ZAGROSELLA RIGAUDII N. GEN., N. SP., A NEW BIOKOVINOIDEAN FORAMINIFER FROM THE MAASTRICHTIAN OF IRAN

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Abstract A new larger benthic foraminifera, *Zagrosella rigaudii* n.gen., n.sp., is described from the Late Maastrichtian of the Tarbur Formation of the Zagros Zone, SW Iran. The new taxon represents almost a homeomorph to the Early Jurassic *Biokovina gradacensis* Gušić. The wall structure of *Zagrosella* n.gen. appears more evolved with larger parapores whereas in *Biokovina* these are thinner, and bifurcating. There are also differences in the endoskeletal structures, being more massive (in the central part of the test) and may fuse in *Biokovina* whereas in *Zagrosella* they occur preferentially on the sides of the chambers, and never fused. *Zagrosella rigaudii* n.gen., n.sp. represents one of the youngest representatives of the Biokovinoidea, a group that became extinct at the Cretaceous-Paleogene boundary.

Keywords: Larger benthic foraminifera, *Biokovinidae*, wall structure, systematics, biostratigraphy

INTRODUCTION

The Late Cretaceous Tarbur Formation, named after the village of Tarbur (Fars Province), and cropping out in the SW Zagros basin, represents a predominantly carbonatic lithostratigraphic unit that contains rich microfauna and microflora associated with rudists (James and Wynd, 1965). It extends from the northwest to the southeast of the Zagros basin along the western edge of the imbricated Zagros zone, between the main Zagros fault and the Sabzposhan fault to the east (Alavi, 2004). Towards the southwest, the Tarbur Formation interfingers with the Gurpi Formation that usually underlies the former in other areas. In the stratigraphic chart of Iran provided in 1995 by the Geological Society of Iran, the Tarbur Formation is assigned to the Campanian-Maastrichtian interval, following the pioneer work of James and Wynd (1965). But, the microfaunal content of the Tarbur Formation is still poorly constrained. Some taxa of benthic foraminifera are indicated and illustrated in various recently published papers (Vaziri-Moghadam et al., 2005; Afghah, 2009, 2016; Maghfouri-Moghaddam et al., 2009; Rajabi et al., 2011; Abyat and Lari, 2015; Abyat et al., 2012, 2015; Afghah and Farhoudi, 2012; Pirbaluti and Abyat, 2013; Pirbaluti et al., 2013; Pirbaluti and Abyat, 2013; Afghah and Yaghmour, 2014). Several determinations however are incorrect and therefore in need for revision.

Preliminary results and critical revisions of the micropalaeontology of the Tarbur Formation were published recently (Schlagintweit and Rashidi, 2016; Schlagintweit et al., 2016a-d). The present paper represents a further contribution to these studies with the description of a new larger agglutinated benthic foraminifera, *Zagrosella rigaudii* n.gen., n.sp. It is worth mentioning here that, this taxon has so far not been illustrated in previous papers on the Tarbur Formation.

STUDIED SECTIONS

The foraminiferal-bearing samples studied are from two sections of the Tarbur Formation (Fig. 1):

a) Naghan section.

The studied area in the folded Zagros belt is located approximately 50 km south west of Naghan town near Gandomkar village and is here named the Naghan section (Fig. 1). At this locality, the Tarbur Formation unconformably rests on the Gurpi Formation and is overlain by the Paleocene Sachun Formation. Lithologically, the Gurpi Formation consists of dark shale, grey calcareous shale with planktonic foraminifera. The Sachun Formation consists of gypsum, red shales, anhydrite and some layer of carbonates.

The thickness of the Tarbur Formation at the Naghan section is about ~ 274 m. It is composed of medium to thick –bedded grey limestone, shales and marls and can be subdivided into five units

- unit 1 (99 m), red to yellow shales
- unit 2 (61 m), medium- to thick-bedded grey limestones with *Loftusia* and rudist debris (calcarenites to calcirudites)
- unit 3 (33 m), intercalation of grey shales and cream to grey, medium- to thick-bedded limestones (cacilutites and calcarenite)
- unit 4 (38 m), thick-bedded to massive, grey to cream-coloured limestones containing broken rudist shells and tests of *Loftusia* (calcarenite, calcilutite to calcirudite)
- unit 5 (~ 41.6 m), shales interbedded with medium- to thick-bedded yellow limestones containing *Loftusia* fragments.

Zagrosella rigaudii n.gen., n.sp. appears in the lower part of unit 2 and disappears in the middle part of unit 4 (Fig. 2). Within this interval it is rather common and almost all specimens illustrated in the present paper are from the Naghan section. It occurs in foraminiferal wackestone-packstone, occasionally associated with dasycladalean algae (Fig. 3).

The Greenwich coordinates of the section base are N 31°47' 52" and E 50° 32' 53 ".

