Facies
DOI 10.1007/s10347-008-0164-2

ORIGINAL ARTICLE

Late Triassic sedimentary evolution of Slovenian Basin (eastern Southern Alps): description and correlation of the Slatnik Formation

Boštjan Rožič · Tea Kolar-Jurkovšek · Andrej Šmuc

Received: 10 March 2008 / Accepted: 10 October 2008

Abstract Successions of the Slovenian Basin structurally belong to the easternmost Southern Alps. During the Late Triassic, they were part of the Adriatic continental margin. Norian–Rhaetian successions of the Slovenian Basin are characterized mainly by dolomite of the Bača Dolomite Formation. However, in the northern part of the basin, Late Triassic limestone is preserved above Bača Dolomite Formation and is formalized as the Slatnik Formation. It is composed of hemipelagic limestone alternating with resedimented limestones. The succession documents an upward progradation of the slope environment composed of three high-frequency cycles. Most prominent progradation is referred to the second, i.e., Early Rhaetian cycle. The Slatnik Formation ends with thin-bedded hemipelagic limestone that records the end-Triassic productivity crisis, or rapid sea-level fall. The overlying resedimented limestones of the Early Jurassic Krikov Formation, document the recovery of production and shedding from the adjacent carbonate platform.

Keywords Slovenian Basin · Late Triassic · Conodonts · Facies analysis · Sedimentary cycles · Triassic-Jurassic boundary

B. Rožič (✉) · A. Šmuc
Geology Department,
Faculty for Natural Sciences and Engineering,
University of Ljubljana, Privoz 11, 1000 Ljubljana, Slovenia
e-mail: bostjan.rozic@ntf.uni-lj.si

T. Kolar-Jurkovšek
Geological Survey of Slovenia,
Dimičeva ulica 14, 1000 Ljubljana, Slovenia

Introduction

The investigated successions are located in the Bohinj Range that forms the southern orographic boundary of the Julian Alps (northwest Slovenia). In the Late Triassic, the Julian Alps were located in the southwestern part of the western Neo-Tethys Ocean passive margin (Fig. 1). During the Triassic period, the area of western Slovenia underwent several evolutionary phases. In the Early Triassic, entire western Slovenia was the clastic-carbonate shelf that in the Anisian turned into the clastic-free Slovenian Carbonate Platform (Buser 1989, 1996). In the latest Anisian and Early Ladinian, the first rifting phase that was related to the opening of the Neo-Tethys Ocean fragmented the vast carbonate platform and a horst and graben structure originated. The entire region exhibited a complex palaeotopographic picture with small carbonate platforms separated by deeper basins (Buser 1989, 1996; Čar 1990). In the Late Ladinian/Early Carnian, the extensional tectonics ceased. Consequently, in the Carnian, carbonate platforms in the NW and SW prograded into the surrounding basins, leaving central western Slovenia deep (Buser 1989, 1996; Šmuc and Čar 2002; Celarc and Ogorelec 2006; Buser et al. 2008; Celarc and Kolar-Jurkovšek 2008). Three palaeogeographic domains formed: the Dinaric Carbonate Platform to the south, the approximately E–W-extending Slovenian Basin (in literature also known as Slovenian Trough or Tolmin Basin) in the middle and the Julian Carbonate Platform to the north. In the latest Triassic, a second rifting phase started, which was related to the initial stages of the Piedmont–Ligurian Ocean opening. It prolonged into the Early Jurassic and caused progressive deepening of the Slovenian Basin. During the Early or Middle Jurassic, the Julian Carbonate Platform drowned and become a pelagic plateau known as the Julian High (Buser 1989, 1996; Šmuc 2005),

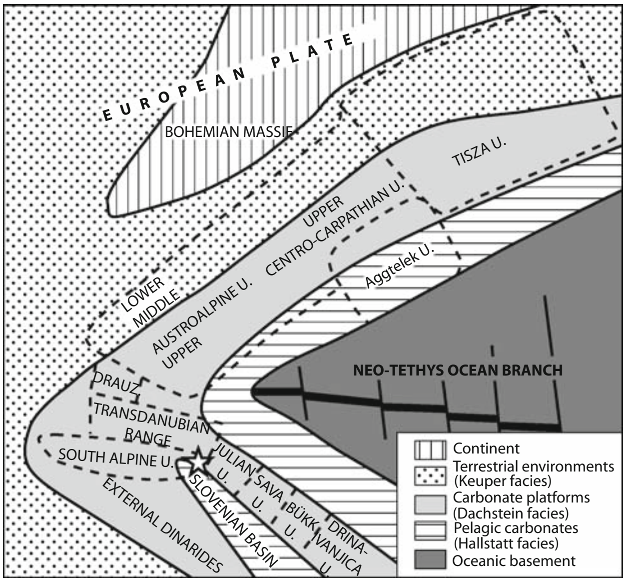


Fig. 1 Palaeogeographical sketch-map of the western Neo-Tethys in the Norian (after Haas 2002). *Star* indicates the location of the northern Slovenian Basin

while the Dinaric Carbonate Platform remained productive throughout the Mesozoic (Buser 1989, 1996; Vlahović et al. 2005).

In the Late Triassic, the carbonate platforms of western Slovenia were characterized by sedimentation on tidal flats forming the thick pile of the Norian–Rhaetian Dachstein Limestone and Main Dolomite (Ogorelec and Rothe 1993; Buser 1996). Locally, in the Late Norian and Rhaetian, coral reefs developed on the southern margins of the Julian Carbonate Platform (Turnšek and Buser 1991; Turnšek 1997). In the Slovenian Basin, the Bača Dolomite Formation deposited (Cousin 1973, 1981; Buser 1989, 1996; Verbovšek 2008). Due to the intensive diagenetic overprinting, the Bača Dolomite Formation remained relatively understudied, and thus the Late Triassic sedimentary evolution of the basin during the Norian–Rhaetian period remained poorly understood.

Recently, we discovered that in the northern Slovenian Basin the part of the Jurassic limestone succession overlying the Bača Dolomite Formation is actually Triassic in age. This recognition encouraged further investigations presented in this paper that include detailed sedimentological studies of the two successions, facies analysis, geological mapping of the area, and conodont dating. The results contribute significantly to the understanding of the sedimentary evolution of the easternmost Southern Alps during the Late Norian and Rhaetian period. This paper provides a formalization of the Slatnik Formation and outlines the major events in the Late Norian–Rhaetian sedimentary evolution of the western part of the Slovenian Basin. Additionally, it includes a correlation with other palaeogeographic domains of the Alpine region.

Geological setting

The Julian Alps structurally form the eastern part of the Southern Alps (Placer 1999; Vrabec and Fodor 2006) and consist of two large nappes: the lower Tolmin Nappe with successions of the Slovenian Basin and the overlying Julian Nappe composed predominantly of Dachstein Limestone of the Julian Carbonate Platform (Fig. 2). Both nappes are thrust over the External Dinarides, characterized by successions of the Dinaric Carbonate Platform. The Tolmin Nappe is additionally divided into three lower-order nappes (Buser 1987): the lowest Podmelec Nappe is overlain by the Rut Nappe and the highest Kobla Nappe. To the present knowledge, the Slatnik Formation occurs only in the Kobla Nappe. This nappe is characterized by the Slovenian Basin succession that is most proximal to the Julian Carbonate Platform and at the same time most distal to the Dinaric Carbonate Platform.

The succession of the Kobla Nappe ranges from the Carnian to the Early Cretaceous. It begins with the Carnian Kobla Formation, which is composed of shale, chert, silt, and cherty limestone. It is overlain first by bedded limestone,

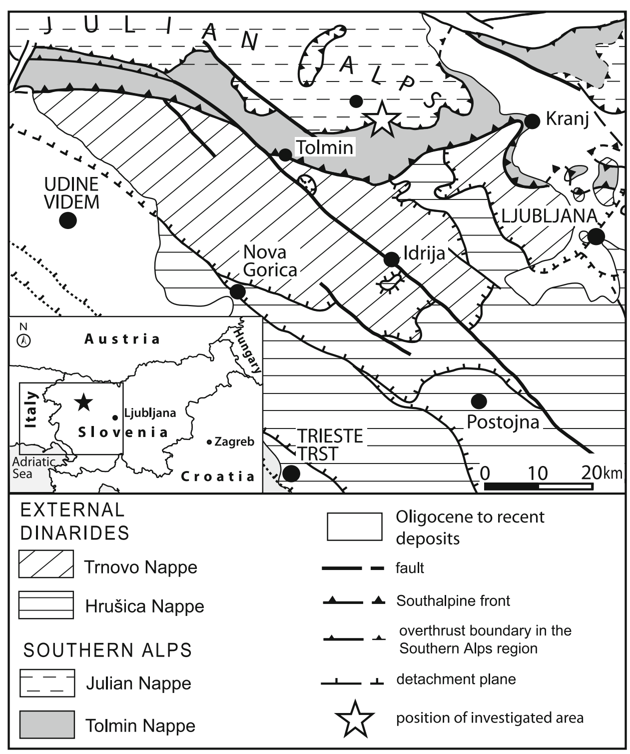


Fig. 2 Location of the studied section and macrotectonic subdivision of western Slovenia (after Placer 1999)

followed by the Bača Dolomite Formation, a bedded dolomite with chert nodules. The Late Norian and Rhaetian are characterized by the Slatnik Formation described in this paper. The Jurassic begins with the Hettangian to Pliensbachian Krikov Formation, composed predominantly of ooidal/peloidal resediments. The Toarcian is represented by the thin marl-dominated Perbla Formation that is overlain by the Aalenian to Early Tithonian Tolmin Formation, characterized by siliceous limestone and radiolarian chert. The latest Jurassic and Neocomian are typified by a pelagic carbonate sedimentation of Biancone Limestone. The succession of the Kobla Nappe ends with the Aptian to Early Cenomanian, shale-dominated Lower Flyschoid Formation.

The geological mapping revealed a complex tectonic structure of the area comprising two larger structural units (Fig. 3): the Kobla Nappe with the above-described basinal succession and the overlying Julian Nappe that is composed of shallow-water Late Triassic reef limestone and Jurassic ooidal limestone. In the mapped area, the tectonic contact within the nappes is exceptionally not a thrust but a normal or strike-slip fault, where the Julian Nappe is relatively lowered along the fault. Strike-slip deformations characterize Neo-Alpine structural evolution of the Julian Alps (Kastelic et al. 2008). The Kobla Nappe, at the researched area, is additionally segmented into two different tectonic blocks exhibiting different developments of the Slatnik Formation, the eastern block at Mt. Slatnik being more proximal. The Slatnik Formation was studied in two sections, each representing the development of a separate tectonic block. In the Kobla area, the upper part of the Slatnik Formation is repeated above the studied section due to a minor thrust (Rožič 2008).

Slatnik Formation

The Slatnik Formation represents the non-dolomitized uppermost part of the Bača Dolomite Formation (later in the text referred to solely as Bača Dolomite). In major parts of the Slovenian Basin, however the Bača Dolomite characterizes the entire Norian–Rhaetian succession (Cousin 1973, 1981; Buser 1989, 1996).

Type locality

The type locality (Kobla section) of the Slatnik Formation is located on the eastern slope of Mt. Kobla ($y = 5{,}420{,}550$, $x = 5{,}121{,}590$, 1,498 m a.s.l.). It was studied along the old mountain path that cuts the slope a few meters below the eastern ridge of Mt. Kobla (Figs. 3, 4). The formation was also studied in the Slatnik section, located near Mt. Slatnik ($y = 5{,}423{,}160$, $x = 5{,}121{,}670$, 1,609 m a.s.l.), 2.5 km eastward from Mt. Kobla (Fig. 3). The formation is named after Mt. Slatnik, to avoid confusion with the Carnian Kobla Formation described by Buser (1986).

