**N. Jb. Geol. Paläont. Abh. 277/1 (2015)**, 43–48
Stuttgart, July 2015

**Article**

# Remarks on the shell structure of *Halkyardia maxima* Cimerman: its umbilical plug and the microspheric form

**Franc Cimerman and Adrijan Košir**

With 3 figures

**Abstract:** The paper presents for the first time the structure of the microspheric form of *Halkyardia maxima* in axial and equatorial thin-section photomicrographs. A very small proloculus (10 µm in diameter) is followed by a spiral composed of 9 chambers, gradually increasing in size. The axial section of the megalospheric form shows that the umbilical plug is not a special morphological formation but results from the accretion of lamellae of consecutive cycles.

**Key words:** Paleogene, Oligocene, foraminifera, *Halkyardia*, microspheric form, Slovenia.

## 1. Introduction

*Halkyardia* is a genus of Paleogene larger foraminifera with a circumtropical cosmopolitan distribution (Boudagher-Fadel 2008). In the early description of *Halkyardia maxima* Cimerman, 1969, from the Oligocene beds near the Village of Poljšica (NW Slovenia, Fig. 1), the species name was chosen to mark its distinction from the Eocene species *Halkyardia minima* Liebus, 1911. The original study was based on sufficient material to make a series of different sections through foraminiferal tests allowing the study of the shell morphology, internal structure and the embryonic apparatus. Most of the sections belonged to megalospheric forms whereas the microspheric generation, generally much less abundant than megalospheric, was determined in two specimens only. To date, the chamber arrangement in the early embryonic part of the microsphere form remained obscure.

In a study of Oligocene successions in the Bohinj Valley (Fig. 1), Herlec (1985) discovered a thin layer of clayey marl rich in *Halkyardia maxima*. A sample of marl yielded abundant megalospheric shells as well as numerous microspheric forms. Microspheres are readily recognizable already by their size, since large specimens reach a diameter of more than 1.5 mm.

Early descriptions of the genus *Halkyardia* and its senior synonyms were based solely on external test shape features (Liebus 1911; Halkyard 1919). Later emended descriptions included internal characteristics but were based exclusively on megalospheric forms (Loeblich & Tappan 1987) or on questionable drawings and a schematic model of both megalospheric and microspheric generations (Bursch 1947). Here we describe and present for the first time the shell architecture of the microspheric form of *Halkyardia maxima*, in particular the embryonic apparatus and umbilical structures.

## 2. Material and methods

The studied material was collected by Uroš Herlec from a layer of clayey marl, 15 cm thick, within the clastic succession of the Gornji Grad beds at the locality Grapa nad Žlanom (46°15’25” N, 13°55’5” E) in the Bohinj Valley (Fig. 1). Nannoplankton assemblage from the marine clay (Sivica) overlying the Gornji Grad beds indicates biozone NP23 (Rupelian, Lower Oligocene; Pavšič & Horvat 2009).


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DOI: 10.1127/njgpa/2015/0494
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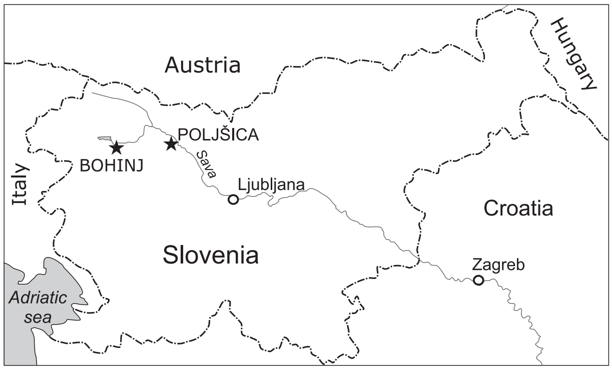


**Fig. 1.** Outline map of Slovenia showing the position of the studied localities, Bohinj and Poljšica.

Foraminiferal tests were picked under a binocular microscope from a residue obtained from the clayey marl sample by disintegration in diluted hydrogen peroxide. To reach the chambers of the embryonic apparatus, individual tests were embedded in vertical position and mounted onto a glass slide with Canada Balsam and then polished nearly to the middle of the test. Subsequently, the specimens were turned for 180° and polished from the other side to reach the thin section nearly to the middle of the test. To make slides of the embryonic apparatus in equatorial plane the specimens were embedded with their ventral side to the glass slide and then polished from the apex downwards to reach the initial spiral of the embryonic apparatus under the apex.

