Krikov Formation indicates that the source area of the resedimented limestone was the north-lying Julian Carbonate Platform marked by deposition of ooidal shoals (Buser 1986, Smuc 2005). At that time, the input from the south-lying Dinaric Carbonate Platform was negligible. This distribution is interpreted to be a consequence of a south-directed current regime (probably wind-driven) on the platforms. The change in composition at the top of the formation, where ooidal/peloidal grainstone is replaced by crinoidal/lithoclastic grainstone, records initial stages of a tectonically induced drowning of the Julian Carbonate Platform. The disintegration and partial subsidence accompanied by the formation of extensive neptunian dikes is dated to the Pliensbachian (Babic 1981, Buser 1996, Smuc 2005, 2010, Smuc & Gorican 2005, Crne et al., 2007). Coeval tectonic activity is also reported from the rest of the Southern Alps (Winterer et al. 1991, Sarti et al. 1992, Bertotti et al. 1993, Clari & Masetti 2002). In the Tolmin Basin tectonic disintegration of the wider area is further manifested in the highly variable thickness of the overlying Perbla Formation (Fig. 14).

At the beginning of the Toarcian, the input of coarse carbonate material into the Tolmin Basin ended due to the termination of shallow-water sedimentation on the Julian Carbonate Platform. The rest of the Jurassic succession is dominated by (hemi)pelagic sediments that show similar trends as observed in other Jurassic basins of Tethyan continental margins (Fig. 15). The Toarcian is marked by clay-rich sediments that change to carbonates at the end of the stage to become siliceous in the Bajocian and finally pure carbonate at the end of the Jurassic. The middle or end-Oxfordian reverse trend from siliceous to more calcareous sedimentation that is reported from the western and central Southern Alps and Apennines is not observed in the Tolmin Basin (for details and references concerning correlation, see Rozic 2009).

After the disintegration of the north-lying Julian Carbonate Platform, resedimented limestones become rare. Scarce calciturbidites occur at the basin margins already in the Toarcian. The simple composition with crinoids and thin-shelled bivalves reveals the deepened margins of the surrounding platforms or slopes as possible source areas. Toarcian crinoidal limestone is known from the northern margin of the Dinaric Carbonate Platform (Crne & Gorican 2008). Carbonate resediments are most common from the Bajocian to the Callovian and only occur in the southern and central parts of the basin. Such facies distribution and composition with abundant ooids and peloids indicate that the source area was the Dinaric Carbonate Platform that at this time was a highly-productive open carbonate shelf (Orehek & Ogorelec 1979, Bosellini et al. 1981). The coeval resedimented limestones in basins that surround the Dinaric Carbonate Platform to the west and southwest show a similar composition and structure but have a much greater thickness and usually mask the background sedimentation. In the Belluno Basin, the corresponding Vajont Limestone reaches more than 600 m (Bosellini et al. 1981, Zempolich & Erba 1999, Clari & Masetti 2002) and in the Budva Basin, the upper member of the Bar Limestone Formation is up to 220 m thick (Gorican 1994). Greater thickness is also known from the Bovec Basin that is today located northwest of the Dinaric Carbonate Platform (Smuc 2005, Smuc & Gorican 2005). This distribution of thickness confirms the interpretation of Bosellini et al. (1981) who proposed the south-westward transporting of material on the Dinaric Carbonate Platform, induced by permanent wind-driven shallow-water and longshore currents. When also considering the distribution of facies associations in the Krikov Formation, we can conclude that such conditions were characteristic and persistent in a wider area at least during the Early and Middle Jurassic. The resedimentation of shallow-water material in the Tolmin Basin ceased during the Callovian and was scarce up until the late Kimmeridgian. During this time, the northern margin of the Dinaric Carbonate Platform was first drowned and later rimmed by a barrier reef (Buser 1978, 1986, Turnsek 1997). At the end of the Kimmeridgian, large areas of the Dinaric Carbonate Platform became subaerially exposed (Tisljar et al. 2002) which led to the demise of barrier reefs (Turnsek 1997). The re-establishment of platform sedimentation followed in the latest Kimmeridgian or early Tithonian, when bedded limestone with *Clypeina jurassica* Favre started to deposit (Buser 1986). This change on the Dinaric Carbonate Platform is recorded in the Tolmin Basin with the re-occurrence of resedimented limestones. Although for this interval no apparent differences of facies associations are observed between the southern and central parts of the basin, a south-lying source area is still evident because resedimented limestones are completely absent in the northern part of the basin. The composition of these beds indicates the different production in the source area compared with the Middle Jurassic resedimented limestones. The platform provided smaller amounts of ooids but simultaneously more abundant (shallow-water) intraclasts and diverse fossils.

The Cretaceous is marked by a strong perturbation in tectonic organization in the wider area and coincide with the onset of a compressive regime in the internal Alpine and Dinaric domains. In the Tolmin Basin, the Aptian-Albian event is reflected in a significant stratigraphic gap and the sedimentation of thick breccias that lie on a highly irregular erosional surface. The diverse platform clasts of different ages indicate a deep erosion also in the south-lying platform area. The succession is afterwards followed by relatively rapid distalization of sedimentary environments when a typical succession of the Lower flyschoid formation, i.e. shales, marls and calciturbidites started to deposit. In the middle Albian, the resedimented limestones became progresively more abundant, which is best documented in the proximal parts of the basin, located close to the south-lying Dinaric Carbonate Platform (Samiee 1999, Rozic 2005). Several coarse-grained breccias provide evidence of multiple erosional events during the Eo-alpine tectonic phase.

3.3. The Bovec Basin

General description

The Bovec Basin was a small N-S trending basin that developed after the disintegration and drowning of the Julian Carbonate Platform in the Early Jurassic (Cousin 1981, Buser 1989, Jurkovsek et al. 1990, Gorican et al. 2003, Smuc 2005, Smuc & Gorican 2005, Crne et al. 2007). To the south-west, the basin was bordered by the Dinaric Carbonate Platform as suggested by abundant platform-derived Middle and Upper Jurassic turbidites. The stratigraphic position of basinal facies above the platform carbonates and structural relationships on Mt. Mangart also show that the basin was juxtaposed to the Julian High. On the other hand, the relation to other Jurassic deep-water areas (Belluno, Tolmin and Bled basins) is unclear. The remnants of the Bovec Basin are exposed in just two

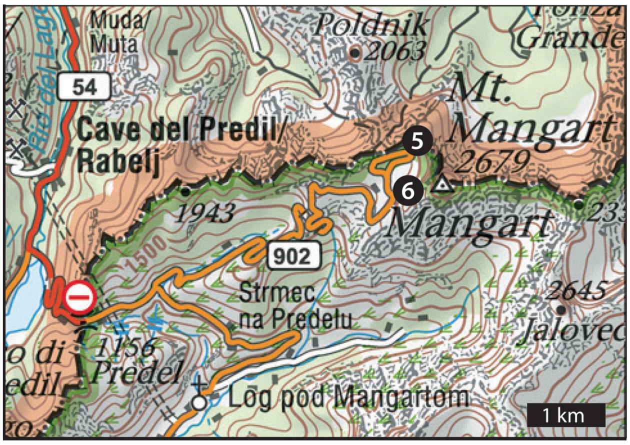


Fig. 23: Geographic location of Stops 5 and 6.

locations: Mt. Mangart Saddle (described below) and the Bavsica Valley, approximately 10 km to the south.

The Mt. Mangart Saddle (Fig. 23) is part of a complex tectonic structure (Fig. 24) comprising two larger structural units: the Mangart and Travnik structural units that are internally thrusted, folded, and disrupted by faults. The Travnik structural unit is composed of Lower Jurassic to middle Cretaceous drowning succession of the Bovec Basin and characterized by an overturned plunging syncline with developed duplex structures (Figs. 25a-b, 26). The Mangart unit, on the other hand, is characterized by Upper Triassic to Late Cretaceous drowning successions of the Julian High and is additionally divided into four subunits: Mali Vrh, Rdeca skala, Drn and Mangart peak subunits.

The drowning succession of the Bovec Basin starts with the Lower Jurassic platform limestones of the Julian Carbonate Platform, overlain by upper Pliensbachian distal-shelf limestones (Sedlo Formation) and followed by Toarcian black shales (Skrile Formation). The Middle and Upper Jurassic deposits of the Bovec Basin are characterized by pelagic siliceous sedimentation and abundant carbonate gravity-flow deposits (Travnik Formation). The succession ends with pelagic, Tithonian to Early Cretaceous Biancone limestone.

Stop 5: Travnik

Pliensbachian to Berriasian

Guided by Andrej Smuc

The Travnik section (Figs. 23, 24) crops out on the Mt. Mangart Saddle and is part of an overturned syncline of the Travnik structural unit (Fig. 26). The Travnik section records a complete Lower Jurassic to Lower Cretaceous succession of the Bovec Basin (Fig. 27). The entire section was first described and dated by Smuc & Gorican (2005); the lithostratigraphic units were then formally defined by Smuc (2005).

Sinemurian to Pliensbachian shallow-water limestone

The dominant lithofacies is a light-gray, massive, medium to well-sorted grainstone composed of intraclasts of peloidal wackestone/packstones and mudstones, peloids, micritized ooids and oncoids (Fig. 28a). The skeletal component consists of echinoderm fragments, gastropods, bivalves, spongiomorphs, fragments of algae and foraminifers. Grains are cemented first by bladed and syntaxial cements and then by coarser sparite. In the uppermost part of shallow-water limestones, up to 1 m

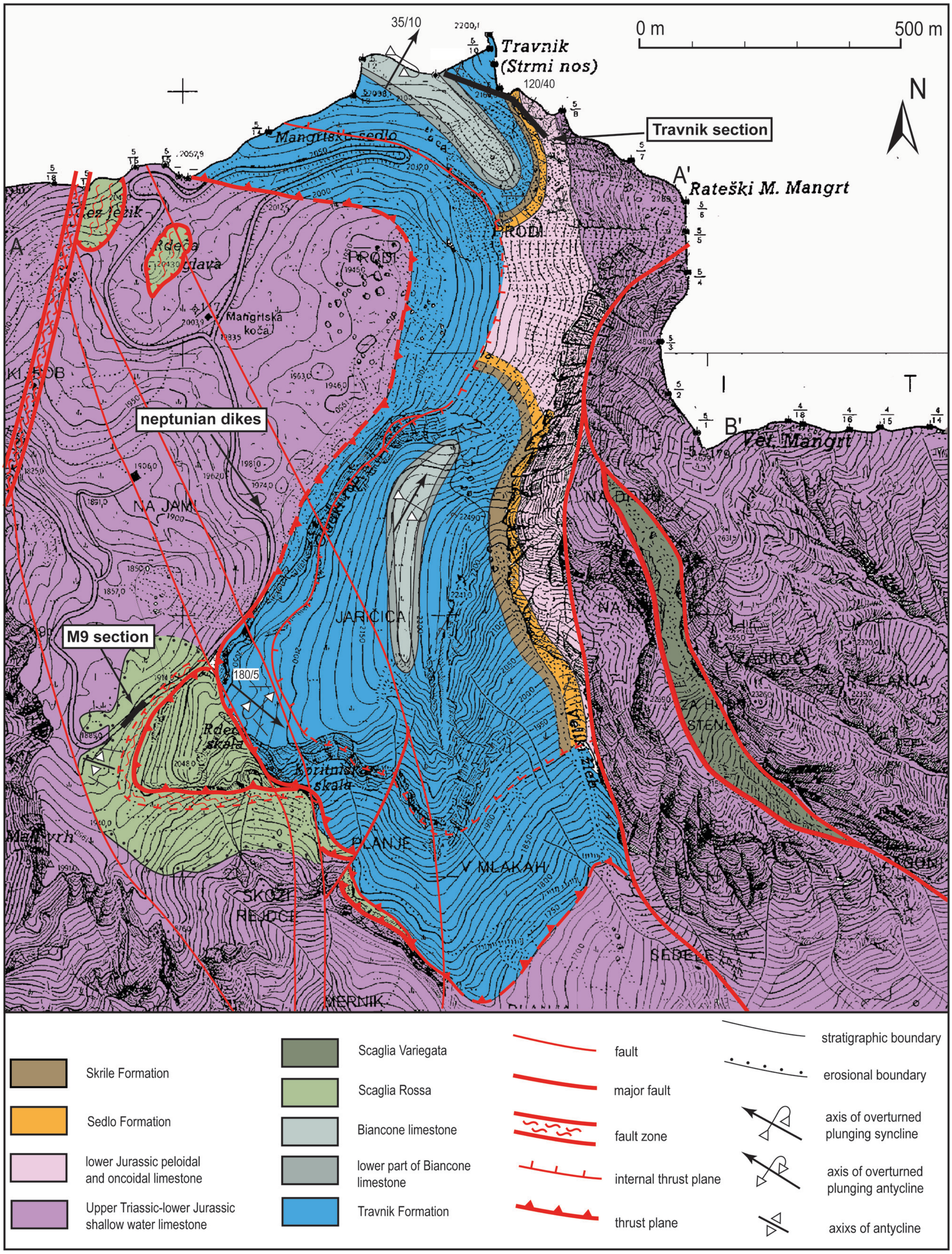


Fig. 24: Geological map of the Mt. Mangart saddle (from Smuc 2005). The Italian territory was not mapped.