Short description

In the type locality, the Slatnik Formation is approximately 100 m thick (Figs. 3, 5). In the lower part, it is composed

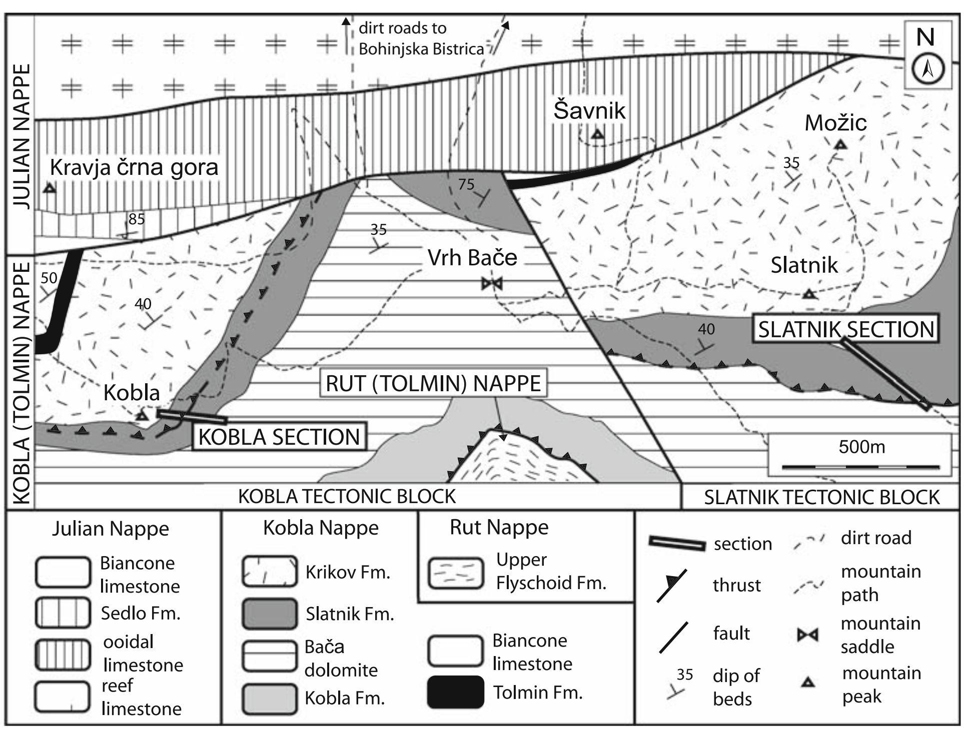


Fig. 3 Geological map of the area between Mt. Kobla and Mt. Slatnik and locations of studied sections

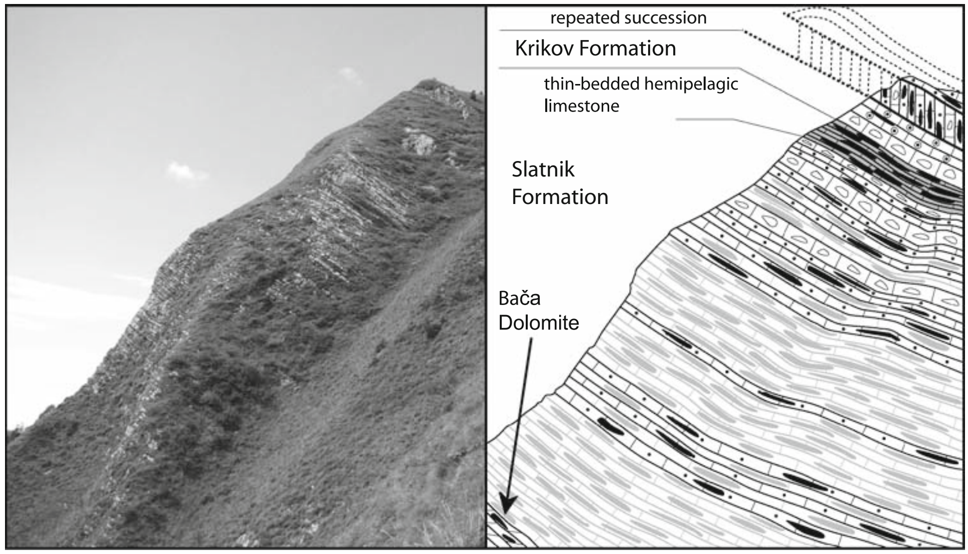


Fig. 4 View of the Mt. Kobla eastern slope with schematic sketch of studied succession

predominantly of hemipelagic limestone with chert nodules, whereas in the upper part, hemipelagic limestone alternates with calcarenites and limestone conglomerate. The lower boundary with the Bača Dolomite is covered but most probably sharp. The upper boundary with the Krikov Formation is sharp. In the Slatnik section, the formation is thinner (50 m) and composed predominantly of calcarenites and limestone conglomerate, whereas hemipelagic limestone intercalations are rare (Fig. 5). In this section, the formation is bounded by minor faults. In both sections, the Slatnik Formation ends with a few-meters-thick interval of thin-bedded hemipelagic limestone. In the Kobla section, the formation is assigned to the Late Norian (Sevatian) to Rhaetian/earliest Hettangian, whereas in the Slatnik section, the lower boundary is younger and assigned to latest Norian (Late Sevatian).

Previous works

The first comprehensive geological work on the area was performed at the beginning of the last century, in connection with the construction of the Bohinj railway tunnel that penetrates the eastern Bohinj Range directly below Mt. Kobla (Kossmat 1907). The overall carbonate succession of the Slovenian Basin was described as Jurassic, although Late Triassic Bača Dolomite had already been recognized in other parts of the basin.

Based on geological mapping of the Julian Alps, Buser (1986, 1987) assigned the Bača Dolomite, the underlying bedded limestone and the Kobla Formation to the Late Triassic. Near the Vrh Bače mountain saddle, the Norian bivalve *Halobia distincta* was found in the limestone interbeds within the Bača Dolomite. On Mt. Kobla, the same section as presented in this paper was subject to the stratigraphic study. The limestone succession overlying the Bača Dolomite was assigned to the Jurassic, although no characteristic Jurassic fossils were found in the lower part of the succession (Buser 1986). The author mentioned the determination of foraminifers *Galeanella panticae*, *Ophtalmidium* sp. and dasyclad alga *Thaumatoporella parvovesiculifera*. At the base of the Krikov Formation a recrystallized *Involutina farinacciae* was determined in the ooidal calcarenite.

Description of type locality

In the type locality, the Slatnik Formation is 102 m thick (Fig. 5). The underlying Bača Dolomite consists of bedded dolomite with chert nodules.

The Slatnik Formation is characterized by bedded (10–50 cm), grey and dark grey, occasionally wavy and even laminated hemipelagic limestone (Fig. 6a). It is wackestone and rarely packstone composed of pellets and fossils, of which the most abundant are calcified radiolarians. Other fossils are sponge spicules, thin-shelled bivalves, ostracods, benthic foraminifers and fragments of echinoderms and brachiopods. Gastropods and, in the upper part of the formation, also juvenile ammonites occur rarely (Fig. 7a). The beds usually contain irregularly shaped replacement chert nodules and are occasionally still dolomitized especially near the bedding planes.

The composition of bedded wackestone elucidates deposition in a deeper-water sedimentary environment. Because in the Late Triassic carbonate plankton was scarce (Gawlick and Böhm 2000) the lime mud must have originated from the surrounding shallow-water environments. Lamination (Tc-d) indicates an occasional redeposition of sediment with fine-grained turbidity currents. A small slump is observed at 29 m in the section (Fig. 5). The slumped beds are composed exclusively of the hemipelagic

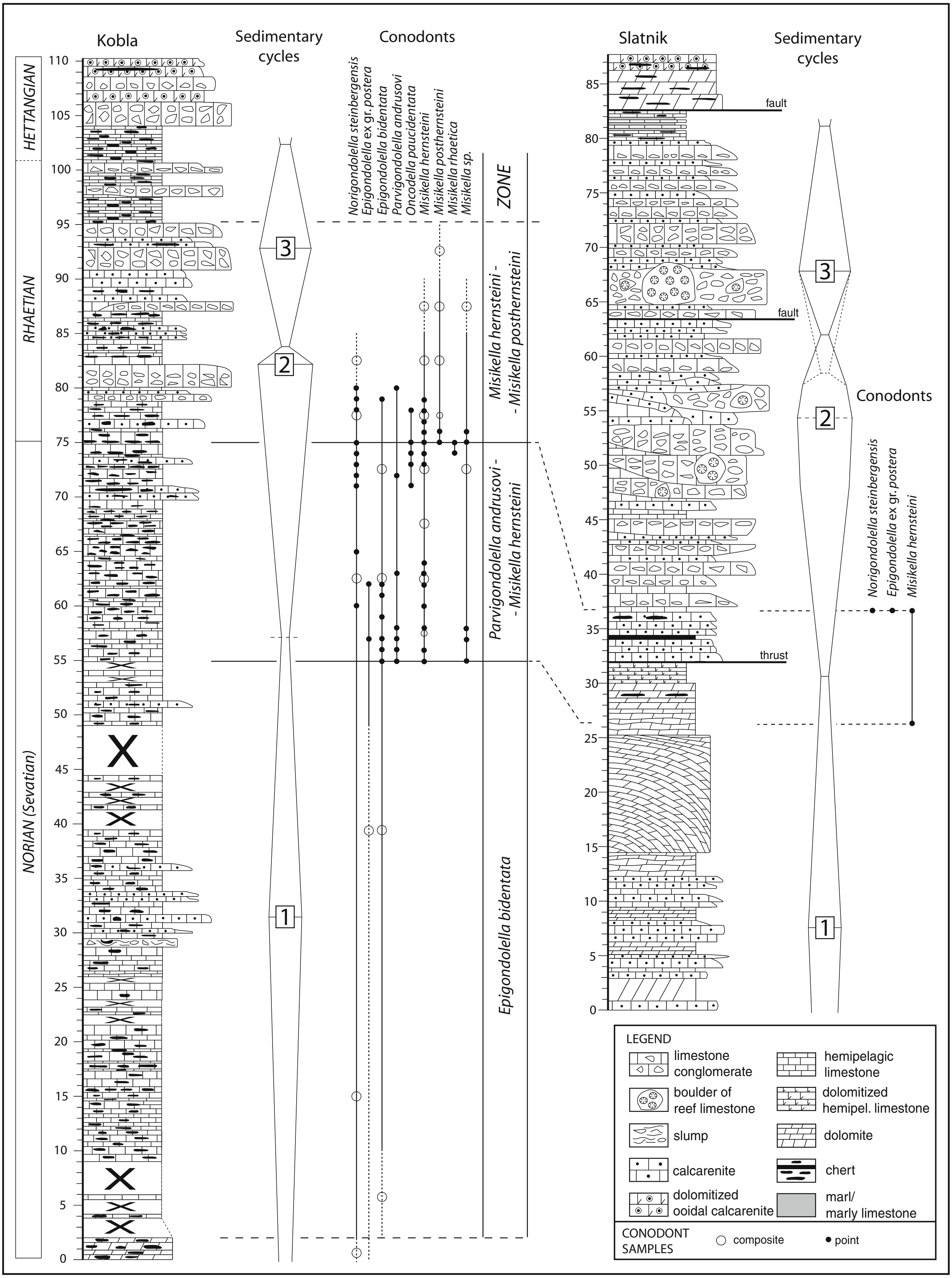


Fig. 5 Kobla and Slatnik sections with sedimentary cycles and conodont datations

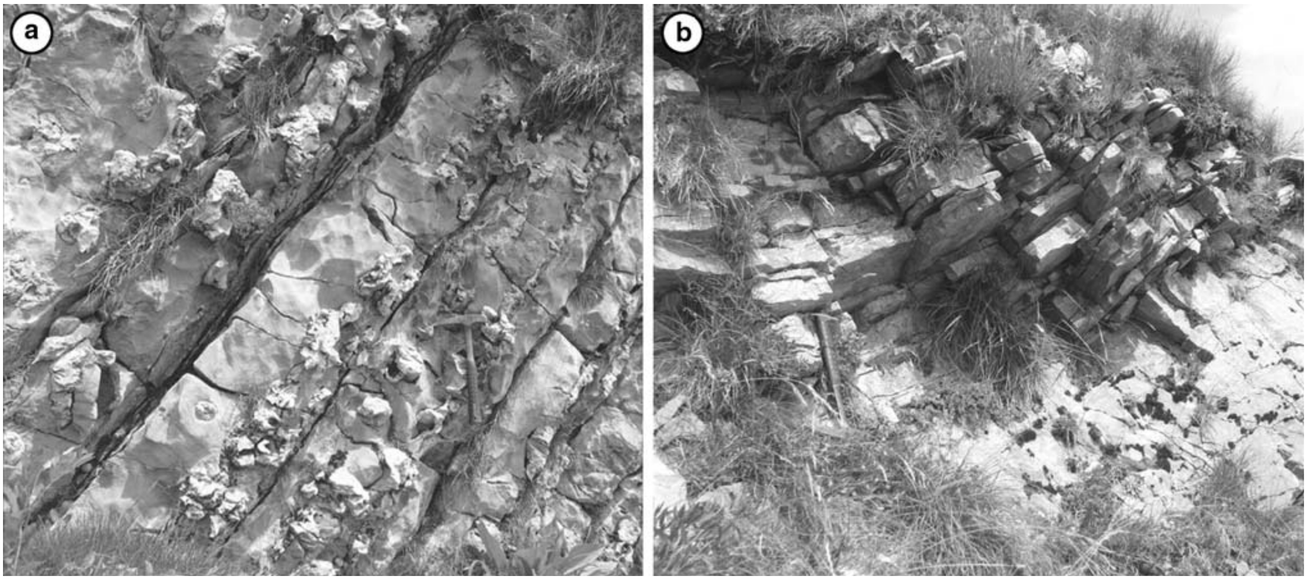


Fig. 6 Hemipelagic limestones of the Slatnik Formation from Kobla section: **a** thicker beds with irregular chert nodules from middle part of the section; **b** last thick conglomerate bed overlain by thin-bedded hemipelagic limestones at the *top* of the section

limestone. They are partly disintegrated into irregularly shaped clasts. Apparently, the sediment creep was short and it froze at the initial stage of debris flow development.

