Robustoconus tisljari n. gen., n. sp., a new larger benthic foraminifer from the Middle Jurassic (Early Bajocian) of the Adriatic Carbonate Platform of Croatia

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1. INTRODUCTION

Larger benthic foraminifera are widely distributed in Jurassic shallow-water carbonates of the Adriatic Carbonate Platform, i.e. the Karst Dinarides (e.g. RADOIĆIĆ, 1966; NIKLER & SOKAČ, 1968; GUŠIĆ, 1969a, b, 1977; VELIĆ, 1977, 2007; GUŠIĆ & VELIĆ, 1978; VELIĆ & SOKAČ, 1978; SCHLAGINTWEIT & VELIĆ, 2011). During recent investigations of Aalenian–Bajocian limestones of Biokovo Mt. and Dubrovnik area, new and poorly known taxa were described by SCHLAGINTWEIT & VELIĆ (2011). Previously, the Middle Jurassic shallow-water carbonates of the Karst Dinarides were considered to be poor in benthic foraminifera. The aforementioned investigations however, have shown that these are distinctly richer in taxa than the Lower Jurassic strata, with many of these representing index forms (VELIĆ, 2007). In the framework of on-going studies, another new Middle Jurassic larger benthic foraminiferan is recognized, described as Robustoconus tisljari n. gen., n. sp.

2. GEOLOGICAL SETTING

The Middle Jurassic platform carbonates containing Robustoconus tisljari n. gen., n. sp. crop out near Osijek in the vicinity of Dubrovnik, southern Croatia (Fig.1). Tectonically, they belong to the southwestern marginal area of the Adriatic Carbonate Platform (VLĂHOVIĆ et al., 2005). These carbonates were deposited in shallow water environments strongly influenced by currents and waves, with the
occasional development and destruction of patch reefs (see SCHLAGINTWEIT & VELIĆ, 2011, for more details). In general, they are represented by various types of skeletal-intraclastic/bioclastic grainstones and oncoidal facies, with abundant tests of larger benthic foraminifera.

This Early Middle Jurassic profile lies ca. 1 km south-southeast of Osojnik, on the road connecting the village with Dubrovnik (Figs. 1–2). Abundant specimens of \textit{R. tisljari} \textit{n. gen., n. sp.} occur in thick bedded skeletal-intraclastic/bioclastic grainstones (sample O-26; Fig. 3), ca. 20 metres above the last occurrence of \textit{Timidonella sarda} \textit{BASSOUL-LETO, CHABRIER & FOURCADE} (see Osojnik section – SCHLAGINTWEIT & VELIĆ, 2011).

3. SYSTEMATIC PALEONTOLOGY

The suprageneric classification of agglutinated-conical benthic foraminifera (= \textit{pro parte} the so-called „larger agglutinated foraminifera“) provided by LOEBLICH & TAPPAN (1987) was criticised recently by VECCHIO & HOTTINGER (2007) as not taking into account the architecture of the exo- and endoskeletal elements and their pattern. Such a scheme was introduced some decades ago by SEPTFONTAINE (1988) and was incorporated in the „year 2000 classification“ of KAMINSKI (2004) that is followed here.

Class Foraminifera

Order Loftusiida KAMINSKI & MIKHALEVICH, 2004
Suborder Orbitolinina KAMINSKI, 2004
Superfamily Pfenderinacea SMOUT & SUDGEN, 1962
Family Hauraniidae SEPTFONTAINE, 1988
Subfamily Amijiellinae SEPTFONTAINE, 1988
Genus \textit{Robustoconus} \textit{nov. gen.}

\textbf{Origin of the name:} robustus (lat.) = robust and \textit{conus} (lat.) = cone. Named after the high-conical test (A- and most B-forms), combined with the thick, coarse hypodermal network.