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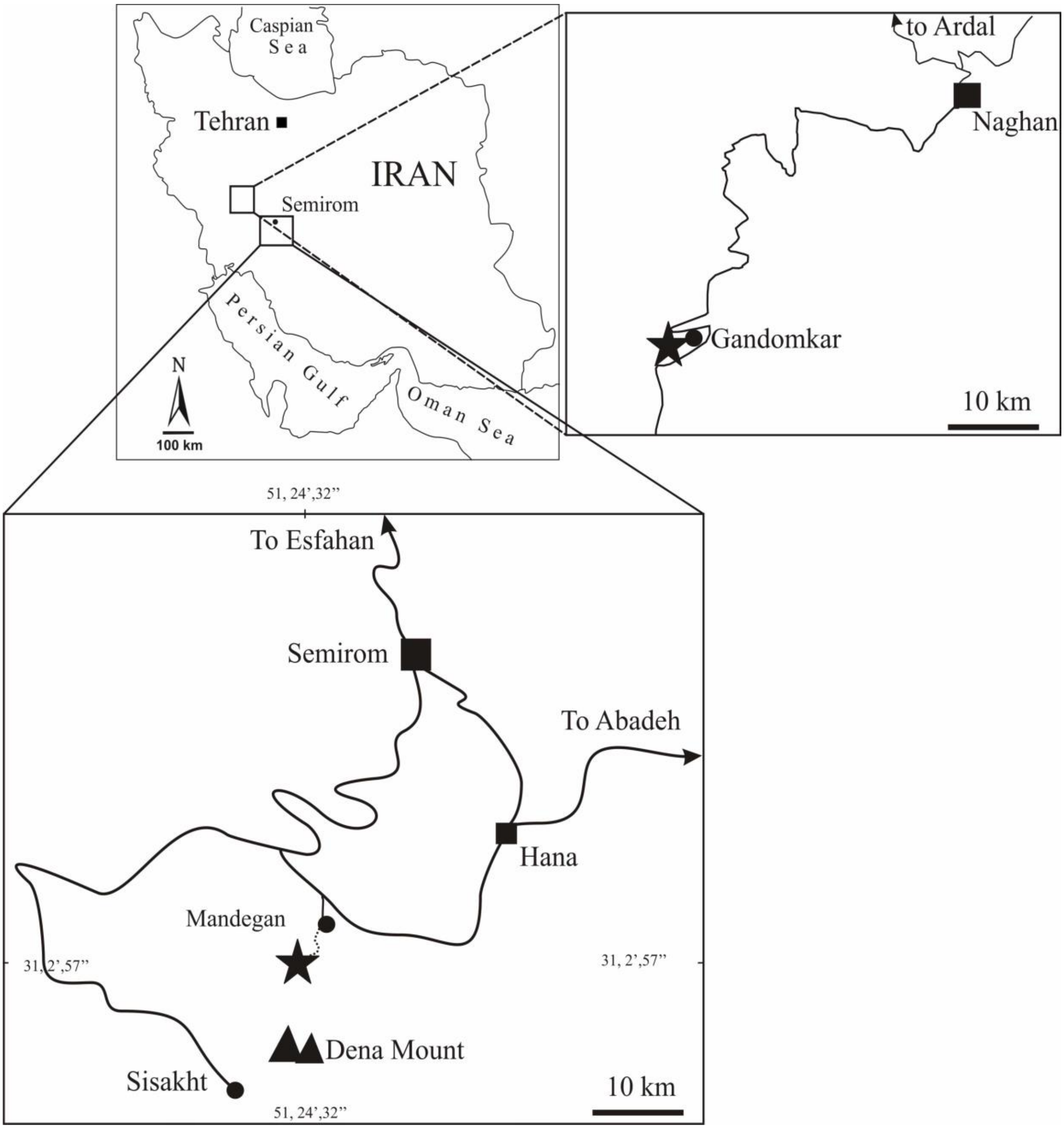

Fig. 1 Location of the studied area and Naghan sections.

a) Mandegan section.

The study area, located in the High Zagros Belt, is situated north of Mount Dena, about 65 km south of the town of Semirom. The section of the Tarbur Formation is exposed about 10 km south of the village of Mandegan, and is here named the Mandegan section (Fig. 1). Here the Tarbur Formation with a thickness of ~272 m overlies conformably the Gurpi Formation. The top of the section is unconformably overlain by conglomerates of the Pliocene Bakhtiari Formation (see Bahrami, 2009, for details). Based on the lithostratigraphy, the section has been subdivided into three units (from base to top): unit 1 is dominated by thick-bedded limestones, unit 2 mostly contains medium-bedded limestones with intercalated marly limestone layers, and unit 3 consists of marly limestone (see also Schlagintweit et al., 2016a, c). The microfacies of the samples bearing *Zagrosella rigaudii* n.gen., n.sp. is the same as for the Naghan section. The Green wich coordinates of the section base are N 31º, 25', 8.13" and E 51º, 24', 34.58".

MATERIAL AND DEPOSITORY

The specimens of the new taxon described and illustrated in the present contribution are from various thin-sections stored at the Ardakan Payame Noor University, Iran, in the Rashidi collection, under the original sample numbers with the prefixes Ng for the Naghan section, and Rt for the Mandegan section. The original material of *Biokovina gradacensis* Gušić, 1977 has been handed over to us for restudy and with the allowance for official storage lacking so far. The material includes 12 thin-sections that are now deposited at the Bayerische Staatssammlung für Paläontologie und historische Geologie, Munich, under the official numbers SNSB-BSPG 2016 XIX 1 to 12. They were formerly labelled Ve-514/1, /2, /4-5, /7-12, /14-15 in Gušić (1977).