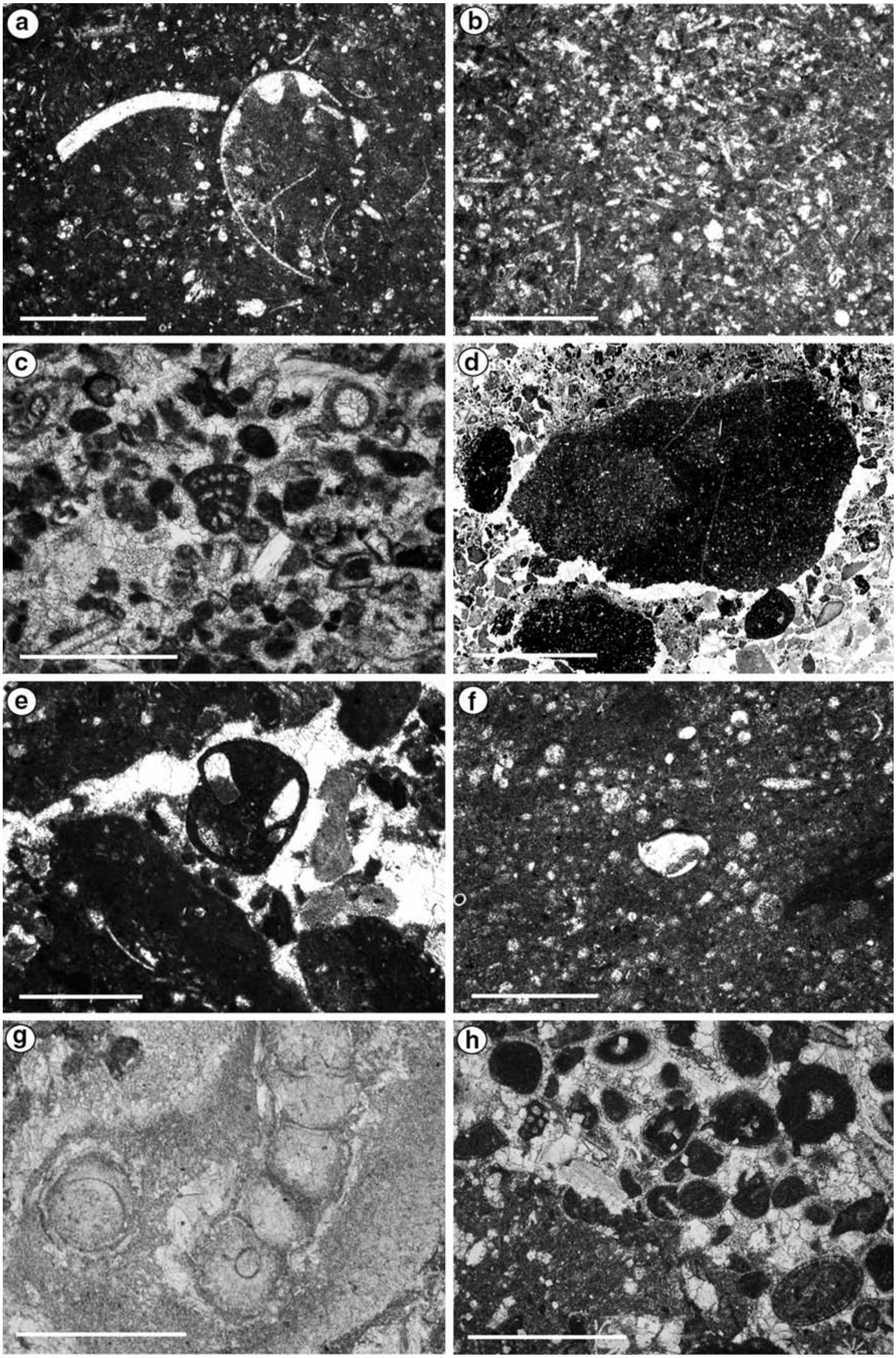
Within hemipelagic limestone, coarse-grained beds are interbedded. These start to occur above 27 m in the formation but are abundant only in the upper 38 m. Calcarenites prevail, but between 75 and 98 m, limestone conglomerate also occurs.

Calcarenites are grey, bedded (3–45 cm), graded, even and wavy laminated. Load casts and load balls were also observed. The fine-grained calcarenite is grainstone or rarely packstone (Fig. 7b) composed predominantly of pellets, peloids, intraclasts and fossils, mostly echinoderm fragments, thin bivalve and ostracod shells, brachiopod fragments, benthic foraminifers and calcified sponge spicules or radiolarians. Coarse- and medium-grained calcarenites are grainstone composed of intraclasts, fossils and rarer pellets and peloids (Fig. 7c). Fossils are predominantly echinoderm fragments and rarer benthic foraminifers, fragmented shells of brachiopods, bivalves and ostracods, gastropods, bryozoans and codiaceans. Graded pebbly calcarenite also occurs (Fig. 7d). Clasts in these beds are the same as those observed in the conglomerate. Calcarenites are partly replaced by chert nodules. Dolomitization is slight and selective, limited to micritic grains, such as peloids or intraclasts.

Sedimentary textures in the calcarenites record the deposition by turbidity currents, where top-cutoff (Ta-b and Ta-c) sequences are most common. The composition of calcarenites (that also compose the matrix of the conglomerate) indicates a shallow-water source area of the resedimented sand-sized material. The presence of reef-dwelling foraminifera *Galeanella panticae* Brönnimann and also *Galeanella tollmanni* Kristan–Tollmann suggests presence of reefs in the source area (Schäfer 1979; Senowbari-Daryan 1980; Senowbari-Daryan et al. 1982). Additionally, a similar composition is reported in the Late Triassic reef-derived resedimented limestones of the Pedata Formation in the Northern Calcareous Alps (Reijmer et al. 1991) and Forni Dolomite Formation in the eastern Southern Alps (Cozzi 2002).

Limestone conglomerate is bedded (12–150 cm) and occasionally graded. Beds are even or rarely channelized. The thickest beds are abruptly overlain by graded calcarenite. A thin (12 cm) convex-upward shaped conglomerate bed was observed (Fig. 8a). A positive relief is flattened by the overlying hemipelagic limestone. Clasts in the conglomerate are dm-sized, well rounded, elongated and oriented parallel to the bedding planes. Four main types of clasts were recog-

Fig. 7 **a** Hemipelagic limestone: wackestone with ammonite, shell fragment and calcified radiolarians, thin-shelled bivalves; middle part of the Kobla section. **b** Fine-grained calcarenite: packstone with pellets, calcified radiolarians and spicules; Kobla section. **c** Medium-grained calcarenite: grainstone with pellets, intraclasts/peloids and fossils: benthic foraminifera, echinoderm and shell fragments; Kobla section. **d** Pebbly calcarenite: grainstone matrix and large wackestone intraclasts/mud-chips; Kobla section. **e** Limestone conglomerate: wackestone intraclasts and grainstone matrix with benthic foraminifera, echinoderms, intraclasts, pellets and peloids; Kobla section. **f** Thin-bedded hemipelagic limestone: wackestone with calcified radiolarians, spicules and ostracod; topmost Kobla section. **g** Limestone conglomerate: framestone clast with *Cheilosporites tirolensis* Wähner; Slatnik section. **h** Calcarenite of the overying Krikov Formation: partially dolomitized grainstone with ooids, peloids, echinoderms, benthic foraminifer and larger wackestone intraclast; Kobla section. *Scale bars* **a**–**c**, **e**–**h** 1 mm, **d** 5 mm ▶


a
b
c
d
e
f
g
h

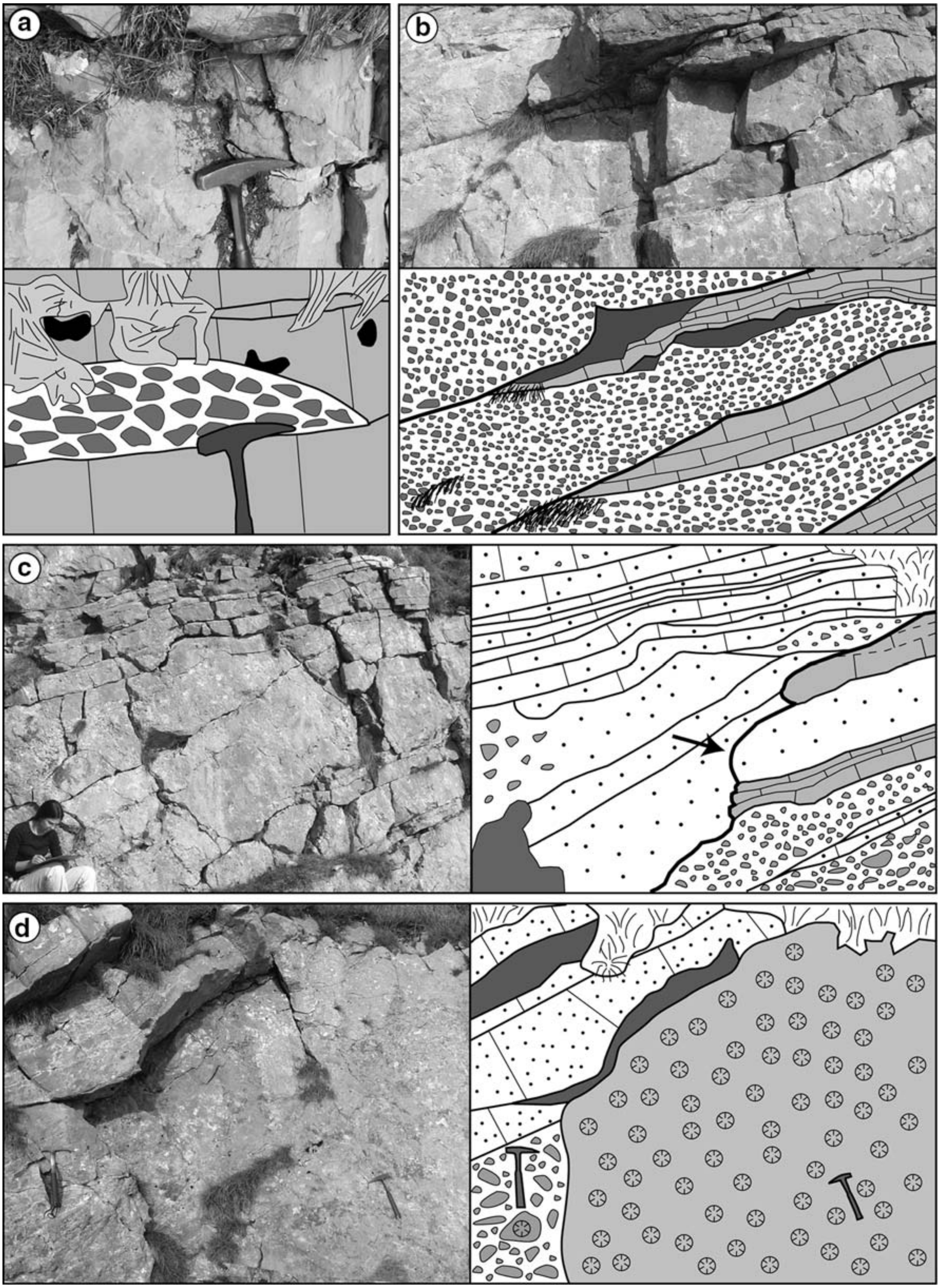


Fig. 8 **a** *Convex-upward shaped bed* of limestone conglomerate overlain by hemipelagic limestone (Kobla section). **b** Three limestone conglomerate beds cutting into underlying hemipelagic limestone and conglomerate beds; height of the photo is 4 m (Slatnik section). **c** Slide scarp (*arrow*), a depression filled by material from subsequent gravity flows and folded beds above the scarp (Slatnik section). **d** Reef-limestone boulder protruding the *top* of the limestone conglomerate bed (Slatnik section)

nized: (1) the most abundant are basinal intraclasts; i.e., rip-up clasts derived from consolidated or semi-consolidated hemipelagic deposits (Fig. 7e); (2) fine-grained grainstone to packstone clasts similar to the fine-grained calcarenite beds of the Slatnik Formation. These clasts are most probably also basinal intraclasts; (3) coarse-grained grainstone clasts composed of micritic intraclasts and codiaceans. Fibrous-rim and mosaic cements indicate the shallow-water origin of these clasts; (4) millimeter-sized bioclasts, predominantly of calcisponges and codiaceans. These bioclasts are commonly recrystallized and/or silicified. The matrix in the conglomerate consists of the previously described coarse- and medium-grained calcarenites (Fig. 7e).