\textbf{Diagnosis:} Test conical to cylindrical, with an early planispiral and involute coiled stage, later rectilinear. Cone base slightly arched in the juvenile stage, becoming distinctly convex in adult chambers. Macrospheric specimen with a small simple subspherical protoclasus. Microspheric tests, large and may be slightly flabelliform. Wall microgranular calcareous, agglutinated, and may include large grains especially in the central part. Chambers subdivided into a marginal and central zone. Coarse exoskeleton of radial (beams and intercalary beams) and horizontal partitions (rafters) forming a network of chamberlets in the marginal zone. The complex central zone consists of anastomizing septal excrescences (with constrictions and swellings) that reach into the cham-
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ber interior, but do not span between two successive septa, leaving instead a continuous open space at the proximal parts of the chambers. This peculiar type of endoskeleton that strongly reduces the volume of the chamber interior may be obscured in specimens where large amounts of agglutinated particles are incorporated in the test. Intracamerol foramina single, interiomarginal in the coiled part, becoming multiple, irregularly distributed in the central zone of the rectilinear part.

Type species: Robustoconus tisljari nov. sp.

Comparisons: Robustoconus belongs to a group of large benthic foraminifera exhibiting a "structure exosqueletique complexe grossiere" (HOTTINGER, 1967) or hauranniiform subepidermal network (réseaux hypodermique) (SEPTFONTAINE, 1980). These forms are included in the family Hau- raniiidae SEPTFONTAINE (see KAMINSKI, 2004). Robustoconus can be compared with Spiraloconulus ALLEMANN & SCHROEDER, 1972, and the allied genus Bostia BASSOULLET, 1998, as well as with Timidonella BASSOULLET, CHABRIER & FOURCADE, 1974.

With respect to Timidonella, only cylindriform macroospheric specimens (e.g. VELIĆ, 2007: pl. 6, fig. 3) can be taken for comparison given that the microospheric generation is characterized by discoidal tests (BASSOULLET et al., 1974). Timidonella possesses an endoskeleton of pillars connecting consecutive septa.

The differences of Robustoconus to both Spiraloconulus and Bostia are more delicate needing comprehensive discussion. Spiraloconulus differs from Robustoconus by the construction of its exoskeleton consisting of a rather narrow marginal zone of thin-walled chamberlets and a large central zone with septa typically agglutinating large grains (ALLE-
MANN & SCHROEDER, 1972; CHERCHI & SCHROEDER, 1981) (Fig. 4). In fact, the central zone is „relatively simple“ in Spirolocylonus where the „partly coarse agglutination of the chamber floors (remark: roofs!) can easily be mistaken for a complex structure“ (ALLEMANN & SCHROEDER, 1972: p. 207). This statement was given for the type-species S. perconigi where the agglutination of foreign material is concentrated within the septa and the chamber interior is more or less free. In S. giganteus, the chamber interior of microospheric specimens may be largely filled with...
oids connected to the septa and to adjacent ooids by means of very thin walls as a biomineralized part of the test. Notwithstanding, BOUDAGHER-FADEL (2008: p. 179) defines the genus *Spiraloconulus* as possessing an „endoskeleton(s) of pillars from septum to septum” obviously adopting the classification of LOEBLICH & TAPPAN (1987), placing the genus within the pillaroid family Spirocyclinidae. In fact, *Spiraloconulus* (and also *Bostia*) is placed in the subfamily Amijiellinae (SEPTFONTAINE, 1988; KAMINSKI, 2004) where representatives usually do not develop pillars. The central zone of *Robustoconus* is made up of a complex structure of anastomizing micritic septal excrescences (with constrictions and swellings) that reach deep into the chamber lumen (= trabéculés micritiques of BASSOULLET, 1998). However, they do not span between two successive septa, instead leaving a continuous open space at the proximal parts of the chambers. Therefore these cannot be termed interseptal pillars (see HOTTINGER, 2006). This type of endoskeleton is often obscured in specimens where large amounts of agglutinated particles are incorporated in the tests of *Robustoconus*. In *Bostia*, BASSOULLET (1996) speaks of an agglutinated endoskeleton. For the genus *Limognella* (see below), SEPTFONTAINE (1988: p. 244) assumes that such an endoskeletal structure is only pretend due to the highly

Figure 4: *Spiraloconulus giganteus* CHERCHI & SCHROEDER from the Bajocian of Mount Biokovo, Croatia. a) Oolitic grainstone with two specimens. b) Longitudinal section. Note the simple central zone composed of large individual ooids that in the lower test portion stretch between two successive septula. c) Longitudinal section. Note ooids (white arrow) and small benthic foraminifer (black arrow) attached to the chamber rooves. Scale bars 0.5 mm.

