

Integrated Rhaetian foraminiferal and conodont biostratigraphy from the Slovenian Basin, eastern Southern Alps

Luka Gale · Tea Kolar-Jurkovšek · Andrej Šmuc ·
Boštjan Rožič

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Abstract Conodonts and re-deposited shallow-water benthic foraminifera co-occur in the Upper Norian-Rhaetian Slatnik Formation of the Slovenian Basin (Southern Alps). The Mt. Kobla and Mt. Slatnik sections were investigated in order to give the first direct correlation between these two groups. The Norian-Rhaetian boundary (NRB) is placed at the First Appearance Datum of the conodont *Misikella posthernsteini* and is approached with the First Occurrence of the foraminifer *Involutina turgida*. An association of *Trocholina turris* with duostominids is a good marker for the Rhaetian. Careful revision of literature combined with our data culminated in reambulation of stratigraphical ranges for several foraminiferal species. The foraminiferal Triassic-Jurassic boundary (TJB) can be defined with the Last Occurrence of *Galeanella tollmanni*, “*Sigmoilina*” *schaeferae* or duostominids. The absence of the uppermost Rhaetian *Misikella ultima* conodont zone and the close coincidence of foraminiferal and conodont TJB could point to the presence of hiati in the upper part of the Slatnik Formation. Consequently, the exact pattern of disappearance of Late Triassic foraminifera at the boundary could not be observed. It is clear, however, that the foraminiferal assemblage was decimated for reef-dwelling foraminifera, duostominids and most of the platform-

dwelling foraminifera. Biotic changes at the TJB are best explained as a result of a biocalcification crisis.

Keywords Foraminifera · Conodonts · Biostratigraphy · Slovenian Basin · Rhaetian · Triassic-Jurassic boundary

1 Introduction

Fossils present the most common and also the most powerful tool for correlation of different stratigraphic sections. Because not every fossil group is present in each section, it is first necessary to establish the correlation between different fossil groups. This can be done only on the basis of the co-occurrence of two (or more) fossil groups in common sections. The problem arises when different organisms occupy completely different environments and the presence of one group often excludes the presence of the other. This is also the case for the Rhaetian: while correlations among the deep-water biota are well established (e.g. Kozur and Mostler 1973; Kozur and Mock 1991; Carter 1993; Gullo 1996; Sephton et al. 2002; Kozur 2003; Carter and Orchard 2004; Muttoni et al. 2004; Ward et al. 2004; Bertinelli et al. 2005; Krystyn and Kuerschner 2005; Rigo et al. 2005; Gallet et al. 2007; Krystyn et al. 2007a, b; Tanner et al. 2007; Williford et al. 2007; Giordano et al. 2008; McRoberts et al. 2008; Krystyn 2008; Rigo et al. 2008, 2009; Giordano et al. 2010; Muttoni et al. 2010; Lucas 2010a; Hüsing et al. 2011), it is mostly not possible to link shallow water biota with deeper living groups. Shallow water carbonate platforms were widespread during the Late Triassic (e.g. Haas 2004; Vlahović et al. 2005; Golonka 2007; Haas et al. 2007) and their stratigraphy is mostly based on algae and benthic foraminifera (Grgasović 1997; Vachard and Fontaine 1988; Barattolo and Romano

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L. Gale · T. Kolar-Jurkovšek
Geological Survey of Slovenia, Dimičeva ulica 14,
SI-1000 Ljubljana, Slovenia

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

2005; Jadoul et al. 2005; Mancinelli et al. 2005; Velić 2007; Rigaud et al. 2010). To date, these two groups have been correlated only to palynomorphs (Peybernes et al. 1988; Haas et al. 1997) and rarely to groups living in deeper waters, i.e. conodonts or ammonoids (Gaździcki and Michalik 1980). The Norian-Rhaetian boundary (NRB) is presently based on conodonts (Kozur 1996; Orchard and Tozer 1997; Krystyn et al. 2007a, b; Krystyn 2008; McRoberts et al. 2008; Rožič et al. 2009; Giordano et al. 2010; Lucas 2010b) and the lack of correlation with benthic foraminifera or green algae results in limited stratigraphic resolution and dubious placements of the age/stage boundaries within shallow-water depositional systems.

We wish to further pursue the correlation of Rhaetian shallow-water benthic foraminifera from the reef and platform areas with the conodonts. We present data from the Upper Norian–lowermost Jurassic Slatnik Formation from the Mt. Kobla and Mt. Slatnik sections (eastern Southern Alps, western Slovenia). The formations consist of calciturbidites that contain rich, predominantly reef-derived foraminiferal assemblages and hemipelagic limestones with conodonts. Hemipelagites predominate in the Mt. Kobla section, which is the more distal of the two sections, and they are subordinate in the more proximal Mt. Slatnik section (Rožič et al. 2009). Consequently, a more precise conodont stratigraphy is established for the Mt. Kobla section, while the conodont data from the Mt. Slatnik section are more robust, but still provide vital information. Both sections contain rich shallow-water benthic foraminiferal assemblages, but the stratigraphically important species *Triasina hantkeni* and *Involutina turgida* were found only in the Mt. Slatnik section. Integrated biostratigraphy from both sections culminates in the strongly improved conodont resolution given by Rožič et al. (2009) and also introduces a precise biostratigraphical distribution of Foraminifera.

The aims of this paper are:

- to provide the first account of the complete foraminiferal assemblage for the Sevatian to Rhaetian period from the Slovenian Basin;
- to re-evaluate and supplement conodont data from the Mt. Kobla section given by Rožič et al. (2009);
- to make the direct correlation between the conodont Sevatian to Rhaetian biozones with benthic foraminifera from the same sections;
- to discuss a significant change in benthic foraminiferal assemblage at the Triassic–Jurassic boundary.

2 Previous research

Though several papers have shown the precise distribution of foraminiferal species in sections (e.g., Gaździcki 1974,

1983; Oravec-Scheffer 1987), there are few correlations with other groups. Peybernes et al. (1988) and Haas et al. (1997) showed the distribution of palynomorphs parallel to foraminifera. The section by Haas et al. (1997) includes the NRB, but control with sporomorphs was not possible across this boundary. Gaździcki and Michalik (1980) found conodonts and ammonoids, as well as some shallow water biota, in the same section as foraminifera, but their sections comprise only the Rhaetian. Pálffy et al. (2007) and Haas et al. (2010) used the Last Occurrence (LO) of Triassic foraminifera as one of the proxies for the TJB but did not give detailed information on the distribution of species. Bertinelli et al. (2005) and Galli et al. (2005) instead provided a full list of taxa from near the TJB in the Lagonegro Basin, but foraminifera were grouped into a single assemblage and their bed-by-bed occurrence is not known. Michalík et al. (2007) used foraminifera to locate the TJB in the Zliechov Basin in the Western Carpathians. Although their assemblage has low diversity (only nine genera) due to the restricted environment, they made an important step towards the correlation with deep-water sections by drawing a carbon isotopic curve alongside the foraminiferal distribution. Hillebrandt (2008) traced foraminifera across the TJB in the Kuhjoch section with well-known ammonoid, palynomorph and isotopic data, but unfortunately, only the families Oberhauserellidae and Duostominidae are present in the section.

3 Geological setting

The Mt. Kobla and Mt. Slatnik sections are located in the eastern part of the Bohinj Range in the Julian Alps (NW Slovenia; Fig. 1a, b). Structurally, the Julian Alps represent an eastern continuation of the Southern Alps and consist of the Tolmin Nappe and the overlying Julian Nappe (Buser 1986; Placer 1999, 2008). The studied sections belong to the Kobla Nappe, a structural subunit of the Tolmin Nappe (Fig. 1c).

During the Triassic, the Southern Alps belonged to the southern passive continental margin of the Meliata branch of the Neotethys Ocean (Haas et al. 1995; Schmid et al. 2008) (Fig. 1d). The studied Late Norian–Rhaetian Slatnik Formation was deposited in the marginal part of the deep water Slovenian Basin, adjacent to the shallow water Julian Carbonate Platform (Rožič et al. 2009) (Fig. 1e). At Mt. Kobla, the formation is composed of hemipelagic limestones, intercalated with calciturbidites; i.e. graded calcarenites and limestone breccias. The succession was deposited in the basin plain to the lower slope environment. At Mt. Slatnik, the more proximal succession consists of resedimented limestones and only sporadic hemipelagites, characterizing deposition on the lower to upper slope sedimentary environment. Although the formation exhibits

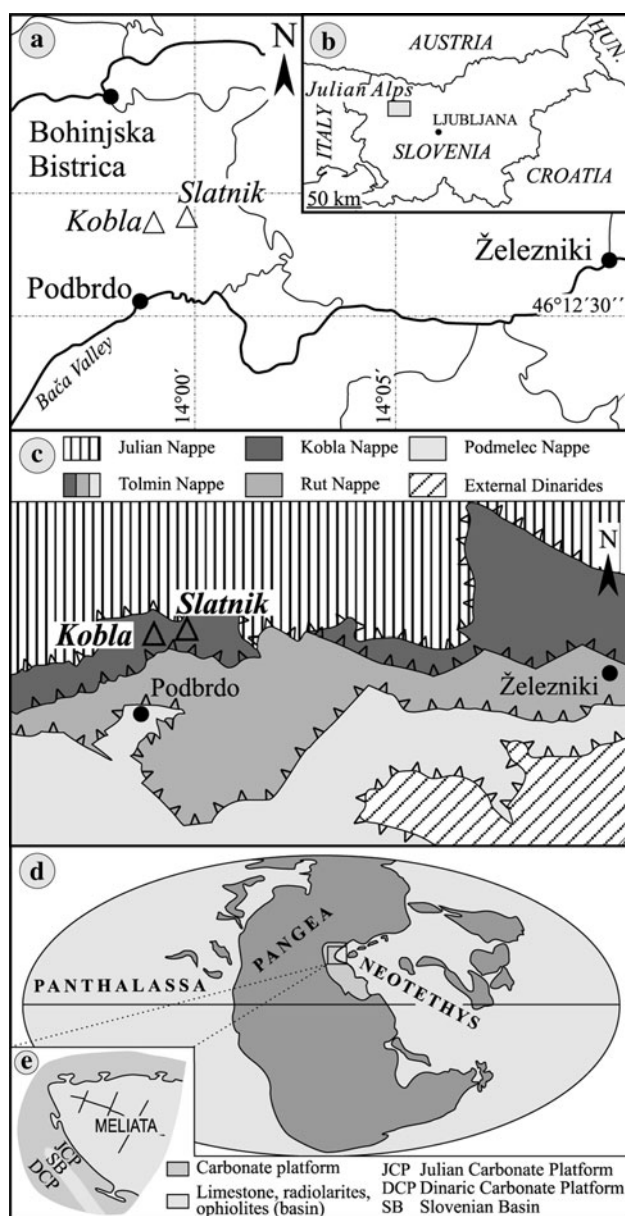


Fig. 1 Geographic and palaeogeographic position of investigated area. **a, b** Position of the studied sections. **c** Structural map of the area in Fig. a (after Buser 1986; and M. Demšar personal communication, 2010) **d, e** Palaeogeographic position of the Slovenian Basin during the Late Triassic. **d** Simplified after Golonka (2007). **e** Simplified after Haas et al. (1995)

apparent differences between both sections, the main progradational/retrogradational sedimentary trends are well recognised and correlated (Rožič et al. 2009). Due to the absence of the uppermost Rhaetian *Misikella ultima* Zone in the upper part of the Slatnik Formation and facies characteristics (i.e. numerous channel structures, coarse-grained resediments), the upper part of the sections possibly contains hiata (H. J. Gawlick and L. Krystyn, 2011, pers. comm.; Goričan et al., 2012).

4 Materials and methods

The first detailed investigation of the Slatnik Formation by Rožič et al. (2009) focused on the facies analysis that was supported by conodont dating. For this study, the hemipelagic limestones of both sections were independently investigated and sampled. At Mt. Kobla, an additional quantity of rock was processed and supplemented with 30 new samples for the interval between 81.5 and 95 m. Fourteen additional samples were processed from the Mt. Slatnik section and eight yielded important supplementary datings; however, only one sample was taken from hemipelagic limestone. The average weight of the samples was 2 kg, with the largest sample weighing 4 kg. A standard technique to recover conodonts was applied, using diluted acetic acid followed by heavy liquid separation. The illustrated conodont elements presented herein were photographed with the JEOL JSM 6490LV Scanning Electron Microscope at the Geological Survey of Slovenia. The taxonomic terminology of the genus *Misikella* and *Epigondolella* of Kozur and Mock (1991) and Orchard (1991) was applied in the paper by Rožič et al. (2009) and is retained herein. The conodont biostratigraphy follows Kozur and Mock (1991) and Kozur (2003). All conodont samples are in the depository of the Geological Survey of Slovenia.

Foraminifera from the Mt. Kobla section were determined from 85 thin sections, 47 × 28 mm and 75 × 49 mm in size, sampling 43 beds. From the Mt. Slatnik section, 48 thin sections from 38 beds were made. The thin sections are stored at the Geological Survey of Slovenia.

Before discussing the stratigraphic value of foraminifera from the Slovenian Basin, we tried to make a revision of the literature data on stratigraphic ranges of the species in assemblages. The ranges in Fig. 2 are thus based on the author's synonymy list (Gale 2012).

