



Biostratigraphy and evolution of the larger rotaliid foraminifera in the Cretaceous-Paleogene transition of the Southern Oman Mountains.

Journal:	<i>Palaeontology</i>
Manuscript ID	PALA-10-18-4344-OA.R3
Manuscript Type:	Original Article
Date Submitted by the Author:	18-Mar-2019
Complete List of Authors:	Vicedo, Vicent; Museu de Ciències Naturals de Barcelona, Palaeontology Robles-Salcedo, Raquel; Museu de Ciències Naturals de Barcelona, Palaeontology Serra-Kiel, Josep; Universitat de Barcelona, Dinàmica de la Terra i de l'Oceà Hidalgo, Cristian; Museu de Ciències Naturals de Barcelona, Palaeontology Razin, Philippe; University of Bordeaux III, ENSEGID, Bordeaux INP, G&E, EA, 4592 Grelaud, Carine; University of Bordeaux III, ENSEGID, Bordeaux INP, G&E, EA, 4592
Key words:	foraminifera, Rotaliidae, Oman, Paleocene, Danian

SCHOLARONE™
Manuscripts

1
2
3 **BIOSTRATIGRAPHY AND EVOLUTION OF LARGER ROTALIID FORAMINIFERA IN THE**
4 **CRETACEOUS–PALEOGENE TRANSITION OF THE SOUTHERN OMAN MOUNTAINS**
5
6
7

8 by VICENT VICEDO¹, RAQUEL ROBLES-SALCEDO¹, JOSEP SERRA-KIEL² DECEASED, CRISTIAN
9 HIDALGO¹, PHILIPPE RAZIN³ and CARINE GRÉLAUD³
10
11

12 ¹ Departament de Paleontologia, Museu de Ciències Naturals de Barcelona, Passeig Picasso s/n, 08003 Barcelona,
13 Spain ; vvicedov@bcn.cat
14

15 ² Universitat de Barcelona, Facultat de Ciències de la Terra. Department of Earth and Ocean Dynamics Martí
16 Franquès s/n, 08028 Barcelona, Spain.
17

18 ³ ENSEGID, Bordeaux INP, G&E, EA, 4592, University of Bordeaux III, allée F. Daguin, 33607 Pessac Cedex, France
19
20
21

22 Typescript received; accepted in revised version
23
24
25
26
27

28 **Abstract:** A site in the western flank of Jabal Ja’alan (Oman Mountains) reveals an exceptional
29 succession across the Cretaceous–Paleogene boundary. The sampled interval comprises a
30 series of carbonates deposited in shallow-water platform environments and belonging to the
31 Murka Formation, which lies between the Simsima and Abat formations of latest Cretaceous
32 and Thanetian age, respectively. The larger foraminifera recovered from this interval belong
33 essentially to the group of larger rotaliids (Rotaliidae). Two new genera and two new species
34 are here described, *Praelockhartia neoakbari* gen. nov., sp. nov. and *Rotaliidium parvum* gen.
35 nov., sp. nov. The former shows a very characteristic architecture of an umbilicus with strong
36 piles and two types of umbilical cavities, while the latter has characteristic dorsal
37 supplementary chamberlets. Other species such as *Rotalia* cf. *jacobi*, *Rotorbinella hensoni*,
38 *Rotospirella conica* and *Lockhartia* sp. complete the rotaliid assemblage. The entire
39 assemblage can be considered to be of late Danian age and to belong to shallow benthic zone
40 SBZ 2. The larger rotaliids appear to have recovered and diversified earlier than any other
41 larger benthic foraminifera in the region after the K/Pg crisis. The rotaliids from the Murka
42 Formation also appear to be linked to the Lockhartiinae and to play a special role in improving
43 our understanding of subsequent diversification in the *Lockhartia* Sea. A new subfamily,
44 Praelockhartiinae, is erected to accommodate all primitive forms that are architecturally close
45 to lockhartiids.
46
47
48
49
50

51 **Key words:** Foraminifera, Rotaliidae, Maastrichtian, Danian, Paleocene.
52
53
54
55