Figure 5: a) Grainstone with abundant *Robustoconus tisljari* showing moderate parallel orientation of their cylinroconical tests. Thin-section 0-26/5. Scale bar 1 mm. b) Two specimens of *Robustoconus tisljari* in longitudinal section, the left one showing an initial spire with protoconch (p). Note the different dimensions and the difference in chamber convexity resulting in a more flattened (left) or convex apertual face (right) in large specimen. The specimen on the right (outlined by the dashed white-line) occurs in a packstone intraclast. Thin-section 0-26/6. Scale bars 0.5 mm.
agglutinated character. In this respect, returning to the genus *Spiraloconulus*, the type-species *S. perconigi* can be considered as a species with no endoskeleton, whereas the short micritic walls connecting adjacent agglutinated grains in *S. giganteus* can be considered as endoskeletal structures.

Concerning the development of the macrospheric embryo, it is uncertain whether in *Robustoconus* it is unilocular or bilocular, e.g. as in *Spiraloconulus perconigi* (see ALLEMANN & SCHROEDER, 1972). In any case it is not complex as in *Timidonella, Orbitopsella, Cymbriaella or Bostia*, composed of a rather large single spherical proloculus that is enclosed by a thin wall and a large spherocochn (e.g. BASSOULLET et al., 1974; BASSOULLET, 1998; FUGA-GNOLI, 1999). In most cases, a single subospherical proloculus is observable in *Robustoconus* with a diameter of 0.1 to 0.2 mm, distinctly smaller than the giant spherocochn of *Bostia* with a size of 0.6 to 1.0 mm (BASSOULLET, 1996: p. 192). In rare cases, a second crescent-shaped chamber, slightly separated from the proloculus is discernible in *Robustoconus* that is interpreted as the first post-embryonic chamber rather than a deuterochon. Let us remember that structural differences in the embryonic apparatus are widely accepted criteria in larger benthic foraminifera. Besides the giant complex embryonic apparatus in *Bostia*, this species also differs from *Robustoconus* by the distinctly reduced to absent initial spire. It should be mentioned that KAMINSKI (2000: p. 269) considers *Bostia* „to represent a more advanced stage in the evolution of the *Spiraloconulus* lineage“.

Last but not least, we also have to mention the genus *Limognella* PELISSIÈ & PEYBERNÉS, 1982. Whereas CHERCHI & SCHROEDER (1983) consider *Limognella* a synonym of *Spiraloconulus*, BASSOULLET (1999: p. 193) stresses morphological differences. A third view was expressed by SEPTFONTAINE (1988: p. 244) regarding *Limognella* a synonym of *Alzonella* BERNIER & NEUMANN, 1970. However, PELISSIÈ & PEYBERNÉS (1982: Pl. 2, Fig. 7) illustrated a single transverse section of a microspheric forms of *Limognella* exhibiting a flattened test with subparallel opposite sides. Transverse sections of *Spiraloconulus* are almost exclusively round (cylindrical enrolled part), and slightly elliptical shapes can only be observed in exceptional cases. There are also examples where test compression is used for genus differentiation, e.g. *Planisepa* (SEPTFONTAINE in KAMINSKI, 2000) versus *Lituosepta* CATI, 1959. The occurrence of both orbitoliniform (*S. perconigi*) and ammonbaculitoid forms (*S. giganteus*) within the same genus, however, makes the test morphology highly problematic as a generic criterion.