5 Results

5.1 Conodont distribution

The distribution of the identified conodont taxa (Figs. 3, 4) is presented in Figs. 5, 6, 7 and 8. We focused on the identification of the *Misikella* representatives, mainly *M. hernsteini* and *M. posthernsteini*, which are the key taxa for the biostratigraphic definition of the Norian–Rhaetian boundary (Kozur and Mock 1974; Gazdzicki et al. 1979; Golebiowski 1986; Krystyn 1987; Kozur and Mock 1991; Kozur 1996; Krystyn et al. 2007a, b; Krystyn 2008; Moix et al. 2007; Giordano et al. 2010). Besides improved stratigraphy, a new result of this conodont study is the

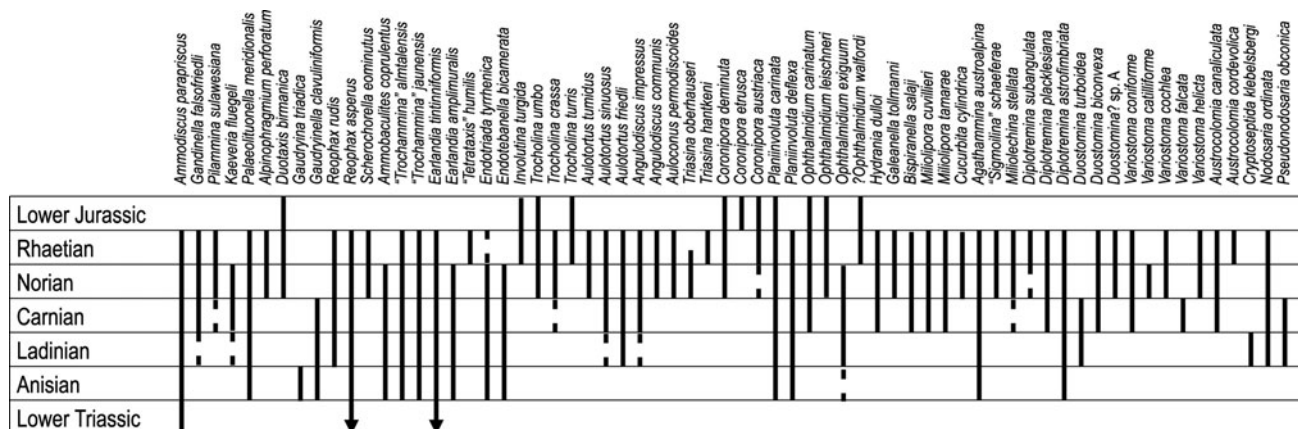


Fig. 2 Stratigraphic ranges of foraminifera found in the Mt. Kobra section. Ranges are based on the author's synonymy list. Stratigraphic resolution is kept at the stage level. In most cases it is not known which criteria for the Rhaetian has been used

recognition of several new taxa: *Misikella buseri*, *Misikella* sp. A, *Misikella* sp. B, *Parvigondolella lata* and *Zieglerioconus rhaeticus* (see Kolar-Jurkovšek 2011).

In determining the conodont elements, a taxonomy considered in Kolar-Jurkovšek (2011) is applied and criteria for some taxa are emphasised here:

The genus *Parvigondolella* includes elements regarded as the ultimate stage in the epigondolellid evolution. However, some authors regard the platformless gondolellid forms as morphological variants or ecostratigraphic morphotypes of *E. bidentata* (Gallet et al. 2007; Krystyn 2008). Discrimination of the platformless forms as a separate genus is therefore reflected in the introduction of different conodont biozones. The biozonation for the Norian-Rhaetian of Hallstatt is based on *Epigondolella* with separation of platformless element denoted as *Epigondolella bidentata* juv. (Krystyn 2008). On the other hand, Kozur and Mock (1991) proposed a biozonation based on recognition of *Parvigondolella* that was modified by Kozur (2003). Their view was later followed by some authors (Jadoul et al. 2007; Moix et al. 2007; Rožič et al. 2009; Muttoni et al. 2010; Kolar-Jurkovšek 2011) and is used in this study.

Misikella hernsteini and *M. posthernsteini* have significant stratigraphic values. Both of them were used as markers in proposals for the candidate GSSP for the base of the Rhaetian stage (e.g. Lucas 2007; Krystyn et al. 2007a, b; Lucas 2010b). In distinguishing *M. posthernsteini* from *M. hernsteini*, we follow Giordano et al. (2010). Some other species of *Misikella* (*M. koessenensis*, *M. rhaetica*), which were used in earlier stratigraphic schemes (Mostler et al. 1978; Krystyn 1987; Kozur and Mock 1991) and may have local stratigraphic values, are also present in investigated sections. The determination of both species renders some difficulties, as the first description of both taxa includes elements that might bear additional denticle(s) behind the

cus (Mostler et al. 1978). Therefore, *M. koessenensis* and *M. rhaetica* should be emended. In the study of the Mt. Kobra faunas, a more limited concept in recognition of the two species was used (Kolar-Jurkovšek 2011). The short and high elements that reveal no posterior denticle, composed of three to five denticles and an appropriate length: height ratio were attributed to *M. koessenensis* sensu lato. However, these elements are herein assigned to *Misikella* sp. B as a compromise suggested by Kozur (pers. comm.).

The elements of *Misikella* with one to two denticles of smaller size behind the cusp and with a widely opened basal area extending nearly full length were attributed to *M. rhaetica* sensu lato by Kolar-Jurkovšek (2011) and illustrated in Rožič et al. (2009, Fig. 9e). Similar specimens are regarded as elongated *M. hernsteini* by some authors (L. Krystyn and H. Kozur, both pers. comm.) and are assigned here to *Misikella* sp. A (sensu Muttoni et al. 2010).

5.1.1 Conodonts from the Mt. Kobra section

The conodont assemblage from the Mt. Kobra section consists of genera *Epigondolella*, *Norigondolella*, *Oncodolella*, *Parvigondolella*, *Misikella* and *Zieglerioconus*.

Norigondolella steinbergensis and *Epigondolella* ex gr. *E. abneptis* were found below the Slatnik Formation, in the upper part of the Bača Dolomite. *Epigondolella bidentata* and *N. steinbergensis* were found in the lowermost part of the Slatnik Formation, where only composite samples were taken. The first *Epigondolella* ex gr. *E. postera* was found around 30 stratigraphic metres higher. Several new species enter the assemblage at the 55 m level (Figs. 5, 6) where precise point-sampling in one-meter-interval steps started. These are: *Epigondolella* ex gr. *E. postera*, *Parvigondolella andrusovi*, *Misikella hernsteini*, *Zieglerioconus rhaeticus* and *Misikella* sp. At the 58 m level, *Misikella* sp.

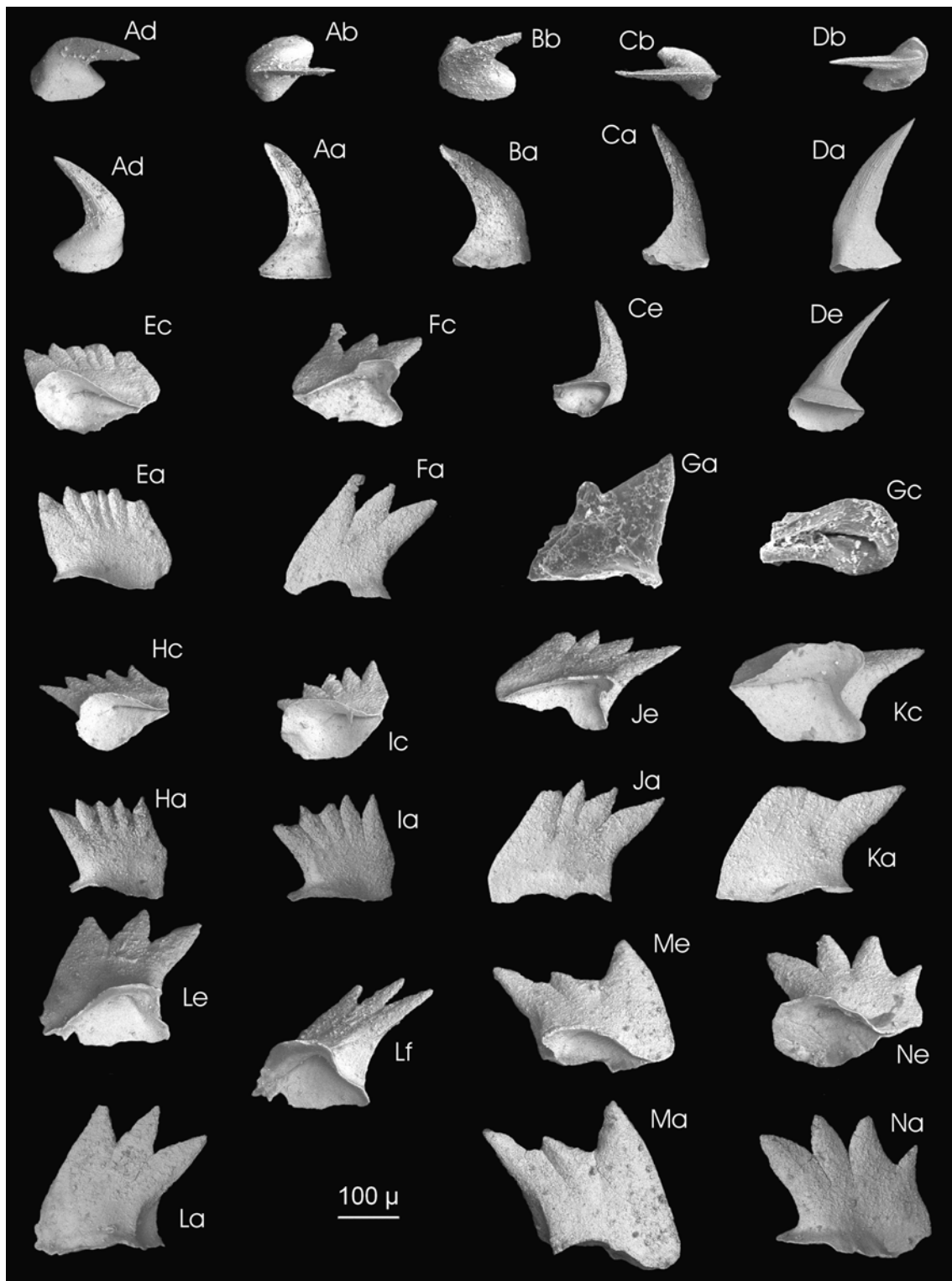


Fig. 3 Conodonts from the Mt. Kobra section. Scale bar 100 μ m. **A–D**, *Zieglerioconus rhaeticus* Kozur and Mock 1991. *Misikella posthernsteini* A. Z. A–C, Sample K2/70-75 (GeoZS 4098). D, Sample K2/82.5 (GeoZS 4403). **E**, Transitional form between *Misikella hemsteini* (Mostler, 1967) and *Misikella* sp. B - highly evolved form. *Misikella posthernsteini* A. Z. Sample K2/90.4 (GeoZS 4420). **F, J–M**, *Misikella posthernsteini* Kozur and Mock 1974. *Misikella posthernsteini* A. Z. F,

Sample K2/88.7 (GeoZS 4416). J, K, Sample K2/85.5 (GeoZS 4409). L, M, Sample K2/90.1 (GeoZS 4419). **G**, *Misikella buseri* Kolar-Jurkovšek 2011. *Misikella posthernsteini* A. Z. Sample K2/76.0 (GeoZS 4242). **H, I, N**, *Misikella* sp. B Mostler, 1978. H, I, *Misikella posthernsteini* A. Z. Sample K2/85.5 (GeoZS 4409). N, Un-named *Misikella* level. Sample K2/93.8 (GeoZS 4424). *a* lateral, *b* upper, *c* lower, *d* oblique lateral, *e* oblique lower, *f* lower posterior view