56 AFTER the great evolutionary success of larger benthic foraminifera during the Late Cretaceous
57 maturation cycle (*sensu* Hottinger 2001), which resulted in a wide distribution and
58 diversification in shallow-marine settings at tropical and subtropical latitudes, the vast majority
59 of species failed to survive the global biological crisis across the Cretaceous–Paleogene (K/Pg)
60

1
2
3 boundary. Whilst these complex-celled, symbiont-bearing organisms suffered greatly from this
4 crisis, the deep-sea benthic foraminifera show lower extinction rates globally (Alegret &
5 Thomas 2005, 2013). The loss of larger foraminifera at the end of the Cretaceous might be
6 linked to critical changes in environmental parameters along shallow-marine platforms such
7 as temperature, light, depth and nutrient supply, i.e., parameters that impacted the mode of
8 life and distribution of larger foraminifera (see, among others, Leutenegger 1984; Hallock
9 1988; Hohenegger 1995; Goldbeck & Langer 2009).

12
13 The K/Pg boundary is one of the best-studied geological crises worldwide, but the
14 paucity of continuous successions across this interval in shallow-water carbonate-platform
15 facies hinders any characterisation of the evolution of benthic communities. In spite of the
16 existence of such carbonate, larger foraminifera-bearing successions (Roger *et al.* 1998;
17 Schlüter *et al.* 2008) in the Oman Mountains, detailed studies of the architecture and
18 phylogenetic relationships of these organisms are still lacking.

21
22 The present paper focuses on the micropalaeontological content of an important site
23 on the western flank of Jabal Ja'alan (Oman Mountains; Fig. 1) that exposes an exceptional
24 succession across the Cretaceous–Paleogene boundary. To date, this has remained largely
25 unstudied, at least as far as larger foraminifera are concerned. Among the foraminiferal
26 assemblages recovered from the stratigraphical succession sampled, we have focused on an
27 analysis and characterisation of the larger rotaliids from the Murka Formation, which
28 encompasses the K/Pg transition (Roger *et al.* 1998; Schlüter *et al.* 2008). The aims of the
29 present paper are to describe the species found in this stratigraphical unit and discuss their
30 phylogenetic relationships. These objectives have allowed a better evaluation of the
31 environmental impact of this global crisis on the history of earliest Paleogene larger
32 foraminifera from a local and a regional perspective.

38 GEOLOGICAL SETTING AND STRATIGRAPHY

40
41 The larger rotaliid foraminifera studied in the present paper were collected from shallow-
42 water platform deposits assigned to the Murka Formation, which comprises uppermost
43 Cretaceous and lowermost Paleogene strata that crop out along the western flank of Jabal
44 Ja'alan in the Oman Mountains. These mountains constitute a geographical unit along the
45 northeastern margin of the Arabian Plate. Due to this location, its geological history has been
46 strongly influenced by major tectonic events related to the collision and suturing of the
47 Tethyan Ocean (Filbrandt *et al.* 1990; Fournier *et al.* 2006). The palaeoenvironmental changes
48 resulting from these tectonic events can be clearly observed, especially in the mid-Cretaceous
49 to lower Paleocene successions, reflecting the change from a stable tectonic period that
50 controlled the sedimentation during the Albian and Cenomanian to the various phases of
51 deformation that occurred during post-Turonian times (Hughes-Clarke 1988; Scott 1990; Van
52 Buchem *et al.* 1996; Grélaud *et al.* 2010, among others).

56
57 During the late Maastrichtian, regional tectonic activity came to a halt and the margins
58 subsided and permitted the persistence of carbonate sedimentation up to the end of the
59 Cretaceous and into the early Paleogene (Roger *et al.* 1998; Serra-Kiel *et al.* 2016). This