**Robustoconus tisljari nov. sp.**

(Figs. 5–10; Pls. 1–4)

**Origin of the name:** In memory and dedication to Josip Tišlar for his numerous contributions to geology, especially to the carbonate sedimentology of the Adriatic carbonate platform (i.e. Karst Dinarides in Croatia, Slovenia, Bosnia and Herzegovina, and Montenegro).

**Holotype:** Longitudinal section illustrated in Fig. 6a, c thin-section 0–26/3.

**Paratypes:** All other specimens illustrated in the present paper.

**Material:** From sample 0–26, 11 thin-sections (2.5 x 7.5 cm) were made, numbered 0–26, 0–26/1 to 0–26/10 each containing about 40 to ~70 variously sectioned specimens.

**Depository:** Croatian Natural History Museum, Demetrova 1, 10000 Zagreb, Croatia.
PLATE 1

*Robustoconus tisljari*, different longitudinal, tangential (a-j) and oblique sections (k-m), mostly of supposedly microspheric specimens; Figure j shows a megalospheric specimen.

Early Bajocian of Croatia.

- a Two specimens in oblique longitudinal section. Note the irregular growth of the uppermost part of the test (arrows) of the specimen on the right. Thin-section 0-26/5.
- b Oblique longitudinal section. Thin-section 0-26/10.
- c Oblique longitudinal section. Thin-section 0-26/2.
- d Longitudinal section. Thin-section 0-26/2.
- e Longitudinal section. Thin-section 0-26/4.
- f Longitudinal section; note the initial test bending. Thin-section 0-26/5.
- g Oblique longitudinal to tangential section. Thin-section 0-26/4.
- h Oblique longitudinal section. Thin-section 0-26/4.
- i Longitudinal-tangential section. Thin-section 0-26/10.
- j Longitudinal section of a juvenile specimen showing initial spire with proloculus. Thin-section 0-26/8.
- k Oblique section. Note the micritic endoskeletal structure of the central zone devoid of agglutinated material (see also Fig. l). Thin-section 0-26/1.
- l Oblique section of a test with an elliptical enrolled part. Thin-section 0-26/2.
- m Oblique section, thin-section 0-26/1.

Scale bars 0.5 mm.
Robustoconus tisljari, different sections of macrospheric specimens.
Early Bajocian of Croatia.

a Oblique longitudinal section of specimen showing initial spire with proloculus. Thin-section 0-26/5.
b Longitudinal section of specimen showing initial spire and proloculus. Thin-section 0-26/10.
c Oblique longitudinal section passing through the proloculus. Thin-section 0-26.
d Oblique longitudinal section of specimen showing initial spire with proloculus. Thin-section 0-26/2.
e Oblique section passing through the proloculus. Thin-section 0-26/5.
f Longitudinal-tangential section cutting the proloculus marginally. Note the subparallel longitudinal orientation of the micritic endoskeletal elements devoid of agglutinated particles (see also Fig. d). Thin-section 0-26/8.
g Oblique section passing through the initial spire and proloculus. Thin-section 0-26.
h-i Longitudinal section cutting the initial spire (with about 9 chambers in h) and proloculus. Thin-sections 0-26/5 and 0-26/8.
j-l Oblique section through the initial part with proloculus. Thin-sections 0-26/4, and O-26/2 (k-l).
m Note the sickle-shaped first post-embryonic chamber (pec). Thin-section 0-26/2.

Scale bars 0.5 mm.
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**PLATE 3**

*Robustoconus tisljari*, transverse to slightly oblique transverse sections of small specimens.

Early Bajocian of Croatia.