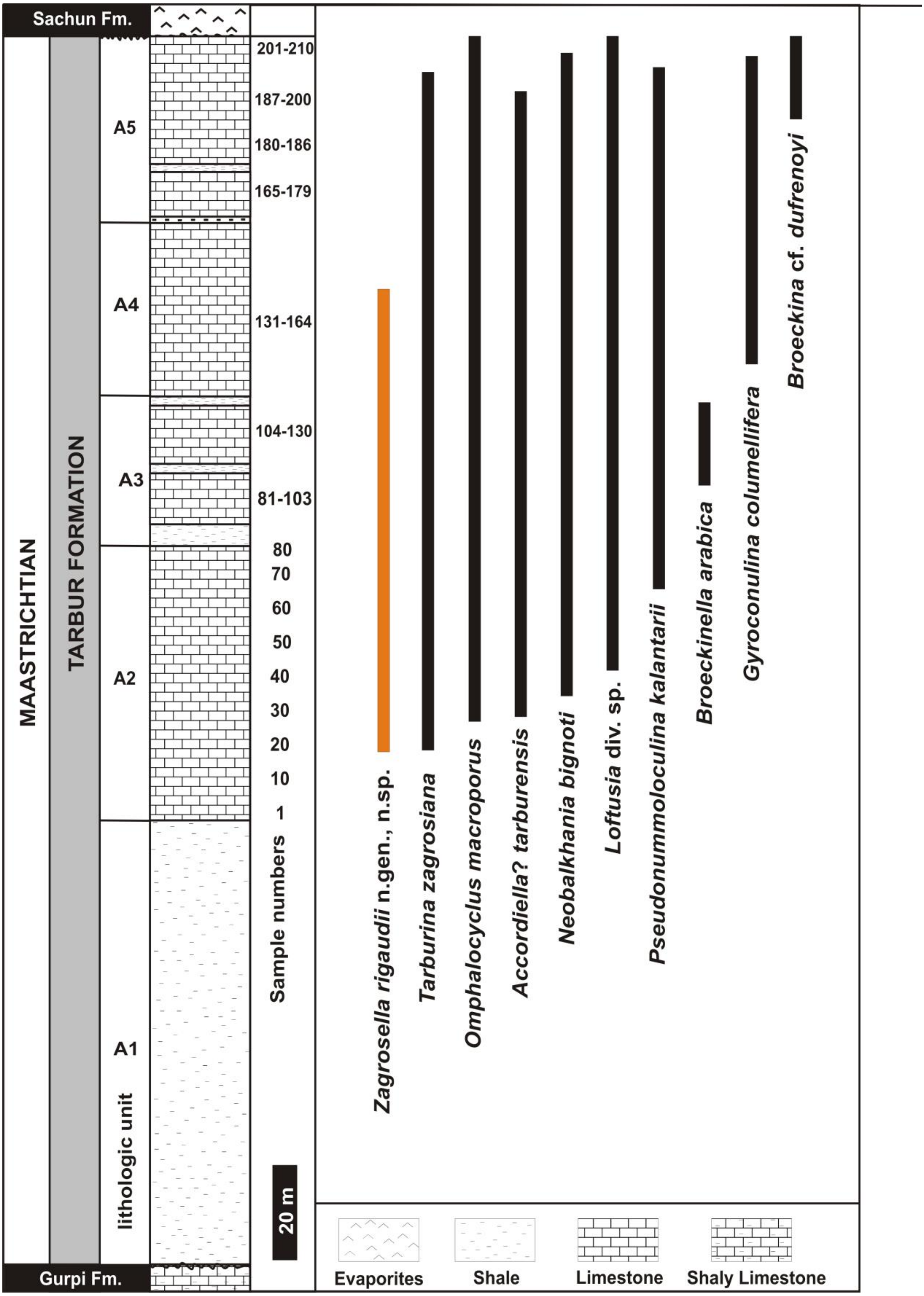

Fig. 2 Vertical distribution (total range) of selected taxa of larger benthic foraminifera in the Tarbur Formation of the Naghan section.

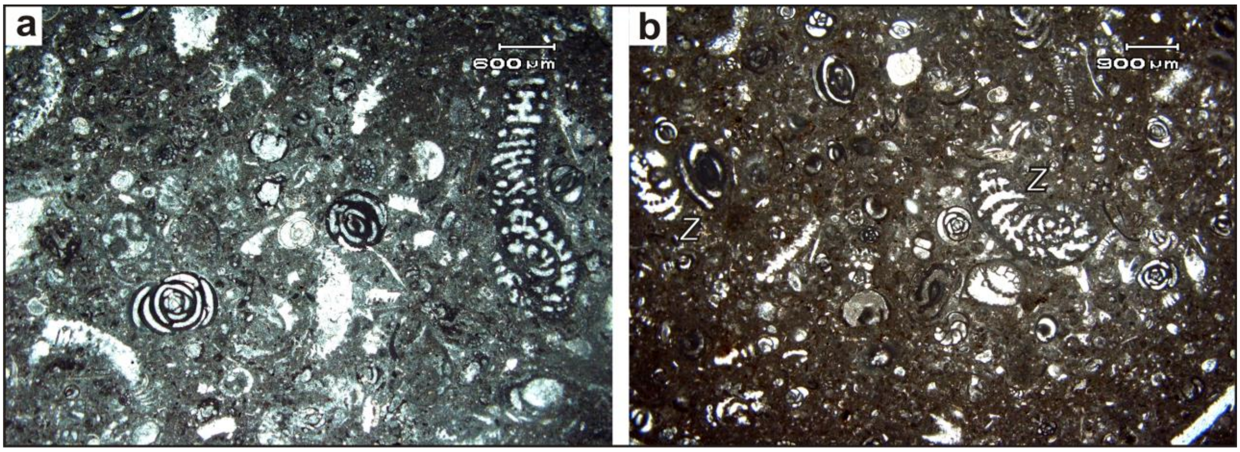

Fig. 3 Typical microfacies of samples with *Zagrosella rigaudii* n.gen., n.sp. (*Z*), from the upper Maastrichtian Tarbur Formation of the Naghan section. **a–b** Wackestones/packstones with benthic foraminifera, among many porcelaneous taxa, and remains of dasycladalean algae. Note the specimen with prominent enrolled stage and alternating pillars in the youngest chambers in **a** (right). Thin-sections: NG 8 (**a**), 2NG 85-4 (**b**).

SYSTEMATICS

The high-rank classification follows Pawlowski et al. (2013). For the low-rank classification see Kaminski (2014). For a glossary of terms, see Hottinger (2006).

Class Foraminifera d'Orbigny, 1826
Subclass Globothalamana Pawlowski et al., 2013
Order Loftusiida Kaminski & Mikhalevich, 2004
Suborder Biokovinina Kaminski, 2004
Superfamily Biokovinoidea Gušić, 1977
Family Biokovinidae Gušić, 1977

Remarks: Loeblich and Tappan (1987, p. 91) defined the Biokovinidae as follows: "Test enrolled, at least in early stage, later may uncoil; wall coarsely perforated, in section appearing almost keriothecal, and honeycomb-like in transverse section; aperture simple, single, or multiple. Jurassic". Loeblich and Tappan (1987) included the three genera *Biokovina* Gušić, 1977, *Bosniella* Gušić, 1977, and *Chablaisia* Septfontaine, 1978. The presence of internal structures (here: pillars) is not mentioned by Loeblich and Tappan (1987), but *Biokovina* possesses endoskeletal pillars. Mikhalevich (2004, p. 257) in addition included the presence of "phrenothekalike structures and endoskeletal elements (pillars)" in the diagnosis of the Biokovinidae. Concerning the "phrenothekalike structures" reference is made to comments included in the species comparison later in the present paper. Mikhalevich transferred *Chablaisia* to the pfenderinids and removed *Bosniella* from the Biokovinidae due to the lack of endoskeletal structures. In the recent classification of agglutinated benthic foraminifera provided by Kaminski (2014), the Biokovinidae includes the three genera *Biokovina* (with endoskeleton; no exoskeleton), *Bosniella* (neither endo- nor exoskeleton), and *Trochamijiella* Athersuch, Banner & Simmons, 1992 (without endoskeleton; with exoskeleton), taxa with and without internal structures. It is worth mentioning that *Trochamijiella* does not fit the family diagnosis provided by Loeblich and Tappan due to the lack of a perforated wall. The new genus *Zagrosella* is here placed into the family Biokovinidae with strict application of the diagnosis provided by Loeblich and Tappan (1987). In fact, at the actual state of knowledge there aren't other families of complex larger benthic foraminifera (with or without Cretaceous representatives) with equivalent or similar morphology and wall structure in which the Maastrichtian taxon from Iran can be accommodated. In any case, *Zagrosella* fits the diagnosis of the superfamily Biokovinoidea Gušić (= Biokovinacea Gušić in Loeblich and Tappan, 1987) whose range was indicated as Lower Jurassic (Middle Jurassic) to Maastrichtian, thereby becoming one of its youngest representatives.