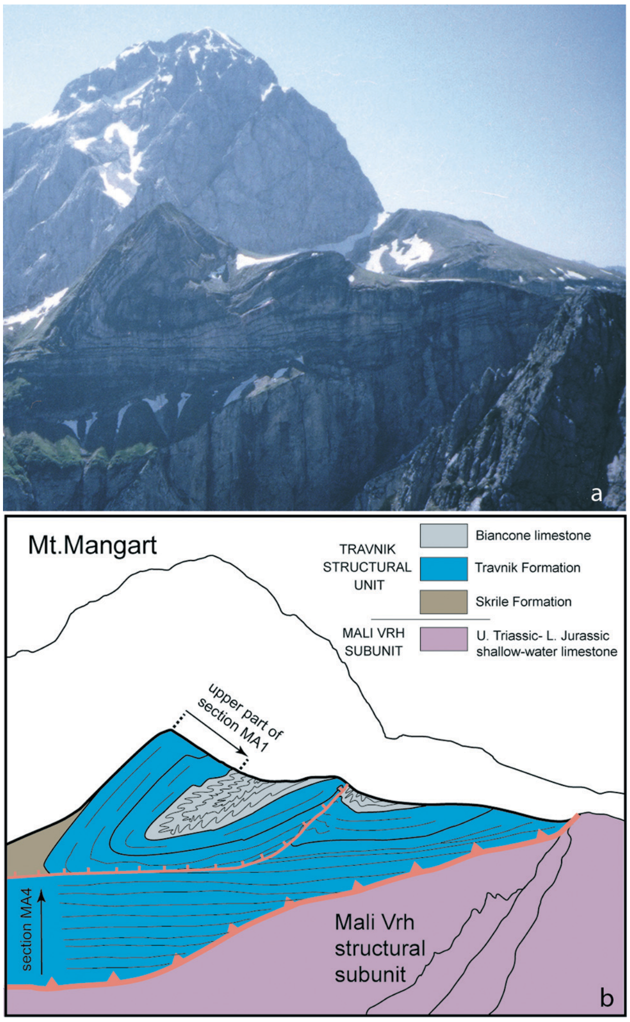


Fig. 25a: View of the northern flank of the Mt. Mangart saddle.
Fig. 25b: Structural sketch of the photograph in Fig. 25a (from Smuc 2005).

thick beds of the above described grainstone alternate with up to 30 cm thick beds of finer-grained wackestone/packstone with peloids, rare ooids, benthic foraminifers (Textulariidae, Valvulinidae, *Lenticulina* sp., and *Agerina martana* (Farinacci)), rare echinoderms, and bivalves.
Grainstones of the lower part were deposited in a sand belt in a marginal part of a carbonate platform. The finer-grained peloidal wackestones/packstones intercalated in the upper part were deposited in a deeper environment located basinward of the marginal sandbelt.
Age: In the upper part of the succession the presence of *Agerina martana* (Farinacci) suggests a Pliensbachian age. In the lower part of the succession *A. martana* is not present so a Sinemurian age for this lower part is possible.

Pliensbachian Sedlo Formation

The lower part of the formation consists of light-brownish-gray, massive to indistinctly bedded bioclastic wackestone to packstone composed mainly of sponge spicules, echinoderm fragments, locally abundant juvenile ammonites, and benthic foraminifers (Textulariidae, *Lenticulina* sp., *Agerina martana* (Farinacci)) (Fig. 28b). The upper part of the formation is characterized by a distinctive greenish rudstone-packstone (Fig. 28c) and red siliceous limestone. The rudstone and packstone are thin-bedded, poorly sorted, and normally graded. The prevalent grains are fragments of echinoderms and diverse intraclasts of underlying lithologies. Other grains include foraminifers (*Lenticulina* sp., *Agerina martana* (Farinacci)), bivalve and brachiopod fragments, and peloids. The red siliceous packstone/wackestone is thin-bedded and consists of abundant, partly calcified, sponge spicules and radiolarians. The matrix is partially impregnated by Fe-Mn oxides. The siliceous packstone/wackestone contains Fe-Mn nodules up to 3 cm in size. They occur throughout the uppermost 1.5 m of the formation and form a 25 cm thick Fe-Mn nodule horizon at the top of the formation.

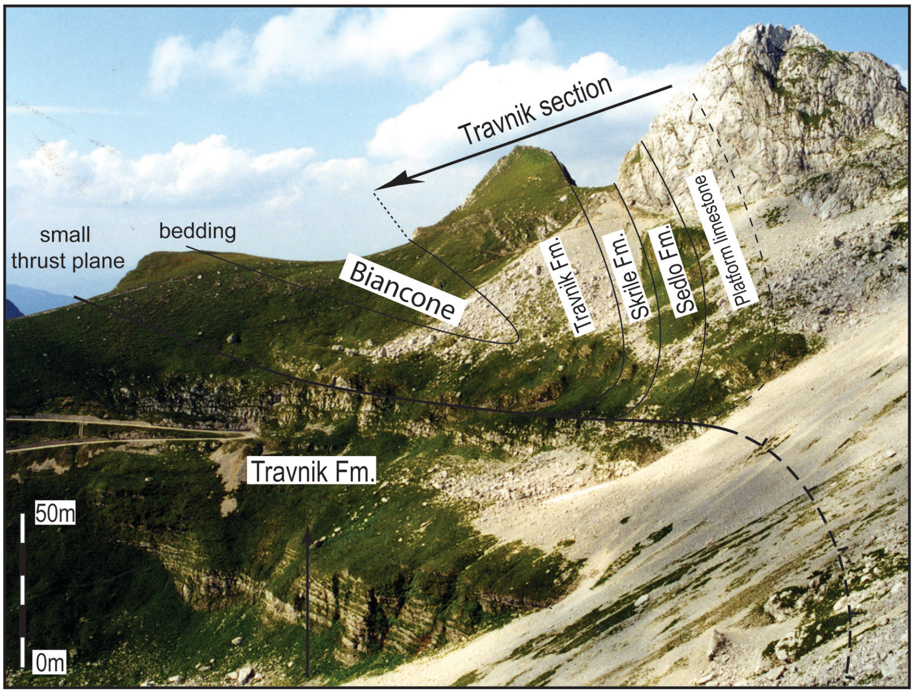


Fig. 26: View of the Mt. Mangart saddle towards the north with marked general tectonic features and the Travnik section. Note that the Travnik section is in an overturned position.

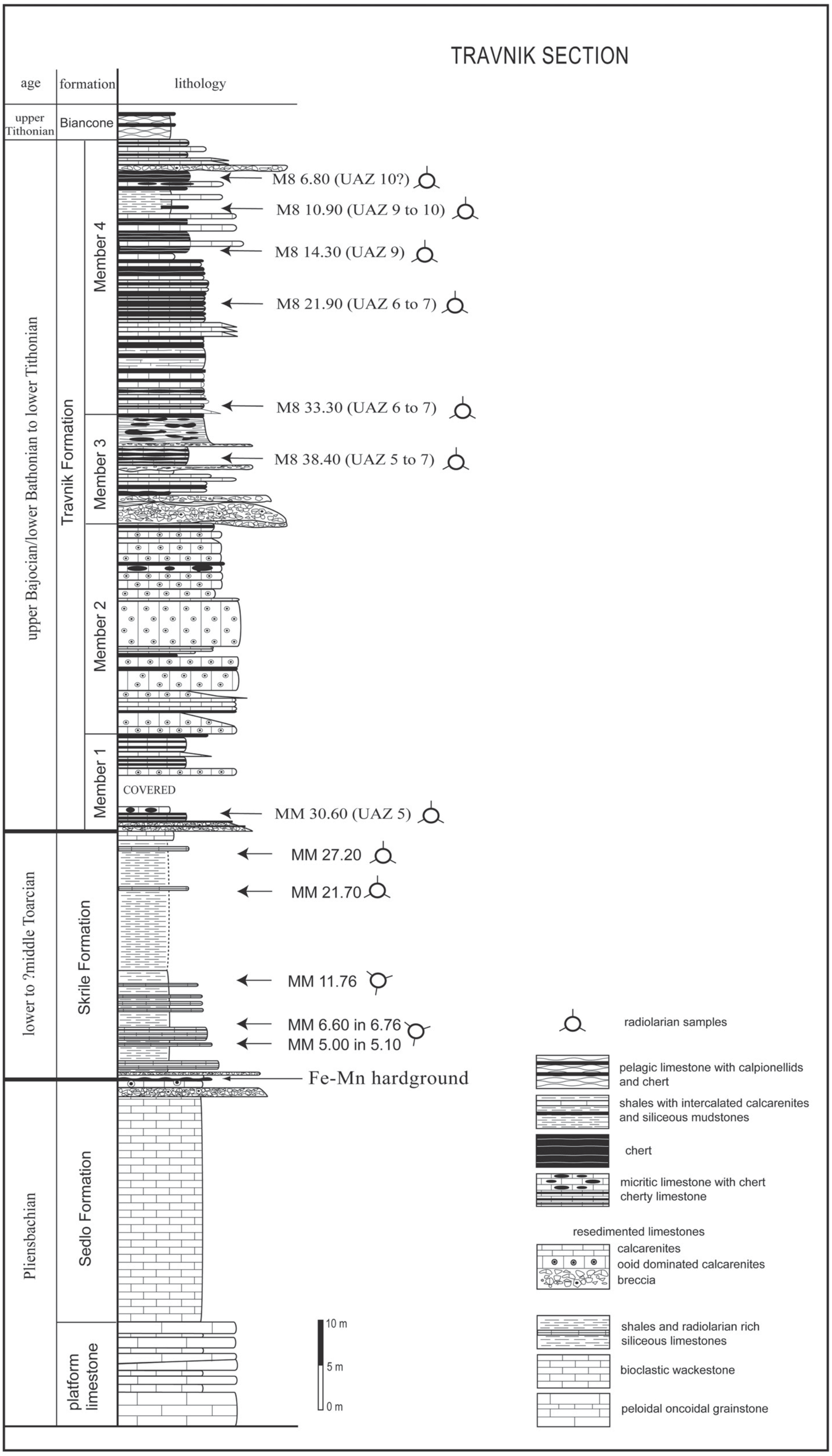


Fig. 27: The Travnik section with the position of the radiolarian samples (from SMUC 2005 and SMUC & GORICAN 2005).

The lower part of the formation was deposited in a deeper depositional environment, most probably that of a distal shelf. Rudstones and packstones in the upper part of the formation are gravity-flow deposits indicating exhumation of the underlying lithologies by synsedimentary extensional tectonics. The uppermost part of the formation is characterized by a condensed interval indicating extremely reduced sedimentation rates that reached their minimum with the formation of the Fe-Mn hardground.