The limestone conglomerate, which mostly exhibits normal grading, was deposited either by high-density turbidity currents or sandy debris flows (i.e., Shanmugam 2000). Thicker beds that are overlain by calcarenite record a two-component gravity flow in which calcarenites were deposited by overriding turbidity flows. A convex-upward bed from the Kobla section exhibits the shape of a debris-flow deposit (cf. Scheibner et al. 2000).

The majority of pebbles originated from the erosion of slope and basin sediments with gravity flows that derived from the reef-dominated platform margin, as evidenced by composition of the matrix.

The Slatnik Formation ends with a 4-m-thick package of thin-bedded hemipelagic limestone, but thinner beds already occur within the last conglomerate beds in the uppermost 10 m of the formation (Fig. 6b). The typical texture is wackestone. The composition of these beds, when compared with hemipelagic limestone of the main part of the formation, exhibits much poorer fossil diversity. It is composed of pellets and fossils, of which calcified radiolarians predominate (Fig. 7f). Sponge spicules, ostracods, benthic foraminifers and echinoderm fragments also occur, sporadically. These beds contain elongated chert nodules.

The contact of the Slatnik Formation with the underlying Bača Dolomite is not exposed. Observations made during the mapping of the area indicate that the boundary is most probably concordant and sharp. The upper boundary of the Slatnik Formation is sharp. It is overlain by the Krikov Formation characterized by resedimented limestones, predominantly ooidal/peloidal grainstone and packstone. At the base, pebbly calcarenites and limestone conglomerate occur. Clasts in these beds are mostly basinal intraclasts, whereas the matrix is partly dolomitized ooidal/peloidal grainstone (Fig. 7h).

Lateral variations

The Slatnik Formation was additionally investigated in the Slatnik section. This is located in the eastern tectonic block (Fig. 3). It shows features of more proximal development than those in the type section, which is evidenced by the facies association where coarser beds prevail (Fig. 5).

In the Slatnik section, the uppermost 30 m of the Bača Dolomite were investigated in the present study. This is a less intensively dolomitized interval in the Bača Dolomite and limestone beds already occur. The limestone beds are hemipelagic limestone or calcarenites akin to the corresponding lithofacies in the Kobla section. Because the boundary between the Bača Dolomite and Slatnik Formation is younger in the Slatnik section (for details see the following chapter), these beds correlate with the first coarser beds that occur in the lower part of the Slatnik Formation in the Kobla section. In the investigated part of the Bača Dolomite there is a large fold that is most likely of tectonic origin.

The Slatnik Formation in the Slatnik section is 50 m thick. It is composed predominantly of calcarenites, pebbly calcarenite and limestone conglomerate. When compared with the type section, these beds are generally thicker (up to 320 cm) and coarser. The thickest and coarsest beds are in the middle part of the formation, where limestone conglomerates are deposited in large channels cutting into the underlying hemipelagic limestone and conglomerate beds (Fig. 8b). In some of the thick beds the conglomerate grades in the calcarenite. Sedimentary structures are equal to those in corresponding beds in the type locality, indicating the same depositional processes. Additionally, an inverse grading was also observed in the limestone conglomerate. Above these beds, the succession is characterized by a synsedimentary slide (Fig. 8c). The analysis of the outcrop elucidates that a clear-cut slide scarp is visible. A depression formed by sliding was later filled up by gravity flows deposits. The slide scarp presumably produced a short-term instability zone, as evidenced by mildly folded calcarenite beds that overlie the slided part of the succession. Silification and dolomitization in the Slatnik section are less intense when compared with the type section.

The composition of beds is similar to those in the type locality. The clasts in the limestone conglomerate are more diverse but basinal intraclasts still prevail. Additionally, it contains framestone clasts (Fig. 7g) and boulders with corals. Boulders can be up to a few meters large and occasionally protrude above the top of the bed (Fig. 8c). Framestone clasts and boulders prove that a reef-dominated platform margin was the source area of these gravity flows.

The Slatnik Formation, similarly to the type locality, ends with thin-bedded hemipelagic limestone. Thin marl/marly limestone interlayers occur within limestone beds.

The overlying Krikov Formation is characterized by ooidal calcarenites with rare chert nodules. The carbonates were affected by intense dolomitization, especially at the base of the formation where bedded dolomite with chert nodules occurs.

The Slatnik Formation in the Slatnik section is bounded by faults. The lower contact is a thrust fault whereas the upper contact is a normal fault. Another normal fault cuts the middle part of the section. Geological mapping revealed that the dislocations along normal faults were minor. The dislocation along the thrust is also minor because above and below the thrust plane (that dips similarly to the bedding planes), conodont elements of a single conodont zone were recovered.

Biostratigraphy

The Slatnik Formation is assigned to the Late Norian to Rhaetian, based predominantly by conodonts. Additionally, the foraminifers *Galeanella panticae* Brönnimann and *Galeanella tollmanni* Kristan–Tollmann were found in calcarenites. In framestone clasts of conglomerate beds the Late Norian–Rhaetian sponge *Cheilosporites tirolensis* Wähner and Norian–Rhaetian corals *Retiophyllia clathrata* Emmrich and *Palaeastraea* sp. were found.

Conodont fauna

Altogether, 57 carbonate samples have been collected and prepared for conodont study. The sampling was performed in two phases. Firstly, 18 composite samples were taken, encompassing the entire Kobla section. In the second phase, detailed sampling was carried out in the Bača Dolomite and the Slatnik Formation in both sections. In the Kobla section, the Norian–Rhaetian boundary interval (from 55 to 80 m) was sampled in the meter spacing (31 point samples). In the Slatnik section, eight point samples for correlative purposes were analyzed. Samples from both units (lithozones) yielded conodonts as expected from previously known data in the region (Kolar-Jurkovšek 1982; Kolar-Jurkovšek et al. 1983). Samples with a weight ranging between 1.5 kg and 4 kg were treated and the average content was 10 conodonts per sample. The CAI (Conodont Alteration Index) of conodonts is low (CAI = 2–3) sensu Epstein et al. (1977).

Kobla section

The recovered conodont faunas are marked by *Epigondollela*, *Norigondolella*, *Parvigondolella*, *Misikella* and *Oncodella*. The distribution of conodont elements is presented in Fig. 5.

The conodont faunas are characterized by the occurrence of *Norigondolella steinbergensis* (Fig. 9h), which is frequent in most samples of the studied section (up to the composite sample from 80 to 85 m), whereas species *Misikella hernsteini* (Fig. 9a, c) is the dominating element in the upper part of the section (from the point sample at 55 m through the composite sample from 85 to 90.9 m).

The faunas of the lower part of the section are mainly composed of co-occurring *N. steinbergensis* and *E. bidentata* (present up to the point sample at 79 m) (Fig. 9f), and only in a few samples are they joined by rare specimens of the *E. postera* group (composite sample from 30 to 49 m through the point sample at 63 m).

The succeeding conodont faunas are characterized by the occurrence of *M. hernsteini*, which is introduced in the point sample at 55 m and its last occurrence is evidenced in the composite sample from 85 to 90.9 m. The first appearance datum (FAD) of *M. hernsteini* coincides with the FAD of *P. andrusovi* (Fig. 9g); both species have a similar range but the latter species has its last appearance datum in the point sample at 80 m. Along with the dominating *M. hernsteini* elements of *N. steinbergensis*, *E.* ex gr. *postera* and *E. bidentata* are also present.

The higher part of the section is characterized by the presence of *Misikella posthernsteini* (Fig. 9b, d) and it partly co-occurs with *M. hernsteini.* The FAD of *M. posthernsteini* is documented in the point sample at 75 m. Species *M. rhaetica* (Fig. 9e) is recorded in a very short interval (point samples at 74 and 75 m) and it first appears just prior to the first appearance of *M. posthernsteini*. *Oncodella paucidentata* (Fig. 9i) also occurs in a rather short interval (from point samples at 72 to 78 m) within the range of *M. hernsteini*, precisely in its higher part.

Based on the stratigraphic occurrence of the determined species, three conodont zones can be differentiated in the investigated section of Kobla:

1) *Epigondolella bidentata* Zone is marked by faunas constituted of two species, *E. bidentata* and *N. steinbergensis*, that are occasionally joined by rare *E.* ex gr. *postera*;
2) *Parvigondolella andrusovi–Misikella hernsteini* Zone. This zone is characterized by common co-occurrence of the two taxa, as well as the common presence of *N. steinbergensis* and *E. bidentata*. The zone is furthermore marked by the rare presence of *E.* ex gr. *postera* in its lower portion and *M. rhaetica* in its upper portion;
3) *Misikella hernsteini–Misikella posthernsteini* Zone. It is based on the FAD of *M. posthernsteini* in the point sample at 75 m. The two *Misikella* species differ in their abundance; *M. hernsteini* greatly outnumbers *M. posthernsteini.* The lower part of the zone is typified by the presence of all conodont taxa that already appeared in the previous zone, whereas the higher part of the zone is represented by the exclusive occurrence of the genus *Misikella* (*M. posthernsteini* and other *Misikella* types).

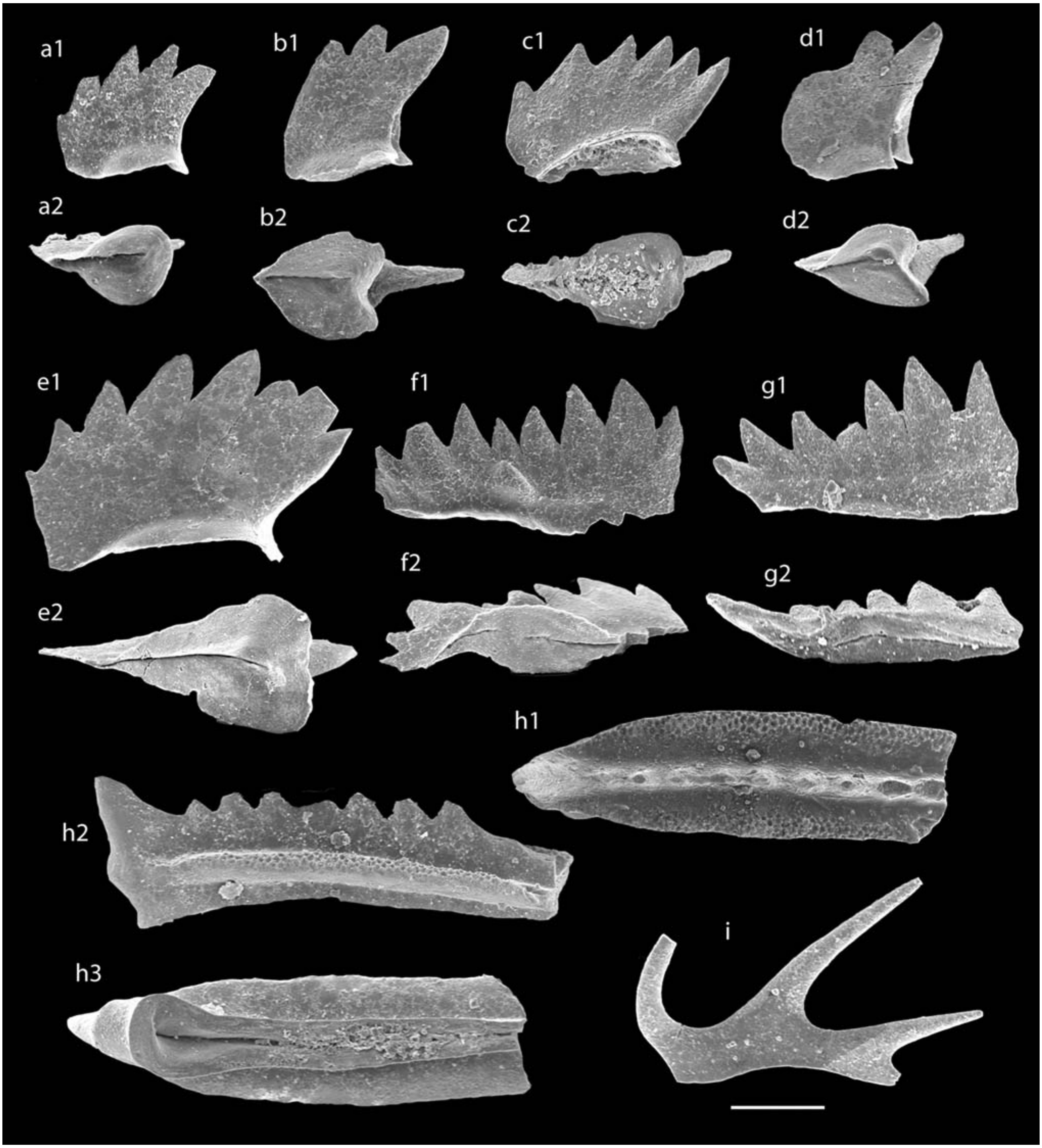


Fig. 9 Conodonts (*scale bar* 100 µm): **a, c** *Misikella hernsteini* (Mostler), sample K2/75 (GeoZS 4242), *1*—lateral view, *2*—lower view. **b, d** *Misikella posthernsteini* Kozur and Mock, **b** sample K2/7 (GeoZS 4096), **d** sample K2/5 (GeoZS 4094), *1*—lateral view, *2*—lower view. **e** *Misikella rhateica* Mostler, sample K2/74 (GeoZS 4239), *1*—lateral view, *2*—lower view. **f** *Epigondolella bidentata* Mosher, sample K2/56 (GeoZS 4226), *1*—lateral view, *2*—lower view. **g** *Parvigondolella andrusovi* Kozur and Mock, sample K2/58 (GeoZS 4228), *1*—lateral view, *2*—lower view. **h** *Norigondolella steinbergensis* (Mosher), sample K2/76 (GeoZS 4242), *1*—oral view, *2*—lateral view, *3*—lower view. **i** *Oncodella paucidentata* (Mostler), sample K2/76 (GeoZS 4242)