Genus *Zagrosella* Schlagintweit & Rashidi, n.gen., n.sp.

Type species: *Zagrosella rigaudii* n.sp.

Origin of the name: The genus name refers to the Zagros Mountains in the southwestern part of Iran.

Horizon and locality: Late Maastrichtian limestones of the Tarbur Formation of the Naghan section (Figs. 1–2).

Description: Test free, rounded margin, oscillating coiling plane in the early stage, later planispiral, and finally maybe uncoiling, rectilinear. Dimorphism is most likely present. Proloculus of the megalospheric form elliptical to globular, with a large or few openings followed by entotebid-shaped chambers significantly increasing in width and height within a few whorls. Chambers in the adult uncoiled stage are saucer-shaped. Chamber interior with few and irregularly distributed endoskeletal pillars preferentially in the youngest chambers. Wall thick, dark-microgranular-like to agglutinated (= calcareous grains) with close-set simple unbranching parapores (pseudokeriotheca-like) displaying polygonal pattern in transverse sections; thin epidermis present, may be decorticated. Foramen basal to multiple in the juvenile stage, later multiple. In the adult part the width of the foramina almost attains the thickness of the massive septa. Possibly microspheric forms without observable proloculus, larger in diameter resulting from distinct broadening of chambers.

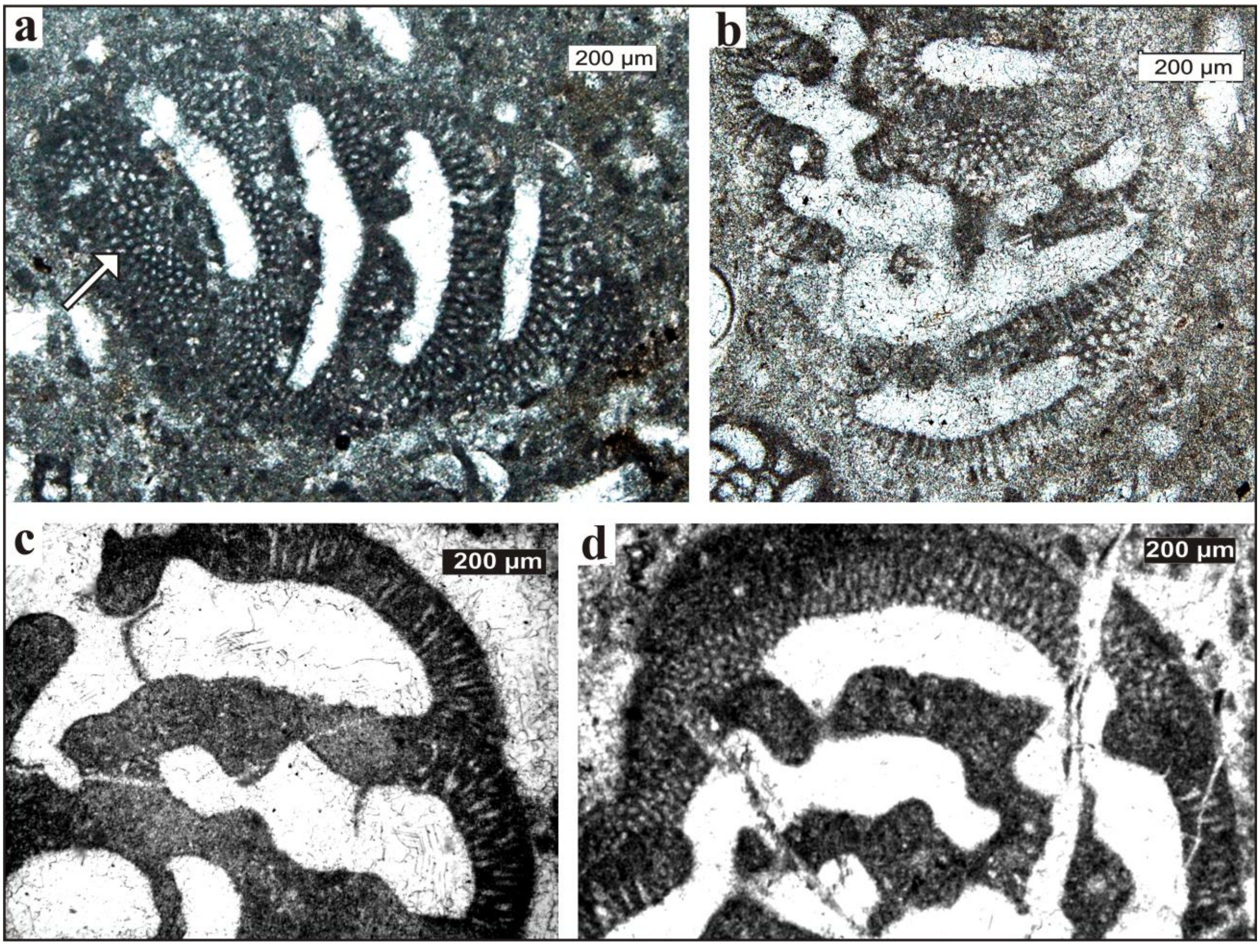

Fig. 4 Wall-structure of *Zagrosella rigaudii* n.gen., n.sp. from the upper Maastrichtian of SW Iran (**a–b**) and *Biokovina gradacensis* Gušić from the Liassic of Croatia (**c–d**). Polygonal parapores are marked with an arrow in **a**. Thin-sections: 2NG 27 (**a**), 2NG 87 (**b**).