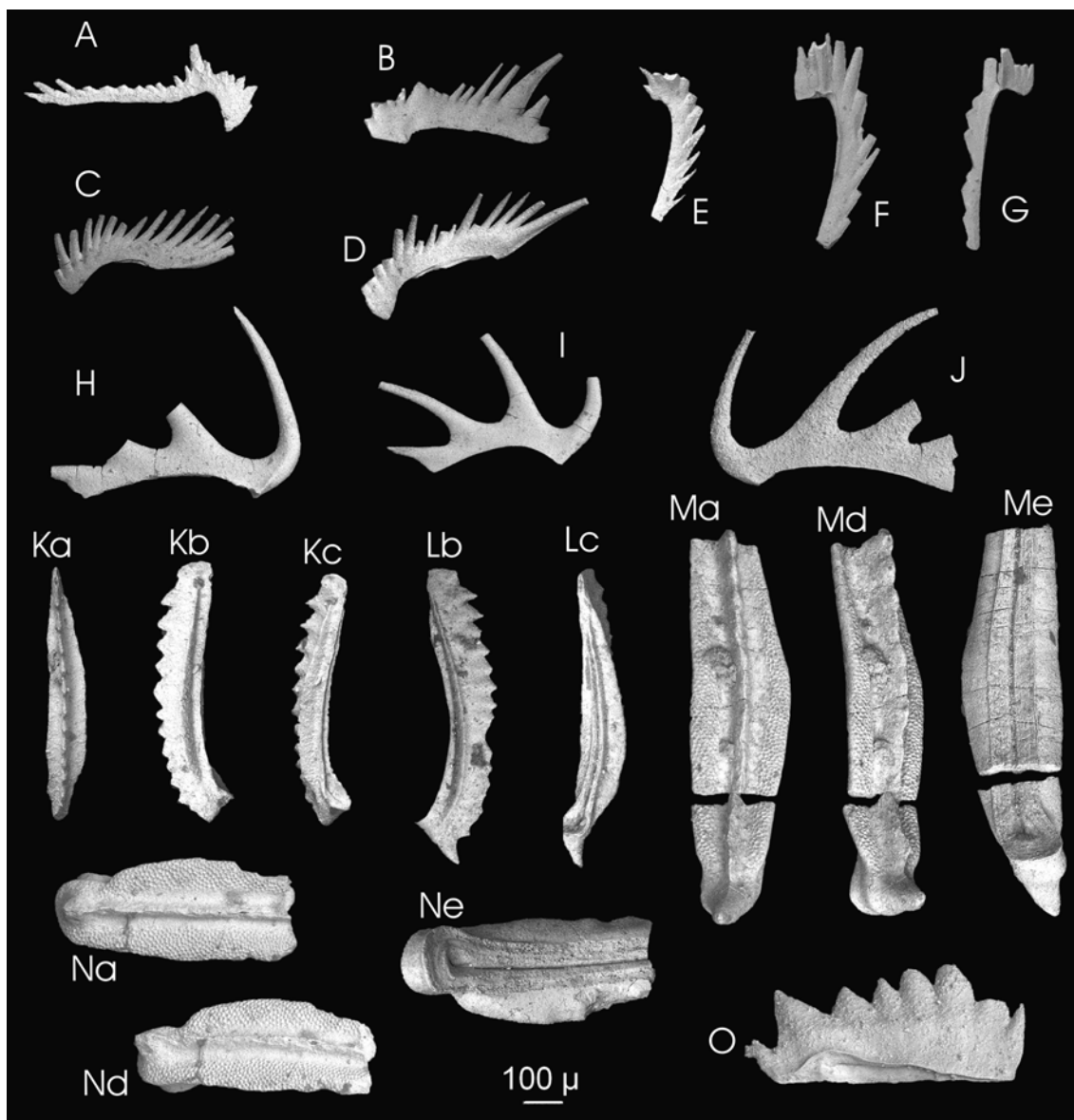


Fig. 4 Conodonts from the Mt. Kobra section. *Misikella posthernsteini* A. Z. Scale bar 100 μ m, in figure O 50 μ m. A–G Ramiform elements: A, S_{3–4} element. B, S_{3–4} element. D, S_{1–2} element. C, ?S element. E, M element. F, G, M element. H–J, *Oncodella paucidentata* (Mostler, 1967). K–N, *Norigondolella steinbergensis* (Mosher, 1968). O, *Parvigondolella andrusovi* Kozur & Mock, 1972. A, H, I,

Sample K2/88.0 (GeoZS 4415). B, C, F, G, Sample K2/82.5 (GeoZS 4403). D, Sample K2/87.6 (GeoZS 4414). E, Sample K2/86.0 (GeoZS 4410). J, Sample K2/89.1 (GeoZS 4417). K, N Sample K2/86.5 (GeoZS 4411). L, M Sample K2/87.0 (GeoZS 4412). O Sample K2/81.7 (GeoZS 4401). a upper, b lateral, c oblique lower, d oblique lateral, e lower view

A and *Misikella* sp. B first occur. *Oncodella paucidentata* was first found in the 71 m level, and stratigraphically the most important *Misikella posthernsteini* at the 75 m level. *Misikella buseri*, described as a new species by Kolar-Jurkovšek (2011), enters the assemblage at the 76 m level. The Last Appearance Datum (LAD) of *Misikella hernsteini* is at 81.5 m, and *Misikella posthernsteini* reaches up to the 91 m level. The last conodonts were retrieved just below the last channelised breccia in the Slatnik Formation, at the 94.5 m level.

5.1.2 Conodonts from the Mt. Slatnik section

The Mt. Slatnik section presents the more proximal development of the two, and very few micritic limestone beds are available for sampling (Figs. 7, 8). The complete assemblage consists of the following species (in the order of first occurrences): *Epigondolella* ex gr. *E. abneptis*, *N. steinbergensis*, *P. andrusovi*, *Misikella* sp. B, *Misikella* sp., *O. paucidentata*, *Z. rhaeticus*, *M. hernsteini*,

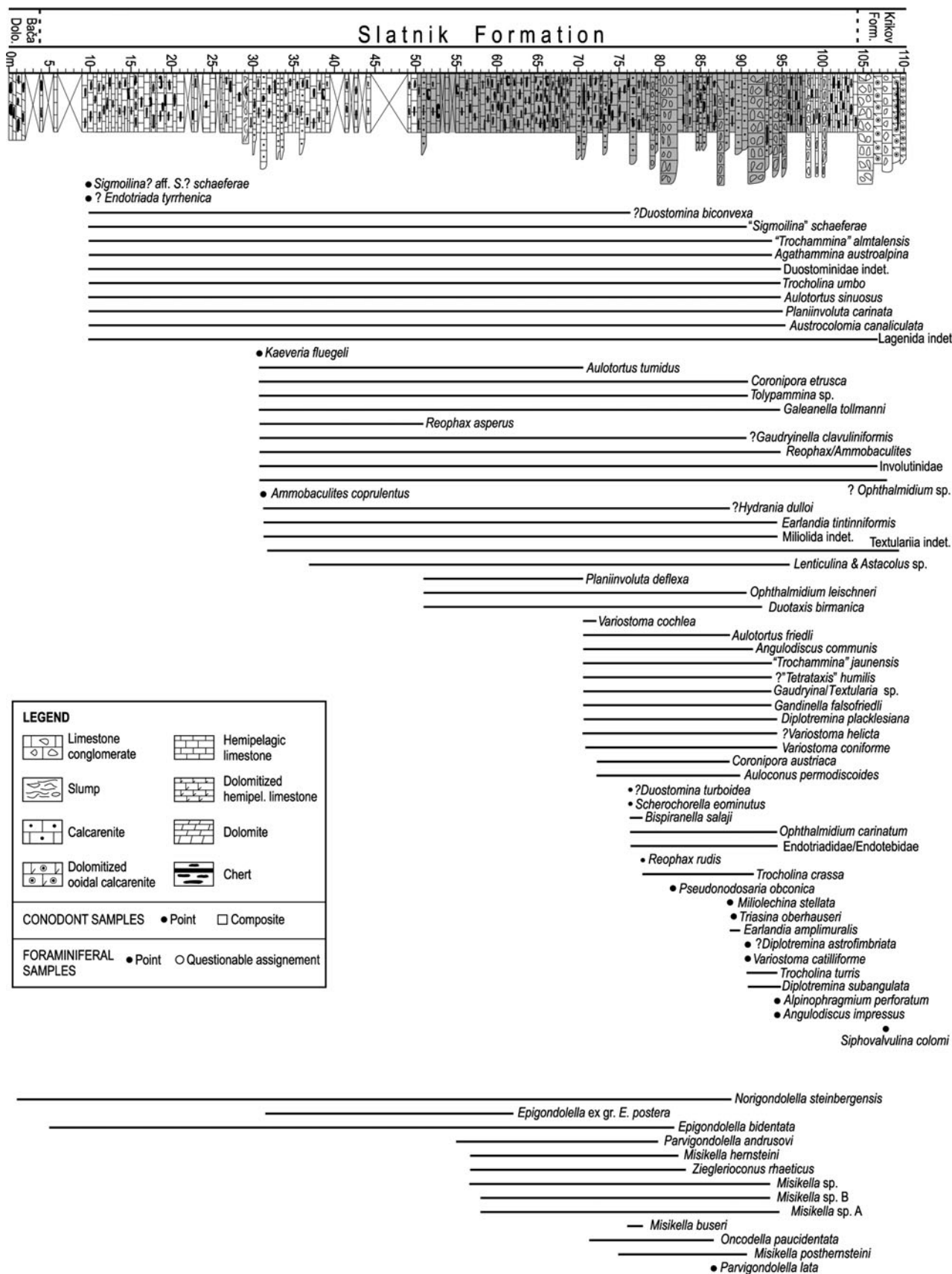
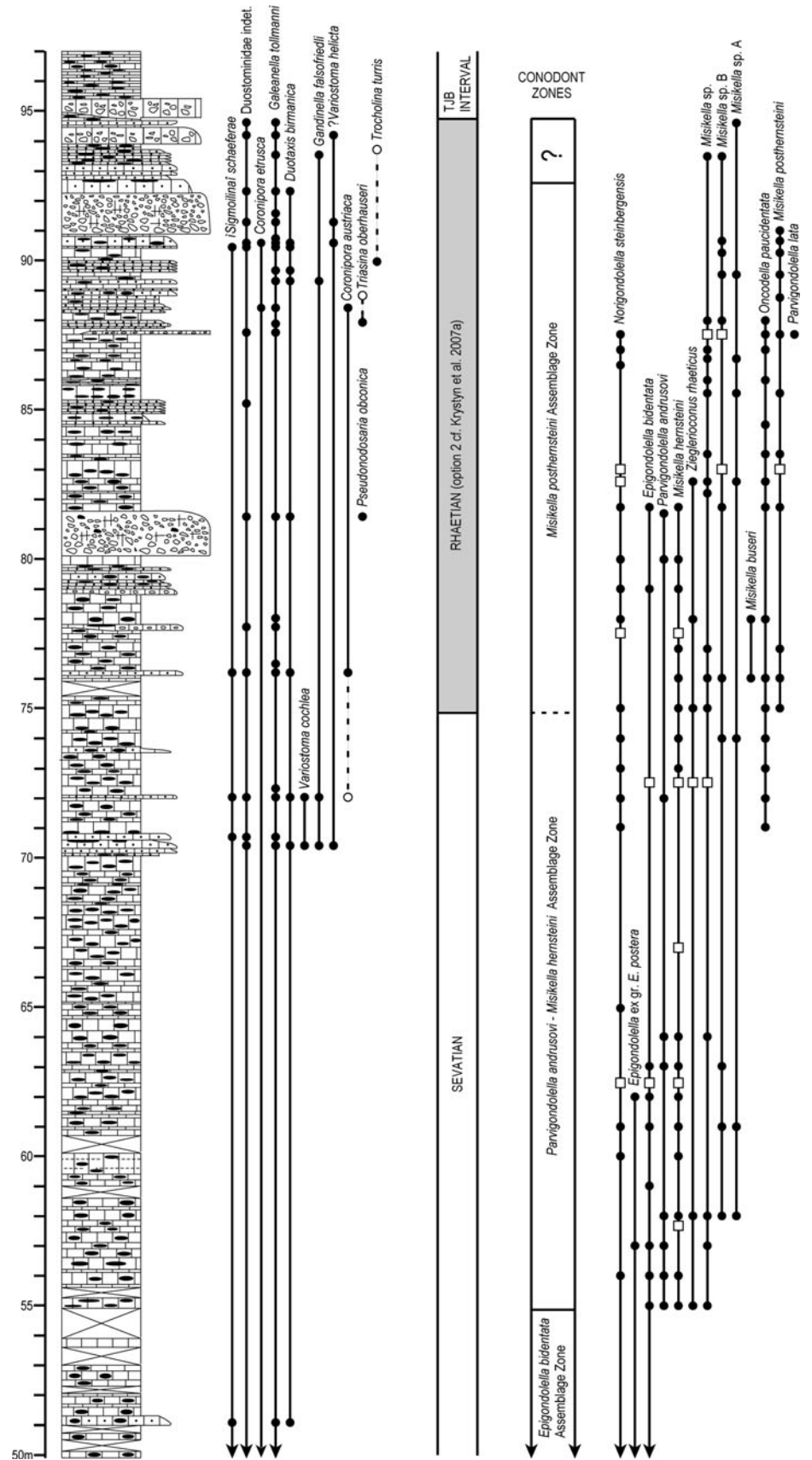


Fig. 5 A simplified Mt. Koba section with distribution of foraminifera and conodonts. Shaded part of the section is shown in detail in Fig. 5. Modified after Rožič et al. (2009)

Fig. 6 An un-simplified part of the Mt. Kobra section (*shaded area* in Fig. 5) including the Norian-Rhaetian and the Triassic-Jurassic boundary interval. See Fig. 5 for legend. Option 2 (the First Appearance Datum of *Misikella posthernsteini*) of Krystyn et al. (2007a) is the favored level for the Norian-Rhaetian Boundary (Kozur 1996)