1
2
3 resulted in deposition of shallow-marine limestones that are now assigned to the Simsima and
4 Murka formations, the latter under a more restricted platform conditions. The Murka
5 Formation, from which the larger rotaliids of the present paper were collected, is a late
6 Maastrichtian to Danian unit that is restricted to the Sur area (Roger *et al.* 1998), overlying the
7 Maastrichtian rudist-bearing Simsima Formation (Glennie *et al.* 1974; Fournier *et al.* 2006 and
8 references therein) and overlain itself by Paleocene and Eocene carbonates and marls of the
9 Abat Formation. In the northern Sur area, on top of the Murka Formation rest upper Danian to
10 lower Selandian carbonates and marls of the Sayq Formation (Serra-Kiel *et al.* 2016). The
11 Murka Formation at Jabal Ja'alan consists of a succession of around 70 metres of carbonates,
12 essentially wackestones, packstones and grainstones that formed in shallow-water platform
13 settings. The first 10 metres are characterised by the absence of larger foraminifera. The
14 overlying limestones yield assemblages that are relatively rich in rotaliids and calcareous algae
15 (Fig. 2).
16
17
18
19
20
21
22

23 MATERIAL AND METHODS

24
25 The section studied is located along the western flank of Jabal Ja'alan (UTM 40 Q 737792
26 2452885; co-ordinates 22°9'53.40"N, 59°18'21.39"E; see Fig. 1) and comprises deposits of a
27 shallow-water platform domain that persisted from the Maastrichtian to the early Paleocene.
28 The palaeontological content of the samples collected was studied by taking thin sections of
29 the hard carbonate rocks. The material illustrated in the present paper (Table 1;
30 Supplementary material) is housed in the palaeontological collections of the Museu de
31 Ciències Naturals de Barcelona (abbreviation MGB).
32
33
34
35
36

37 SYSTEMATIC DESCRIPTIONS (by Vicent Vicedo and Raquel Robles-Salcedo)

38
39 This published work and the nomenclatural acts it contains have been registered with
40 Zoobank: <http://zoobank.org/References/2C593081-4021-4396-9FE1-3CA5E22596E5>
41

42 Class GLOBOTHALAMEA Pawlowski, Holzmann & Tyszka, 2013

43 Order ROTALIIDA Delage & Hérouard, 1896

44 Superfamily ROTALIOIDEA Ehrenberg, 1839

45 Family ROTALIIDAE Ehrenberg, 1839

46 Subfamily ROTALIINAE Ehrenberg, 1839

47 **Genus** ROTORBINELLA Bandy, 1944

48 *Type species. Rotorbinella colliculus* Bandy, 1944.
49
50
51
52

53 *Rotorbinella hensoni* (Smout, 1954)
54
55
56
57
58
59
60

Figure 3

1954 *Rotalia hensoni* Smout, p. 45, pl. 15, fig. 8.

1972 *Rotalia perovalis* (Terquem); Samuel *et al.*, pl. 37, figs. 1–4.

1972 *Rotalia* sp. 1; Samuel *et al.*, pl. 37, fig. 5.

1972 *Rotalia* ? sp. 2; Samuel *et al.*, pl. 37, fig. 6.

2006 *Rotorbinella* sp.; Hottinger, p. 86, pl. 2, figs. 11–16.

2014 *Rotorbinella detrecta* Hottinger, p. 26, pl. 3/4A–H.

Description. Shell lamellar, with low conical morphology. Periphery acute with imperforate keel. Dorsal side evolute and convex with smooth surface; ventral side flat to slightly convex. Aperture simple and in interomarginal position. No dimorphism recognised. Proloculus around 40–45 μm in diameter, followed by trochospirally arranged chambers. Adult shells with diameters of 0.7–0.9 mm and height of 0.3–0.5 mm, with 3–4 trochospiral whorls and 7–8 chambers in ultimate whorl. Height/diameter (H/D) ratio varying between 0.7 and 0.9. Umbilical zone filled with massive structure consisting of single umbilical pile, or umbilical plug, standing free and separated from foliar tips by deep spiral fissure. Umbilical plate separating main chamber lumen from umbilical spiral canal. Folia small and imperforate, with foliar sutures.