Remarks and comparisons: The wall structure of *Zagrosella* with its "uniform, parallel, radial elements covered by some kind of tectum" (Hottinger, 2006, p. 29) can be compared with the keriotheca-like (or pseudokerithecal) texture of some Mesozoic larger benthic foraminifera (e.g., Schroeder et al., 1975; De Castro, 1981; Septfontaine, 1981; Banner et al., 1991; Rigaud et al., 2015). Regarding differences to parapores (or canaliculi), the differences are vague and not clearly delimited (Hottinger, 2006: "usually much larger"…"often more irregular"). *Zagrosella* n.gen. is morphologically very similar to the Liassic *Biokovina* Gušić, 1977, both monospecific genera. The wall structure of *Zagrosella* appears more evolved with larger parapores (diameter 0.01 to 0.03 mm, see description below) whereas in *Biokovina* these are thinner (but with overlapping range), and bifurcating (diameter ~0.01 to 0.15 mm). There are also differences in the endoskeletal structures, being more massive (in the central part of the test) and may fuse in *Biokovina* whereas in *Zagrosella* they occur preferentially on the sides of the chambers, sometimes only partially differentiated from the chamber wall, and never fused. They are here interpreted as pillars (originating from the septa), not as septula (originating from the wall) (see Hottinger, 2006) or strengthenings (see Rigaud et al., 2013). Another morphologically similar genus of the family Biokovinidae is *Bosniella* Gušić, 1977. It differs from *Zagrosella* above all by its chambers lacking any endoskeletal structures. In the Late Cretaceous, it can be compared to some extent (e.g., similar wall-structure, strengthenings) with *Braciana* Schlagintweit & Cvetko-Tesovic, 2016 (Santonian?-lower Campanian of Croatia). The latter differs from *Zagrosella* n.gen. above all by its test morphology (elongate compressed), and the foraminal characteristics (several close-set openings, equal in diameter to the wall alveolae, and may have short peristomal rims at their margins) (see Schlagintweit and Cvetko-Tešović, 2016 for details).

Last but not least we note morphological similarities to the Late Jurassic *Labyrinthina* Weynschenk that differs above all from *Zagrosiella* by its wall being "agglutinated, simple in structure, microgranular, imperforate" (Loeblich and Tappan (1987, p. 96).

Zagrosella rigaudii Schlagintweit & Rashidi, n.sp.
Figs. 3 pars, 4a–b, 5–7

Origin of the name: The species name refers to Sylvain Rigaud (Singapore) for his outstanding contributions to the micropalaeontology and phylogeny of benthic foraminifera.

Holotype: Slightly oblique equatorial section illustrated in Figure 5A, thin-section NG 88.

Paratypes: Figs. 5B–G, 6, 7A–B.

Description: Test free, lenticular, with oscillating plane of coiling in the early stage, later planispiral, and finally maybe uncoiling, rectilinear. It is compressed axially,

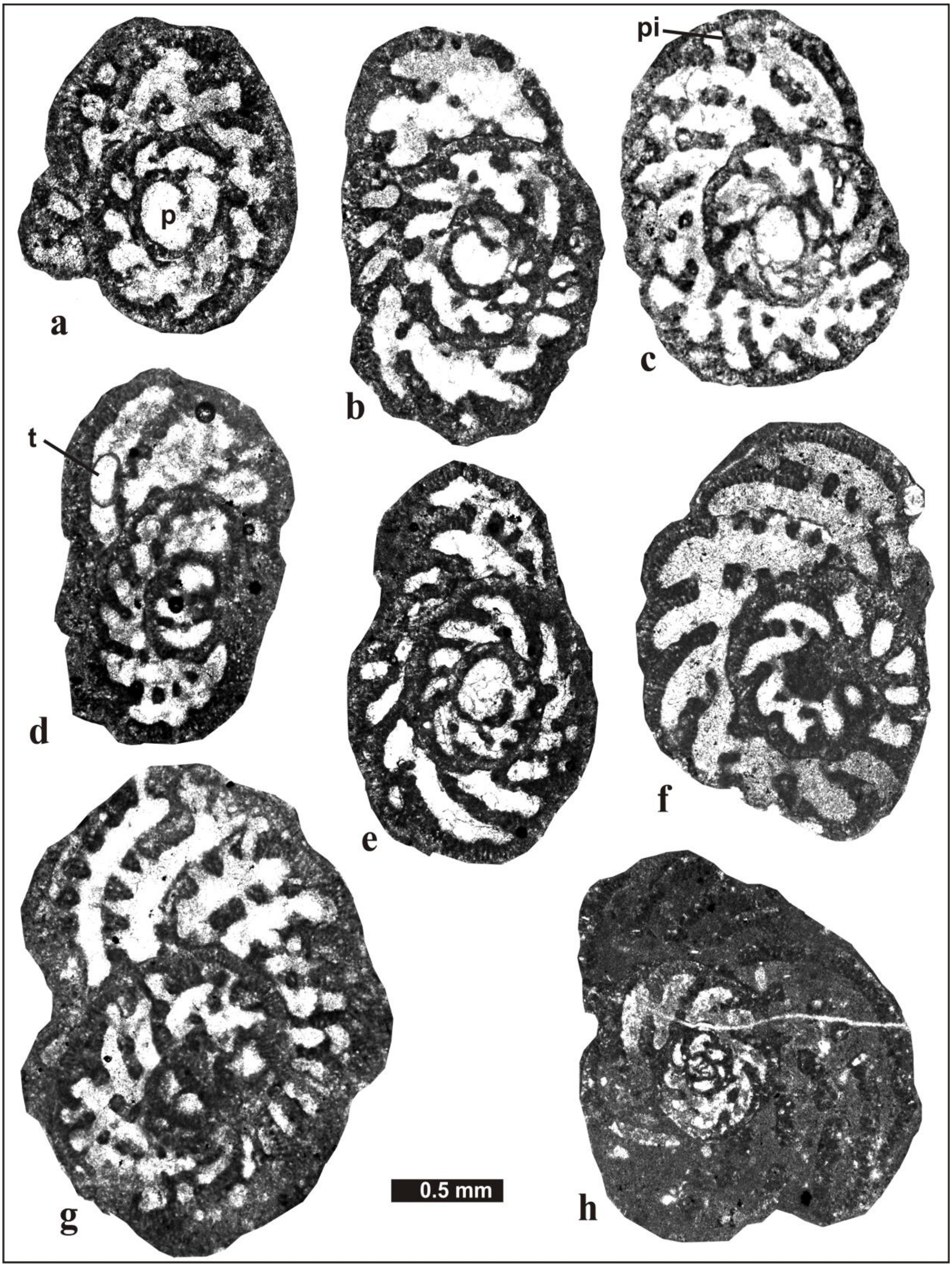

Fig. 5 *Zagrosella rigaudii* n.gen., n.sp., upper Maastrichtian Tarbur Formation of the Naghan section, Zagros Zone, SW Iran. **a**, **c**, Equatorial sections, **b**, **d–g**, Oblique equatorial sections. **h**, Equatorial section of a microspheric specimen. Abbreviations: p = proloculus, pi = pillar, t = structures interpreted as cryptoendolithic thaumatoporellaceans. Thin-sections: NG 88 (**a**), 2NG 94 (**b**), 2NG 91 (**c**), 2NG 85 (**d**), NG 88 (**e**), NG 14 (**f**), 2NG 98 (**g**), NG 38-1 (**h**).