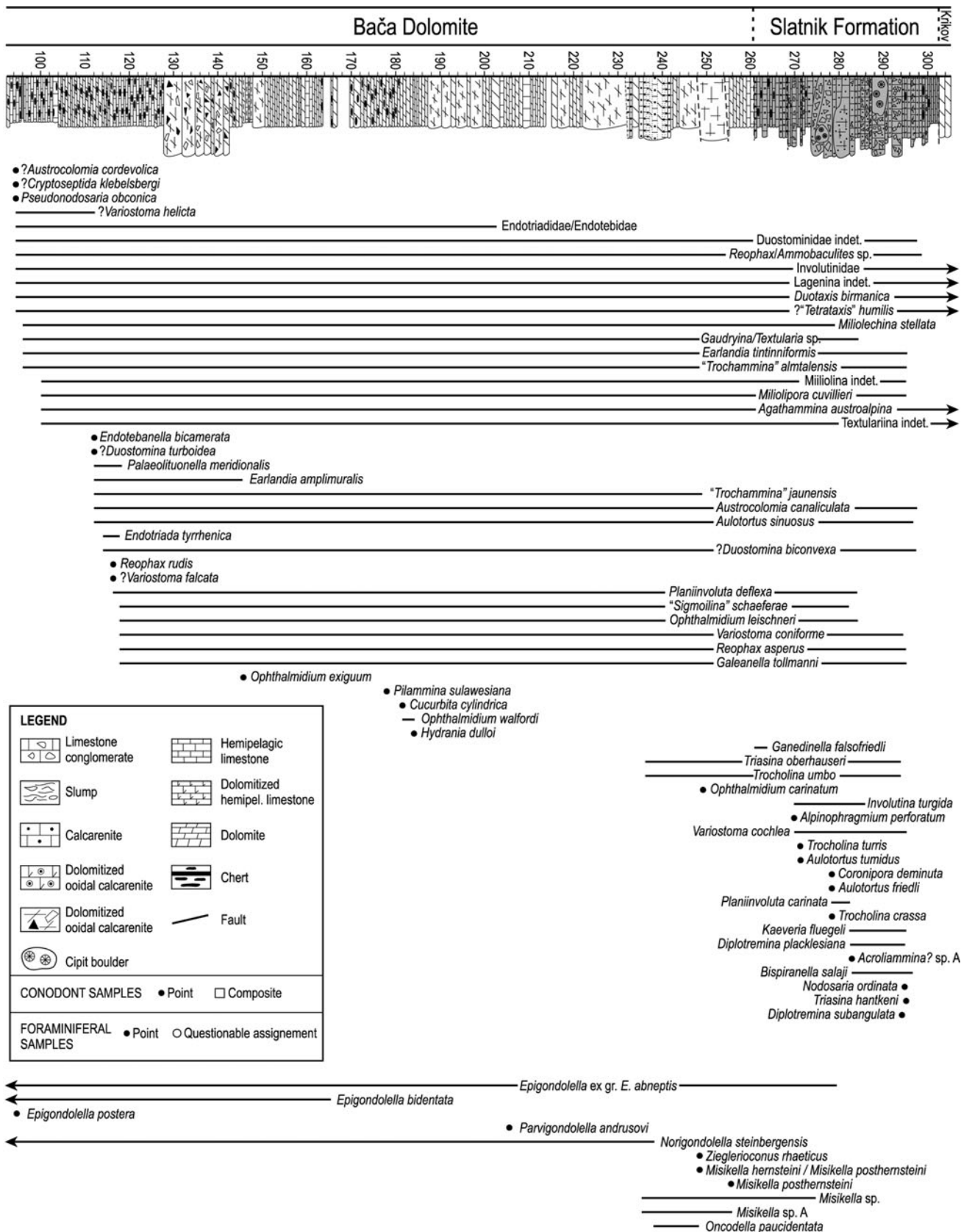
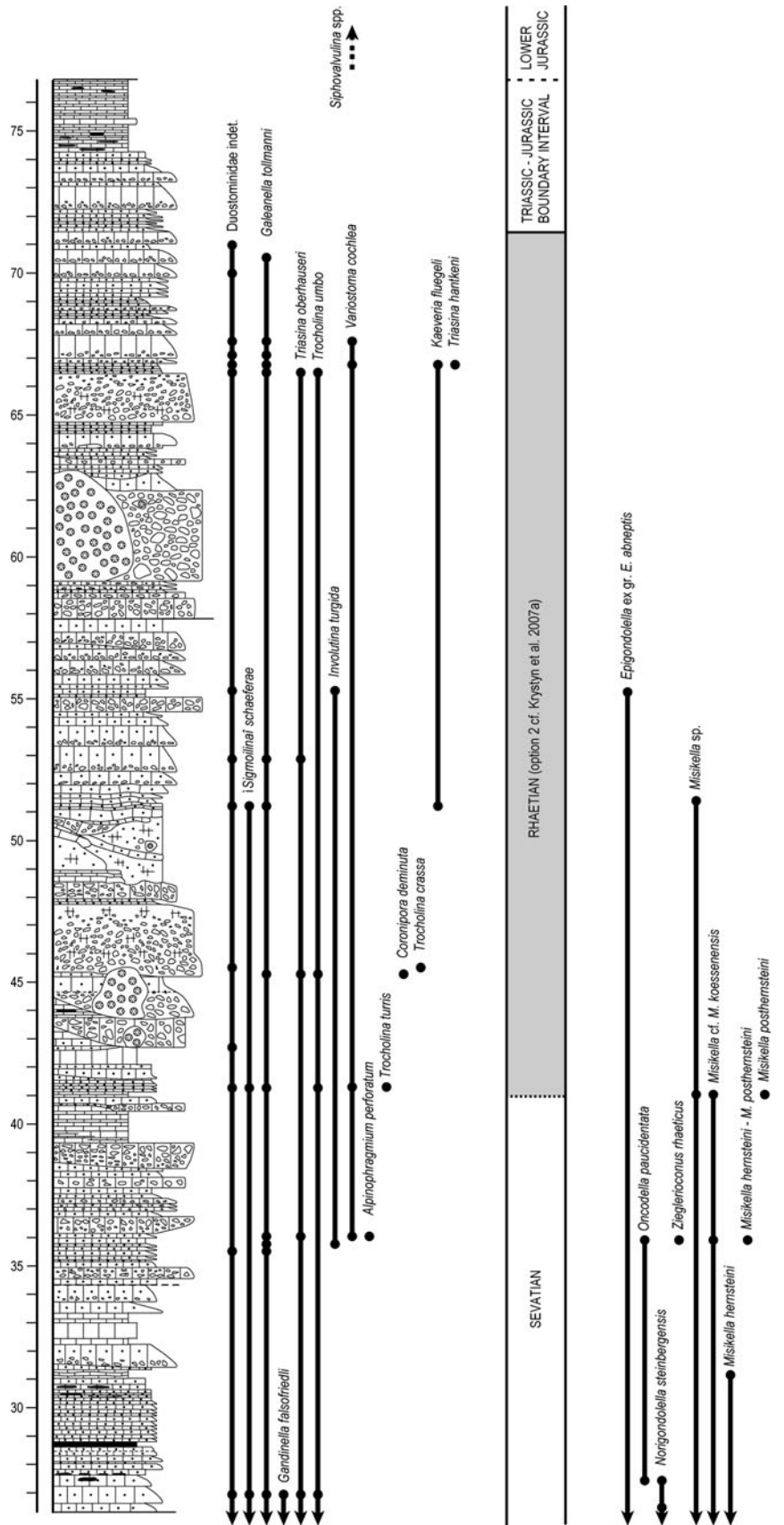


Fig. 7 A simplified Mt. Slatnik section with distribution of foraminifera and conodonts. Shaded part of the section is shown in detail in Fig. 8. See Fig. 5 for legend

Fig. 8 An un-simplified upper part of the Mt. Slatnik section. Note the difference in meters compared to Fig. 7. See Fig. 5 for legend



transitional form between *M. hernsteini* and *M. posthernsteini*, *M. posthernsteini*.

Most samples were taken from very fine-grained packstones so at least a short-term resedimentation cannot be totally excluded. However, clearly re-sedimented older elements from the upper part of the Slatnik Formation (above the 67 m level) were easily recognised due to their fragmented nature and different colour. The stratigraphic occurrence of *E. abneptis* is confined in Slovenia to the Norian strata (Kolar-Jurkovšek 1991, Buser et al. 2007). It is important to note that *Misikella posthernsteini* was found in the residue of micritic, hemipelagic limestone. The Norian-Rhaetian boundary can thus be set between the 36 m level (with a transitional form between *M. hernsteini* and *M. posthernsteini*) and the 41 m level (with *M. posthernsteini*).

5.2 Foraminiferal distribution

Among foraminifera, two types of assemblages are distinguished. The first type is found in hemipelagites. It is characterised by low diversity and abundance. Lagenides predominate, presumably representing in situ associations. The second type of assemblage is limited to calcarenites (packstone, grainstone and fine-grained rudstone), which were interpreted as turbidity current deposits (Rožič et al. 2009; Gale 2010, 2011; Gale et al. 2011). These assemblages are low in abundance, but highly diversified, comprising 50 genera and 69 species. Reef-dwelling forms predominate, with a minor admixture of platform and fore-reef dwelling forms.

The lithological dependence of foraminifera is responsible for some apparent abrupt appearances of many species in the lower part of the Slatnik Formation, but these are a consequence of a rather small number of calciturbiditic beds in the lower, Sevatian part of the sections. Data become more consistent in the upper part of the formation where calcarenites and breccias predominate. The occurrences and local ranges of all determined foraminifera are shown in Figs. 4 and 5 and the foraminifera are shown in Figs. 9, 10, 11 and 12.

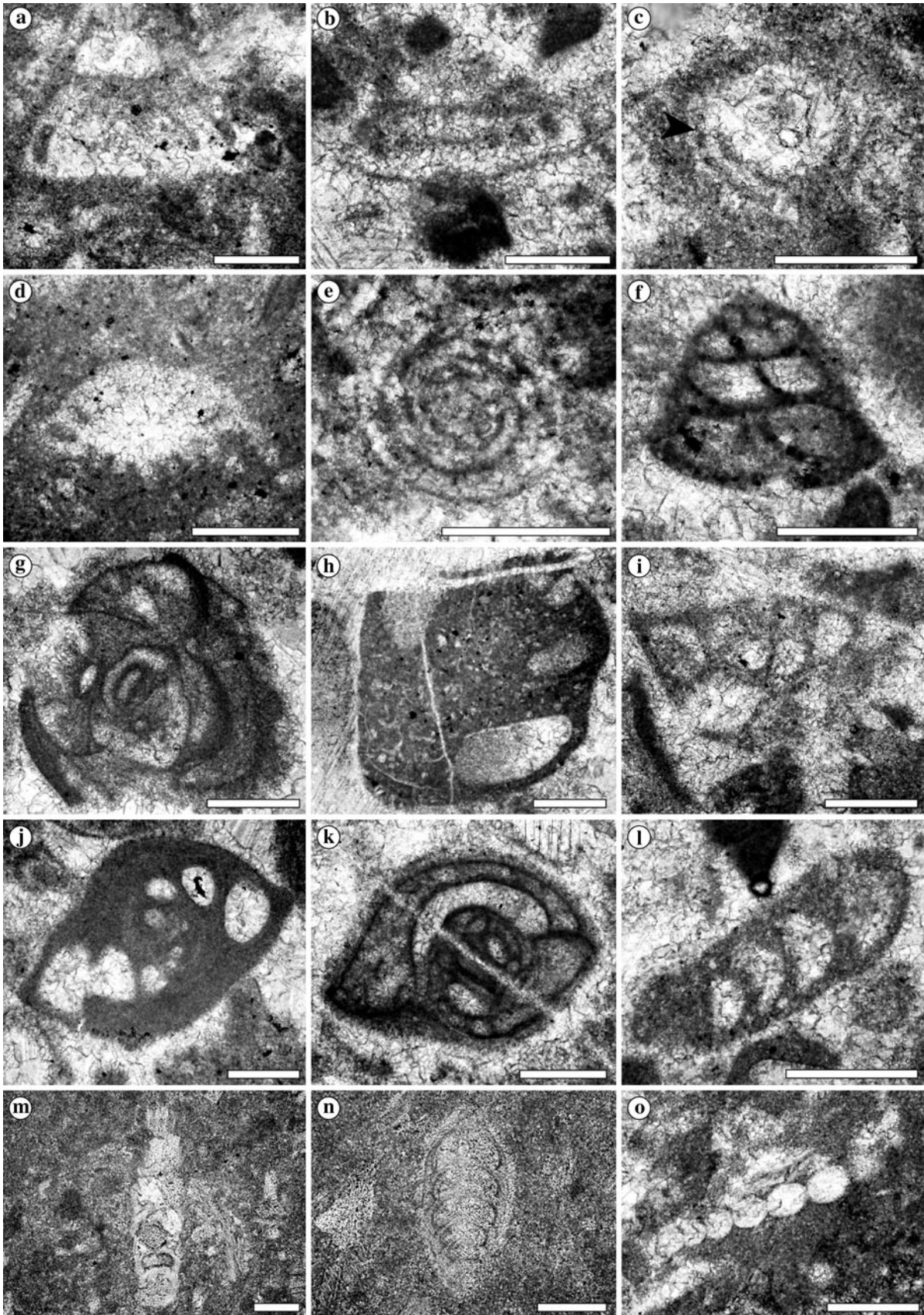
5.2.1 Foraminifera from the Mt. Kobra section

Foraminifera were first recorded 10 m above the base of the Slatnik Formation (Figs. 5 and 6). This sample is the only one yielding specimens of *Endotriada tyrrenica*. The FO of “*Sigmoilina*” *schaeferae* is also recorded at this level, as well as the FO of “*Trochammina*” *almtalensis*, *Agathammina austroalpina*, *Trocholina umbo*, *Aulotortus sinuosus*, *Planiinvoluta carinata*, *Austrocolomia canaliculata* and ?*Duostomina biconvexa*. With the exception of the latter species, all reach the uppermost part of the Slatnik