Slatnik section

For comparative purposes, eight samples were treated for conodonts and two of them were productive. The recovered fauna yields rare but characteristic elements of *E. bidentata*, *E.* ex gr. *postera*, *Norigondolella steinbergensis* and *M. hernsteini.* The determined taxa enable this fauna to be assigned to the *Parvigondolella andrusovi–Misikella hernsteini* Zone.

Discussion on the Norian–Rhaetian biozonation

In the zonation scheme of Kozur (2003), the typical co-occurrence of *M. hernsteini* and *M. posthernsteini* marks the *M. hernsteini–M. posthernsteini* subzone of the *M. posthernsteini* Assemblage Zone. Its stratigraphic range is in accordance with the Rhaetian *Paracochloceras suessi* and *Choristoceras haueri* ammonoid Tethyan Zones of Krystyn (1987, 1991). The position of this conodont subzone corresponds to the conodont zonation proposed by Kozur and Mock (1991). A correlation scheme of Late Triassic ammonoid and conodont zonations after Kozur (2003) is presented in Table 1. It must be noted that a slightly modified generic concept has been used in this study, namely *Epigondollela* instead of *Mockina*.

Just recently, a proposal to define the Norian–Rhaetian boundary was presented by Krystyn et al. (2007). Three marker events have been put forward to define this boundary and option 2 is based on the FAD of *M. posthernsteini* and it correlates to the FO of *Paracochloceras suessi* (Krystyn et al. 2007). As the definition of the Norian–Rhaetian boundary is not the scope of this study, it will not be discussed herein, but this boundary is therefore rather arbitrarily placed at the FAD of *M. posthernsteini*.

Sedimentary environment

The facies associations were classified according to the classical work on carbonate resediments of Mullins and Cook (1986). The lower part of the Kobla section is dominated by hemipelagic limestone (facies G) that rarely contains calcarenites (facies C) and a single bed of conglomerate of a lime-mud matrix (facies F). Such an association implies basin plain deposits. The upper part of the Kobla section is characterized by alternating hemipelagic limestones (Facies G), calcarenites (Facies C), pebbly calcarenite (Facies A) and clast-supported conglomerate (Facies A). This association indicates a deposition on the lower slope: more precisely, the outer apron sedimentary environment.

In the Slatnik area, the formation consists predominantly of calcarenites (Facies C), pebbly calcarenite (Facies A) and clast-supported conglomerate (Facies A), whereas hemipelagic limestone (Facies G) is rare. The association is characteristic of sedimentation in the lower slope: more precisely, the inner apron. The middle part of the Slatnik section is dominated by clast-supported conglomerate (Facies A) that is channelized in hemipelagic limestone (Facies G). Such an association, together with the overlying slide, indicates an upper slope sedimentary environment.

Although an apparent difference is observed between the Kobla and the Slatnik sections, the succession in both sections records obvious upward changes to more proximal sedimentary environments: (1) in the Kobla section, from the basin plain to the outer apron and (2) in the Slatnik section, from the inner apron to the upper slope. Based on the conodont biostratigraphy the major progradation took place in the Early Rhaetian. In the upper part of the Slatnik section, a retrogradation trend is observed, whereas in the Kobla section, the same trend is less expressed. In both sections, the Slatnik Formation ends with a few-meters-thick horizon of thin-bedded, hemipelagic limestone (Facies G), almost devoid of gravity redeposited sediments. It seems likely that paleoenvironmental stress caused or at least amplified the sedimentary change. It is marked by (1) considerable decrease of fossil diversity in the hemipelagic limestone and (2) increased terrigenous input observed in the Slatnik section. Alternatively, the abrupt change in the facies association at the top of the Slatnik Formation may also suggest prominent and quick back-stepping of the active shallow-marine factory.

Table 1 Correlation of Late Triassic ammonoid and conodont zonations after Kozur (2003)

<table>
<tr><th colspan="2">Stage</th><th colspan="2">Ammonoid Zone</th><th colspan="2">Conodont Zone</th></tr>
<tr><td rowspan="5" colspan="2">Rhaetian</td><td rowspan="2">Chorist. marshi</td><td>Choristoceras marshi</td><td colspan="2">Misikella ultima</td></tr>
<tr><td>Choristoceras ammonitiforme</td><td rowspan="4">Misikella posthernsteini</td><td rowspan="2">Misikella koessenensis</td></tr>
<tr><td rowspan="2">Chorist. haueri</td><td>Vandaites stuerzenbaumi</td></tr>
<tr><td>Choristoceras haueri</td><td rowspan="2">M. hernsteini-M. posthernsteini</td></tr>
<tr><td colspan="2">Cochloceras suessi</td></tr>
<tr><td rowspan="4">Norian</td><td rowspan="3">Sevatian</td><td colspan="2">Sagenites reticulatus</td><td colspan="2">Misikella hernsteini-Parvigondolella andrusovi</td></tr>
<tr><td colspan="2">Sagenites quinquepunctatus</td><td rowspan="2">Mockina bidentata</td><td>subzone 1</td></tr>
<tr><td colspan="2">Halorites macer</td><td>subzone 2</td></tr>
<tr><td>Alaun.</td><td colspan="2">Mesohimavatites columbianus</td><td colspan="2">Mockina postera</td></tr>
</table>

Sedimentary cycles

Within the general sedimentary trend described above, three high-frequency progradation/retrogradation cycles are recognized in both sections (Fig. 5). The first cycle is less prominent and Late Norian (probably Middle Sevatian) in age. In the Kobla section, maximum progradation is marked by the first coarse-grained beds that occur between 30 and 36 m in the section. It is followed by retrogradation documented in the following succession, which is composed almost exclusively of hemipelagic limestone. In the Slatnik section, the first cycle is expressed in the corresponding coarse-grained limestone beds that still occur within the Bača Dolomite (in the Slatnik section, the boundary between the Bača Dolomite and the Slatnik Formation is younger). Overlying beds are dolomitized and folded but the retrogradation is still recognizable in the diagenetically less altered hemipelagic limestone interval that occurs 2 m below the thrust.

The second cycle of Early Rhaetian age is the most distinctive. In the Kobla section, the progradation begins with coarse-grained beds that start to occur above 70 m in the section. The maximum progradation is marked by the first thick limestone conglomerate bed at 80 m in the section. This bed is overlain by the 2 m of hemipelagic limestone recording the retrogradation. In the Slatnik section the progradation is visible from the upward coarsening and thickening trend above the thrust. The channelized beds that start to occur above 44 m in the section also indicate the slope progradation. The maximum progradation is expressed as channelized limestone conglomerate beds overlain by a slide (45–57 m in the section). The retrogradation is observed in the following 5 m, where even-bedded and generally less coarse-grained beds prevail. The maximum retrogradation lies within an interval of thin-bedded, fine-grained calcarenites at around 62 m in the section. It could also be located just above the slide (52 m in the section).

The third cycle is Late Rhaetian to earliest Hettangian in age. In the Kobla section, the progradation is observed in the coarsening and thickening upward trend that starts at 85 m in the section. The maximum progradation is recognized at the top of the second (and last) thick limestone conglomerate bed (93 m in the section). Above this bed, coarse-grained beds become thinner and rarer, indicating a retrogradation. The third progradation in the Slatnik section is disrupted by the fault. It is still evident due to the much thicker and more coarse-grained beds across the fault. The maximum progradation is placed above the last thick limestone conglomerate bed (63 m in the section). The following retrogradation is expressed in the fining and thinning trend observed until 80 m in the section.

In both sections, the Slatnik Formation ends with thin-bedded hemipelagic limestone that marks a sudden change in sedimentary conditions. In the Slatnik section, it is especially abrupt. In the Kobla section, recording a more distal setting, the change appears more gradual, especially due to two limestone conglomerate beds that lie within the thin-bedded hemipelagic limestone succession. It is probably latest Rhaetian/earliest Hettangian in age.

Triassic–Jurassic boundary

According to the conodont dating, the Triassic-Jurassic boundary can be recognized in the distinct horizon of thin-bedded hemipelagic limestone in the uppermost part of the Slatnik Formation. This is the first well-exposed boundary section in the Slovenian Basin. The horizon records a cessation of the carbonate input from the Julian Carbonate Platform, probably related to palaeoenvironmental stress as evidenced by reduced fossil diversity and bed thickness accompanied by increased terrigenous input. Rhaetian clay-rich sediments are well known in the western Southern Alps (Jadoul et al. 2007), Transdanubian Range (Haas 2002), Northern Calcareous Alps (Gawlick 2000) and Western Carpathians (Michalík 2004). Simultaneously, in the intraplatform Slovenian Basin the succession is devoid of terrigenous material until the latest Rhaetian because it was previously diluted by high carbonate input from the platform areas.

To elucidate the possible factors that led to the described change, a comparison is made with numerous recent studies focused on the Triassic–Jurassic boundary. The boundary records one of the five major extinction events of the Phanerozoic (Stanton Jr and Flügel 1987; Sepkoski Jr 1996; Hallam and Wignall 1997, 1999; Hallam 2002; Tanner et al. 2004). Although the mechanisms that led to the extinction are still debated, two processes that mark the boundary are common to all studied sections: (1) the biocalcification crisis at the end of the Triassic followed by recovery in the Hettangian (Pálfy et al. 2001, 2007; Ward et al. 2001, 2004; Galli et al. 2005, 2007; Ciarapica and Passeri 2005; Ciarapica 2007; Van de Schootbrugge et al. 2007) and (2) a sea-level drop coupled with subsequent transgression at the boundary or slightly preceding it. The second event is reported globally (McRoberts et al. 1997; Hallam 1997; Hesselbo et al. 2002, 2004; Guex et al. 2004; Galli et al. 2005; Ciarapica and Passeri 2005; Jadoul et al. 2005, 2007; Krystyn et al. 2005; Ciarapica 2007; Wignall et al. 2007).

Both processes can explain the cessation of carbonate input from the Julian Carbonate Platform to the Slovenian Basin, but it is more likely that the end-Triassic biocalcification crisis had a prevailing effect. It led to the demise of coral reefs on the platform margin and probably reduced the overall production (and consequent shedding) of the carbonate material, as reflected in the reduced bed thickness of the hemipelagic limestone in the topmost Slatnik Formation. Additionally, it is recorded in the reduced fossil diversity in these beds. The overlying resedimented limestones of the Krikov Formation (ooidal/peloidal limestone and limestone conglomerate) correlate with the reestablishment of the productive Julian Carbonate Platform in the Early Jurassic, characterized by extensively diversified sedimentation from the end of the Triassic, especially on the platform margin.

Alternatively, if the sea-level fall was rapid (cf. Hallam 1997, 2001), it would have caused a subaerial exposure of the reef-dominated platform margin and drastically reduced the carbonate production. Although the Triassic–Jurassic boundary on the platform has not yet been studied in detail, it is generally considered to be concordant. It is placed below the first occurrence of ooidal limestone beds that overlie the Dachstein Limestone, whereas no evidence of subaerial exposure is reported (Buser 1986; Jurkovšek et al. 1990). Therefore, it seems less probable that the rapid sea-level fall caused the observed sedimentary change in the Slatnik Formation. Furthermore, in the studied successions of the western Southern Alps and Hungary, the Triassic–Jurassic boundary falls within the succession that records a transgressive trend (Pálfy et al. 2001, 2007; Galli et al. 2005, 2007). Similarly, in the Slatnik Formation, the boundary most probably lies within the uppermost retrogradation interval.