Age: The common presence of *Agerina martana* (FARINACCI) in the lower part of the formation suggests a Pliensbachian age. Because the overlying Skrile Formation is Early Toarcian in age (see below), the Fe-Mn hardground at the top of the Sedlo Formation approximately corresponds to the Pliensbachian/Toarcian boundary.

Toarcian Skrile Formation

The formation is represented by black laminated calcareous organic-rich shales with interbeds of black siliceous limestone (Fig. 29). In the upper part of the formation, the shales are brown. The shales contain quartz, smectite and illite, and Mn oxides (Jenkyns 1988, Jurkovsek et al. 1990). The TOC values range between 0.3% and 1.89% (Sabatino et al. 2009), and the manganese content is high (up to 8.8%) in the basal portion and decreases (1.8% or less) upsection (Jenkyns 1988, Sabatino et al. 2011). The intercalated siliceous limestones are thin-bedded packstones to mudstones. In the lower part of the formation, the siliceous limestone shows both normal and inverse grading, parallel and ripple cross-lamination (Ta-d Bouma sequences), while upsection, only indistinct parallel lamination is present (Td Bouma sequence). The limestone is composed mainly of radiolarians, sponge spicules, intraclasts of lime mudstone, and phosphate grains (Fig. 28d). The matrix is micrite with a high organic matter content. The formation ends with 0.90 m of light-green, thin-bedded, laminated mudstone.

The Skrile Formation records a high input of terrigenous clayey material. Black organic-rich shales in the lower part of the formation were deposited during the Early Toarcian Oceanic Anoxic Event (OAE). The intercalated siliceous limestones are typical of low-density turbidites. The nature of resedimented grains indicates the redeposition of material only within the sedimentary basin.

Age: The Early and possibly Middle Toarcian age of this formation was constrained with radiolarians (Gorican et al. 2003). The studied sediments are typical black shales and were classically attributed to the Early Toarcian OAE (Jenkyns & Clayton 1986, Jenkyns 1988). This correlation with the anoxic event has recently been reinforced by detailed organic carbon-isotope studies that reveal a negative C-isotope anomaly through the entire Skrile Formation (Sabatino et al. 2009).

Bajocian to Lower Tithonian Travnik Formation

On the basis of the lithology, structure and composition of resedimented limestones, the Travnik Formation is subdivided into four members. The formation's age was determined with radiolarians from intervening cherts (Smuc & Gorican 2005). For the type section, productive samples with corresponding radiolarian zones (according to Baumgartner et al. 1995b) are indicated (Fig. 27). The following Unitary Association zones (UAZ) were determined: UAZ 5 (latest Bajocian - early Bathonian) at the base of the formation, UAZ 6-7 (middle Bathonian to late Bathonian-early Callovian), UAZ 9 (middle-late Oxfordian) and, near the top of the formation, UAZ 10 (late Oxfordian-Kimmeridgian). In other, more complete sections, the base of the formation is older and assigned to UAZ 3 (early-middle Bajocian) (Smuc 2005).

Member 1 represents the base of the formation and is laterally diachronous and variably developed. In complete sections it is characterized by carbonate mudstones with radiolarians, with intercalated fine- to coarse-grained calciturbidites. In the upper part of the member, limestone breccia with glauconite grains also occurs and calciturbidites become more abundant. In condensed successions, as in the case of the Travnik section, only the upper part of Member 1 is present.

In more complete nearby sections (e.g., sections MA 3 and MA 4 of Smuc 2005) Member 1 starts with bedded (5 to 70 cm thick) homogeneous mudstone/wackestone (Fig. 30) composed of calcified radiolarians, filaments with intercalated beds and lenses of replacement chert (Fig. 28e). Upwards, the intercalations of calcarenites and siliceous limestones start to occur. The calcarenites are medium- to fine-grained, beds thicken up to 20 cm and exhibit mainly a Tb Bouma division, while Ta and Tc Bouma sequences are rare. Lamination is defined by the alternation of thicker packstone laminae mostly composed of ooids and thinner laminae where filaments predominate. Other grains are peloids, echinoderm fragments, benthic foraminifers (Textulariidae, *Lenticulina* sp.), phosphate, and glauconite grains. The siliceous limestone is thinner bedded packstone/wackestone and mainly exhibits Tb-d Bouma sequences. It is composed of partially calcified radiolarians, filaments and very rarely sponge spicules, echinoderm fragments, and phosphate. The upper part of Member 1 is characterized by a few gray to green, medium-thick beds of fine-grained, poorly- to medium-sorted clast-supported breccia that grades into calcarenite. The breccia consists of abundant glauconite grains, filaments, echinoderms, ooids, bivalve fragments, foraminifers (Textulariidae, *Lenticulina* sp.), radiolarians, sponge spicules, and various lithoclasts of older lithologies (Fig. 28f). The calcarenite exhibits Tb Bouma divisions and has the same bioclasts as breccias, but contains more ooids and highly evolved glauconite grains and is devoid of lithoclasts. Member 1 ends with the alternation of the previously described medium-grained ooidal calcarenites and thin-bedded siliceous limestones with radiolarians.

The homogeneous mudstone/wackestones represent background deposits sedimented by a pelagic settling. However, since planktic carbonate producers were scarce in the Middle Jurassic, the majority of carbonate deposited by a pelagic settling was also allochthonous and exported off-platform. Thus, these background pelagic limestones are interpreted to be periplatform ooze deposits. The thin-bedded siliceous packstone/wackestone was deposited by low-density turbidity currents, while calcarenites were deposited by sandy turbidite currents. Breccias are a product of gravelly, high-density turbidity currents. Different lithoclasts of the older Jurassic formations indicate the exhumation and partial erosion of the underlying deposits. The presence of evolved to highly evolved glauconite grains in the breccia and calcarenite is indicative of long-term sediment starvation in the provenance area.

This type of deposition with the predominance of pelagic sediments with only a minor intercalation of the fine- to coarse-grained calciturbidites is characteristic of distal basin floor environments. However, in the upper part of Member 1 calciturbidites are more common and thus

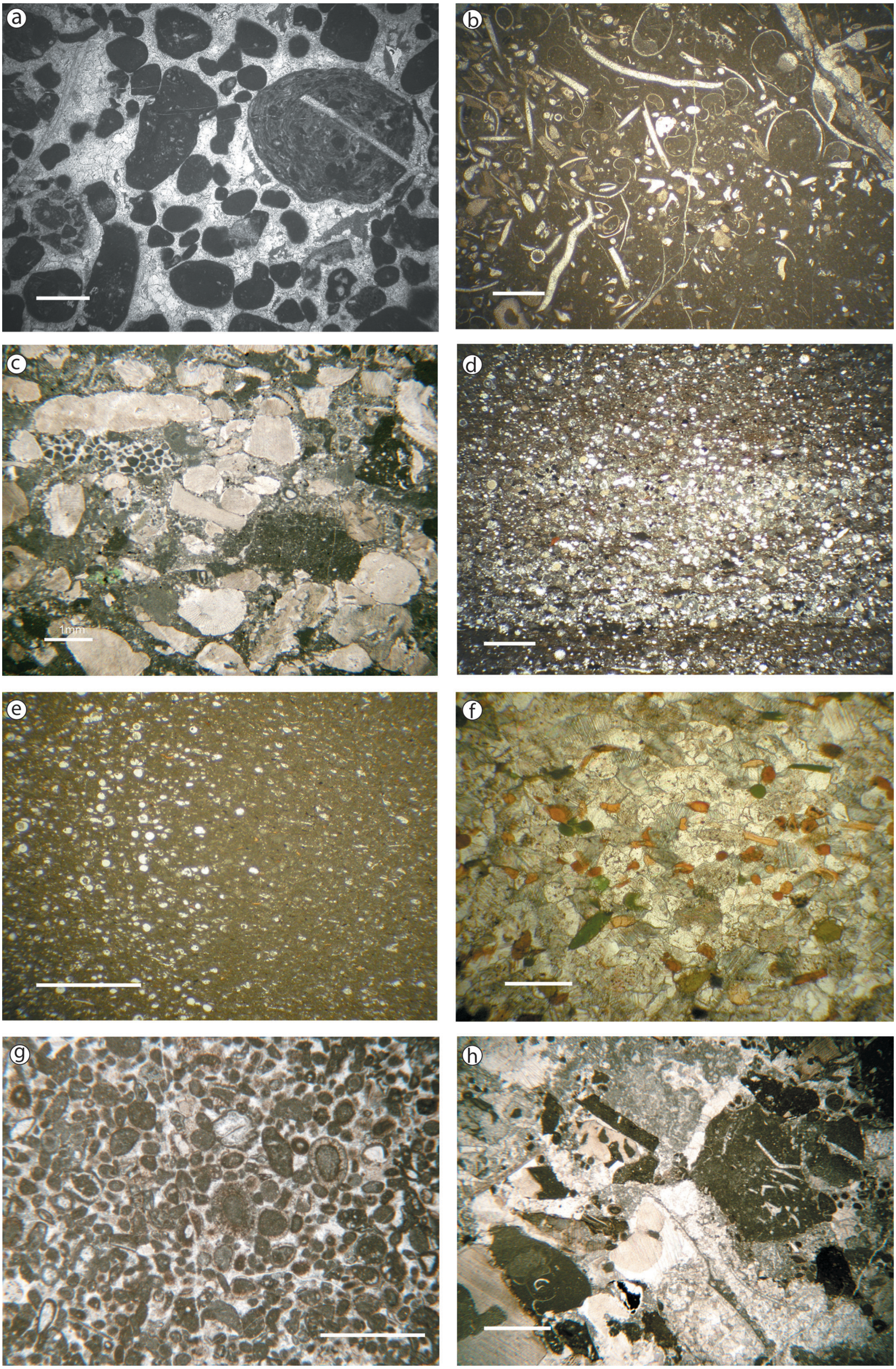

a
b
c
1mm
d
e
f
g
h

Fig. 28: Microfacies of the Travnik section (Stop 5). Scale bars are 1 mm long. a) Platform limestones: grainstone with peloids, intraclasts of mudstones and oncoids; b) Sedlo Formation: bioclastic limestone with juvenile ammonites, sponge spicules, and echinoderm fragments; c) Sedlo Formation: rudstone with echinoderms, and intraclasts of peloidal pacsktones, and mudstones; d) Skrile Formation: normally graded siliceous limestone with radiolarians and mudchips; e) Member 1 of the Travnik Formation: micritic limestone with calcified radiolarian moulds; f) Member 1 of the Travnik Formation: calcarenite with echinoderm fragments, phosphate and glauconite grains; g) Member 2 of the Travnik Formation: packstone with ooids. peloids, benthic foraminifers; h) Member 3 of the Travnik Formation: carbonate breccia with lithoclasts of members 1 and 2 of the Travnik Formation, Sedlo Formation and fragments of stromatoporoids.

Fig. 29: Skrile Formation: shales with interbedded black siliceous limestones. The section is in an overturned position.

Fig. 31: Member 2 of the Travnik Formation: limestone megabed (arrow). The section is in an overturned position.

indicate a gradual change from the distal basin floor to a distal lower slope environment.

Member 2 is represented almost exclusively by 0.3-5 m thick beds (Fig. 31) of medium- to coarse-grained calciturbidites, which are massive or show Ta-c Bouma sequences. Packstones to grainstones are composed of ooids while other grains (echinoderms, peloids, foraminifers (Textulariidae, Involutinidae, Lituolidae)), and micritic intraclasts are rare (Fig. 28g). Black chert nodules are present in some beds.

Thinner calcarenite beds were deposited by sandy turbidity currents, while the thicker structureless beds most probably represent deep-water massive sand bodies and were deposited by highly concentrated sandy turbidity currents. The deposition of medium- to coarse- grained calciturbidites indicates a lower slope environment.

Fig. 30: Member 1 of the Travnik Formation: bedded limestone with chert.