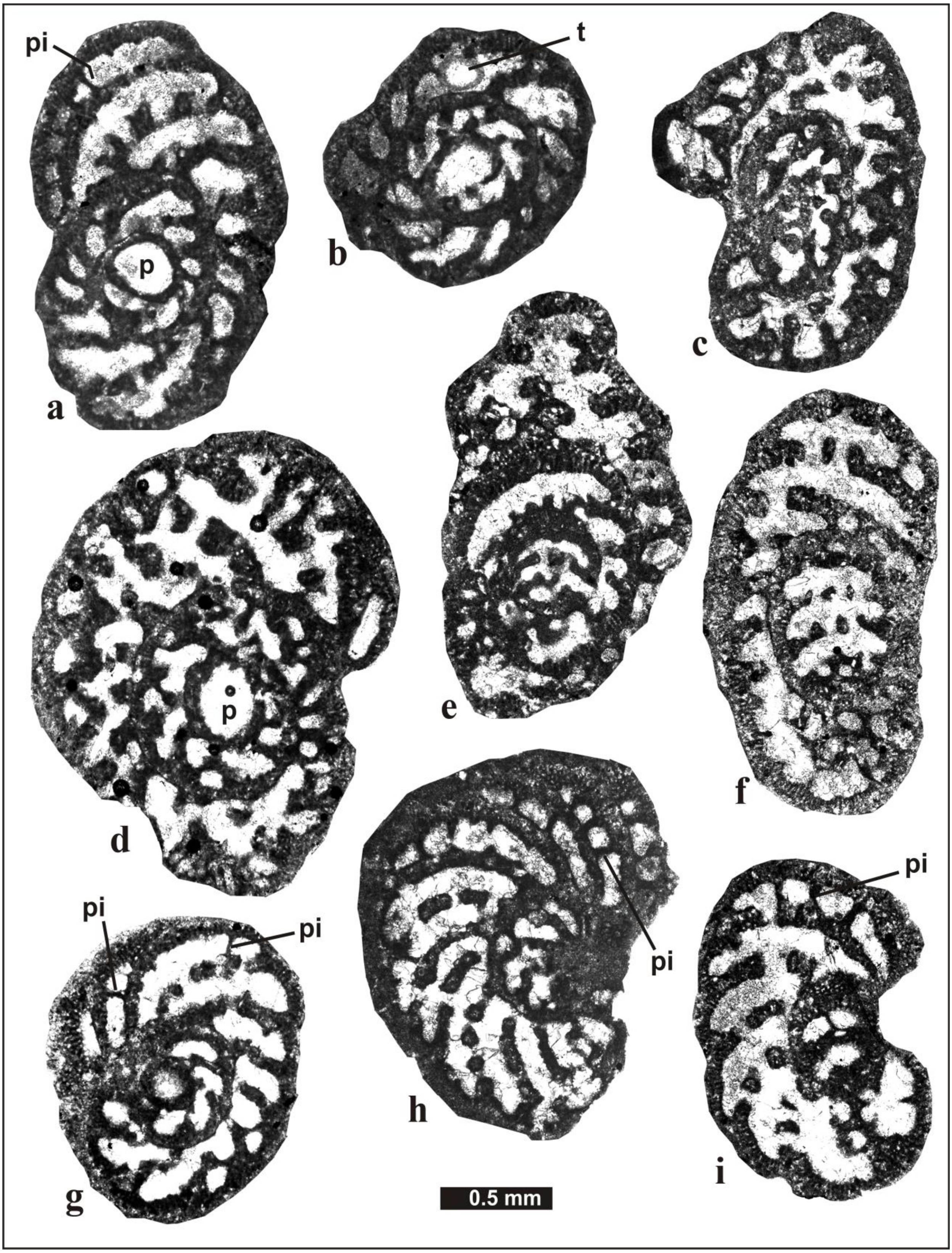

Fig. 6 *Zagrosella rigaudii* n.gen., n.sp., upper Maastrichtian Tarbur Formation of the Naghan section, Zagros Zone, SW Iran. **a–d**, **g**, Oblique equatorial sections. **e–f**, **h–i**, Oblique sections. Abbreviations: p = proloculus, pi = pillar, t = structures interpreted as cryptoendolithic thaumatoporellaceans. Thin-sections: 2NG 98 (**a**), NG 92 (**b**), NG 91 (**c**), 2NG 85 (**d**), NG 49 (**e**), NG 86 (**f**), 2NG 84 (**g**), NG 83-2 (**h**), NG 84 (**i**)

Table 1 Differences between the Liassic *Biokovina gradacensis* Gušić and the late Maastrichtian *Zagrosella rigaudii* n.gen., n.sp.

Genus and species	*Biokovina gradacensis* Gušić, 1977	*Zagrosina rigaudii* n.gen., n.sp.
size (A-form)	up to 3 mm	up to 3 mm
coiling	planispiral, uncoiling and seriate	
diameter proloculus (A-form)	simple, about 0.12 mm	simple, 0.19-0.31 mm (mean 0.26 mm)
foramina/aperture	„first single, broad, mostly central, but already the second chamber may have a cribrate aperture; in the uncoiled stage it is always cribrate"	
diameter foramina (uncoiled stage)	0.1-0.15 mm	0.05-0.12 mm
wall thickness	0.07-0.13 mm (Gušić, 1977: ~0.1 mm)	0.05-0.1 mm
diameter of parapores	0.007-0.01 mm (Gušić, 1977: ~0.01 mm)	0.09-0.025 mm
branching of parapores	yes	no
epidermis	yes	yes
endoskeleton	often fused pillars in the uncoiled part	more delicate pillars preferentially in the uncoiled part
Stratigraphic distribution	Liassic (early Pliensbachian)	(Late) Maastrichtian

displaying a rounded margin. Dimorphism is most likely present. Assumed microspheric specimens without observable proloculus, and chambers broadening distinctly in the last whorl; tendency to uncoil not observable or not present (Fig. 5H). Proloculus of megalospheric form elliptical to globular, with a large or few openings followed by entotebid-shaped chambers significantly increasing in width and height up to 2.5 whorls. There are 11-16 chambers in the last whorl. Chambers in the adult uncoiled and rectilinear stage, usually two to three, rarely up to ten chambers (e.g., specimen in Fig. 3A), and saucer-shaped. They may occasionally be arranged slightly off the coiling plane.