Formation. The succeeding 20 m of the section consist of hemipelagic limestones devoid of allochthonous material. With the renewed deposition of coarser material, several taxa enter the assemblage. Among them are single but undisputable specimens of *Kaeveria fluegeli*, *Ammobaculites corpulentus*, *Aulotortus tumidus*, *Coronipora etrusca* and *Galeanella tollmanni*. The last species, as well as “*S.*” *schaeferae*, are abundant, well preserved and easily recognisable throughout the upper part of the Slatnik Formation. *Hydrania dulloi* also appears at this level, but the assignment of this species is questionable, with only one higher level yielding more than one specimen. At 50 m, “*Duotaxis birmanica*” appears, and numerous specimens of this species were recovered up to the top of its range. *Planiinvoluta deflexa*, which is also first encountered at this level, differs from *P. carinata* in having up to four times less dense coiling. Several important species appear slightly above 70 m, among them *Variostoma cochlea* (with a very short range that could be extended if ?*Variostoma helicta* is reassigned as *V. cochlea*), “*Tetrataxis*” *humilis*, *Aulotortus friedli*, *Angulodiscus communis*, *Gandinella falsofriedli* and *Variostoma coniforme*. *Variostoma coniforme* is especially abundant and easily recognisable higher in the section. Single specimens of *Coronipora austriaca* and *Auloconus permodiscoides* were found in slightly younger beds. The appearance of *Reophax rudis* soon follows. An abundance of *Bispiranella salaji* (*Orthotrinacria* cf. *O. expansa* auct.) is prominent. *Triasina oberhauseri* appears at 88 m. *Variostoma catilliforme*, named a marker fossil for the Norian by Kristan-Tollmann (1976—cf. Haas et al. 1997), was found soon after, alongside *Trocholina turris*. One of the last positive samples contained *Alpinophragmium perforatum* embedded in an intraclast. The calcarenite bed directly overlying the last bed of hemipelagic limestone that yielded conodonts (at 94.5 m of the section) contains abundant foraminifera. Higher in the section, the assemblage is severely diminished. Though the following breccia layer was sampled several times, it yielded only lagenides (recognisable are genera *Lenticulina*, *Pseudonodosaria* and *Austrocolomia*) and is thus in strong contrast with lithologically similar lower breccia layers with many Triassic foraminifera. Lagenids are joined by agglutinated foraminifera, involutinids and small *Ophthalmidium* only above 11 m in the section. *Siphovalvulina* spp. appear soon after, 12 m above the last duostominids.

5.2.2 Foraminifera from the Mt. Slatnik section

The first foraminifera were found in the non-dolomitised parts of the underlying Bača Dolomite, almost 140 stratigraphic metres below the Slatnik Formation (Fig. 7). Allodapic limestones yielded several species. Of particular



◀ **Fig. 9** Foraminifera from the Mt. Kobla and Mt. Slatnik sections. Scale bar 200 μm , in figures n–p 100 μm . **a** ?*Coronipora etrusca*. Sample 70308. **b** ?*Coronipora austriaca*. Sample 70295. **c** *Triasina oberhauseri*. Sample 70308. Note rare pillars in the last whorl (arrowhead). **d** *Trocholina umbo*. Sample 70631. **e** *Gandinella falsofriedli*. Sample 70284. **f** “*Duotaxis birmanica*”. Sample 70295. **g** *Galeanella tollmanni*. Tangential section. Sample K2-94.20. **h** ?*Variostoma helicta*. Sample K2-70.40. **i** *Variostoma catilliforme*. Sample 70277. **j** “*Sigmoilina*” *schaeferae*. Sample 70324. **k** *G. tollmanni*. Sample 70295. **l** *Ammobaculites corpulentus*. Sample 70276. **m** ?*Austrocolomia cordevolica*. Sample 70087. **n** ?*Cryptoseptida klebelsbergi*. Sample 70080. **o** *Nodosaria ordinata*. Sample 70248

importance are *M. cuvillieri*, *D. birmanica*, *A. perforatum* and *M. stellata*. The last three species are only known from the Norian and Rhaetian. *Palaeolituonella meridionalis*, several species of duostominids, “*S.*” *schaeferae* and *G. tollmanni* were found at 115 m level. From the upper part of the Bača Dolomite, the findings of *P. sulawesiana*, *C. cylindrica*, *H. dulloi*, *G. falsofriedli*, *T. oberhauseri* and *Tr. umbo* are important. Questionable *Ophthalmidium walfordi* has been rarely cited in the literature and is not reported from strata older than Rhaetian until now (Gaździcki 1983). Calciturbidites of the succeeding Slatnik Formation are even richer in benthic foraminifera. Stratigraphically the most important is the finding of *Involutina turgida* (9 m above the fault separating the Bača Dolomite from the Slatnik Formation) from the immediate neighbourhood of the conodont NRB, although this form is difficult to recognise due to the susceptibility of its test to diagenetic changes. *Duotaxis metula* appears in the same level. The first occurrence of *Tr. turris* is recorded five metres higher. Twenty-two metres into the Slatnik Formation, *C. deminuta*, *Tr. crassa* and, soon after, *K. fluegeli* were found. The last “*S.*” *schaeferae* was determined five metres higher, and the last *T. oberhauseri* still five metres higher (the 66.5 m level in Fig. 8). Immediately above the Last Occurrence of *T. oberhauseri*, a single specimen of *Triasina hantkeni* was recovered. Duostominidae last until the 71 m level (on Fig. 8). Only lagenids were found in calcarenites above the LO of duostominids. These, last calcarenites of the Slatnik Formation, are followed by an interval of platy limestones of the topmost Slatnik Formation. The Slatnik Formation is separated from the Krikov Formation by a fault and the lower part of the latter is dolomitised. The first unfaulted beds of the Krikov Formation yielded Early Jurassic *Siphovalvulina* spp. and some of the more tolerant foraminiferal taxa.

6 Discussion

In the following text, we firstly set the stratigraphic frame on the basis of conodonts, to which the actual stratigraphic ranges of foraminifera are compared.

6.1 Conodont stratigraphic framework

Three Late Triassic conodont zones were recognised in the Mt. Kobla section (Fig. 6). The FAD of *Misikella posthernsteini* was taken as the marker for the base of the Rhaetian, as the currently most favoured option (Kozur 1996; Krystyn et al. 2007a, b; McRoberts et al. 2008; Rožič et al. 2009; Giordano et al. 2010; Lucas 2010b).

The lower part of the Slatnik Formation belongs to the *E. bidentata* Zone. Species *E. bidentata*, *N. steinbergensis* and *Epigondolella* ex gr. *E. postera* delineate the Sevatan age. The interval between the 55 m and the 75 m levels belongs to the *P. andrusovi* – *M. hernsteini* Zone. Up to the 92.5 m level, the *M. posthernsteini* Zone follows. According to H. J. Gawlick and L. Krystyn (2011, pers. comm.), the unusually long span of the *M. posthernsteini* Zone and the absence of the uppermost Rhaetian *Misikella ultima* Zone (see Krystyn 2008; Krystyn et al. 2009) points to the presence of hiati in this part of the section. This is in accordance with the development of the sediment by-pass zone during the forced regression (Gale et al. 2012).

In contrast, the low abundance of conodonts and the possibility of reworking in the Slatnik section prevent detailed subdivision into conodont zones. Fortunately, there is a low probability that the single sample yielding *M. posthernsteini* contains a reworked assemblage due to its micritic nature.

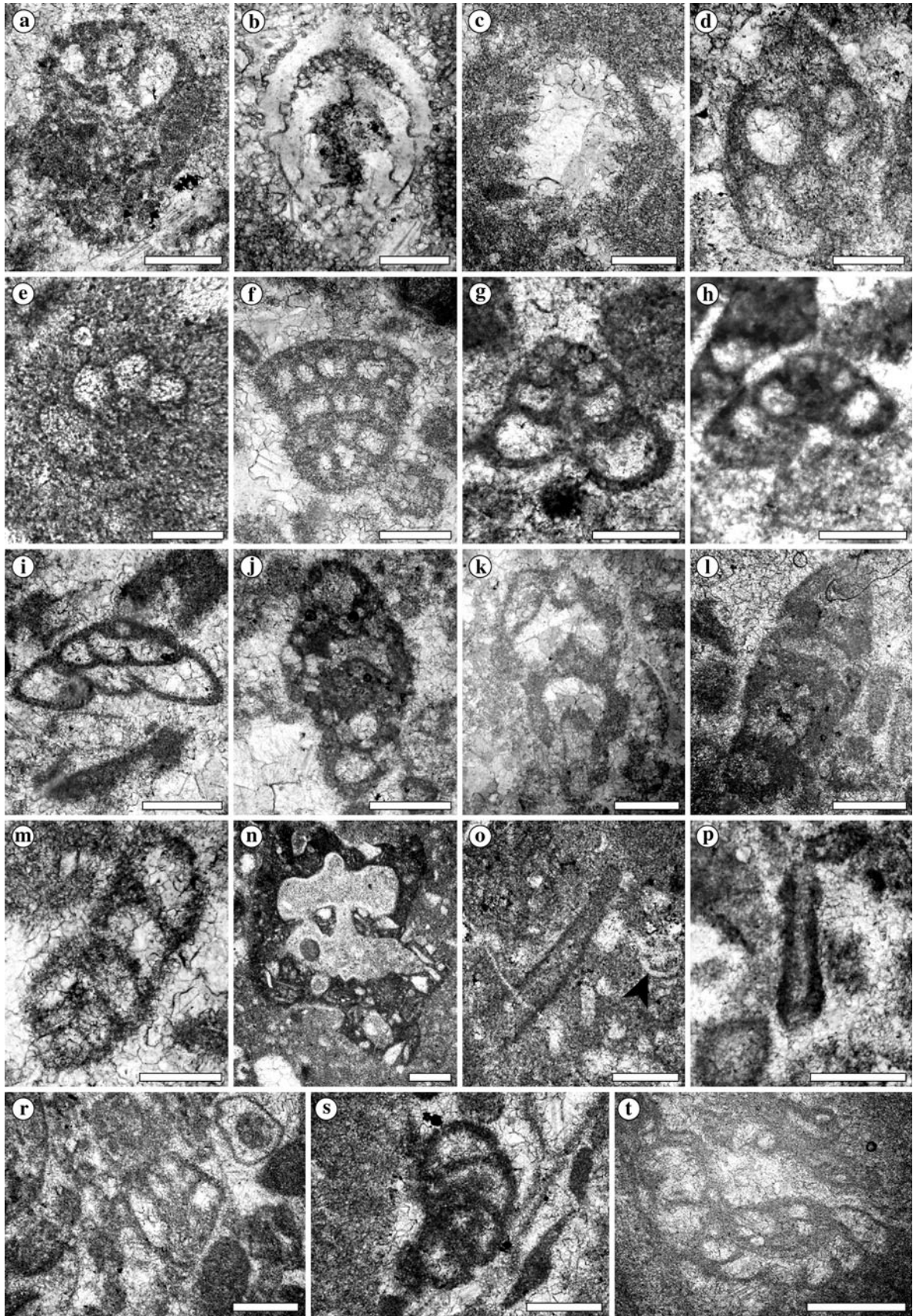
6.2 Stratigraphic value of foraminifera

From the foraminiferal assemblage of the Mt. Kobla and Mt. Slatnik sections, potentially stratigraphically the most useful species are chosen for discussion on the basis of their ranges in Fig. 2. Furthermore, we focus on the species, that are used in the existing biozonation schemes (e.g. Gaździcki 1974, 1983; Salaj 1977; Gaździcki et al. 1979; Salaj et al. 1983, 1988; Abate et al. 1984; Vachard and Fontaine 1988; Peybernes et al. 1988; He and Norling 1991; Chiocchini et al. 1994; Grgasović 1997; Peybernes et al. 1998; Mancinelli et al. 2005; Velić 2007).

6.2.1 *Galeanella tollmanni*

Genus *Galeanella* Kristan, 1958 is one of the most typical Late Triassic genera. *Galeanella panticae* Brönnimann et al., 1973 and *Galeanella lucana* Miconnet et al., 1983 are treated here as junior synonyms of *Galeanella tollmanni* (Kristan, 1957) (see also Kristan-Tollmann 1990).

The stratigraphic range of *G. tollmanni* is from the Norian to the Rhaetian (e.g. Kristan 1957; Kristan-Tollmann 1964, 1990; Brönnimann et al. 1973; Schäfer 1979; Wurm 1982; Zaninetti et al. 1982; Al-Shaibani et al. 1983; Miconnet et al. 1983; Senowbari-Daryan 1983; Matzner



◀ **Fig. 10** Foraminifera from the Mt. Kobla and Mt. Slatnik sections. Scale bar for figures **b–d, e, g, h, m** 100 μm , for figure **r** 250 μm , for figure **t** 500 μm , for others 200 μm . **a** *Variostoma cochlea*. Sample 70295. **b** *Pseudonodosaria obconica*. Sample K2-81.40. **c** *Trocholina turris*. Sample K2-94.20. **d** *Siphovalvulina colomi*. Sample K2-107.60. **e** *Endotriada tyrrhenica*. Sample 70294. **f** *Kaeveria fluegeli*. Sample K2-30.70. **g** “*Trochammina*” *almtalensis*. Sample 70284. **h** “*Trochammina*” *jaunensis*. Sample 70284. **i** ? “*Tetrataxis*” *humilis*. Sample 70276. **j** *Reophax rudis*. Sample 70327. **k** *Reophax asperus*. Sample K2-30.70. **l** *Scherochorella eominutus*. Sample 70304. **m** ?*Gaudryinella clavuliniformis*. **n** *Alpinophragmium perforatum*. **o** *Earlandia tintinniformis*. Arrowhead points to holothuria *Theelia* sp. Sample 70297. **p** *Earlandia amplimuralis*. Sample 70308. **r** ?*Variostoma falcata*. Sample 69859. **s** *Endotebanella bicamerata*. Sample 69858. **t** *Acroliammina?* sp. A. Sample 70286

1986; Martini et al. 1997), which is also in accordance with our data. Peybernes et al. (1988) determined *Galeanella panticae*, *Galeanella laticarinata* Zone from the base of the Norian to the end of the Rhaetian.