Member 3 starts with several, up to 2.60 m thick, carbonate breccia beds, some of which are capped by fine-grained, parallel-laminated packstone/wackestone (Fig. 32). The breccias are grain-supported, graded and composed of up to 5 cm large lithoclasts of the underlying lithologies of members 1 and 2, and older Jurassic formations (Fig. 28h). Other grains are abundant fragments of echinoderms, fragments of stromatoporoids, corals and foraminifers (Textulariidae, Involutinidae, Lituolidae). The overlying laminated fine-grained packstone/wackestone is composed of small echinoderm fragments, filaments and micritized ooids. The middle part of Member 3 is dominated by thin- to medium-bedded, coarse- to fine-grained calcarenites showing Ta-Tc Bouma divisions. They have a similar composition to the limestones of Member 2, but contain fewer ooids. Calcarenites are overlain by thin-bedded siliceous limestones with radiolarians exhibiting Tb-d Bouma divisions. Member 3 ends with a 3 m thick bed composed of 30 cm thick breccia at the base, which abruptly passes into massive fine-grained, indistinctly laminated packstone/wackestone with chert nodules. The breccia has the same composition as the breccias in the lower part of Member 3. The packstone/wackestone with chert nodules is composed of filaments, echinoderm fragments, rare ooids, phosphate grains and pyrite.

The base of Member 3 is characterized by amalgamated breccia beds that are interpreted as debris-flow deposits. Individual breccia beds are directly overlain by fine-grained

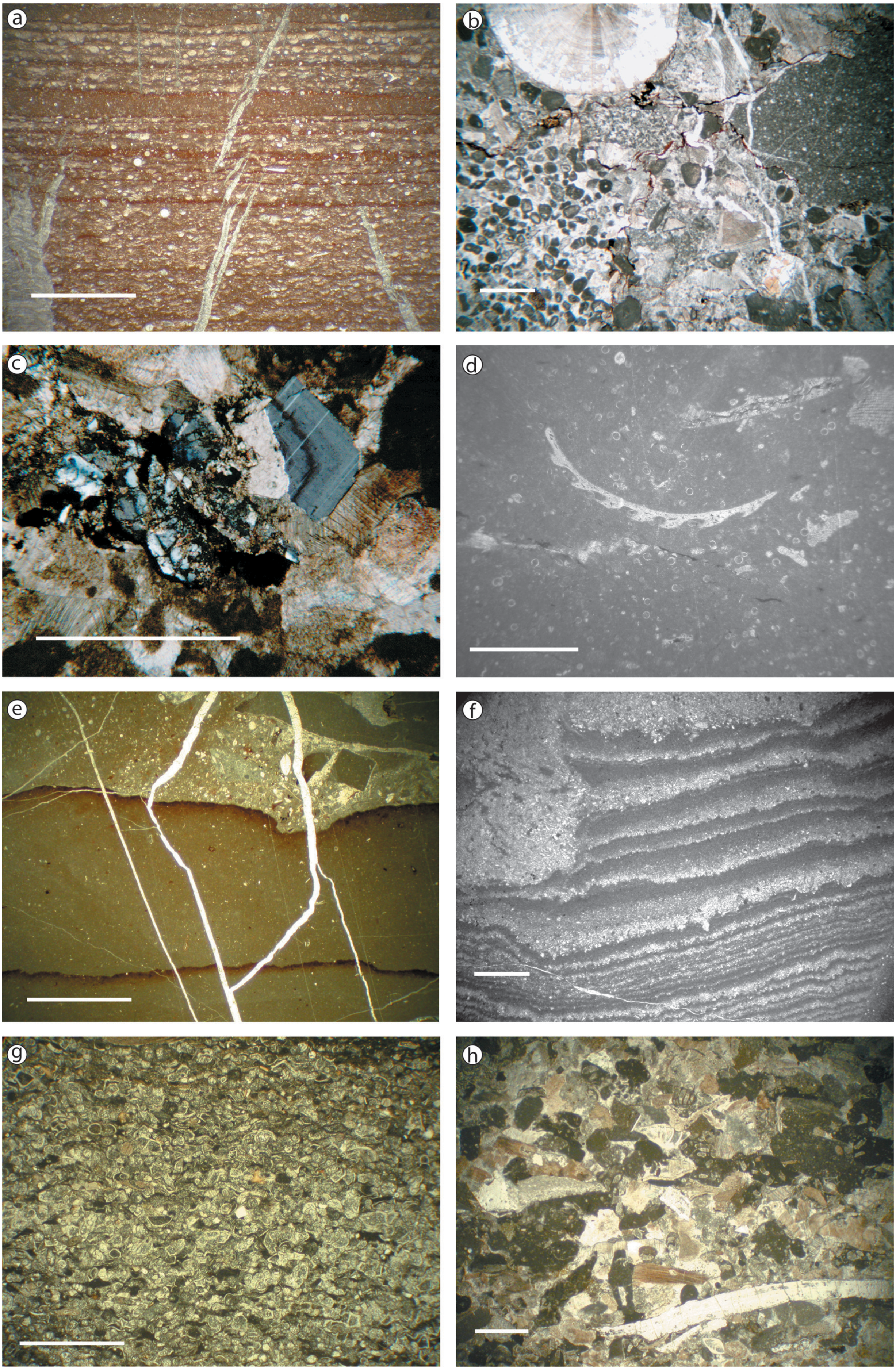
Fig. 32: Member 3 of the Travnik Formation: erosional contact between breccias and fine-grained calcarenites.

calcarenites interpreted to be the dilute "tail'' of the same gravity flow that produced each breccia bed, thus indicating a substantial sediment by-pass. The coarse- to fine-grained calcarenites from the middle part of Member 3 were deposited by sandy turbidity currents and represent top-cut-off Bouma sequences. The siliceous limestones with Tb-d Bouma sequences were deposited by low-density turbidity currents. The massive breccia bed that grades to a fine-grained limestone with chert nodules in the uppermost part of the member was deposited by a highly concentrated turbidity current.

The breccia beds bounded by erosional surfaces are considered to be the most diagnostic facies of the basal portions of many erosional and mixed channel-fill sequences. Member 3 represents the most high-energy facies association deposited in an upper slope environment most proximal to the source area, i.e. to the adjacent Dinaric Carbonate Platform.

Member 4 is represented by the background pelagic sedimentation of cherty limestones, cherts, and radiolarian-bearing marls with an intercalation of mostly fine- with some coarse-grained calciturbidites and breccias. The lower part of the member is characterized by thin-bedded, parallel-laminated black cherts and cherty limestones (the same composition as the cherty limestones of Member 3) with intercalated thin-bedded, fine- to coarse-grained calcarenites exhibiting Ta-b and Tb-d Bouma divisions. The calcarenites are packstones with filaments, peloids, echinoderm fragments, foraminifers (Textulariidae, Involutinidae, Lituolidae), phosphate grains and rare ooids. In coarse-grained facies, reworked lithoclasts of members 1, 2 and 3 occur. In the middle part of Member 4, thin beds of orange replacement chert are present. The upper part of Member 4 starts with red radiolarian cherts with intercalated coarse-grained and graded calcarenites (Ta Bouma divisions), and continues with a 2.5 m thick, clay-rich package containing intercalations of red calcareous clay-rich chert (Fig. 33a) and coarse-grained calcarenites. The calcarenites have the same composition as in the lower part of the member. The member ends with red laminated and, in places, graded radiolarian-rich marls with intercalations of a carbonate breccia and coarse-grained calcarenites. The intercalated coarse-grained calcarenites are packstones to grainstones composed of peloids, echinoderm grains, foraminifers, rare small ooids and mudstone clasts. In the uppermost part of Member 4, the calcarenites are composed exclusively of echinoderm fragments. The breccia bed in the upper part of Member 4 is coarse-grained, grain-supported and mainly composed of large lithoclasts of underlying lithologies of the Travnik Formation (Fig. 33b), other grains are echinoderms, belemnites, peloids, foraminifers (Textulariidae, Valvulinidae), fragments of algae, corals and rare euhedral detritic grains of bytownite-anorthite feldspars (Fig. 33c). The cherts, calcareous clayey cherts and marls of Member 4 represent the background pelagic sedimentation. The carbonate admixture in these beds can be either of pelagic or platform origin. Lamination and, in places, grading suggest hydrodynamic sorting. The fine- to medium-grained calcarenites were deposited by low- to medium-density turbidity currents and are base-missing Bouma sequences. Coarse-grained calcarenites belong to the Ta-b Bouma divisions and were deposited by sandy, high-density

Fig. 33: Microfacies at Stop 5 (Figs. 33/a-d) and Stop 6 (Figs. 33/e-h). Scale bars are 1 mm long. a) Member 4 of the Travnik Formation: laminated, radiolarian-rich marl; b) Member 4 of the Travnik Formation: carbonate breccia with lithoclasts of Members 1, 2, 3 of the Travnik Formation, belemnites and peloids; c) Member 4 of the Travnik Formation: breccia with echinoderms and euhedral detritic grains of bytownite-anorthite feldspar; d) Biancone limestone: mudstone with calpionellids, aptychi, and calcified radiolarian moulds; e) Neptunian dikes: the lower part of the photo is mudstone with Fe-Mn crusts of the 1st generation. The upper part of the photo is dominated by a wackestone with echinoderms and mudstone intraclasts of 2nd generation; f) Neptunian dikes: fine-grained laminated calcite in the 2nd generation of neptunian dikes; g) Scaglia rossa: packstone with abundant globotruncanids; h) Scaglia rossa: calcarenite with mudstone lithoclasts, *Inoceramus* sp., and fragments of echinoderms.


a
b
c
d
e
f
g
h

turbidity currents. The breccia bed in the uppermost part of the member is a debris-flow deposit. Member 4 is characterized by the presence of abundant pelagic sediments with intercalation of the fine- to coarse- grained calciturbidites that indicate deposition in a distal slope environment.

Late Tithonian to Neocomian Biancone limestone

The Biancone limestone is bedded pelagic limestone containing chert. It conformably overlies the Travnik Formation. The lower part consists of red nodular thin beds of mudstone to wackestone mainly composed of calpionellids, aptychi, and calcified radiolarians with rare echinoderms and benthic foraminifers (Fig. 33d). Beds of red replacement chert that are up to a few centimeters thick occur within nodular limestones. A few beds of calcarenite exclusively composed of echinoderm fragments are intercalated in the lowermost part. In the lowermost part *Crassicollaria* sp. and *Calpionella alpina* (LORENZ) are present, while in the middle part *Calpionella elliptica* (CADISCH) occurs. The upper part is a strongly tectonized light-gray wackestone/mudstone with chert nodules containing calcified radiolarian moulds.

The Biancone limestone was deposited by normal pelagic sedimentation in a deeper-water environment. In places the nodular bedding suggests the influence of sea-bottom currents that caused slower sedimentation rates and early selective cementation.

Age: The Late Tithonian age at the base is suggested by calpionellids and also inferred from the stratigraphic position (SMUC & GORICAN 2005, SMUC 2005). The light-gray limestone in the upper part contains late Valanginian-early Hauterivian radiolarians (UAZ 17-18 of BAUMGARTNER et al. 1995b) (GORICAN & SMUC 2004).

3.4. The Julian High

General description

The term Julian High (BUSER 1996) refers to the drowned parts of the former Julian Carbonate Platform that, in the late Early Jurassic, became an isolated submarine high with condensed sedimentation of Rosso Ammonitico type limestone (SMUC 2005, SMUC 2010, SMUC & ROZIC 2010). The areas where the Pliensbachian to Tithonian pelagic deposits are preserved only as neptunian-dike fills also correspond to the Julian High (e.g., the Mangart structural unit, see Fig. 24). All successions of the Julian High are now exposed in the Julian Nappe.