Chamber interior (mostly of the youngest chambers) with few and irregularly distributed endoskeletal structures (pillars) (e.g., Figs. 5C, 6H). The diameter of the pillars is rather variable but generally reduced. Wall thick, dark, microgranular-like to agglutinated (= calcareous grains) with close-set simple (unbranching) parapores (pseudo-keriotheca-like) arranged perpendicular to the surface; epidermis thin, but often may be eroded. In transverse sections, the parapores display a polygonal pattern (Fig. 4A). Foramen basal to multiple in the juvenile stage, later multiple. In the adult part the width of the few foramina almost attains the thickness of the massive septa.

Dimensions (in mm):

Diameter of proloculus: 0.16–0.31 (mostly 0.2–0.24)
Equatorial diameter: up to 1.6
Axial diameter: up to 0.95
Height: up to 3 (e.g., specimen with long uncoiled part illustrated in Fig. 3A).
Chamber height (lumen) enrolled stage: 0.08–0.12
Thickness of septa (adult stage): 0.08–0.12
Wall thickness: 0.06–0.1
Diameter of pillars: 0.02–0.04

Comparison: *Zagrosella rigaudii* n.gen., n.sp. is morphologically similar to *Biokovina gradacensis* Gušić, 1977 (Fig. 8). The differences between both species are compiled in Table 1. It is worth mentioning here that the so-called phrenothekalike structures reported by Gušić (1977) from *Biokovina*, were interpreted by Schlagintweit and Velic (2012) as representing cryptoendolithic thaumatoporellaceans (incertae sedis) dwelling inside the empty chambers of dead foraminiferan shells. They are also reported from *Zagrosella rigaudii* n.gen., n.sp. (Fig. 5D, Fig. 6B, 7E, K–L). Due to our interpretation these are not part of the foraminiferan test, and were therefore not included in the description. Inside empty and dead foraminiferan tests, they could obviously squeeze like a flexible tube (presumably under pressure) through the foraminal openings from one chamber to the next. The moving behaviour together with the occurrence in completely shaded microhabitats excludes the idea of thaumatoporellaceans belonging to photosynthetic algae (for further details see Schlagintweit and Velic, 2012 and Schlagintweit et al., 2013).

STRATIGRAPHY

Zagrosella rigaudii n.gen., n.sp. has been observed in the Naghan section and the Mandegan section (see Schlagintweit and Rashidi, 2016, for further details). Based on larger benthic foraminifera [e.g., *Loftusia* ssp., *Siderolites calcitrapoides* Lamarck, *Gyroconulina columellifera* Schroeder & Darmoian, *Omphalocyclus macroporus* (Lamarck)], the Tarbur Formation in the studied sections is Maastrichtian. *Neobalkhania bignoti* was originally described by Cherchi et al. (1991) from the upper Maastrichtian of Croatia. Besides, they also noted its occurrence in time-equivalent strata from Greece, leading Cherchi et al. (1991, p. 288) to conclude that *N. bignoti* represents "an excellent marker of this time interval" (see also Fleury, 2014, Fig. 3). A late Maastrichtian age for the samples with *Zagrosella rigaudii* n.gen., n.sp. can be concluded. This conclusion is also in line with the occurrence of *Siderolites calcitrapoides* Lamarck in the lower samples of the Mandegan section, as this taxon has its first appearance in the latest early Maastrichtian (according to Robles Salcedo, 2014).

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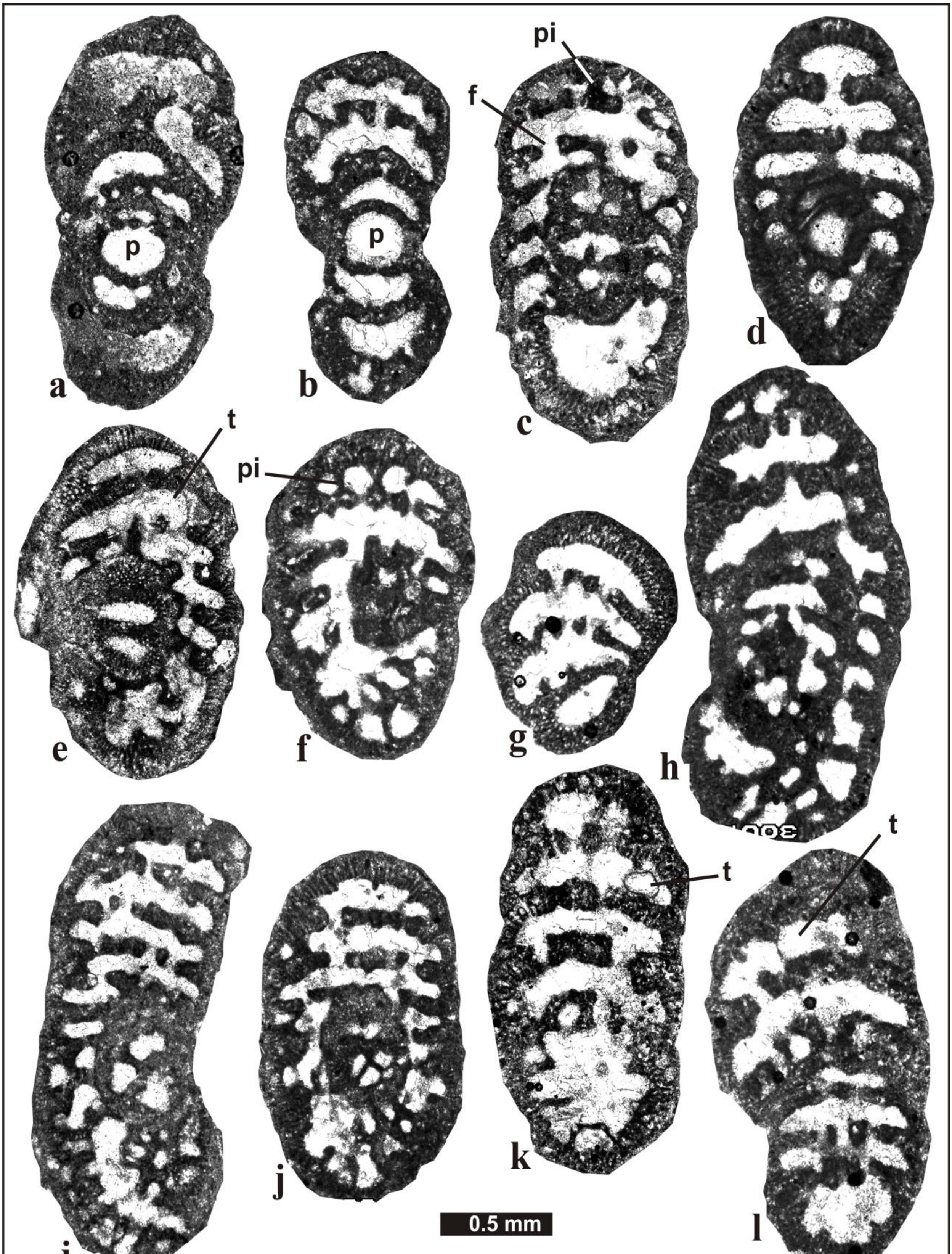