- a Thin-section 0-26/7.
- b Thin-section 0-26/2.
- c Thin-section 0-26.
- d Thin-section 0-26/2.
- e Thin-section 0-26/3.
- f Thin-section 0-26.
- g Thin-section 0-26/9.
- h Thin-section 0-26/4.
- i Note the large agglutinated grains (amongst a small textulariid foraminifer) in the central zone. Thin-section 0-26/5.
- j Thin-section 0-26/5.
- k Thin-section 0-26/5.
- l Thin-section 0-26/6.
- m Thin-section 0-26/6.
- n Thin-section 0-26/7.
- o Thin-section 0-26/8.
- p Thin-section 0-26/9.
- q Thin-section 0-26/8.
- r Thin-section 0-26/10.
- s Thin-section 0-26/8.

Scale bars 0.5 mm.
PLATE 4
Robustoconus tisljari, transverse to slightly oblique transverse sections of large specimens.
Early Bajocian of Croatia.

a Thin-section 0-26/4.
b Note the strongly reduced chamber volume resulting from the dense and thick anastomizing endoskeletal network. Thin-section 0-26/2.
c Note the transect of part of the septum with irregular distributed tiny foramina (white dashed circle). Thin-section 0-26/2.
d Thin-section 0-26/3.
e Thin-section 0-26/3.
f Thin-section 0-26/6.
g Thin-section 0-26/7.
h Note the anastomosing septulae (as) of the central zone. Thin-section 0-26/5.
i Thin-section 0-26/7.
j Thin-section 0-26/7.
k Thin-section 0-26/9.
l Note the transect of part of the septum with irregular distributed tiny foramina (white dashed circle). Thin-section 0-26/8.
Scale bars 0.5 mm.
**Type-locality:** the road cut on the eastern slope of Sv. Ilija hill, ca. 1 km SSE from Osijek, on the road from Osijek to Dubrovnik (GPS, x=6506425, y=4728797; Fig. 2).

**Type-level:** thick bedded, light-brownish coloured to white skeletal-intraclastic/bioclastic grainstone/rudstone limestone of Lower Bajocian age.

**Diagnosis:** Being monospecific so far, the species diagnosis corresponds to the genus diagnosis.

**Description:** Test high conical to cylindrical, with an early planispiral and involute coiled stage, later rectilinear in specimens attributed to megalospheric forms (e.g., Fig. 6a, Pl. 2b, d). Occasionally, tests with irregular protuberances (“pseudo-branching”) at the ventral side (Fig. 8b) or slightly flabelliform outline (Figs. 8d-e) are observed in addition.
The test height of adult specimens is most frequently within the range of 1.7 mm to 2.5 mm. The greatest observed specimen measures 5.9 mm in height and 1.54 mm in diameter (Pl. 1a).

The short initial planispirally involute coiled part (height ~0.3 to 0.5 mm) consists of about one (?) one and a half) whorl(s) of low crescent-shaped chambers (5 to 10 in number). This part may be apical or eccentric in position. Transverse sections through the enrolled part are approximately circular to slightly elliptical. In the coiled part, the intracamerall foramina are single and interio-marginal in position. Transverse sections through the enrolled part are approximately circular to slightly elliptical. In the coiled part, the intracamerall foramina are single and interio-marginal in position (Fig. 7b). The macrospheric proloculus is simple with a diameter of ~0.1 mm to ~0.2 mm (most values between 0.13 and 0.16 mm). In sections parallel to the plane of coiling the shape of the proloculus is subspherical, whereas in sections perpendicular to the plane of coiling it appears ovally compressed (Fig. 6a). The proloculus is followed by a second crescent-shaped chamber closely attaching the proloculus (Pl. 2, Fig. m). It is interpreted as the second post-embryonic chamber rather than as a deuterococonch. The uncoiled rectilinear stage corresponds to the main part of the test with up to about 15 uniserial chambers. During ontogeny, the almost flat chamber base successively becomes distinctly convex as appears also the ventral surface of the cone. In transverse sections, the rectilinear part is round, occasionally slightly elliptical (P1s. 3–4) and in rare cases also with some marginal embayments visible in transverse section (Fig. 8f). Other test irregularities may result from very large agglutinated particles (Fig. 8c).