6.2.2 “*Sigmoilina*” *schaeferae*

The stratigraphic range of “*S.*” *schaeferae* is from the Norian to the Rhaetian (Zaninetti et al. 1982; Al-Shaibani et al. 1983; Salaj et al. 1983; Matzner 1986; Trifonova 1993; Senowbari-Daryan et al. 2010). In the Mt. Slatnik and Mt. Kobla sections, the combination of “*S.*” *schaeferae* with *G. tollmanni* provides a better consistency of data for the Norian-Rhaetian range. Both species are easily recognisable.

6.2.3 *Involutina turgida*

Involutina turgida is difficult to recognise due to neomorphic changes of its wall. Additionally, its abundance is low. Despite these deficiencies, it has never been reported from strata older than Rhaetian (e.g. Kristan 1957; Koehn-Zaninetti 1969; Matzner 1986; Kristan-Tollmann and Colwell 1992). It was found in the Mt. Slatnik section, between the transitional form from *M. hernsteini* to *M. posthernsteini*. Current data thus suggest its use as a proxy for the Norian-Rhaetian boundary, although further research is needed.

6.2.4 *Trocholina turris*

As in the case of *I. turgida*, *Trocholina turris* did not appear before the Rhaetian (Kristan-Tollmann 1986a, 1990; Kristan-Tollmann and Gramann 1992; Zaninetti et al. 1992; Senowbari-Daryan et al. 2010) and is better known from the Lower Jurassic (Ramovš and Kristan-Tollmann 1967; Brönnimann et al. 1970; Gušić 1975; Gaździcki 1983; Blau 1987b; Blau and Haas 1991; Ebli 1993; Böhm et al. 1999). It was found in both measured

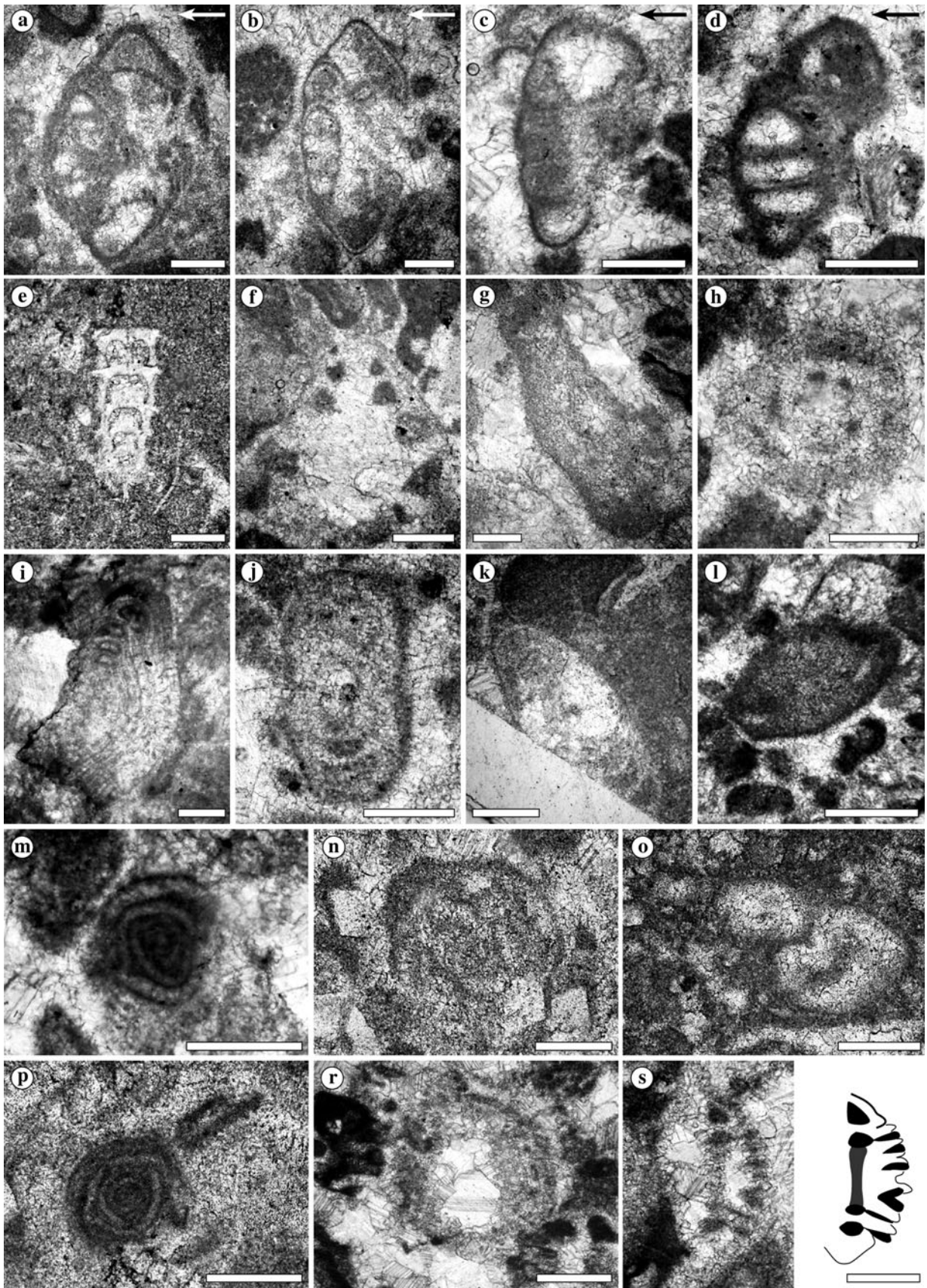
sections above the FAD of *M. posthernsteini*. Both species were also found in coexistence on Papua New Guinea by Kristan-Tollmann (1986b).

6.2.5 *Duostominidae*

The family Duostominidae comprises the genera *Duostomina*, *Diplostromina*, *Variostoma*, *Krikoumbilica* and *Papillaria* (di Bari and Laghi 1996). Duostominids first appeared in the Lower Triassic (Rettori et al. 1994; di Bari and Rettori 1996) and became extinct at the end of the Triassic (Kristan-Tollmann 1960; Chiocchini et al. 1994; di Bari and Rettori 1996; Hillebrandt and Urlichs 2008; Gale et al. 2011). They are among the most abundant foraminifera in both sections and are continuously present throughout the Slatnik Formation. As duostominids are easily recognisable as a group and cover a wide spectrum of environments, their LO makes a good marker for the Triassic-Jurassic boundary.

6.2.6 *Triasina hantkeni*

The type material of *Triasina hantkeni* was collected from Dachstein Limestone in Hungary by Majzon (1954). The age of the new species was determined in the absence of guide fossils as Norian and/or Rhaetian. Cros and Neumann (1964) determined species in the Rhaetian and/or Hettangian beds of the Dolomites. Again, the stratigraphic age was only robustly determined on the basis of superposition (above the Dolomia Principale and below Lower Jurassic beds). Oberhauser (1964) found *T. hantkeni* in Upper Norian (i.e. Rhaetian) beds of Austria. Bosellini and Broglio Loriga (1966) determined the species in the Rhaetian and/or Hettangian strata of the Dolomites and cited its age as undivided Norian-Hettangian. Pantić (1967) found the species in Serbia, Salaj et al. (1967), Gaździcki and Zawadzka (1973), Gaździcki et al. (1979) in the Western Carpathians, and Kristan-Tollmann (1970) in Austria. All place it in the Rhaetian. Bassoulet and Guernet (1970) confirmed its presence in Greece, marking the age as Rhaetian or Hettangian. Gaździcki (1974) gave the species range from the Norian and/or Rhaetian to Hettangian. Gušić (1975) declined the Hettangian age, because the association of *T. hantkeni* with Early Jurassic fossils was not proven. His opinion was followed by Zaninetti (1976) and Piller (1978). Gaździcki and Michalik (1980) finally determined the overlapping ranges of *T. hantkeni*, the bivalve *Rhaetavicula contorta* and the conodont *M. posthernsteini*. According to Gaździcki (1983), the range of *T. hantkeni* (*T. hantkeni* and *Glomospirella friedli* Assemblage Zone) corresponds to “*Choristoceras*” *haueri* and “*Choristoceras*” *marshi* ammonoid zones. Salaj et al. (1983) assumed that the age



◀ **Fig. 11** Foraminifera from the Mt. Kobla and Mt. Slatnik sections. Scale bar 200 µm, in figure e 100 µm, in figure r 400 µm. Arrow in figures a–d shows the correct orientation of specimens. **a** ?*Duostomina biconvexa*. Sample K2-76.30. **b** *Diplotremina subangulata*. Sample 70322. **c** *Diplotremina placklesiana*. Sample K2-70.40. **d** ?*Diplotremina astrofimbriata*. Sample 70329. **e** *Austrocolomia canaliculata*. Sample 70294. **f** *Trocholina crassa*. Sample 70327. **g** *Aulotortus tumidus*. Sample 70326. **h** *Aulotortus friedli*. Sample 70326. **i** *Aulotortus sinuosus*. Sample 70627. **j** *Angulodiscus impressus*. Sample 70298. **k** *Angulodiscus communis*. Sample K2-91.30. **l** *Auloconus permodisoides*. Sample 70295. **m** *Ophthalmidium exiguum*. Sample 70067. **n** *Pilamina sulawesiana*. Sample 70081. **o** *Cucurbita cylindrica*. Sample 70071. **p** ?*Ophthalmidium walfordi*. Sample 70072. **r** *Triasina hantkeni*. Sample 70247. **s** *Involutina turgida* (with hand-drawing). Sample 70256

of *T. hantkeni* corresponds to the “*Choristoceras*” *marshi* ammonoid zone, but with a possibility of its presence already in the upper part of the older “*Rhabdoceras*” *suessi* zone. According to Krystyn et al. (2007a, b), the *Paracochloceras suessi* zone starts with the FAD of *M. posthernsteini*. However, there is a dispute, as Krystyn et al. (2007a, b) place the FO of *T. hantkeni* (with question mark), as well as the FO of *R. contorta*, already in the lower part of their Sevatian 1. Ciarapica and Zaninetti (1984), Abate et al. (1984) and Dumont and Zaninetti (1985) placed *T. hantkeni* zone in the Rhaetian. Following the chronological order of publications, the species was later found in the Norian and/or Rhaetian Dachstein Limestone of the Transdanubian Range (Oravec-Scheffer 1987), in Albania (Pirdeni 1988) and in Japan (Kristan-Tollmann 1990). At the same time, Peybernes et al. (1988) cited *T. hantkeni* zone from *Rhaetavicula contorta* beds in French Pyrenees. Zaninetti et al. (1992) and Chiocchini et al. (1994) attributed *T. hantkeni* zone (respectively *T. hantkeni* and *Griphoporella curvata* zone) to the Rhaetian. Martini et al. (1995) adopted a Late Norian to Rhaetian age of *T. hantkeni*; however, their specimens from Indonesia were found above the FAD of *M. posthernsteini*. Peybernes et al. (1988) count *T. hantkeni* as solely Rhaetian in age. Grgasović (2003, unpublished) declines the Late Norian age of *T. hantkeni*. According to him, the FO of *T. hantkeni* corresponds to the FO of *R. contorta* and the FO of *M. posthernsteini*. He correlates this event with the base of the *Vandaites sturzenbaumi* zone, which is, however, again not in accordance with data from the Steinbergkogel section (Krystyn et al. 2007a, 2007b). Martini et al. (2004) and Mancinelli et al. (2005) kept the Late Norian to Rhaetian age of the *T. hantkeni* zone. Velić (2007) names *T. hantkeni* the guide fossil for the Rhaetian, but does not refer to other fossil groups.

To summarise: (1) the total range of *T. hantkeni* corresponds to the range of the “*Choristoceras*” *haueri* and “*Choristoceras*” *marshi* ammonoid zones, sensu Gaździcki (1983); (2) the FO of *T. hantkeni* is co-temporal or younger than the FAD of *M. posthernsteini* (see Gaździcki and

Michalik 1980; Martini et al. 1995); (3) the range of *T. hantkeni* overlaps with the range of *R. contorta* (see Gaździcki and Michalik 1980). When the FAD of *M. posthernsteini* is chosen as the base of the Rhaetian, *T. hantkeni* marks the Rhaetian age.

Triasina hanteni was found only in the Mt. Slatnik section in a single level, just above the last occurrence of *T. oberhauseri* and well above the Norian-Rhaetian boundary.