Correlation

The Norian–Rhaetian succession of the Slovenian Basin is correlated with the basinal formations of the Dinarides, the Southern Alps, the Transdanubian Range, and the Northern Calcareous Alps (Fig. 10). Due to the close correspondence of the Northern Calcareous Alps and Western Carpathian successions (Michalík 1993, 2004; Mandl 2000), the latter are not presented in the figure.

The Norian–Rhaetian succession of the Slovenian Basin is characterized by carbonates of Bača Dolomite and in the northern part of the basin by the Late Norian to Rhaetian Slatnik Formation. It differs from the successions of the inner, i.e., approximately western to north-western, part of the discussed Neo-Tethyan passive margin (Figs. 1, 10). In all correlated units, the Early to Middle Norian inner Neo-Tethyan passive margin is characterized by sedimentation

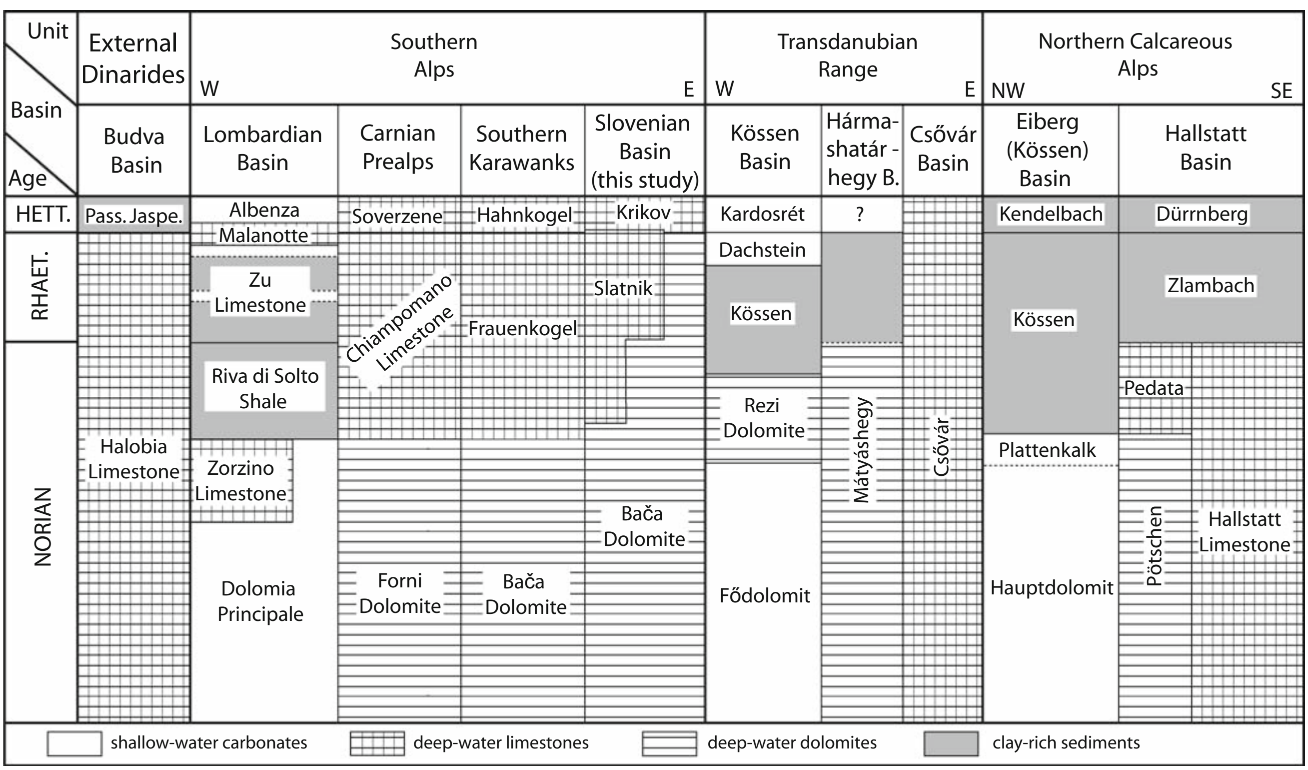


Fig. 10 Correlation of Norian–Hettangian Triassic basinal formations of the western Neo-Tethys compiled from Budva Basin: Cafiero and Di Capoa Bonardi (1980); Goričan (1994), Lombardian Basin: Jadoul et al. (1994, 2007); Galli et al. (2007), Carnian Prealps: Cozzi (2002); Cozzi and Podda (1998), Southern Karawanks (Karawanken) Mountains: Krystyn et al. (1994); Lein et al. (1995); Ogorelec et al. (1999); Kolar-Jurkovšek et al. (2005), Slovenian Basin: Cousin (1973, 1981); Buser (1987, 1996; this paper), Transdanubian Range: Haas (2002); Haas and Budai (1999); Haas and Tardy-Filácz (2004), Northern Calcareous Alps: Mandl (2000); Gawlick (2000); Gawlick and Böhm (2000); Gawlick et al. (2001); Krystyn et al. (2005)

of shallow-water Main Dolomite. The origination of basins is marked by thin-bedded carbonates that were replaced in the Late Norian and Rhaetian by formations rich in the terrigenous input. In the Northern Calcareous Alps these successions remain relatively shallow until the Late Rhaetian (Krystyn et al. 2005). The succession of the Slovenian Basin also differs from that of the Hallstatt Basin located in the outer Neo-Tethyan passive margin (preserved mainly in the Northern Calcareous Alps and Western Carpathians), which is characterized by the often condensed limestones of the Hallstatt Formation. It correlates better with the Norian Pötschen and Pedata Formations that formed proximal to the Dachstein Platform. The Rhaetian of the entire Hallstatt Basin is typified by the marly Zlambach Formation and thus different from the carbonate succession of the Slovenian Basin.

The Norian–Rhaetian of the Slovenian Basin correlates well with the intraplatform basins of the Neo-Tethyan passive margin (Fig. 10). These basins are dominated by the carbonates, whereas terrigenous material occurs only sporadically. The Budva and Csővár basins are dominated by limestones throughout the Norian–Rhaetian. Simultaneously, other basinal successions begin with dolomite-rich successions and pass upward in limestone-dominated formations. The Rhaetian part of the Mátyáshegy Formation contains a higher terrigenous content. It is therefore akin to the Zlambach Formation and differs from the Slatnik Formation.

The Slovenian Basin correlates best with the intraplatform basins of the eastern Southern Alps, i.e., basins of Carnian Prealps and basinal succession of Klek/Hahnkogel Unit in the Southern Karavanke (Karawanken) Mountains. In order to explain a possible palaeogeographic connection between the tectonically isolated, small Klek/Hahnkogel Unit and the Slovenian Basin, Krystyn et al. (1994) introduced a tectonic nappe concept. The concept proposed extensive lateral displacements of the Slovenian Basin and was later supported by an elevated CAI (Conodont Colour Alteration Index) in the Tolmin Nappe (Slovenian Basin) in contrast to surrounding tectonic units, i.e., the Julian Nappe (Julian Carbonate Platform) and the External Dinarides (Dinaric Carbonate Platform) (Krystyn et al. 1999). Our CAI data coincide with previously established elevated values, but the sedimentary facts argue against the proposed connection. Two major differences exist between the Frauenkogel (Baba/Frauenkogel in Ogorelec et al. 1999) and Slatnik formations: (1) in the lower part of the Frauenkogel Formation, three very thick (up to 31 m) mass-flow breccias characterize the succession, whereas the coeval part of the Slatnik Formation is completely devoid of such deposits and (2) the Rhaetian part of the Frauenkogel Formation consists of fine-grained limestones, whereas in the Slatnik Formation coarse-grained limestones typify the succession. Furthermore, the facies association of the Slatnik Formation indicates the closest palaeogeographic proximity of the Julian Carbonate Platform although today the successions belong to the tectonic units with different CAI values. We conclude that the potential palaeogeographic connection of the Klek/Hahnkogel Unit with the Slovenian Basin remains questionable.

Discussion

Two major sedimentary changes are recorded in the Late Norian–Rhaetian Slatnik Formation that characterize the evolution of the northern Slovenian Basin: (1) the progradation of slope environments, which reached its maximum in the Early Rhaetian and was followed by less distinctive retrogradation and (2) a sudden cessation of resedimentation of the coarse and probably also the fine carbonate material in the latest Triassic.

The Middle to Late Norian period in the western Neo-Tethyan passive margin is characterized by intensified tectonic subsidence. It is recorded by the formation of basins in the inner part of the passive margin (Michalík 1993; Haas 2002; Jadoul et al. 2007). Additionally, in the Transdanubian Range, the intraplatform Fekete-hegy Basin formed, probably during the Middle Norian (Haas 2002). In the Hallstatt Basin, the Late Norian tectonics is indicated by breccia and increased subsidence (Gawlick 2000; Gawlick and Böhm 2000). In the Northern Calcareous Alps, the impact of extensional tectonics is additionally evidenced by syn-sedimentary folds and slumps in the basin-margin Seefeld Beds, which otherwise mark regional transgressive event (Satterley and Brander 1995, Gawlick and Böhm 2000). In the Carnian Prealps, accelerated subsidence is reflected in the upward change from a prograding to an aggrading platform margin (Cozzi and Podda 1998; Cozzi 2002). The thick mass-flow breccias are reported in the Bača and Frauenkogel formations in the Southern Karavanke (Karawanken) mountains (Krystyn et al. 1994; Lein et al. 1995).

Although the impact of intensified tectonic activity is manifested all across the western Neo-Tethyan passive margin, it is not reflected in the studied sections of the Slatnik Formation (Fig. 3). The coarse-grained beds and minor slump are related to the first, less distinct progradation of the Julian Carbonate Platform. This event coincides with the development of highly productive reefs (dated as Late Norian–Rhaetian; Turnšek and Buser 1991; Turnšek 1997) on the platform margin that most probably enhanced the progradation rate. The Late Norian progradation of carbonate platforms is reported also from the Csővár Basin (Haas and Budai 1999; Haas 2002) and the Northern Calcareous Alps (Reijmer et al. 1991; Krystyn and Lein 1996; Gawlick

2000). Nevertheless, the impact of Late Norian tectonic activity on the Slovenian Basin is not excluded because: (1) in other parts of the basin, intraformational breccias and slumps occur in the upper part of the Bača Dolomite (Rožič 2006), but these successions lack precise chronostratigraphic dating and (2) progradations in the Northern Calcareous Alps and Transdanubian Range are reported until the latest Norian (Reijmer et al. 1991; Haas 2002). In contrast, in the eastern Southern Alps the progradation ceased earlier (Cozzi 2002; this paper), which is probably a consequence of the accelerated subsidence.

The Early Rhaetian is characterized by rather heterogeneous sedimentary conditions in different parts of the western Neo-Tethyan passive margin. In the Slatnik Formation, the most prominent progradation marks the Early Rhaetian. Coarse-grained limestone conglomerate beds mark the maximum progradation and record the sea-level lowstand (cf. Bosellini 1984, 1989; Masetti et al. 1991, Spence and Tucker 1997; Reijmer 1998). This event correlates with the sea-level lowstand recorded in the Lombardian Basin (Gaetani et al. 1998; Jadoul et al. 2007) and/or the Transdanubian Range (Haas 2002; Haas and Tardy-Filácz 2004). According to Haas and Budai (1999), the Early Rhaetian lowstand event is younger in the Lombardian Basin than in the Transdanubian Range. The maximum progradation observed in the Slatnik Formation more likely coincides with the sea-level lowstand of the Lombardian Basin. In the Northern Calcareous Alps a major retrogradation of the platform is reported on the Norian/Rhaetian boundary. It is related to the widest spreading of the clay-rich Kössen and Zlambach formations (Gawlick 2000). The described differences indicate regional tectonics to be an important factor governing the Early Rhaetian relative sea-level fluctuations in different parts of the western Neo-Tethyan passive margin. It was combined with a more humid climate, which resulted in the increased terrigenous input.