Initially, slight grinding using F600 grit silicon carbide was used but the method turned out to be too rough for the small size of the embryonic chambers in microspheric forms. Better results were obtained by gentle, step by step polishing of the apex using F2400 grit aluminum oxide powder which gradually exposed the proloculus and the initial spiral. Thin sections were examined and photographed in plane polarized light with a Leitz Orthoplan microscope.

## 3. Systematic paleontology

Subphylum Foraminifera d'Orbigny, 1826
Order Rotaliida Delage & Hérouard, 1896
Suborder Rotaliina Delage & Hérouard, 1896
Superfamily Planorbulinoidea Schwager, 1877
Family Cymbaloporidae Cushman, 1927
Subfamily Halkyardiinae Kudo, 1931

Genus *Halkyardia* Heron-Allen & Earland, 1919

**Type species:** *Cymbalopora radiata* von Hagenow var. *minima* Liebus, 1911

**Species included:** *Cymbalopora radiata* von Hagenow var. *minima* Liebus, 1911; *H. bartrumi* Parr, 1934; *H. bikiniensis* Cole, 1954; *H. maxima* Cimerman, 1969; *H. minima* (Liebus, 1911); *H. ovata* (Halkyard, 1919); *H. ucrainica* Yartseva, 1964.

**Diagnosis:** Based on Boudagher-Fadel (2008, pl. 6.27, fig. 12). Test biconvex, with an embryont consisting of a large protoconch and deuteroconch, and two primary auxiliary chambers. The umbilicus is filled with horizontal bilamellae and connecting pillars.

**Stratigraphic range:** Middle Eocene (Lutetian) to Middle Oligocene (Rupelian).

**Geographic distribution:** Slovenia, Italy, France, Spain, Germany, Turkey, Azerbaijan, Armenia, Iran, Oman, India; Pacific: Bikini Atoll, Marshall Islands; New Zealand.

**Remarks:** Loeblich & Tappan (1987: 593, pl. 652, figs. 1-13) described characteristics of the genus *Halkyardia* Heron-Allen & Earland, 1919: "*Test commonly small, up to 1,3 mm in diameter, biconvex, spiral side more convex, megalospheric test with large hemispherical protoconch, large deuteroconch, and two primary auxiliary chambers, later chambers in numerous cycles, small as seen from the spiral side, arched toward the periphery and alternating in position with those of the preceding cycle, only those of the final whorl visible on the opposite side, where the chambers appear elongate, inflated, and tubular, umbilical region beneath the embryonic chambers filled with a wide perforate plug formed by horizontal lamellae and connecting pillars, periphery subangular, peripheral outline lobulate; wall calcareous, optically radial, thickened by addition of lamellae on the distinctly perforate spiral side; no aperture other than the surface pores.*"

As we see the authors mentioned the megalospheric embryo only. The internal architecture of the test of the genus *Halkyardia* was presented in detail by Bursch (1947: 29-43) who, however, erroneously considered his material as belonging to *H. minima* of Liebus. He noted that the chambers were only visible on the margin of the test and on the ventral side where they were arranged radially around a coarsely porous umbilical filling. His sketches, based on thin sections, show both a megalospheric and a microspheric embryonic