The drowning succession of the Julian High is characterized by strongly condensed Bajocian to Tithonian Rosso Ammonitico type limestone of the Prehodavci Formation (SMUC 2005, CRNE et al. 2007, SMUC 2010, SMUC & ROZIC 2010) that unconformably overlies a thick pile of Upper Triassic to Lower Jurassic platform limestones of the Julian Carbonate Platform. The succession continues with the Upper Tithonian to Neocomian Biancone limestone, middle Cretaceous Scaglia variegata, Turonian to Campanian Scaglia rossa and upper Campanian to Maastrichtian sandstones (COUSIN 1981, BUSER 1986, JURKOVSEK 1987, JURKOVSEK & KOLAR-JURKOVSEK 1987). In the most condensed successions the Lower Jurassic shallow-water limestones are cut by numerous polyphase neptunian dikes and directly overlain by the Scaglia variegata or Scaglia rossa (GORICAN & SMUC 2004, SMUC 2005, CRNE et al. 2007, SMUC 2010, SMUC & ROZIC 2010). The Prehodavci Formation (not seen in this excursion) unconformably overlies the Pliensbachian platform limestone. The contact is marked by an irregular unconformity with oval-shaped depressions, up to 3 m deep and 10 m wide, cut into the Lower Jurassic platform limestone. The Prehodavci Formation is overlain by the upper Tithonian pelagic Biancone limestone. The formation reaches a maximum thickness of about 15 m and consists of condensed limestones of the Rosso Ammonitico type subdivided into three members. The Lower Member consists of red, well-bedded bioclastic limestone with Fe-Mn nodules passing into light-gray, faintly nodular limestones. The Middle Member consists of thin-bedded, red marly limestones. The Upper Member unconformably overlies the Lower or the Middle Member. It is represented by red nodular limestone, and by red marly limestones with abundant *Saccocoma* sp.

Stop 6: The road to Mt. Mangart Saddle

Guided by ANDREJ SMUC

At Stop 6 (see Fig. 23 for the location) chaotic breccias of neptunian dikes and Scaglia rossa are exposed.

Neptunian dikes

The Jurassic neptunian dikes on Mt. Mangart are cut into Upper Triassic to Lower Jurassic platform limestone of the Julian Carbonate platform (SMUC 2005, CRNE et al. 2007, SMUC 2010, SMUC & ROZIC 2010). The following geometries of the dikes were observed: irregular dissolution cavities, thin penetrative fractures, larger fractures with sharp sidewalls, and laterally confined breccia bodies. Inside a complex neptunian dike system, two main generations of infillings were differentiated. The first generation is heterogeneous and consists of bioclastic limestones, representing uniquely preserved sediments subdivided into five different microfacies. The second generation is more common and typically consists of coarse-grained breccias with host-rock clasts and marly limestone matrix containing echinoderms.

First generation of neptunian dikes: The first generation of neptunian dikes was formed by sediment infill and cement precipitation in three types of voids:

(A) irregular cavities ranging from a few centimeters up to few decimeters with undulate walls (Fig. 34);

(B) smaller breccia bodies, only a few decimeters in size;

(C) thin fractures, a few millimeters wide and several decimeters long, penetrating the host rock and consequently forming mosaic breccias.

Microfacies of the first generation includes:

A) pink wackestone-packstone with ostracod fragments, foraminifers, spicules and echinoderms;

B) ostracod coquinas;

C) red packstone with lithoclasts of host rock and rare bioclasts;

Fig. 34: Neptunian dikes with irregular-undulate walls.

D) gray mudstone to wackestone with sponge spicules and radiolarians; and
E) red mudstone (Fig. 33e) along with different generations of cements.

The fracture formation and void filling of the first generation of neptunian dikes is dated as Pliensbachian and is interpreted as having been caused by the Julian Carbonate Platform dissection due to the widely recognized Early Jurassic Tethyan rifting.

Second generation of neptunian dikes: The neptunian dikes of the second generation are far greater in dimension and abundance compared to those of the first generation.

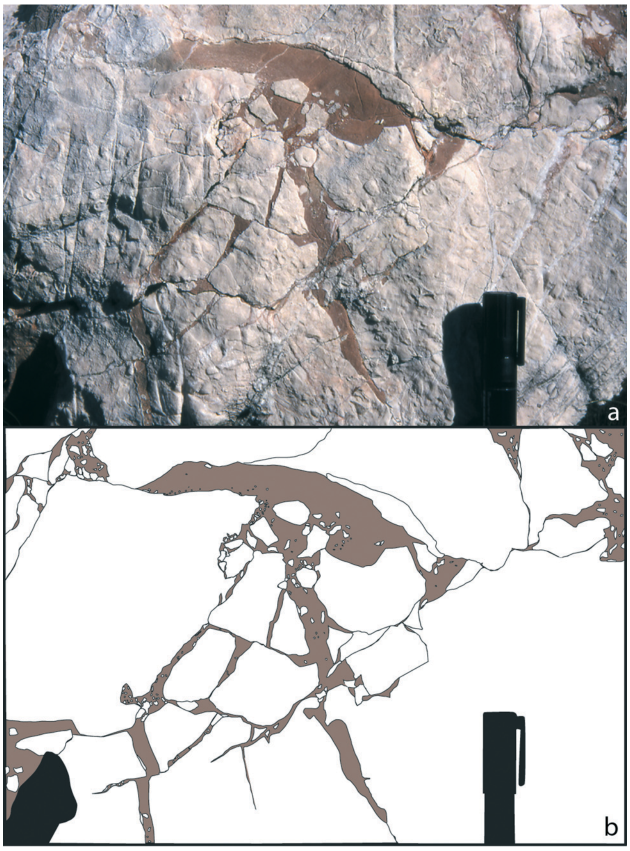


Fig. 35: Photograph (a) and a sketch (b) of a jigsaw (neptunian dike) breccia.

The following geometries have been recognized: A) laterally confined breccias; and B) variously oriented fractures with sharp sidewalls, up to a few dm wide and up to 1 m deep. The laterally confined breccias, up to 20 m wide and more than a few meters deep, most probably represent vertical fractures filled with chaotic breccias; in places a mosaic structure is observed, which is more evident in smaller sized breccias (Fig. 35a, b).

The second generation of neptunian dikes is characterized by two lithotypes: common chaotic polymictic breccias and monomictic breccias exclusively containing host-rock clasts that are only present as laterally confined breccias of smaller dimensions. Polimictic breccia include host rock clasts with the first generation of neptunian dikes, clasts of micritic and microsparitic limestone, black clasts, clasts of graded packstone to wackestone with pelagic pelecypods and isolated clasts of the first generation of neptunian dikes. The matrix is mostly red, in places gray, marly limestone (wackestone to packstone) containing echinoderm fragments. In thin sections, the normal grading of breccia into calcarenite or calcilutite can be observed. Horizontal, vertical and oblique laminations are present in places (Fig. 33f).

The timing of the formation of the second generation is only broadly constrained, ranging from the Pliensbachian to the Late Cretaceous. Close to the peak of Mt. Mangart, the blocky breccia of a dike is in stratigraphic contact with the overlying Scaglia variegata, which yielded early Albian radiolarians (GORICAN & SMUC 2004, see Fig. 24 for the location).

Overall, not many of the sediments filling the neptunian dikes on Mt. Mangart correspond to sediments deposited in "normal" stratigraphic successions in the Julian Alps. This could be due to the fact that sedimentation in small voids or narrow channels differs fundamentally from sedimentation on the sea floor. Nevertheless, since a long time gap exists on the Julian High from the Pliensbachian to the Bajocian, sediments filling neptunian dikes may represent the only preserved sediments of that age on the Julian High.

Turonian and Senonian Scaglia rossa

On the Mt. Mangart saddle the Scaglia rossa crops out only in the Mali Vrh and Rdeca skala subunits of the Mangart structural unit. In the Mali Vrh subunit, the Scaglia rossa unconformably overlies Upper Triassic to lower Lower Jurassic shallow-water limestone cut by large neptunian dykes, while the structural subunit Rdeca skala consists only of completely tectonized Scaglia rossa.

The succession of Scaglia rossa is composed of thin-bedded red and subordinately gray wackestone (Fig. 36) that exhibits horizontal lamination and, in places, normal and inverse grading and ripple cross-lamination (Ta, Ta-c Bouma divisions). The limestone is mainly composed of small keel-less globular foraminifers and globotruncanids with a developed single keel (Fig. 33g). Sponge spicules, calcified radiolarians, echinoderm fragments, small sparitic grains, phosphate, glauconite and quartz grains are rare. Within these limestones, medium-grained calcarenite and coarse-grained breccia occur. The calcarenite bed is 10 cm thick and normally graded, and the base is erosional. It

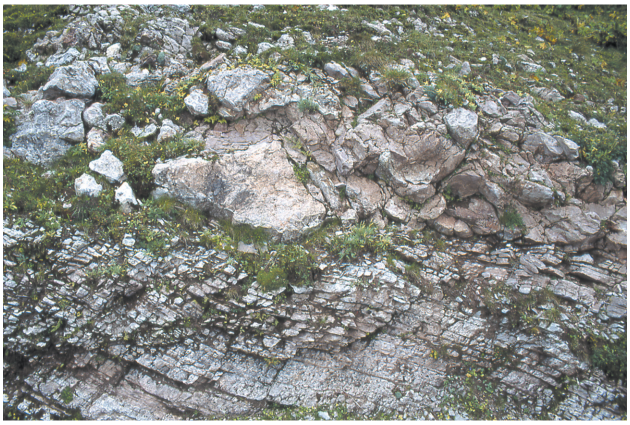


Fig. 36: Scaglia rossa: thin-bedded limestone, overlain by coarse-grained breccia.

consists of lithoclasts of limestones with planktic foraminifers and mudstones, laminated and graded siliceous limestones with radiolarians, shallow-water peloidal grainstones, and cherts (Fig. 33h). Bioclasts are fragments of *Inoceramus* sp., fragments of echinoderms, and benthic foraminifers. Grains are cemented by granular sparitic cement and syntaxial cement around echinoderm grains. A breccia bed is present in the upper part of the section. It is poorly-sorted, normally graded and clast supported. Clasts are up to 1 m large and include: limestones with globotruncanids, wackestone to mudstone with calcified sponge spicules, normally graded and horizontally laminated red siliceous limestones with radiolarians, red cherts, red laminated marly wackestones to packstones with abundant *Saccocoma*, fragments of echinoderms, aptychi and benthic foraminifers, pelletoidal limestones, light-gray packstone to grainstone composed of peloids, fragments of limestone with fenestral porosity, algae fragments, benthic foraminifers, and echinoderm fragments, laminated and normally graded wackestone with pellets and foraminifers, light-gray, shallow-water limestones with neptunian dikes. The matrix of the breccia is a wackestone with planktic foraminifers, described in the lower part of the succession.

The thin-bedded wackestones were deposited by low-density turbidity currents. The normally graded calcarenite bed represents a top-cut-off Bouma sequence and was deposited by medium-grained turbidity currents. The coarse-grained breccia is considered to be the product of a hyperconcentrated gravity flow. The presence of various clasts of older strata in the calcarenite and breccia indicates the exhumation of underlying lithologies by synsedimentary extensional tectonics and erosion at least down to Upper Jurassic deposits (clasts of red marly wackestones with abundant *Saccocoma*). The presence of *Inoceramus* sp., fragments of echinoderms, and benthic foraminifers indicates an input from coeval shallow-water areas.

4. Summary: Latest Triassic to mid-Cretaceous evolution of sedimentary basins in NW Slovenia

The stratigraphic evolution is summarized (Fig. 37) and briefly discussed in time intervals representing the main stages of the region's geodynamic history.

End Triassic and Early Jurassic - rifting and extension

After the major drowning unconformity in the Late Carnian, the marginal reefs of the Julian Carbonate Platform rapidly prograded over the surrounding basinal areas (Celarc & Kolar-Jurkovsek 2008 and references therein). In the Norian and Rhaetian, more than 1000 m of the peritidal Dachstein Limestone with characteristic Lofer cycles (locally interfingering with the Hauptdolomite) were deposited in the interior of the platform. The platform was rimmed by a narrow reef crest (see Turnsek 1997 and Buser 2009 for the distribution of Norian-Rhaetian reefs). Somewhat deeper basins also existed, as evidenced by bedded carbonates containing chert nodules and layers (the Baca Dolomite and Slatnik Formation in the Tolmin Basin, Zatrnik Limestone in the Bled Basin).