The Late Rhaetian in the whole western Neo-Tethyan Realm is marked by the progradation of the platforms (Haas and Budai 1999; Gawlick 2000; Jadoul et al. 2007). This event is also recorded in the upper part of the Slatnik Formation. Maximum progradation is once more marked by thick, coarse-grained limestone conglomerate beds. It records the sea-level fall that occurs at the Triassic–Jurassic boundary or slightly precedes it (Haas and Budai 1999; Hesselbo et al. 2004; Galli et al. 2005; von Hillebrandt et al. 2007; Ciarapica 2007). The event is reported globally, but coinciding tectonic activity is well manifested. For example, in the Northern Calcareous Alps, the sea-level lowstand is amplified by the tectonic uplift (Krystyn et al. 2005), whereas simultaneously it is not reported in the Csővár Basin; i.e., it is masked by accelerated subsidence (Haas 2002). In the whole realm the disintegration and partial drowning of the large carbonate platforms occurred at this time (Michalík 1993; Mandl 2000; Clari and Masetti 2002; Haas and Tardy-Filácz 2004).

The Rhaetian sedimentary cycles of the Slatnik Formation are herein explained as a consequence of the relative sea-level fluctuations induced by regional tectonic events. The impact of the Rhaetian tectonics is evidenced by large reef boulders that occur in the limestone conglomerates of the Slatnik Formation and most probably originated in tectonically triggered collapses of the Julian Carbonate Platform margin. Continuous Late Triassic tectonic activity is also well manifested in the close-situated Carnian Prealps (Carulli et al. 1998).

Intense, climate-induced terrigenous influx characterizes the Late Norian and especially Rhaetian successions of the inner as well as the external Neo-Tethyan passive margin (Jadoul et al. 1994, 2007; Gawlick 2000; Mandl 2000; Haas 2002; Michalík 2004; Krystyn et al. 2005). In the Slatnik Formation, elevated terrigenous content is not observed because it was diluted by high carbonate input from the surrounding platforms. Similarly, the terrigenous content is present only sporadically in other intraplatform basins (Goričan 1994; Krystyn et al. 1994; Cozzi 2002; Haas 2002). The marl-rich interval in the Slatnik Formation is observed only within thin-bedded hemipelagic limestone on the topmost part of the formation in the Slatnik section. As discussed above, this distinct interval probably contains the Triassic–Jurassic boundary. The relative increase in terrigenous material is directly related to the cessation of the carbonate input from the adjacent platform that was caused by the biocalcification crisis and/or sea-level fall that characterize the Triassic–Jurassic boundary (Hallam 1997; McRoberts et al. 1997; Pálfy et al. 2001; Galli et al. 2005; Krystyn et al. 2005; and many others).

Conclusions

The Norian–Rhaetian succession of the Slovenian Basin is characterized mainly by Bača Dolomite, i.e., bedded dolomite with chert nodules. The exception is the Late Norian and Rhaetian limestone succession in the northern part of the basin, proximal to the Julian Carbonate Platform. This succession was studied in two sections and is formalized in this paper as the Slatnik Formation. In the type locality (the Kobla section) the formation is composed predominantly of hemipelagic limestone alternating in the upper part with resedimented limestones, i.e., calcarenites and limestone conglomerate beds. In the second locality (the Slatnik section), coarser beds prevail due to deposition in a more proximal sedimentary environment. In both sections, a slope progradation trend is recorded: (1) in the Kobla section, in a change from the basin plain to the lower outer apron and (2) in the Slatnik section, from the inner apron to the lower slope. This general trend is superimposed by three progradation/retrogradation cycles. The first cycle is Late Norian and less prominent. It correlates with platform progradations from the eastern Southern Alps, eastern Transdanubian Range, and Northern Calcareous Alps. The second cycle contributes the main sedimentary change and records the Early Rhaetian lowstand. Poor correlation within other units of the Neo-Tethyan passive margin indicates that variable tectonic activity had a prominent effect on the regional relative sea-level fluctuations. The third cycle records the globally reported Late Rhaetian sea-level lowstand. The Slatnik Formation ends with a few-meters-thick horizon of thin-bedded hemipelagic limestone punctuated in a more proximal depositional setting with marl interlayers. This distinct horizon records the end-Triassic productivity crisis or regionally reported rapid sea-level fall. The overlying resedimented limestones, mostly ooidal/peloidal calcarenites of the Krikov Formation, document the Early Jurassic recovery of carbonate production on the Julian Carbonate Platform.

Acknowledgements This study was financed by the Slovenian Research Agency. Rajka Radoičić is sincerely thanked for the determination of foraminifers and Dragica Turnšek for sponges and corals. Stanko Buser, Špela Goričan, Jernej Pavšič and Dragomir Skaberne are acknowledged for numerous consultations and support. Mirč Udovč and Kata Cvetko are thanked for the preparation of thin sections. Petra Žvab, Nina Rman, Nastja Rogan and Mojca Kavčič are thanked for assistance during the geological mapping. Boštjan Bradaškja and Damjan Ulamec are thanked for the help on the fieldwork. Marija Petrović and Stane Zakrajšek are thanked for technical assistance.

References

Bosellini A (1984) Progradation geometries of carbonate platforms: examples from the Triassic of the Dolomites, Italy. Sedimentology 31:1–24. doi:10.1111/j.1365-3091.1984.tb00720.x

Bosellini A (1989) Dynamics of Tethyan carbonate platforms, vol 44. Special Publications. SEPM, Tulsa, pp 3–4

Buser S (1986) Tolmač k Osnovni geološki karti SFRJ 1: 100 000 lista Tolmin in Videm (Udine). Zvezni geološki zavod, Beograd, 103 pp

Buser S (1987) Osnovna geološka karta SFRJ 1: 100 000, list Tolmin. Zvezni geološki zavod, Beograd

Buser S (1989) Development of the Dinaric and Julian carbonate platforms and the intermediate Slovenian Basin (NW-Yugoslavia). In: Carulli GB, Cucchi F, Radrizzani CP (eds) Evolution of the Karstic carbonate platform: relation with other periadriatic carbonate platforms. Mem Soc Geol Ital 40(1987):313–320

Buser S (1996) Geology of western Slovenia and its paleogeographic evolution. In: Drobne K, Goričan Š, Kotnik B (eds) The role of impact processes in the geological and biological evolution of planet earth. International workshop, ZRC SAZU, Ljubljana, pp 111–123

Buser S, Kolar-Jurkovšek T, Jurkovšek B (2008) Slovenian Basin during Triassic in the light of conodont data. Boll Soc Geol Ital 127:257–263

Cafiero B, Di Capoa Bonardi P (1980) Stratigraphy of the pelagic Triassic in the Budva-Kotor area (Crna Gora, Montenegro Yugoslavia). Boll Soc Paleont Ital 19:179–204

Čar J (1990) Kotna tektonsko—erozijska diskordanca v rudiščnem delu srednjetriasne tektonske zgradbe. Geologija 31/32:267–284

Carulli GB, Cozzi A, Longo Salvador G, Ponton M, Podda F (1998) Evidence of sedimentary tectonic activity during the Norian-Lias (Carnian Prealps, northern Italy). Mem Soc Geol Ital 53:403–415

Celarc B, Ogorelec B (2006) The progradation of the Carnian–Norian carbonate platform in the Martuljek Mountain Group (Julian Alps, Slovenia). In: Režun B (ed) 2. Slovenski geološki kongres, Idrija, 26.-28. September 2006. Zbornik povzetkov. Idrija: Rudnik živega srebra v zapiranju, pp 42–43

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

Ciarapica G (2007) Regional and global changes around the Triassic–Jurassic boundary reflected in the late Norian–Hettangian history of the Apennine basins. Palaeogeogr Palaeoclimatol Palaeoecol 244:34–51. doi:10.1016/j.palaeo.2006.06.022

Ciarapica G, Passeri L (2005) Late Triassic and Early Jurassic sedimentary evolution of the Northern Apennines: an overview. Boll Soc Geol Ital 124:189–201

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, Palermo, pp 271–315

Cousin M (1973) Le sillon slovene: les formations triasiques, jurassiques et neocomiennes au Nord-Est de Tolmin (Slovenie occ., Alpes mer.) et leurs affinites dinariques. Bull Soc Geol Fr 7(XV):326–339

Cousin M (1981) Les repports Alpes—Dinarides. Les confins de I'Italie et de la Yougoslavie. Soc Geol Nord 5:1–519

Cozzi A (2002) Facies patterns of a tectonically-controlled Upper Triassic platform–slope carbonate depositional system (Carnian Prealps, northeastern Italy). Facies 47:151–178. doi:10.1007/BF02667711

Cozzi A, Podda F (1998) A platform to basin transition in the Dolomia Principale of the M. Pramaggiore area, Carnian Prealps, northern Italy. Mem Soc Geol Ital 53:387–402

Epstein AG, Epstein JB, Harris LD (1977) Conodont Color Alteration—an index to organic metamorphism. US Geological Survey of Professional Paper, vol 995, pp 1–27

Gaetani M, Gnaccolini M, Jadoul F, Garzanti E (1998) Multiorder sequence stratigraphy in the Triassic system of the western Southern Alps. In: Graciansky P, Hardenbol J, Jacquin T, Vail PR (eds) Mesozoic and Cenozoic Sequence stratigraphy of European Basins, vol 6. Special Publications. SEPM, Tulsa, pp 70–717

Galli MT, Jadoul F, Bernasconi SM, Weissert H (2005) Anomalies in global carbon cycling and extinction at the Triassic/Jurassic boundary: evidence from a marine C-isotope record. Palaeogeogr Palaeoclimatol Palaeoecol 216:203–214. doi:10.1016/j.palaeo.2004.11.009

Galli MT, Jadoul F, Bernasconi SM, Cirilli S, Weissert H (2007) Stratigraphy and palaeoenvironmental analysis of the Triassic–Jurassic transition in the western Southern Alps (Northern Italy). Palaeogeogr Palaeoclimatol Palaeoecol 244:52–70. doi:10.1016/j.palaeo.2006.06.023

Gawlick HJ (2000) Paläogeographie der Ober-Trias Karbonatplattform in den Nördlichen Kalkalpen. Mitt Ges Geol Burgbaustud Osterr 44:45–95

Gawlick HJ, Böhm F (2000) Sequence and isotope stratigraphy of Late Triassic distal periplatform limestones from the Northern Calcareous Alps (Kälberstein Quarry, Berchtesgaden Hallstatt Zone). Int J Earth Sci 89:108–129. doi:10.1007/s005310050320

Gawlick HJ, Suzuki H, Missoni S (2001) Nachweis von unterliassischen Beckensedimenten in Hallstätter Fazies (Dürrnberg-Formation) im

Bereich der Hallein—Berchtesgadener Hallstätter Zone und dea Lammer Beckens (Hettangium-Sinemurium). Mitt Ges Geol Burgbaustud Osterr 45:39–55

Goričan Š (1994) Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budva Zone (Dinarides, Montenegro). Mem Geol 18:1–177

Guex J, Bartolini A, Atuderoi V, Taylor D (2004) High-resolution ammonite and carbon isotope stratigraphy across the Triassic–Jurassic boundary at New York Canyon (Nevada). Earth Planet Sci Lett 225:29–41. doi:10.1016/j.epsl.2004.06.006

Haas J (2002) Origin and evolution of Late Triassic backplatform and intraplatform basins in the Transdanubian range, Hungary. Geol Carpathica 53:159–178

Haas J, Budai T (1999) Triassic sequence stratigraphy of the Transdanubian range (Hungary). Geol Carpathica 50:459–475

Haas J, Tardy-Filácz E (2004) Facies changes in the Triassic–Jurassic boundary interval in an intraplatform basin succession in Csővár (Transdanubian Range, Hungary). Sediment Geol 168:19–48. doi:10.1016/j.sedgeo.2004.03.002

Hallam A (1997) Estimates of the amount and rate of sea-level changes in across the Rhaetian–Hettangian and Pliensbachian–Toarcian boundaries (latest Triassic to early Jurassic). J Geol Soc London 154:773–779. doi:10.1144/gsjgs.154.5.0773

Hallam A (2001) A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. Palaeogeogr Palaeoclimatol Palaeoecol 167:23–37. doi:10.1016/S0031-0182(00)00229-7

Hallam A (2002) How catastrophic was the end-Triassic mass extinction? Lethaia 35:147–157. doi:10.1080/002411602320184006

Hallam A, Wignall PB (1997) Mass extinctions and their aftermath. Oxford University Press, Oxford, 318 pp

Hallam A, Wignall PB (1999) Mass extinction and sea-level changes. Earth Sci Rev 48:217–258. doi:10.1016/S0012-8252(99)00055-0

Hesselbo SP, Robinson SA, Surlyk F, Piasecki S (2002) Terrestrial and marine extinction at the Triassic–Jurassic boundary synchronized with major carbon-cycle perturbation: a link to initiation of massive volcanism? Geology 30:251–254. doi:10.1130/0091-7613(2002)030<0251:TAMEAT>2.0.CO;2

Hesselbo S, Robinson SA, Surlyk F (2004) Sea-level change and facies development across potential Triassic–Jurassic boundary horizons, SW Britain. J Geol Soc London 161:365–379

von Hillebrandt A, Krystyn L, Kuerschner WM (2007) A candidate GSSP for the base of Jurassic in the Northern Calcareous Alps (Kuhjock section, Karwendel Mountains, Tyrol, Austria). ISJS Newsl 34:2–20