6.2.7 *Triasina oberhauseri*

Triasina oberhauseri is often included in foraminiferal biostratigraphy (Gaździcki et al. 1979; Salaj 1977; Gaździcki 1983; Zaninetti et al. 1992). However, the stratigraphic range of the species is not clearly defined and is poorly correlated with other fossil groups (Röhl et al. 1991). Salaj (1977) placed its FO in the Middle Norian (Alaunian). Gaździcki et al. (1979) established the *Semiinvoluta clari*—*Triasina oberhauseri* Assemblage Zone, spanning the Alaunian—Sevatian interval. Gaździcki (1983) later cited the Lacinian—Lower Rhaetian age, from the *Mojsisovicsites kerri* to *Cochloceras suessi* ammonoid zones. Specimens defined by Bystrický (1975) as *Triasina hantkeni* were revised as *T. oberhauseri*; thus, the co-existence of the latter species with *Rhaetavicula contorta* and *Austrihrynchia cornigera* (both considered as index species of the Rhaetian s.s.—cf. Gaździcki et al. 1979; Grgasović 2003, unpublished) was proven (Gaździcki 1983). Salaj et al. (1983) showed *T. oberhauseri* as spanning the Alaunian “*Halorites* horizon”, the “*Rhabdoceras*” *suessi* and the lower part of the “*Choristoceras*” *marshi* ammonoid zone, thus reaching the lower Rhaetian s.s. The Norian to basal Rhaetian (i.e., the lower part of the *Triasina hantkeni* Total Range Zone) range was also cited by Abate et al. (1984). In the zonation by Peybernes et al. (1988) the *Triasina oberhauseri* Total Range Zone spans only Lacinian and Alaunian time, but no explanation is given.

In summary, the upper limit of *T. oberhauseri* could be placed above the FAD of *M. posthernsteini*.

Triasina oberhauseri is rare in the Mt. Kobla section, with only one reliable and one unreliable determination. Both specimens are from the same interval, inside the range of *M. posthernsteini*. The species’ LO is slightly below the FO of *Tr. turris*. In the Mt. Slatnik section, *T. oberhauseri* first occurs about 13 m below the FAD of *M. posthernsteini*. It reaches high into the Rhaetian and its LO is just below the single occurrence of *T. hantkeni*.

6.3 Foraminifera with extended ranges

Based on the data from the Mt. Kobla and Mt. Slatnik sections, the stratigraphic ranges of some taxa are

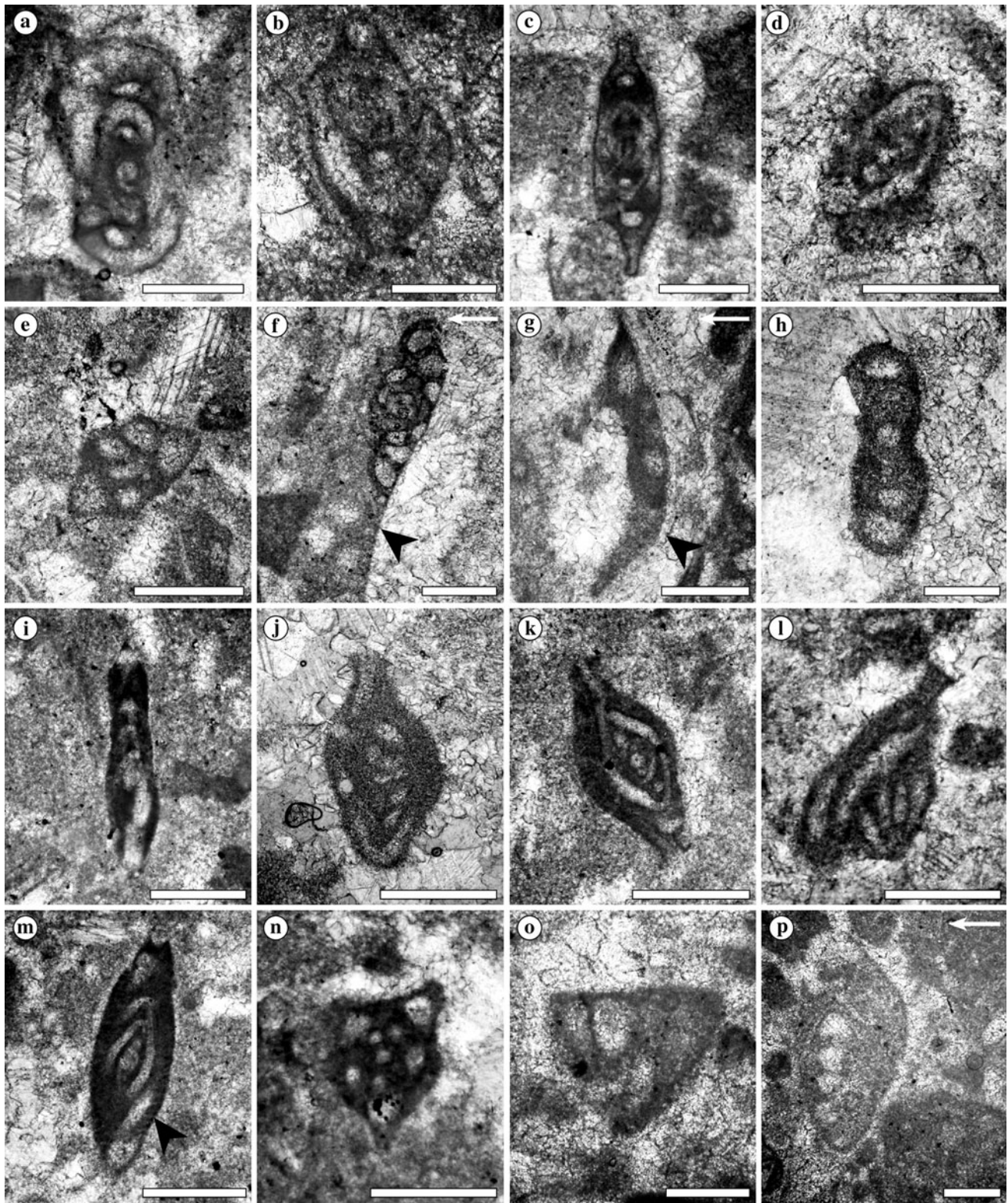


Fig. 12 Foraminifera from the Mt. Kobra section. *Scale bar* 200 μm , in figure **d** 50 μm , in figures **b**, **h** 100 μm . *Arrows* in figures **f**, **g**, **p** show the correct orientation of specimens. **a**, **b** Longitudinal section of *G. tollmanni*. Sample 70298. **c** *Bispiranella salaji* comb. nov. Sample 70327. **d**, **e** *Agathammina austroalpina*. Sample 70293. **f** *Planiinvoluta carinata*. Sample 70277. **g** *Planiinvoluta deflexa*. Arrowhead points to the

surface of attachment (shell). Sample K2-51.60. **h** *Ophthalmidium leischneri*. Sample K2-51.60. **i** *Ophthalmidium carinatum*. Sample 70277. **j** *Hydrania dulloi*. Sample K2-30.70. **k**, **m** *Miliolipora cuvillieri*. Note coarse pores (arrowhead) in figure **k**. Sample 70308. **l** Miliolida. Sample 70276. **n** ?*M. cuvillieri*. Sample 70308. **o** *Variostoma coniforme*. Sample 70306. **p** ?*Duostomina turboidea*. Sample 70304

extended. Table 1 gives a shortened synonymy list for these species and their stratigraphic ranges according to the literature data, compared with the data from the Slovenian Basin. Besides the stratigraphic ranges of foraminifera according to the literature, we also give our own (L.G.) opinion on the stratigraphic ranges of the species. The range is considered extended when differing from the general information given in the literature (i.e. compared to the ranges without discarding questionable or wrong determinations). In contrast, Fig. 2 shows the ranges according to the critical evaluation of the literature.

6.4 Foraminiferal demise at the Triassic-Jurassic boundary

Foraminifera are often cited as a group that was not affected by environmental changes at the Triassic-Jurassic boundary (e.g., Hallam 2002; Tanner et al. 2004). In contrast, Kuznetzova et al. (2004) reported an extinction of about 32 % of the genera and two orders at the boundary. Galli et al. (2005) argued for a true extinction of the shallow-water benthic foraminifera at the TJB that was not simply the result of a habitat loss. Pálffy et al. (2007) marked significant changes in the foraminiferal assemblage, but these are partly masked by facies changes. The assemblage immediately after the TJB thus contains only long-ranging taxa, without typical Lower Jurassic forms (Pálffy et al. 2007). A prolonged period of recovery was observed also by Fugagnoli (2004) and Barattolo and Romano (2005). Kuerschner et al. (2007) and Hillebrandt and Urlichs (2008) showed that changes also happened among the planktonic foraminifera. Clémence et al. (2010) marked a substantial decline in diversity and abundance in the intra-platform basins of the Northern Calcareous Alps that took place simultaneously with the crisis of nannoplankton, and the post-traumatic foraminiferal assemblage is dominated by a disaster genus » *Trochammina* «. Kaminski et al. (2010) quantified changes in diversity among agglutinated foraminifera, but these were only mildly affected at the boundary.

The presence of possible hiatus in the upper part of the Slatnik Formation does not allow detailed tracking of the changes in the foraminiferal assemblage, but a marked difference between the Late Triassic and the Lower Jurassic assemblages can nevertheless be observed. Empirical observations of the changes in the foraminiferal assemblage were quantified using the Shannon-Wiener index H' (see Hammer and Harper 2006; Türkmen and Kazanci 2010). To exclude the differences in diversity due to (micro)facies differences, only coarse-grained packstones and fine-grained rudstones were considered. The diversity index thus reflects changes in reef and back-reef area, i.e. in the source area for turbidity currents.

Figure 13 shows changes in diversity for the Mt. Slatnik and Mt. Kobla sections. The average value of H' prior to the TJB is 1.86 (Mt. Slatnik) and 2.23 (Mt. Kobla), and it drops after the TJB down to 0.82 and 0.35, respectively. The relatively high average values of H' for the Slatnik Formation match the idea of a community from a mature and stable reef environment (see Türkmen and Kazanci 2010). The higher H' values for Mt. Kobla section are attributed solely to the higher proportion of packstones relative to rudstones, due to the more distal position of the section.

The foraminiferal assemblage of the Slatnik Formation is markedly more diversified than the assemblage of the Krikov Formation, despite the same granulation of sampled beds. The diversity is lower, especially on account of foraminifera from the reef-area and duostominids. Both groups completely disappear at the Triassic-Jurassic boundary. The diversity is also lower among the back-reef foraminifera. As is evident from the grain composition, the platform morphology changed from reef-rimmed in Late Triassic to a carbonate ramp in Lower Jurassic. The disappearance of reef-dwelling foraminifera can thus be explained solely with the loss of their habitat, i.e. reefs. The disappearance of reefs in the Tethyan area is well known (Flügel 2002; Kiessling et al. 2007) and is attributed to the fall in relative sea-level (Borsato et al. 1994; McRoberts et al. 1997; Hallam and Wignall 1999; Hallam 2002; Hautman 2004; Lucas and Tanner 2004; Jadoul et al. 2005; Lindström and Erlström 2006; Ciarapica 2007; Khalifa 2007; but see Gómez et al. 2007), followed by transgression of oxygen-depleted water (Barras and Twitchett 2007; Ruhl et al. 2010), or to a biocalcification crisis (e.g. McRoberts and Newton 1995; McRoberts et al. 1997; Galli et al. 2005; Huynh and Poulsen 2005; Iannace et al. 2005; Ciarapica 2007; van de Schootbrugge et al. 2007; Ruhl et al. 2010; Črne et al. 2011). As yet, there is no evidence for a sea-level fall from this area.

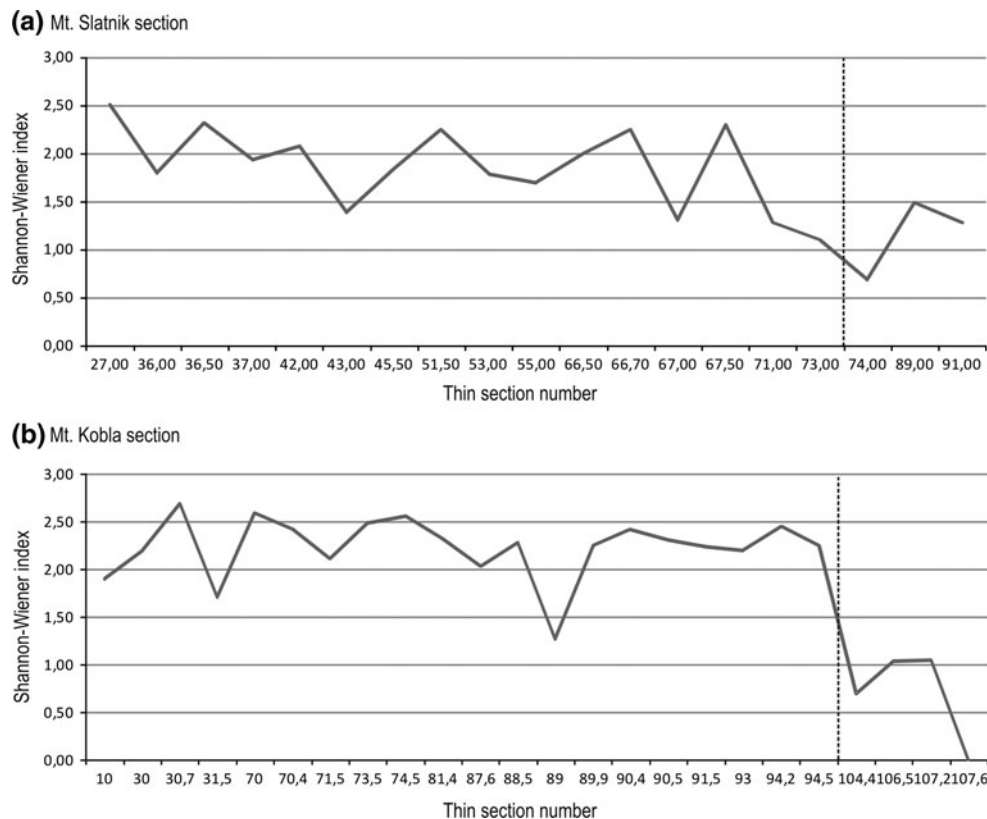
The boundary was crossed by ecologically less demanding taxa, which could occupy a broader set of environments, especially small lagenids, simple agglutinates and *Ophthalmidium*. They are soon joined by few other taxa (*Duotaxis* spp., *Siphovalvulina* spp., Involutinidae), which lived on the platform. According to the literature (see Fig. 2) other species are expected to cross the boundary: *D. birmanica*, *D. metula*, *Tr. umbo*, *Tr. turris*, *I. turgida*, *C. deminuta*, *C. etrusca*, *C. austriaca*, *P. carinata*, *O. carinatum*, *O. leischneri* and ?*O. walfordii*. Of these, only *P. carinata* was found immediately above the boundary. Other species could be Lazarus taxa, therefore re-entering the community higher up in the sections.