Each chamber is subdivided into a marginal zone and a central zone (P1s. 3–4). The marginal zone consists of radial partitions (beams and 1 to 2 intercalary beams) and short horizontal partitions forming a network of chamberlets (Fig. 9). The diameter of these chamberlets exhibiting polygonal outlines varies between 0.06 and 0.08 mm in shallow tangential sections. Towards the chamber interior, the chamberlets increase in size along with a thickening of the exoskeletal elements. There may be 2 to 3 (rarely 4) rows of chamberlets per chamber displaying an irregular alternating position (Fig. 8c, upper part).
The central zone is made up of rather thick micritic septal excrescences (with constrictions and swellings) showing a general subparallel orientation toward the test axis (e.g. Pl. 2f). As visible in transverse sections, they form an anastomosing network (Pls. 3–4). This structure forms a peculiar type of endoskeleton that may occupy large parts of the chamber lumen (e.g., Pl. 4b). The amount and also the size of agglutinated grains is rather variable. In many cases these grains are clearly recognizable as small lithoclasts with micritic rims or small benthic foraminifera (Fig. 8c, Pl. 3i, p). Homogeneous micritic grains (peloids) may also be agglutinated and are often indistinguishable from thickenings of the endoskeletal elements. In longitudinal sections, a continuous open space in the proximal part of the chamber base is discernible (Fig. 6, Pl. 1c-e). No interseptal structures (pillars) are present. Laterally, the endoskeletal elements fuse with those of the exoskeleton.

In the uniserial stage, there are numerous tiny intercameral foramina (width about 0.01 to 0.03 mm) piercing the septa and exhibiting an irregular distribution throughout the middle part of the central zone (Pl. 4c, 1).

Remarks: Irregular aberrant tests as observed in Robustoconus are reported for instance from the Middle Jurassic Bostia irregularis (BASSOULLET, 1998), the Upper Jurassic Anchispircoyclina (RAMALHO, 1971) or the Lower Cretaceous Torremiroella (BRUN & CANÉROT, 1979). The reasons for these abnormalities are unknown. Tests of Spiraloconulus giganteus displaying both irregular internal structures and external morphologies were reported by CHERCHI & SCHROEDER (1981) resulting from large agglutinated ooids. In another case, partial test damage of Robustoconus tisljari (Fig. 8e) was the most likely cause of unusual growth. Test abnormalities are also reported from modern benthic foraminifera. They may be related to environmental stress conditions, e.g., warm water sources in deep sea areas (MERIĆ et al., 2003) or other factors (see for example, MUHKOPADHYAY, 2012).

A test dimorphism is assumed for Robustoconus. This can be suggested from specimens with a clear pronounced proloculus in a given size range (Pl. 2), whereas in other specimens it is not detectable in longitudinal sections. Megalospheric forms are usually high-cylindrical, whereas slightly flabelliform tests can be referred to B-forms (Fig. 8d-e). Another indication was obtained from the size dimensions. In thin-sections, 242 transverse sections were measured resulting in a range from 0.32 to 1.54 mm for the test width (Fig. 11). The data show two maxima, from which the smaller one (between 0.6 and 0.65 mm) is attributed to macroospheric specimens. However, it must be noted that this is only an interpretation, as from the inner structure the two generations cannot be distinguished. Therefore the data are assumed as representing a mixture of both generations and adult/juvenile specimens within a given assemblage.

Stratigraphy: According to the foraminiferal assemblage at the type locality (Fig. 3), the stratigraphic range of Robustoconus tisljari n. gen. n. sp. can be considered as Early Bajocian.

Microfacies: Sample 0–26 represents an intraclastic grainstone clearly dominated by the overall presence of tests of Robustoconus tisljari (Fig. 5). Other foraminifera include common textulariids and some rare specimens of Bosniella bassoulleti SCHLAGINTWEIT & VELIC. Calcareous algae are very rare and are only represented by scattered porostromat algae and rare debris of an unknown tiny Clypeina species. Remains of gastropods (including nerineids) are common.

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