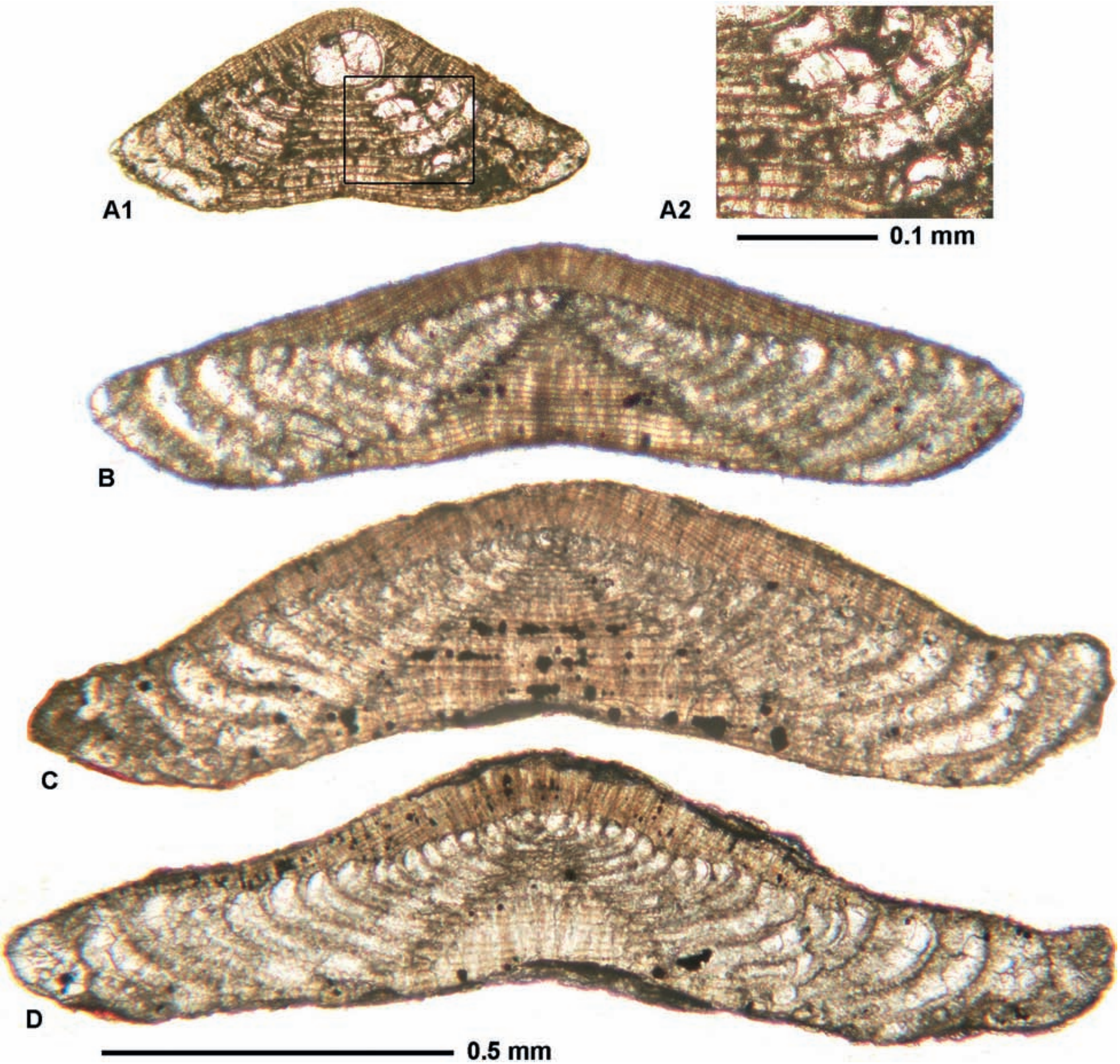


**Fig. 2.** Axial sections of *Halkyardia maxima* CIMERMAN. **A** – Megalospheric form, sample Hk-1112-7 from CIMERMAN (1969). Fig. A2. is a detail of Fig. A1 showing the lamellae forming the outer wall of a chamber. **B** – Microspheric form, sample V-8. **C** – Microspheric form, thin sample V-14. **D** – The largest microspheric specimen found (sample V-15), 1.56 mm in diameter, with 18 chambers seen, approximately 11 lamellae in the dorsal thickening. The section is not made directly through the center, therefore only 12 lamellae in the umbilical plug are recognizable. In the top of the plug some juvenile chambers appear.

apparatus but are presented very schematically, especially the latter form. BURSCH also draw a model of the internal structure of the test; the umbilical plug was considered a special feature called umbilical filling ("Umbilikalfüllung").