Whether the disappearance of shallow-water foraminifera could be explained by changes in relative sea-level, this does not hold for duostominids. Representatives of this

Table 1 Shortened synonymy list for foraminiferal species from the Mt. Kobia and Mt. Slatnik sections, whose stratigraphic ranges have been changed (see text)

Species (with reliability of determination)	Synonymy list (*questionable or wrong determination; **determined as different species; p.p. part of the material correctly identified)	Stratigraphic range according to the literature data (assuming all determinations are correct)	Stratigraphic range based on the critical evaluation of the literature determinations (wrong and questionable determinations excluded)	Local range in the Mt. Kobia and Mt. Slatnik sections (extended range in bold)
<i>G. triadica</i> (?)	Kristan-Tollmann (1964), p.p. Salaj et al. (1983), *Oravec-Scheffer (1987), Kobayashi et al. (2006)	Anisian - Norian	Anisian	Norian and Rhaetian
<i>E. amplimuralis</i> (+)	Pantić (1972), Borza (1975), Salaj et al. (1983), Oravec-Scheffer (1987), Rettori et al. (1994), Bérczi-Makk (1996c), Isintek et al. (2000)	Anisian - Norian	Anisian - Norian	Norian - Rhaetian
<i>E. bicamerata</i> (+)	Salaj et al. (1967), Trifonova (1993), *Fontaine et al. (1988), Bérczi-Makk (1996b)	Anisian - Norian (cf. Trifonova, 1993)	Anisian - Norian	Norian - Rhaetian
<i>C. etrusca</i> (?)	Pirini (1966), Blau (1987a, b), Böhm et al. (1999), Velledits and Blau (2003)	Early Jurassic	Early Jurassic	Norian - Rhaetian
<i>O. walfordii</i> (?)	**Zaninetti et al. (1982), Gaździcki (1983)	Rhaetian - Early Jurassic (cf. Gaździcki, 1983)	Rhaetian - Early Jurassic	Norian
<i>Di. placklesiana</i> (+)	Kristan-Tollmann (1960), **Babić et al. (1979), **Oravec-Scheffer (1987), **Ciarapica et al. (1987), **Benjamini (1988), Vettorel (1988), *Kristan-Tollmann (1990, 1991), **Röhl et al. (1991), p.p. Zaninetti et al. (1992), **Kobayashi (1996)	Rhaetian	Carnian - Rhaetian	Norian - Rhaetian
<i>Di. astrofimbriata</i> (?)	Kristan-Tollmann (1960), p.p. Premoli-Silva (1971), *Gaździcki and Smit (1977), *Babić et al. (1979), *Kristan-Tollmann (1983), *Salaj et al. (1983), *He (1984), p.p. Oravec-Scheffer (1987), *Benjamini (1988), *Vettorel (1988), p.p. Kristan-Tollmann (1991), *Trifonova (1994), *Bérczi-Makk (1996a, 1996b), *Kobayashi (1996), *He (1999), *Kobayashi et al. (2005)	Anisian - Norian (cf. Trifonova, 1994)	Anisian - Rhaetian	Rhaetian
<i>Du. turboidea</i> (+)	Kristan-Tollmann (1960), Vettorel (1988), *Bérczi-Makk (1996b)	Carnian - Rhaetian (cf. Vettorel, 1988)	Ladinian - Carnian	Norian - Rhaetian
<i>V. falcata</i> (?)	**Kristan-Tollmann (1964), Kristan-Tollmann (1973)	Carnian	Carnian	Norian
<i>A. cordevolica</i> (?)	Oberhauser (1967)	Rhaetian	Rhaetian	Norian
<i>C. klebelsbergi</i> (?)	Oberhauser (1960), *Gaździcki et al. (1978), *Salaj et al. (1983), Di Bari (1997)	Permian, Anisian - Ladinian (cf. Salaj et al., 1983)	Ladinian	Norian
<i>N. ordinata</i> (+)	**Nagy (1964), Trifonova (1965), *Gaździcki (1974), *Gaździcki et al. (1975), *Salaj et al. (1983), *Trifonova & Čatalov (1983), p.p. Oravec-Scheffer (1987), Salaj et al. (1988), *Kristan-Tollmann (1990), Trifonova (1994), *Marquez et al. (1994), *Bérczi-Makk (1996b), **Bérczi-Makk (1996b)	Ladinian - Norian - Rhaetian? (cf. Trifonova, 1994)	Ladinian - Rhaetian	Rhaetian
<i>P. obconica</i> (+)	Oravec-Scheffer (1965), **Resch (1972), Trifonova (1977), p.p. Oravec-Scheffer (1978), *Trifonova & Čatalov (1983), Oravec-Scheffer (1987), Trifonova & Čatalov (1988), Samuel (1991), Trifonova (1994), *Bérczi-Makk (1996c), p.p. Pevný & Salaj (1997), He (1999)	Ladinian - Norian (cf. Trifonova, 1994)	Ladinian - Carnian	Rhaetian

Fig. 13 Changes in Shannon-Wiener diversity index in Mt. Slatnik (a) and Mt. Kobra (b) sections. Numbers on horizontal axis indicate meters in Figs. 6 and 8. The dashed vertical line separates samples from the Slatnik Formation (left) from samples from the Krikov Formation (right) and roughly coincides with the Triassic-Jurassic boundary. The ragged appearance of the diversity line is due to differences in granulation, as the influence of lithology could not be totally reduced



family can be found in a broad set of environments, from the platform (Hohenegger and Lobitzer 1971; Schäfer and Senowbari-Daryan 1978; Wurm 1982; Bérczi-Makk 1996a; Martini et al. 2004) to the basin (Kristan-Tollmann 1986a, 1988, 1990; di Bari and Baracca 1998). The disappearance of duostominids could point to a change in biochemical factors (oxygen level or ocean acidification, i.e. the biocalcification crisis), not merely to the habitat loss. A better understanding of the ecological demands of duostominids could thus provide further answers about environmental changes at the Triassic-Jurassic boundary.

7 Conclusions

The Slatnik Formation comprises interfingering hemipelagic limestones and calciturbidites deposited during the Late Norian-end-of-Rhaetian in the northern part of the Slovenian Basin (Rožič et al. 2009). Shallow water benthic foraminifera, derived from the adjacent Julian Carbonate Platform (cf. Buser 1986, 1989, 1996) are present, in addition to conodonts.

The NRB is placed at the FAD of *M. posthernsteini*, while foraminifera are not a good marker for this boundary. The exception could be the FO of *Involutina turgida*. The TJB is defined with the LO of duostominids and some other

typical Late Triassic foraminifera, such as *G. tollmanni* and “*S.*” *schaeferae*.

An abrupt and significant change in foraminiferal assemblage from highly diversified to severely depleted is recorded across the TJB. While the disappearance of reef and back-reef dwelling forms could be explained solely by the change in relative sea-level, the extinction of duostominids cannot be related to the loss of their habitat. Thus, a biocalcification crisis seems a plausible explanation.

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Appendix A

Foraminifera recognized in Mt. Slatnik and Mt. Kobra sections (see Figs. 9–12).

Ammodiscus parapriscus Ho, 1959

Gandinella falsofriedli (Salaj, Borza & Samuel, 1983)

Pilamina sulawesiana Martini, Vachard & Zaninetti, 1995

- Kaeveria fluegeli* (Zaninetti, Altiner, Dager & Ducret, 1982)
- Palaeolituonella meridionalis* (Luperto, 1965)
- Alpinophragmium perforatum* Flügel, 1967
- Duotaxis birmanica* Zaninetti & Brönnimann, in Brönnimann et al., 1975
- Gaudryina triadica* Kristan-Tollmann, 1964
- Gaudryinella clavuliniformis* Trifonova, 1967
- Reophax rudis* Kristan-Tollmann, 1964
- Reophax asperus* Cushman & Waters, 1928
- Scherochorella eominutus* (Kristan-Tollmann, 1964)
- Ammobaculites corpulentus* Efimova, 1974
- “*Trochammina*” *almtalensis* Koehn-Zaninetti, 1969
- “*Trochammina*” *jaunensis* Brönnimann & Page, 1966
- Earlandia tintinniformis* (Mišik, 1971)
- Earlandia amplimuralis* (Pantić, 1972)
- “*Tetrataxis*” *humilis* Kristan, 1957
- Endotriada tyrrhenica* Vachard, Martini, Rettori & Zaninetti, 1994
- Endotebanella bicamerata* (Salaj in Salaj et al., 1967)
- Involutina turgida* Kristan, 1957
- Trocholina umbo* Frentzen, 1941
- Trocholina crassa* Kristan, 1957
- Trocholina turris* Frentzen, 1941
- Aulotortus tumidus* (Kristan-Tollmann, 1964) emend. Piller, 1978
- Aulotortus sinuosus* Weynschenk, 1956
- Aulotortus friedli* (Kristan-Tollmann, 1962) sensu Piller (1978)
- Angulodiscus impressus* Kristan-Tollmann, 1964
- Angulodiscus communis* Kristan, 1957
- Auloconus permodisoides* (Oberhauser, 1964)
- Triasina oberhauseri* Koehn-Zaninetti & Brönnimann, 1969
- Triasina hantkeni* Majzon, 1954
- Coronipora deminuta* Blau, 1987
- Coronipora etrusca* (Pirini, 1966)
- Coronipora austriaca* (Kristan, 1957)
- Planiinvoluta carinata* Leischner, 1961
- Planiinvoluta deflexa* Leischner, 1961
- Ophthalmidium carinatum* (Leischner, 1961)
- Ophthalmidium leischneri* (Kristan-Tollmann, 1962)
- Ophthalmidium exiguum* Koehn-Zaninetti, 1969
- ?*Ophthalmidium walfordi* Häusler, 1887
- Hydrania dulloi* Senowbari-Daryan, 1983
- Galeanella tollmanni* (Kristan, 1957)
- Bispiranella salaji* (Samuel & Borza, 1981) comb. nov.
- Miliolipora cuvillieri* Brönnimann & Zaninetti in Brönnimann et al., 1971
- Miliolipora tamarae* Gale, Rettori & Martini in Gale et al., 2011
- Cucurbita cylindrica* (Senowbari-Daryan, 1983)
- Agathammina austroalpina* Kristan-Tollmann & Tollmann, 1964
- “*Sigmoilina*” *schaeferae* Zaninetti, Altiner, Dager & Ducret, 1982
- Miliolechina stellata* Zaninetti, Ciarapica, Cirilli & Cadet, 1985
- Diploremmina subangulata* Kristan-Tollmann, 1960
- Diploremmina placklesiana* Kristan-Tollmann, 1960
- ?*Diploremmina astrofimbriata* Kristan-Tollmann, 1960
- Duostomina turboidea* Kristan-Tollmann, 1960
- ?*Duostomina biconvexa* Kristan-Tollmann, 1960
- Duostomina* sp. A
- Variostoma coniforme* Kristan-Tollmann, 1960
- Variostoma catilliforme* Kristan-Tollmann, 1960
- Variostoma cochlea* Kristan-Tollmann, 1960
- Variostoma falcata* Kristan-Tollmann, 1973
- ?*Variostoma helicta* (Tappan, 1951)
- Austrocolomia canaliculata* (Kristan-Tollmann, 1964) sensu Oberhauser, 1967
- ?*Austrocolomia cordevolica* Oberhauser, 1967
- ?*Cryptoseptida klebelsbergi* (Oberhauser, 1960)
- Nodosaria ordinata* Trifonova, 1965
- Pseudonodosaria obconica* (Reuss, 1868)

Appendix B

Conodonts recognized in Mt. Slatnik and Mt. Kobla sections (see Figs. 3–4).

- Epigondolella* ex gr. *E. abneptis* (Huckriede, 1958)
- Epigondolella bidentata* Mosher, 1968
- Epigondolella* ex gr. *E. postera* (Kozur & Mostler, 1971)
- Misikella buseri* Kolar-Jurkovšek, 2011
- Misikella hernsteini* (Mostler, 1967)
- Misikella posthernsteini* Kozur & Mock, 1974
- Misikella* sp. A
- Misikella* sp. B
- Misikella* sp.
- Norigondolella steinbergensis* (Mosher, 1968)
- Oncodella paucidentata* (Mostler, 1967)
- Parvigondolella andrusovi* Kozur & Mock, 1972
- Parvigondolella lata* Kozur & Mock, 1974
- Zieglerioconus rhaeticus* Kozur and Mock, 1991

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