In the latest Triassic and earliest Jurassic, intensified extensional tectonics resulted in gravitational instabilities, well documented by several breccia levels in the Tolmin Basin. Calcareous turbidites of the Krikov Formation then accumulated until the Pliensbachian. The facies distribution of this formation clearly indicates that the shallow-water carbonate material was mainly derived from the Julian Carbonate Platform, which was still productive during the early Early Jurassic. Most of the coeval Hierlatz limestone in the Bled Basin is also turbiditic in origin and may have been sourced from the same carbonate platform.

The rifting-related tectonic activity culminated in the late Pliensbachian when an accelerated subsidence pulse caused the break up and drowning of the Julian Carbonate Platform. This event is well marked in the stratigraphic record of all depositional basins. The interior part of the former platform became the intrabasinal Julian High, which was characterized by a break in deposition until the Bajocian. Neptunian dikes of the first generation are also ascribed to the Pliensbachian. The Bovec Basin originated on a more deeply subsided block. The Pliensbachian subsidence pulse in the incipient Bovec Basin is reflected in a change from platform to deeper-water limestone with echinoderms, juvenile ammonites and sponge spicules (Sedlo Formation). In the Bled Basin, the same event was responsible for the deposition of the coarse-grained Ribnica breccia. Only in the Tolmin Basin were the changes in facies more gradual. However, crinoidal limestones start to predominate in the uppermost part of the Krikov Formation and mark the initial stage of tectonically induced drowning in the source area. Moreover, the overlying Toarcian Perbla Formation, mostly composed of marls and shales, varies significantly in thickness from 2 to 135 m and thus provides evidence of a considerable basin-floor relief that was mainly created during the Pliensbachian tectonic event.

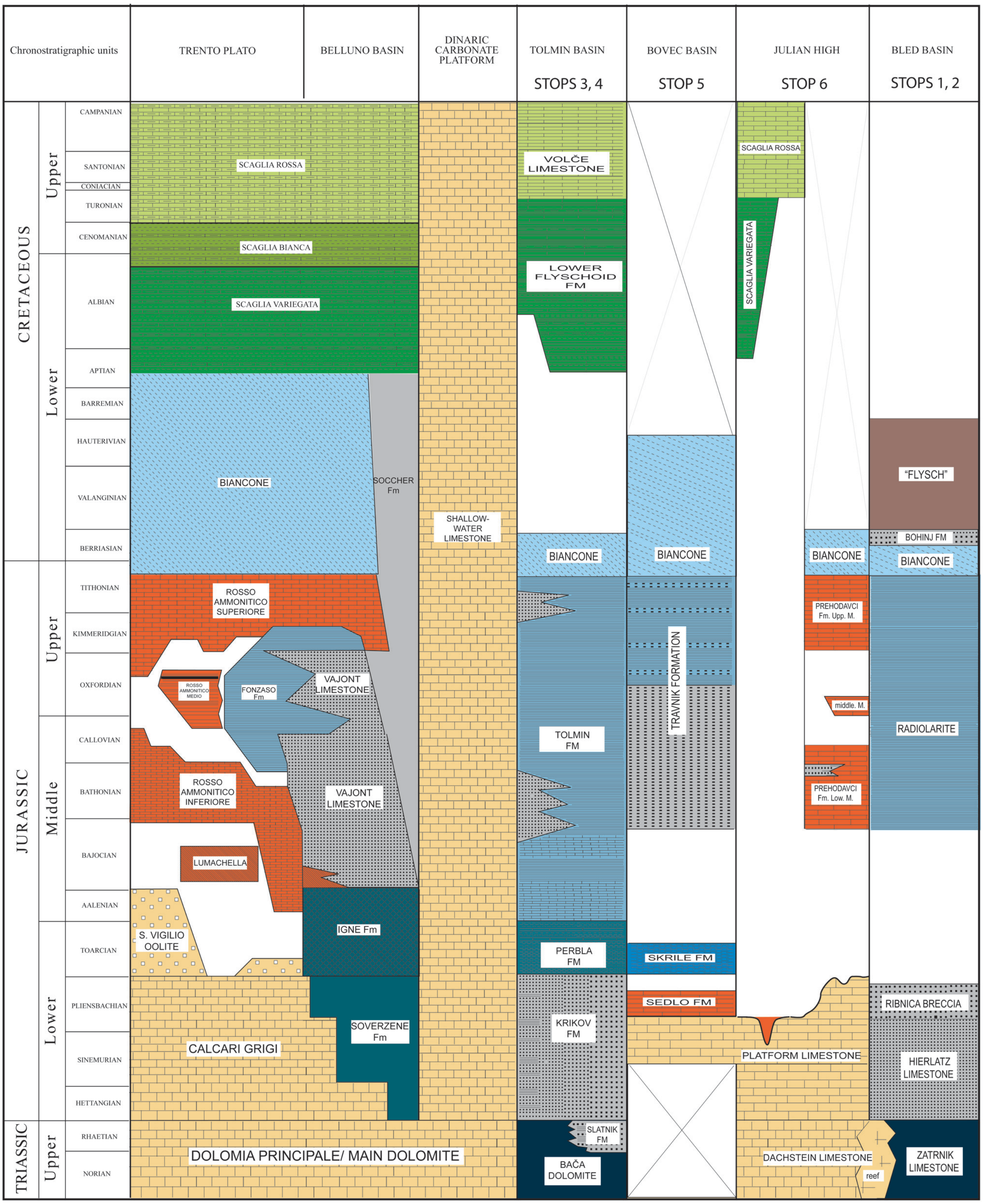


Fig. 37: Chronostratigraphic overview of Upper Triassic to Cretaceous formations of the Southern Alps in NE Italy and NW Slovenia.
The Trento Plateau and the Belluno Basin: Jurassic from Baumgartner et al. (1995a), Cretaceous according to Lehner (1992).
The Tolmin Basin: Rozic (2006, 2009), Rozic et al. (2009), Gale (2010), Cretaceous according to Caron & Cousin (1972), Rozic (2005).
The Bovec Basin and the Julian High: Smuc (2005), Smuc & Gorican (2005), Smuc & Rozic (2010).
The Bled Basin: Cousin (1981), Kukoc et al. (2012).

From late Early Jurassic to Late Jurassic - post-rift evolution and beginning of subduction/accretion in the Neotethys

The Toarcian sediments are characteristically clay-rich and are preserved in the Tolmin Basin (Perbla Formation) and in the Bovec Basin (Skrile Formation). They include shales enriched in organic matter that accumulated during the Early Toarcian oceanic anoxic event. Aalenian deposits are known only from the Tolmin Basin and consist of dark-gray, thin-bedded siliceous limestones that alternate with rare chert beds (lower member of the Tolmin Formation). In the Bajocian, the second major subsidence phase occurred as documented by pronounced shifts to deeper-water facies and a long stratigraphic gap. The Bovec and Bled basins at that time evolved into true deep-water basins with radiolarian cherts as back-ground sediments and the Julian High became a typical submarine plateau with condensed sedimentation of the Rosso Ammonitico type limestone. In the Tolmin Basin, where the sedimentation was continuous from the Aalenian, the facies shifted from siliceous limestone (lower member of the Tolmin Formation) to typical green and upsection red radiolarian chert (upper member of the Tolmin Formation). The Bajocian event coincided with the opening of the Alpine Tethys (see BILL et al. 2001 for a review of biostratigraphic ages) implying that thermal subsidence could be the principal cause of the deepening. However, at least for the Bled Basin which shows clear Dinaric affinities, this explanation is unlikely because the Neotethys had opened much earlier, in the Middle Triassic, and was already in a convergent regime in the Middle Jurassic (e.g., SCHMID et al. 2008 and the references therein). An alternative explanation is that the subsidence was caused by flexural bending when the Adriatic margin approached the subduction zone of the Neotethys (cf. SCHERREIKS et al. 2010). The pronounced silica enrichment, well recorded in the Tolmin Basin, was a regional phenomenon as well and was related not only to subsidence but also to enhanced surface productivity as suggested by carbon isotope studies (BARTOLINI et al. 1996, O'DOGHERTY et al. 2006). Reorganization of the plate boundaries leading to the opening of a deep-water connection with the eastern Tethys could be responsible for substantial modifications in the oceanic circulation that, in turn, had a major long-term impact on climate and surface productivity (BAUMGARTNER 1987, BILL et al. 2001).

From the late Bajocian to the early Tithonian radiolarian cherts and shales characterized all basinal areas. A notable difference exists in the proportion of intervening carbonate gravity-flow deposits. Resedimented limestones are abundant in the Bovec Basin and also common in the Tolmin Basin. In contrast, the Middle to Upper Jurassic succession of the Bled Basin is devoid of resedimented limestones. The proportion of shale is far greater in the Bled Basin than in the other two basins. This facies distribution suggests that the Bovec and Tolmin basins were located close to the Dinaric Carbonate Platform but the Bled Basin had a more distal position.

End Jurassic and Early Cretaceous - early phases of orogeny

The topographic differences generated during Early and Middle Jurassic subsidence events were by the end of the Jurassic diminished due to the high sediment input in the basins. The area of the Tolmin Basin, the Bovec Basin and the Julian High was covered by a relatively similar basinal sedimentation from the late Tithonian to the Turonian. Two major lithologies are distinguished in the Lower Cretaceous: micritic limestone with chert (Biancone limestone) overlain by a succession of marls, shales and rarely cherts, including abundant carbonate breccias in areas which were close to the Dinaric Carbonate Platform (Lower flyschoid formation in the Tolmin Basin, Scaglia variegata in the Julian High). The contact between the two lithostratigraphic units is always erosional, the Biancone limestone is only partly preserved or, in places, it is entirely missing.

The stratigraphic record of the Bled Basin is very different. The Biancone limestone forms a thick succession which terminates with Berriasian carbonate breccias and calcarenites (Bohinj Formation). Upsection, the clay content increases and pelagic limestone beds become subordinate. These sediments grade into mixed siliciclastic-carbonate turbidites of Valanginian-Hauterivian age.

The overall stratigraphy in the Julian Alps provides a good record of events related to the progressive closure of the Neotethys. Following the Late Jurassic obduction (DIMITRIJEVIC 1997, KARAMATA 2006), a carbonate platform formed on top of the ophiolitic nappes. This platform (the Bohinj Carbonate Platform) is not preserved but can be reliably inferred from the platform-limestone clasts in the Bohinj Formation. The overlying turbidites with clastic admixtures are the oldest classical synorogenic deposits in the area. They mark the initial stages of the Eo-alpine orogeny, which started during the Late Valanginian and reached its climax during the Albian to Turonian (FAUPL & WAGREICH 2000, SCHMID et al. 2004, 2008). In the Tolmin Basin, the coarse-grained basal breccias of the Lower flyschoid formation and the associated erosional unconformity are good indicators of synsedimentary tectonism. These breccias are Albian or latest Aptian in age, which agrees well with the timing proposed for the intensification of the Eo-alpine orogeny. In the marginal parts of the Julian High, the correlative Scaglia variegata in rare places directly overlies the blocky breccias filling the second generation of neptunian dikes. Age control on the second generation of neptunian dikes is still scarce. However, according to the present knowledge on regional tectono-sedimentary evolution, it seems most likely that the formation of deep fractures and blocky breccias on the Julian High was linked to the strong tectonic activity around the Aptian-Albian boundary.

Acknowledgements

The research for this excursion was funded by the Slovenian Research Agency (project numbers: J1-4198, P1-0008, P1-0011, P1-0025, P1-0195). We thank Murray James Bales (Ljubljana) for English corrections of the final text.

References

Aubouin, J. (1963): Essai sur la paléogéographie post-triasique et l'évolution secondaire et tertiaire du versant sud des Alpes orientales (Alpes méridionales; Lombardie et Vénétie, Italie; Slovénie occidentale, Yougoslavie). - Bulletin de la Société Géologique de France, (7), **V**: 730-766, Paris.