*Halkyardia maxima* CIMERMAN, 1969
Figs. 2-3

1969 *Halkyardia maxima* n. sp. – CIMERMAN, p. 296, pl. 57, figs. 1-11.
2002 *Halkyardia maxima* CIMERMAN. – CAHUZAC & POIGNANT, pl. 2, fig. 14.
?2004 *Halkyardia* sp. – MENKVELD-GFELLER & DECROUEZ, p. 322, fig. 4.1.
2010 *Halkyardia maxima* CIMERMAN. – BENEDETTI, p. 202, pl. 2, figs. 3-4; text-figs. 6-8.

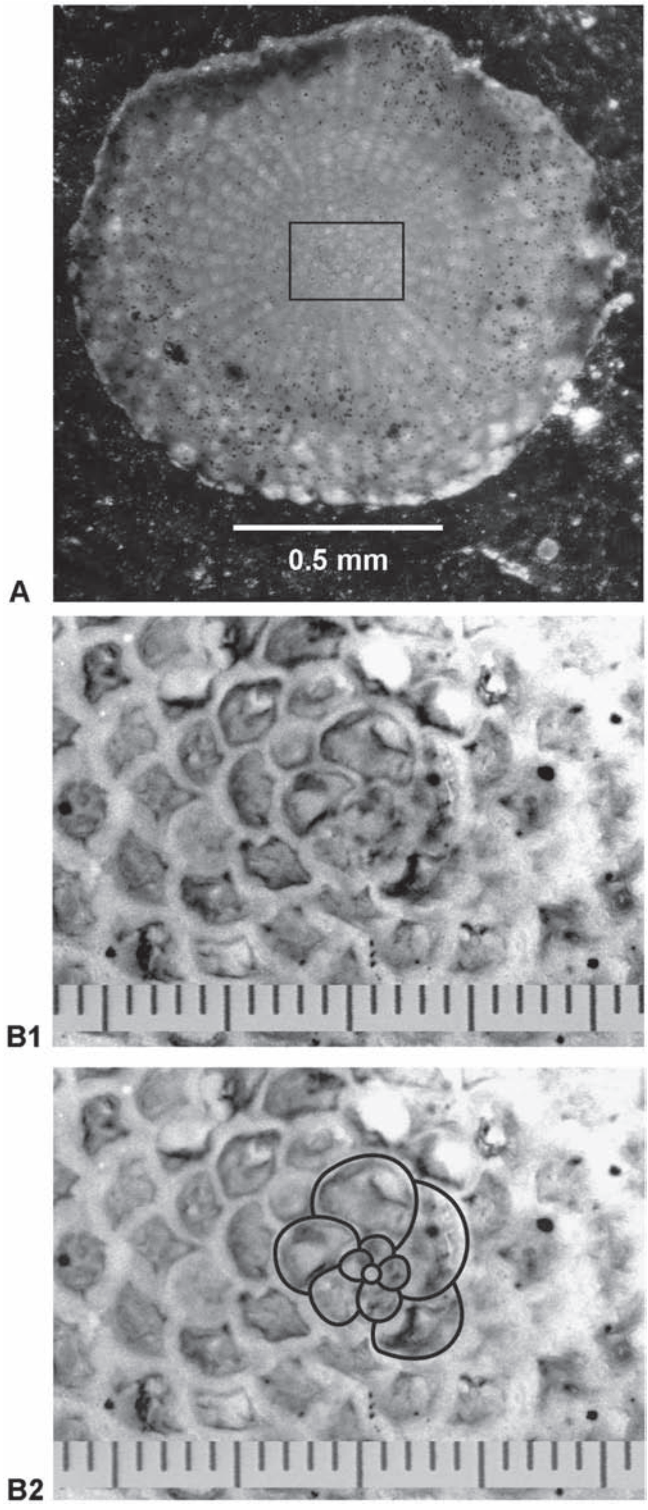


**Fig. 3.** Microspheric form of *Halkyardia maxima* CIMERMAN. **A** – Thin section V-5 comprising a whole test; photomicrograph taken from the spiral side of the test in transmitted light in oblique darkfield. **B** – Close-up view showing detail of the initial part of the embryonic apparatus of the same specimen; the spiral trace in Fig. B2 is emphasized with a black line.