Jadoul F, Masetti D, Cirilli S, Berra F, Claps M, Frisia S (1994) Norian-Rhaetian stratigraphy and paleogeographic evolution of the Lombardy Basin (Bergamasc Alps): excursion B1, 15th IAS Regional Meeting, pp 5–38

Jadoul F, Galli MT, Calabrese L, Gnaccolini M (2005) Stratigraphy of Rhaetian to lower Sinemurian carbonate platforms in western Lombardy (Southern Alps, Italy): paleogeographic implications. Riv Ital Paleont Strat 111:285–303

Jadoul F, Galli MT, Muttoni G, Rigo M, Cirilli S (2007) The late Norian–Hettangian stratigraphic and paleographic evolution of the Bergamasc Alps. Geoitalia 2007, Pre-Congress Field Trip Guide Book-FW02, Rimini, pp 1–33

Jurkovšek B, Šribar L, Ogorelec B, Jurkovšek-Kolar T (1990) Pelagic Jurassic and Cretaceous beds in the western part of the Julian Alps. Geologija 31/32:285–328

Kastelic V, Vrabec M, Cunningham D, Gosar A (2008) Neo-Alpine structural evolution and present-day tectonic activity of the eastern Southern Alps: the case of the Ravne Fault, NW Slovenia. J Struct Geol 30:963–975. doi:10.1016/j.jsg.2008.03.009

Kolar-Jurkovšek T (1982) Konodonti iz amfiklinskih skladov in baškega dolomita. Geologija 25:167–188

Kolar-Jurkovšek T, Buser S, Jurkovšek B (1983) Zgornjetriasne plasti zahodnega dela Pokljuke. Rudarsko metalurški zbornik 30:151–185

Kolar-Jurkovšek T, Gaździcki A, Jurkovšek B (2005) Conodonts and foraminifera from the “Raibl Beds” (Carnian) of the Karavanke Mountains, Slovenia: stratigraphical and palaeobiological implications. Geol Q 49:429–438

Kossmat F (1907) Geologie des Wocheiner Tunnels und der südlichen Anschlusslinie. Denkschr Math Nat Kl 1, 83:6–140

Kozur HW (2003) Integrated ammonoid, conodont and radiolarian zonation of the Triassic. Hallesches Jb Geowiss B25:49–79

Kozur H, Mock R (1991) New Middle Carnian and Rhaetian conodonts from Hungary and the Alps. Stratigraphic importance and tectonic implications for the Buda mountains and adjacent areas. Jb Geol B-A 134:271–297

Krystyn L (1987) Zur Rhät-Stratigraphie in den Zlambach-Schichten (vorläufiger Bericht). Sitz Ber Akad Wiss Wien Math Nat Kl 196:21–36

Krystyn L (1991) A Rhaetian Stage—Chronostratigraphy, subdivisions and their intercontinental correlation. Albertiana 8:15–24

Krystyn L, Lein R, Schlaf J, Bauer FK (1994) Über ein neues obertriadisch-jurassisches Intraplattformbecken in den Südkarawanken. Jubiläumsschrift 20 Jahre Geologische Zusammenarbeit Österreich-Ungarn Teil 2:409–416

Krystyn L, Lein R (1996) Triassische Becken und Plattformsedimente der östlichen Kalkalpen. Ber Geol BA Wien 33:1–23

Krystyn L, Gawlick HJ, Lein R (1999) CAI patterns of Slovenia—implications for the tectonic history. Tubinger Geowiss Arbeiten A52:161–162

Krystyn L, Böhm F, Kürschner W, Delecat S (2005) The Triassic–Jurassic boundary in the Northern Calcareous Alps. 5th Field workshop IGCP 458, Field Guide A1-A14

Krystyn L, Bouquerel H, Kuerschner W, Richoz S, Gallet Y (2007) Proposal for a candidate GSSP for the base of the Rhaetian Stage. N M Mus Nat Hist Sci Bull 41:189–199

Lein R, Schaf J, Müller PJ, Krystyn L, Jesinger D (1995) Neue Daten zur Geologie des Karawanken-Straßentunnels. Geol Palaont Mitt Innsbruck 20:371–387

Mandl GW (2000) The Alpine sector of the Tethyan shelf—examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps. Mitt Osterr Geol Ges 92:61–77

Masetti D, Neri C, Bosellini A (1991) Deep-water asymmetric cycles and progradation of carbonate platforms governed by high-frequency eustatic oscillations (Triassic of the Dolomites, Italy). Geology 19:401–424. doi :10.1130/0091-7613(1991)019<0336:DWACAP>2.3.CO;2

McRoberts CA, Furrer H, Jones DS (1997) Palaeoenvironmental interpretation of a Triassic–Jurassic boundary section from Western Austria based on palaeoecological and geochemical data. Palaeogeogr Palaeoclimatol Palaeoecol 136:79–95. doi:10.1016/S0031-0182(97)00074-6

Michalík J (1993) Mesozoic tensional basins in the Alpine–Carpathian shelf. Acta Geol Hung 36:395–403

Michalík (2004) (ed) IGCP 458: Triassic/Jurassic boundary event. Third field workshop Stará Lesná, Slovakia. Veda, Bratislava, pp 1–72

Mullins HT, Cook HE (1986) Carbonate apron models: Alternatives to the submarine fan model for paleoenvironmental analysis and hydrocarbon exploration. Sediment Geol 48:37–79. doi:10.1016/0037-0738(86)90080-1

Ogorelec B, Rothe P (1993) Mikrofazies, Diagenese und Geochemie des Dachsteinkalkes und Hauptdolomits in Süd-West Slowenien. Geologija 35:81–182

Ogorelec B, Orehek S, Budkovič T (1999) Lithostratigraphy of the Slovenian Part of Karavanke Road Tunnel. Abh Geol B-A 56:99–112

Pálfy J, Demény A, Haas J, Hetényi M, Orchard MJ, Vető I (2001) Carbon isotope anomaly and other geochemical changes at the Triassic–Jurassic boundary from a marine section in Hungary. Geology 29:1047–1050. doi:10.1130/0091-7613(2001)029<1047:CIAAOG>2.0.CO;2

Pálfy J, Demény A, Haas J, Carter ES, Görög A, Halász D, Oravecz-Scheffer A, Hetényi M, Márton E, Orchard MJ, Ozsvárt P, Vető I, Zajzon N (2007) Triassic–Jurassic boundary events inferred from integrated stratigraphy of the Csővár section, Hungary. Palaeogeogr Palaeoclimatol Palaeoecol 244:11–33. doi:10.1016/j.palaeo.2006.06.021

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

Reijmer JJG (1998) Compositional variations during phases of progradation and retrogradation of Triassic carbonate platform (Picco do Vallandro/Dürrenstein, Dolomites, Italy). Geol Rundsch 87:436–448

Reijmer JJG, Ten Kate WGHZ, Sprenger A, Schlager W (1991) Calciturbidite composition related to exposure and flooding of a carbonate platform (Triassic, Eastern Alps). Sedimentology 38:1059–1074. doi:10.1111/j.1365-3091.1991.tb00371.x

Rožič B (2006) Sedimentology, stratigraphy and geochemistry of Jurassic rocks in the western part of the Slovenian Basin. Ph.D. thesis, University of Ljubljana, 148 pp

Rožič B (2008) Upper Triassic and Lower Jurassic limestones from Mt. Kobla in the northern Tolmin Basin: tectonically repeated or continuous succession? RMZ Mater Geoenviron 55:345–362

Satterley AK, Brander R (1995) The genesis of Lofer cycles of the Dachstein Limestone, Northern Calcareous Alps, Austria. Geol Rundsch 84:287–292. doi:10.1007/s005310050006

Schäfer P (1979) Fazielle Entwicklung und palökologische Zonierung zweier obertriadischer Riffstrukturen in den Nördlichen Kalkalpen ("Oberrhät"-Riffkalke, Salzburg). Facies 1:3–245. doi:10.1007/BF02536461

Scheibner C, Kuss J, Marzouk AM (2000) Slope sediments of Paleocene ramp-to-basin transition in NW Egypt. Int J Earth Sci 88:708–724. doi:10.1007/s005310050299

Senowbari-Daryan B (1980) Fazielle und paläontologische Untersuchungen in oberrhätischen Riffen (Feichtenstein- und Gruberriff bei Hintersee, Salzburg, Nördliche Kalkalpen). Facies 3:1–237. doi:10.1007/BF02536456

Senowbari-Daryan B, Schäfer P, Abate B (1982) Obertriadische Riffe und Rifforganismen in Sizilien (Beiträge zur Paläontologie und Mikrofazies obertriadischer Riffe im alpin-mediterranen Raum, 27). Facies 6:165–184. doi:10.1007/BF02536684

Sepkoski JJ Jr (1996) Patterns of the Phanerozoic extinction: a perspective from global data bases. In: Walliser OH (ed) Global events and event stratigraphy in the Phanerozoic. Springer, Berlin, pp 35–51

Shanmugam G (2000) 50 years of the turbidite paradigm (1950s–1990s): deep-water processes and facies models—a critical perspective. Mar Pet Geol 17:235–342. doi:10.1016/S0264-8172(99)00011-2

Šmuc A (2005) Jurassic and Cretaceous Stratigraphy and Sedimentary Evolution of the Julian Alps, NW Slovenia. ZRC, ZRC SAZU, Ljubljana, 98 pp

Šmuc A, Čar J (2002) Upper Ladinian to Lower Carnian sedimentary evolution in the Idrija—Cerkno region, Western Slovenia. Facies 46:205–216. doi:10.1007/BF02668081

Spence GH, Tucker ME (1997) Genesis of limestone megabreccias and their significance in carbonate sequence stratigraphic models: a review. Sediment Geol 122:163–193. doi:10.1016/S0037-0738(97)00036-5

Stanton RJ Jr, Flügel E (1987) Paleoecology of Upper Triassic reefs in the Northern Calcareous Alps: reef communities. Facies 16:157–186. doi:10.1007/BF02536751

Tanner LH, Lucas SG, Chapman MG (2004) Assessing the record and causes of Late Triassic extinctions. Earth Sci Rev 65:103–139. doi:10.1016/S0012-8252(03)00082-5

Turnšek D (1997) Mezozoic Corals of Slovenia. ZRC, ZRC SAZU, Ljubljana, 512 pp

Turnšek D, Buser S (1991) Norian–Rhetian coral reef buildups in Bohinj and Rdeči rob in Southern Julian Alps (Slovenia). Razprave IV razreda SAZU 32:215–257

Van de Schootbrugge B, Tremolada F, Rosenthal Y, Bailey TR, Feist-Burkhardt S, Brinkhuis H, Pross J, Kent DV, Falkowski PG (2007) End-Triassic calcification crisis and blooms of organic-walled 'disaster species'. Palaeogeogr Palaeoclimatol Palaeoecol 244:126–141. doi:10.1016/j.palaeo.2006.06.026

Verbovšek T (2008) Diagenetic effects on well yield of dolomite aquifers in Slovenia. Environ Geol 53:1173–1182. doi:10.1007/s00254-007-0707-9

Vlahović I, Tišljar J, Velić I, Matičec D (2005) Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. Palaeogeogr Palaeoclimatol Palaeoecol 220:333–360. doi:10.1016/j.palaeo.2005.01.011

Vrabec M, Fodor L (2006) Late Cenozoic tectonics of Slovenia: structural styles at the Northeastern corner of the Adriatic microplate. In: Pinter N, Grenerczy G, Weber J, Stein S, Medak D (eds) The Adria microplate: GPS geodesy, tectonics and hazards. NATO Science Series, IV, Earth and Environmental Sciences, vol 61, pp 151–168

Ward PD, Haggart JW, Carter ES, Wilbur D, Tipper HW, Evans T (2001) Sudden productivity collapse associated with the Triassic–Jurassic boundary mass extinction. Science 292:1148–1151. doi:10.1126/science.1058574

Ward PD, Garrison GH, Haggart JW, Kring DA, Beattie MJ (2004) Isotopic evidence bearing on Late Triassic extinction events, Queen Charlotte Islands, British Columbia, and implications for the duration and cause of the Triassic/Jurassic mass extinction. Earth Planet Sci Lett 224:589–600. doi:10.1016/j.epsl.2004.04.034

Wignall PB, Zonneveld JP, Newton RJ, Amor K, Sephton MA, Hartley S (2007) The end Triassic mass extinction record of Williston Lake, British Columbia. Palaeogeogr Palaeoclimatol Palaeoecol 253:385–406. doi:10.1016/j.palaeo.2007.06.020