Babic L. (1981): The origin of „Krn Breccia" and the role of the Krn area in the Upper Triassic and Jurassic history of the Julian Alps. - Vjestnik Zavoda za geoloska i geofizicka istrazivanja, ser. A Geologija, **38/39**: 59-87, Zagreb.

Babic, L. & Zupanic, J. (1978): Mladi mezozoik Ivanscice. - (In: Babic L., Jelaska V., (Eds.): Vodic ekskurzije 3. Skupa sedimentologa Jugoslavije), 11-23, Croatian Geological Society, Zagreb.

Bartolini, A., Baumgartner, P.O. & Hunziker, J.C. (1996): Middle and Late Jurassic carbon stable-isotope stratigraphy and radiolarite sedimentation of the Umbria - Marche Basin (Central Italy). - Eclogae geologicae Helvetiae, **89**: 831-879, Basel.

Baumgartner, P.O. (1987): Age and genesis of Tethyan Jurassic Radiolarites. - Eclogae geologicae Helvetiae, **80**: 831-879, Basel.

Baumgartner, P.O., Martire, L., Gorican, S., O'Dogherty, L., Erba, E. & Pillevuit, A. (1995a): New Middle and Upper Jurassic radiolarian assemblages co-occurring with ammonites and nannofossils from the Southern Alps (Northern Italy). - (In: Baumgartner P.O., O'Dogherty L., Gorican S., Urquhart E., Pillevuit A. & De Wever P. (Eds.): Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrences, Systematics, Biochronology), Mémoires de Géologie (Lausanne), **23**: 737-749, Lausanne.

Baumgartner, P.O., Bartolini, A., Carter, E.S., Conti, M., Cortese, G., Danelian, T., De Wever, P., Dumitrica, P., Dumitrica-Jud, R., Gorican, S., Guex, J., Hull, D.M., Kito, N., Marcucci, M., Matsuoka, A., Murchey, B., O'Dogherty, L., Savary, J., Vishnevskaya, V., Widz, D. & Yao, A. (1995b): Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on Unitary Associations.- (In: Baumgartner, P.O., O'Dogherty, L., Gorican, S., Urquhart, E., Pillevuit, A. & De Wever, P. (Eds.): Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrences, Systematics, Biochronology), Mémoires de Géologie (Lausanne), **23**: 1013-1038, Lausanne.

Bassoullet, J.-P. (1997): Les grands foraminifères. - (In: Groupe Français d'Étude du Jurassique. Biostratigraphie du Jurassique ouest-européen et méditerranéen: Zonations parallèles et distribution des invertébrés et microfossiles - Cariou, E. & Hantzpergue, P. Coord.), Bulletin du Centre de Recherche Elf Exploration Production, Mémoires, **17**: 293-304, Pau.

Bernoulli, D., Bertotti, G. & Froitzheim, N. (1990): Mesozoic faults and associated sediments in the Austroalpine-South Alpine continental margin. - Memorie della Società Geologica Italiana, **45**: 25-38, Roma.

Berra, F., Galli, M.T., Reghellin, F., Torricelli, S. & Fantoni, R. (2009): Stratigraphic evolution of the Triassic-Jurassic succession in the Western Southern Alps (Italy): the record of the two-stage rifting on the distal passive margin of Adria. - Basin Research, **21**: 335-353, Oxford.

Berra, F., Jadoul, F. & Anelli, A. (2010): Environmental control on the end of the Dolomia Principale/Hauptdolomit depositional system in the central Alps: Coupling sea-level and climate changes. - Palaeogeography, Palaeoclimatology, Palaeoecology, **290**: 138-150, Amsterdam.

Bertotti, G., Picotti, V., Bernoulli, D. & Castellarin, A. (1993): From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous. - Sedimentary Geology, **86**: 53-76, Amsterdam.

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

Bosellini, A., Masetti, D. & Sarti, M. (1981): A Jurassic „Tongue of the ocean" infilled with oolitic sands: the Belluno Trough, Venetian Alps, Italy. - Marine Geology, **44**: 59-95, Amsterdam.

Budkovic T. (1978): Stratigrafija Bohinjske doline. - Geologija, **21**: 239-244, Ljubljana.

Buser, S. (1978): Razvoj jurskih plasti Trnovskega gozda, Hrusice in Logaske planote. - Rudarsko - metalurski zbornik, **4**: 385-406, Ljubljana.

Buser, S. (1979): Triassic beds in Slovenia. - (In: Drobne, K. (Ed.): 16th European micropaleontological colloquium, Zagreb - Bled, Yugoslavia, 8th - 16th September 1979), 17-25, Ljubljana (Croatian Geological Society & Slovenian Geological Society).

Buser, S. (1986): Osnovna geoloska kata SFRJ 1: 100.000. Tolmac listov Tolmin in Videm (Udine). - 1-103, Zvezi geoloski zavod, Beograd.

Buser, S. (1987): Osnovna geoloska karta SFRJ 1: 100 000, list Tolmin in Videm. - Zvezni geoloski zavod, Beograd.

Buser, S. (1989): Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian Basin (NW Yugoslavia). - Memorie della Società Geologica Italiana, **40** (1987): 313-320, Roma.

Buser, S. (1996): Geology of western Slovenia and its paleogeographic evolution. - (In: Drobne, K., Gorican, S. & Kotnik, B. (Eds.): The Role of Impact Processes in the Geological and Biological Evolution of Planet Earth), 111-123, International workshop, ZRC SAZU, Ljubljana.

Buser, S. (2009): Geological map of Slovenia 1:250,000. - Geoloski zavod Slovenije, Ljubljana.

Buser, S., Pavsic, J. & Radoicic, R. (1979): Spodnjekredne plasti v Bohinju. - Rudarsko-metalurski zbornik, **26/4**: 385-393, Ljubljana.

Buser, S. & Draksler, V. (1993): Slovenija - Geoloska karta 1:500,000. - Geodetski zavod Slovenije, Ljubljana.

Buser, S., Kolar-Jurkovsek, T. & Jurkovsek, B. (2007): Triasni konodonti slovenskega bazena / Triassic conodonts of the Slovenian Basin. - Geologija, **50/1**: 19-28, Ljubljana.

Buser, S., Kolar-Jurkovsek, T. & Jurkovsek, B. (2008): The Slovenian Basin during the Triassic in the light of conodont data. - Bollettino della Società Geologica Italiana, **127**: 257-263, Roma.

Caron, M. & Cousin, M. (1972): Le sillon slovène: les formations terrigènes crétacées des unités externes au Nord-Est de Tolmin (Slovénie occidentale). - Bulletin de la Société Géologique de France, **14**: 34-45, Paris.

Celarc, B. & Kolar-Jurkovsek, T. (2008): The Carnian-Norian basin-platform system of the Martuljek Mountain Group (Julian Alps, Slovenia): progradation of the Dachstein carbonate platform. - Geologica Carpathica, **59**: 211-224, Bratislava.

Chiocchini, M., Farinacci, A., Mancinelli, A., Molinari, V. & Potetti, M. (1994): Biostratigrafia a foraminiferi, dasicladali e calpionelle delle successioni carbonatiche mesozoiche dell'Appennino centrale (Italia). - Studii geologici Camerti, Spec. Publ: 9-129, Camerino.

Clari, P. & Masetti, D., (2002): The Trento Ridge and the Belluno Basin. - (In: Santantonio, M. (Ed.): General Field Trip Guidebook, VI International Symposium on the Jurassic System, 12-22 September 2002), 271-315, Palermo.

Cousin, M. (1970): Esquise géologique des confins italo-yougoslaves: leur place dans les Dinarides et les Alpes méridionales. - Bulletin de la Société Géologique de France, (7), **XII**: 1034-1047, Paris.

Cousin, M. (1973): Le sillon slovène: les formations triasiques, jurassiques et néocomiennes au Nord-Est de Tolmin (Slovénie occidentale, Alpes méridionales) et leurs affinités dinariques. - Bulletin de la Société Géologique de France, (7), **XV**: 326-339, Paris.

Cousin, M. (1981): Les rapports Alpes-Dinarides. Les confins de l'Italie et de la Yougoslavie. - Société géologique du Nord, Publication nº 5, Vol. I: 1-521, Vol. II Annexe: 1-521, Villeneuve d'Ascq.

Crne, A.E., Smuc, A. & Skaberne, D. (2007): Jurassic neptunian dikes at Mt Mangart (Julian Alps, NW Slovenia). - Facies, **53**: 249-265, Erlangen.

Crne, A. E. & Gorican, S. (2008): The Dinaric Carbonate Platform margin in the Early Jurassic: a comparison between successions in Slovenia and Montenegro. - Bollettino della Società Geologica Italiana, **127**: 389-405, Roma.

Crne, A. E., Weissert, H. J., Gorican, S. & Bernasconi, S. M. (2011): Biocalcification crisis at the Triassic-Jurassic boundary recorded in the Budva Basin (Dinarides, Montenegro). - Geological Society of America Bulletin, **123**: 40-50, Boulder.

Dimitrijevic, M.D. (1997): Geology of Yugoslavia. - 1-187, (Geoinstitute) Beograd.

Doglioni, C. & Bosellini, A. (1987): Eoalpine and mesoalpine tectonics in the Southern Alps. - Geologische Rundschau, **76**: 735-754, Stuttgart.

Doglioni C. & Siorpaes C. (1990): Polyphase deformation in the Col Bechei area (Dolomites-Northern Italy). - Eclogae geologicae Helvetiae, **83**: 701-710, Basel.

Faupl, P. & Wagreich, M. (2000): Late Jurassic to Eocene Palaeogeography and Geodynamic Evolution of the Eastern Alps.- Mitteilungen der Österreichischen Geologischen Gesellschaft, **92**: 79-94, Wien.

Gale, L. (2010): Microfacies analysis of the Upper Triassic (Norian) „Baca Dolomite": early evolution of the western Slovenian Basin (eastern Southern Alps, western Slovenia). - Geologica Carpathica, **61**: 293-308, Bratislava.

Gawlick, H.-J. & Böhm, F. (2000): Sequence and isotope stratigraphy of Late Triassic distal periplatform limestones from the Northern Calcareus Alps (Kälberstein Quarry, Berchtesgaden Hallstatt Zone). - International Journal of Earth Sciences (Geologische Rundschau), **89**: 108-129, Stuttgart.

Gawlick, H.J. & Schlagintweit, F. (2006): Berriasian drowning of the Plassen carbonate platform at the type - locality and its bearing on the early Eoalpine orogenic dynamics in the Northern Calcareous Alps (Austria). - International Journal of Earth Sciences (Geologische Rundschau), **95**: 451-462, Berlin.

Gianolla, P., De Zanche, V. & Mietto, P. (1998): Triassic sequence stratigraphy in the Southern Alps (Northern Italy): definition of sequences and basin evolution. - (In: De Graciansky, P.C., Hardenbol, J., Jacquin, T. & Vail, P. R. (Eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins). - SEPM Special Publication, **60**: 719-746, Tulsa.

Gorican, S. (1994): Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budva Zone (Dinarides, Montenegro). - Mémoires de Géologie (Lausanne), **18**: 1-177, Lausanne.

Gorican, S., Smuc, A. & Baumgartner, P.O. (2003): Toarcian Radiolaria from Mt. Mangart (Slovenian-Italian border) and their paleoecological implications. - Marine Micropaleontology, **49**: 275-301, Amsterdam.

Gorican, S. & Smuc, A. (2004): Albian Radiolaria and Cretaceous stratigraphy of Mt. Mangart (western Slovenia). - Razprave IV. Razreda SAZU, **45/3**: 29-49, Ljubljana.

Gorican, S., Pavsic, J. & Rozic, B. (2012): Bajocian to Tithonian age of radiolarian cherts in the Tolmin Basin (NW Slovenia). - Bulletin de la Société Géologique de France, in press, Paris.

Haas, J. & Budai, T. (1999): Triassic sequence stratigraphy of the Transdanubian Range (Hungary). - Geologica Carpathica, **50**: 459-475, Bratislava.