**Emended diagnosis:** Test lenticular, usually concavo-convex, more rarely planoconvex (especially the smaller tests), sometimes even somewhat biconvex. The dorsal side always convex, changeable is only the ventral side. Embryonic chambers very large.

**Stratigraphic range:** Lower Oligocene (Rupelian).

**Geographic distribution:** Slovenia, Italy (BENEDETTI 2010), France (CAHUZAC & POIGNANT 2002), Spain (SERRA-KIEL et al. 1996), Turkey (SIREL & GÜNDÜZ 1979; AKKIRAZ et al. 2011).

## 4. Structural analysis from axial sections

### 4.1. Microspheric forms

Axial sections of the largest specimens are shown in Fig. 2. Thin section V-15 (Fig. 2D) shows an axial section of the largest specimen with the test diameter of 1.56 mm. In thin section V-14 (Fig. 2C) dorsal thickening above the embryonic apparatus and the umbilical plug under it is clearly visible. The umbilical plug is composed of 18 lamellae; the spiral side shows 17 lamellae. Around 15 chamber cycles are visible. The number of chamber cycles and lamellae cannot be exactly established because they condense towards the apex or are not clearly distinguishable due to preservation. It is, however, clear that the umbilical plug and the dorsal thickening share the same origin. In each new chamber cycle the outer lamella mantels almost the entire test. Under the embryonic apparatus, devoid of new chambers added at each cycle, lamellae accrete directly one on another. A similar pattern is seen on the dorsal side where lamellae do not reach the apex to embed the whole test but terminate close to it.

The specimen in section V-8 (Fig. 2B) shows 18 lamellae in the umbilical plug and 19 lamellae on its dorsal side. About 14 chamber cycles are visible. The fact that the number of lamellae in the umbilical plug is larger than the number of chamber cycles is a result of the growth pattern. The chambers are added in concentric cycles, where each new chamber is added alternately between two older chambers. Therefore, the axial section never shows all the chamber cycles but all the lamellae – either on the umbilical or the dorsal side.

### 4.2. Megalospheric form

The axial section of a megalospheric form (Fig. 2A; sample Hk-1112-7 of CIMERMAN 1969) clearly shows that individual lamellae, forming an outer wall of a chamber (Fig. 2A2), extend to the umbilical space and consequently fill it up. The umbilical plug ("Umbilikalfüllung" of BURSCH 1947), therefore, does not represent a special morphological element but merely results from the accretion of lamellae of all consecutive cycles.

### 4.3. Embryonic apparatus of a microspheric form

Thin section V-5 comprises a whole test of a microspheric form. Photomicrograph (Fig. 3A) was taken from the spiral side of the test in transmitted light in oblique darkfield. Fig. 3B1 and 3B2 show a detail of the initial part of the embryonic apparatus of the same specimen. The proloculus is spherical but is not completely visible due to its small size. The estimated diameter of the proloculus is 10 µm. It is followed by a spiral composed of 9 chambers, gradually increasing in size with the last chamber measuring 50 µm in diameter. From the ninth chamber onwards, the test growth proceeds in chamber cycles.

### Acknowledgements

UROŠ HERLEC generously allowed us to study his material from the Bohinj Valley. DUJE KUKOČ prepared Fig. 1. ŠPELA GORIČAN edited the plates and greatly improved the text. We acknowledge the constructive review and comments of the anonymous reviewer.

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Manuscript received: March 10th, 2015.
Revised version accepted by the Bonn editor: March 16th, 2015.

### Address of the authors:

Franc Cimerman, Adrijan Košir, Ivan Rakovec Institute of Palaeontology, Research Centre of the Slovenian Academy of Sciences and Arts, Novi trg 2, SI-1000 Ljubljana, Slovenia; e-mail: cimerman@zrc-sazu.si; adrijan@zrc-sazu.si