Fig. 7 *Zagrosella rigaudii* n.gen., n.sp., upper Maastrichtian Tarbur Formation of the Naghan section (except **i** from the Mandegan section), Zagros Zone, SW Iran. **a–b,** Axial sections. **c**, Slightly oblique subaxial section. **d**, Subaxial section. **e–l**, Oblique sections. Abbreviations: f = foramen, pi = pillar, t = structures interpreted as cryptoendolithic thaumatoporellaceans. Thin-sections: 2NG 60-1 (**a**), NG 85 (**b**), 2NG 94 (**C**), 2NG 15 (**d**), 2NG 27 (**e**), 2NG 83 (**f**), 2NG 39 (**g**), NG 94 (**h**), Rt 67-3 (**i**), NG 90 (**j**), NG 86 (**k**), 2NG 85 (**l**).

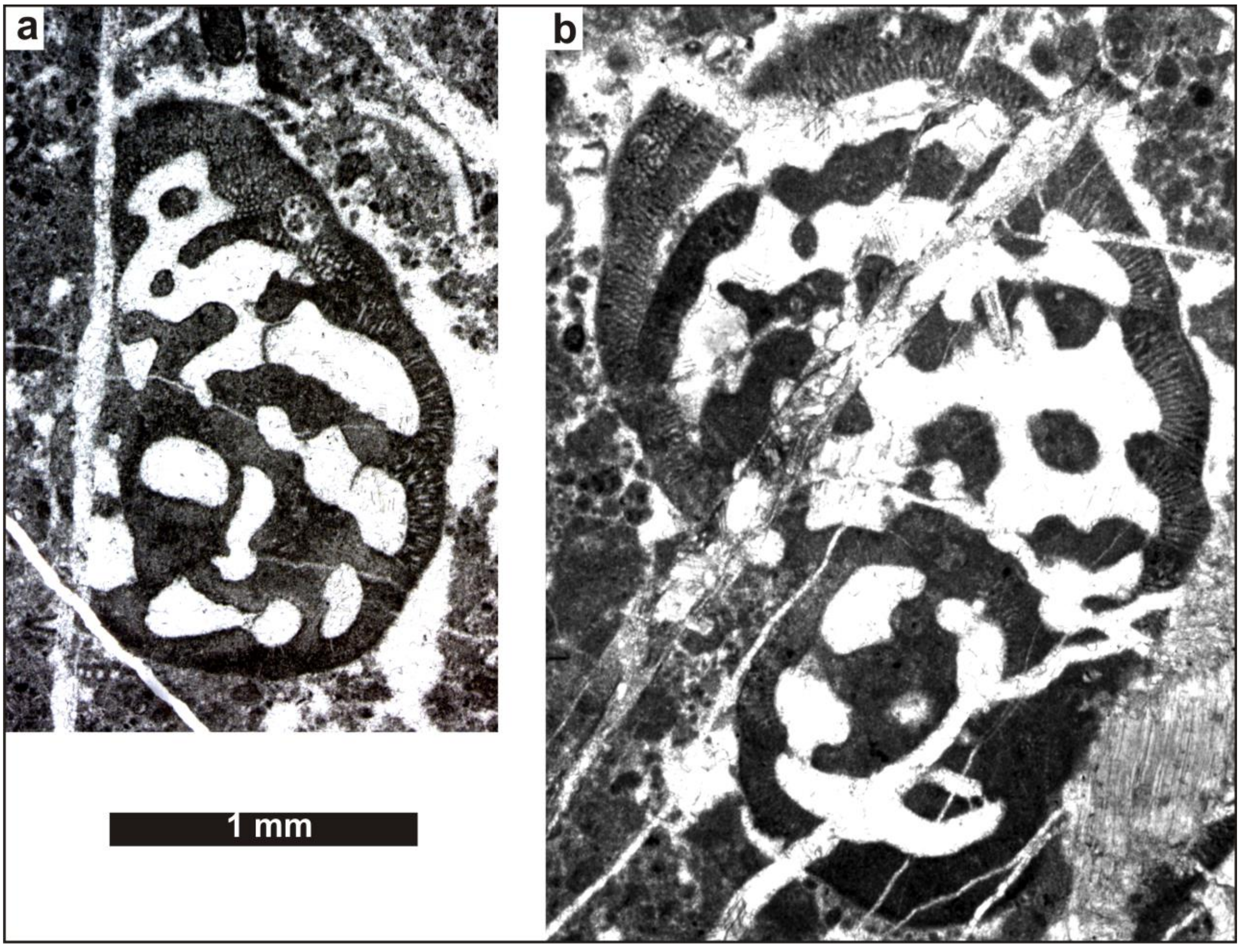

Fig. 8 *Biokovina gradacensis* Gušić, Liassic of Croatia. Photographs made from the original thin-section material of Gušić (1977: A see plate 2, fig. 2, and B see plate 1, fig. 2).

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