Härtel, F. (1920): Stratigraphische und Tektonische Notizen über das Wocheiner Juragebiet. - Verhandlungen der Geologischen Staatsanstalt, **8-9**: 134-153, Wien.

Jenkyns, H.C. (1988): The Early Toarcian (Jurassic) anoxic event: stratigraphic, sedimentary and geochemical evidence. - American Journal of Science, **288**: 101-115, New Haven.

Jenkyns, H.C. & Clayton, C.J. (1986): Black shales and carbon isotopes in pelagic sediments from the Tethyan Lower Jurassic. - Sedimentology, **33**: 87-106, Oxford.

Jenkyns, H.C, Géczy, B. & Marshall, J.D. (1991): Jurassic manganese carbonates of central Europe and the early Toarcian anoxic event. - The Journal of Geology, **99**: 137-149, Chicago.

Jurkovsek, B. (1986): Osnovna geoloska karta SFRJ 1: 100.000, list Beljak in Ponteba. - Zvezni geoloski zavod, Beograd.

Jurkovsek, B. (1987): Osnovna geoloska karta SFRJ 1: 100.000. Tolmac listov Beljak in Ponteba. - 1-58, Zvezni geoloski zavod, Beograd.

Jurkovsek, B. & Kolar-Jurkovsek, T. (1987): Krinoidi iz tithonijsko-valanginijskih plasti vzhodno od Vrsnika (Julijske Alpe). - Geologija, **30**: 5-21, Ljubljana.

Jurkovsek, B., Sribar, L., Ogorelec, B. & Kolar-Jurkovsek, T. (1990): Pelagic Jurassic and Cretaceous beds in the western part of the Julian Alps. - Geologija, **31/32**: 285-328, Ljubljana.

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

Kolar-Jurkovsek, T. (2011): Latest Triassic conodonts of the Slovenian Basin and some remarks on their evolution. - Geologija, **54**: 81-90, Ljubljana.

Kolar-Jurkovsek, T., Buser, S. & Jurkovsek, B. (1983): Zgornjetriasne plasti zahodnega dela Pokljuke. - Rudarsko-metalurski zbornik, **30/2-3**: 151-185, Ljubljana.

Kukoc, D., Gorican, S & Kosir, A. (2012): Lower Cretaceous carbonate gravity-flow deposits from the Bohinj area (NW Slovenia): evidence of a lost carbonate platform in the Internal Dinarides. - Bulletin de la Société Géologique de France, in press, Paris.

Lehner, B.L. (1992): Die mesozoische Ablagerungsgeschichte des nördlichen Trentino (Südalpen, Norditalien)). - Profil, **3**: 1-129, Stuttgart.

Luzar-Oberiter, B., Mikes, T., von Eynatten, H. & Babic, L. (2009): - Ophiolitic detritus in Cretaceous clastic formations of the Dinarides (NW Croatia): evidence from Cr-spinel chemistry. - International Journal of Earth Sciences (Geologische Rundschau), **98**: 1097-1108, Berlin.

Mikes, T., Christ, D., Petri, R., Dunkl, I., Frei, D., Báldi-Beke, M., Reitner, J., Wemmer, K., Hrvatovic, H. & Von Eynatten, H. (2008): Provenance of the Bosnian Flysch. - Swiss Journal of Geosciences, **101/Supplement 1**: S31-S54, Basel.

Missoni, S. & Gawlick, H.-J. (2011): Jurassic mountain building and Mesozoic-Cenozoic geodynamic evolution of the Northern Calcareous Alps as proven in the Berchtesgaden Alps (Germany). - Facies, **57**: 137-186, Erlangen.

O'Dogherty, L., Sandoval, J., Bartolini, A., Bruchez, S., Bill, M. & Guex, J. (2006). - Carbon-isotope stratigraphy and ammonite faunal turnover for the Middle Jurassic in the Southern Iberian paleomargin. - Palaeogeography, Palaeoclimatology, Palaeoecology, **239**: 311-333, Amsterdam.

Ogorelec, B., Sribar, L. & Buser, S. (1976): O litologiji in biostratigrafiji volcanskega apnenca. - Geologija, **19**: 125-151, Ljubljana.

Ogorelec, B. & Dozet, S. (1997): Upper Triassic, Jurassic and Lower Cretaceous beds in eastern Sava Folds - Section Laze at Bostanj (Slovenia). - Rudarsko-metalurski zbornik, **44/3-4**: 223-235, Ljubljana.

Orehek, S. & Ogorelec, B. (1979): Sedimentoloske znacilnosti jurskih in krednih karbonatnih kamnin na Trnovskem gozdu. - Geoloski vjesnik, **32**: 185-192, Zagreb.

Oven, M., Misic, M., Rozic, B. & Horvat, A. (2007): Geokemicne in mineraloske analize Perblanske formacije Slovenskega bazena. - Geoloski zbornik, **19**: 79-82, Ljubljana.

Placer, L. (1999): Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. - Geologija, **41**: 223-255, Ljubljana.

Rainer, T., Herlec, U., Rantitsch, G., Sachsenhofer, R.F. & Vrabec, M. (2002): Organic matter maturation vs clay mineralogy: A comparison for Carboniferous to Eocene sediments from the Alpine - Dinaride junction (Slovenia, Austria). - Geologija, **45**, 513-518, Ljubljana.

Rainer, T., Sachsenhofer, R.F., Rantitsch, G., Herlec, U. & Vrabec, M. (2009): Organic maturity trends across the Variscan discordance in the Alpine-Dinaric Transition Zone (Slovenia, Austria, Italy): Variscan versus Alpidic thermal overprint. - Austrian Journal of Earth Sciences, **102**: 120-133, Wien.

Rozic, B. (2005): Albian-Cenomanian resedimented limestone in the Lower flyschoid Formation of the Mt. Mrzli Vrh Area (Tolmin region, NW Slovenia). - Geologija, **48/2**: 193-210, Ljubljana.

Rozic, B. (2006): Sedimentology, stratigraphy and geochemistry of Jurassic rocks in the western part of the Slovenian Basin. - 1-148, Ph.D. Thesis, University of Ljubljana.

Rozic, B. (2009): Perbla and Tolmin formations: revised Toarcian to Tithonian stratigraphy of the Tolmin Basin (NW Slovenia) and regional correlations. - Bulletin de la Société Géologique de France, **180**: 411-430, Paris.

Rozic, B. & Popit, T. (2006): Resedimented limestones in Middle and Upper Jurassic succession of the Slovenian Basin. - Geologija, **49**: 219-234, Ljubljana.

Rozic, B., Kolar-Jurkovsek, T. & Smuc, A. (2009): Late Triassic sedimentary evolution of Slovenian Basin (eastern Southern Alps): description and correlation of the Slatnik Formation. - Facies, **55**: 137-155, Erlangen.

Rozic, B. & Smuc, A. (2011): Gravity-flow deposits in the Toarcian Perbla Formation (Slovenian Basin, NW Slovenia). - Rivista Italiana di Paleontologia e Stratigrafia, **117/2**: 283-294, Milano.

Sabatino, N., Neri, R., Bellanca, A., Jenkyns, H., Baudin, F., Parisi, G. & Masetti, D. (2009): Carbon-isotope records of the Early Jurassic (Toarcian) oceanic anoxic event from the Valdorbia (Umbria-Marche Apennines) and Monte Mangart (Julian Alps) sections: palaeogeographic and stratigraphic implications. - Sedimentology, **56**: 1307-1328, Oxford.

Sabatino, N., Neri, R., Bellanca, A., Jenkyns, H.C., Masetti, D. & Scopelliti, G. (2011): Petrography and high-reolution geochemical records of Lower Jurassic manganese-rich deposits from Monte Mangart, Julian Alps. - Palaeogeography, Palaeolimatology, Palaeoecology, **299**: 97-109, Amsterdam.

Samiee, R. (1999): Fazielle und diagenetische Entwicklung von Plattform-Becken-Übergängen in der Unterkreide Sloweniens. - 1-185, PhD Thesis, University of Erlangen.

Sarti, M., Bosellini, A. & Winterer, E.L. (1992): Basin Geometry and Architecture of a Tethyan Passive Margin, Southern Alps, Italy. - (In: Watkins, J.S., Zhiqiang, F. & McMillen, K.J. (Eds.): Geology and Geophysics of Continental Margins), AAPG Memoir, **53**: 241-258, Tulsa.

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

Schettino, A. & Turco, E. (2011): Tectonic history of the western Tethys since the Late Triassic. - Geological Society of America Bulletin, **123**: 89-105, Boulder.

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

Schmid, S.M., Fügenschuh, B., Kissling, E. & Schuster, R. (2004): Tectonic map and overall architecture of the Alpine orogen. - Eclogae Geologicae Helvetiae, **97/1**: 93-117, Basel.

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

Smuc, A. (2005): Jurassic and Cretaceous stratigraphy and sedimentary evolution of the Julian Alps, NW Slovenia. - 1-98, (Zalozba ZRC/ZRC Publishing), Ljubljana.

Smuc, A. (2010): Jurassic and Cretaceous neptunian dikes in drowning successions of the Julian High (Julian Alps, NW Slovenia). - RMZ - Materials and Geoenvironment, **57/2**: 195-214, Ljubljana.

Smuc, A. & Gorican, S. (2005): Jurassic sedimentary evolution of a carbonate platform into a deep-water basin, Mt. Mangart (Slovenian-Italian border). - Rivista Italiana di Paleontologia e Stratigrafia, 111: 45-70, Milano.

Smuc, A. & Rozic, B. (2010): The Jurassic Prehodavci Formation of the Julian Alps: easternmost outcrops of Rosso Ammonitico in the Southern Alps (NW Slovenia). - Swiss Journal of Geosciences, **103**: 241-255, Basel.

Svetlicic, E., Milanic, B., Skrinjar, P., Smuc, A. & Rozic, B. (2011): Jurske plasti Slovenskega bazena v narivni luski Macjega potoka na juznih pobocjih Crne prsti. - Geoloski zbornik, **21**: 122-126, Ljubljana.

Tisljar, J., Vlahovic, I., Velic, I. & Sokac, B. (2002): Carbonate Platform Megafacies of the Jurassic and Cretaceous Deposits of the Karst Dinarides. - Geologia Croatica, **55**: 139-170, Zagreb.

Turnsek, D. (1985): Carnian coral *Thamnotropis rakoveci* n.sp. from Perbla near Tolmin (NW Yugoslavia). - Razprave IV. razreda SAZU, **26**: 305-312, Ljubljana.

Turnsek, D. (1997): Mezosoic Corals of Slovenia. - 1-512, (Zalozba ZRC/ZRC Publishing), Ljubljana.

Turnsek, D., Buser, S. & Ogorelec, B. (1987): Upper Carnian Reef Limestone in Clastic Beds at Perbla near Tolmin (NW Yugoslavia). - Razprave IV razreda SAZU, **27**: 37-64, Ljubljana.

Vlahovic, I., Tisljar, J., Velic I. & Maticec, D. (2005): Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. - Paleogeography, Paleoclimatology, Paleoecology, **220**: 333-360, Amsterdam.

Winterer, E.L. & Bosellini, A. (1981): Subsidence and sedimentation on Jurassic passive continental margin, Southern Alps, Italy. - AAPG Bulletin, **65**: 394-421, Tulsa.

Winterer, E.L., Metzler, C.V. & Sarti, M. (1991): Neptunian dykes and associated breccias (Southern Alps, Italy and Switzerland) - role of gravity sliding in open and closed systems. - Sedimentology, **38**: 381-404, Oxford.

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

Zempolich, W.G. & Erba, E. (1999): Sedimentologic and chemostratigraphic recognition of third-order sequences in resedimented carbonate: the Middle Jurassic Vajont Limestone, Venetian Alps, Italy. - (In: Harris, P.M., Saller, A.H. & Simo, J.A. (Eds.): Advances in Carbonate Sequence Stratigraphy: Application to Reservoirs, Outcrops and Models), SEPM Special Publication, **63**: 335-370, Tulsa.