Remarks. As pointed out by Hottinger (2014, p. 24), *R. hensoni* has traditionally been used to encompass “Rotorbinellas lacking features of specific character” and appearing over an extensive wide stratigraphical range, from the Paleocene to lower Ypresian. The controversy surrounding *R. hensoni* is rooted in the original paper by Smout (1954), who described the species solely on the basis of external characters, without mention of the nature of its internal features such as the size of the embryo or the number of chambers per whorl. According to current consensus, however, morphometric data are essential in the study of populations and, in particular, in specific classification. The fact that Smout illustrated only a single specimen (Smout, 1954, pl. 15, fig. 8) did not help in the clarification of the specific characters of *R. hensoni*, hampering later revisions of this species. Aware of all the controversy around *R. hensoni*, Hottinger restudied the type material in the collections of the Natural History Museum (London). It would appear that Hottinger was not able to complete this architectural revision in particular before his death, as is suggested by the unfinished sketch of the holotype published in his monograph (Hottinger, 2014, p. 28, fig. 3.2). In line with this, Hottinger’s remarks on *R. hensoni* (*op. cit.*, p. 24) did not clarify the controversy because he did not present any detailed description of the type material in terms of morphometry. To make matter worse, some important features that can be observed in his illustrations do not match those mentioned by Smout. The scale bar of Hottinger’s sketch of the holotype indicates a diameter of 1.3 mm, i.e., larger than the 0.9 mm given in the original description by Smout as maximum diameter. Further, Hottinger’s illustrated specimens of *R. hensoni* were collected from upper Paleocene and lower Eocene strata in southern France, which means a different stratigraphical and palaeogeographical context to that of Smout’s material, which was from “the lower part of the Paleocene of Qatar”. Considering all these facts, we can affirm that *R.*

1
2
3 *hensoni* remains a taxon of uncertain architectural characteristics that needs a careful revision
4 and redefinition by means of a restudy of the type material. This is beyond the scope of the
5 present paper. Any future study should include a comprehensive overview of all populations
6 that have been attributed to date to *R. hensoni* in order to evaluate its intraspecific variability
7 based on a solid stratigraphical background. In the meantime, the external description and
8 dimensions given by Smout for *R. hensoni* should be used to constrain the specific
9 identification, grouping all the “small-sized” and stratigraphically older populations. The
10 specimens illustrated by Hottinger as *R. hensoni* could represent a different species, due to the
11 larger size and different (i.e., younger) stratigraphical context. In contrast, both the external
12 features of our specimens and their stratigraphy match the description supplied by Smout for
13 *R. hensoni*. Further, the species *R. detrecta*, described by Hottinger (2014), from the shallow
14 benthic zone (SBZ) 2 of the Pyrenees shows similar morphometrics to *R. hensoni* (i.e.,
15 maximum diameters of 0.8 mm and 0.9 mm, respectively; height of 0.3 mm and H/D ratios of
16 0.4 for both species). *Rotorbinella detrecta* should be considered a junior synonym of *R.*
17 *hensoni*.
18
19
20
21
22

23
24
25 Genus ROTALIA Lamarck, 1804

26
27 *Type species. Rotalites trochidiformis* Lamarck, 1804.
28
29

30
31
32 *Rotalia cf. jacobi* Sander, 1962

33
34 Figure 4

35
36 1962 *Rotalia jacobi* Sander, pp. 15, 16, pl. 3, figs. 13–20.
37

38 1991 *Rotalia saxorum* d’Orbigny; Wan, p. 10, pl. 1, figs. 11–12.
39

40
41 *Description.* Test conical with thin lamellar wall. Dorsal side smooth and evolute, lacking
42 ornamentation, showing merely weak spiral suture. Ventral side flat to slightly convex. No
43 dimorphism observed. Embryo composed of protoconch and deuterococonch with diameters of
44 66–78 μm and 53–65 μm , respectively, followed by chambers arranged trochospirally in at
45 least 2 to 3 whorls, with 7–9 chambers in ultimate whorl. Maximum diameter observed about
46 0.9 mm and height about 0.5 mm. H/D ratio around 0.6. Umbilical zone filled with
47 characteristic columella produced by fusion of foliar adaxial tips. Ventral face covered by thin
48 cylindrical papillae. Foliar suture strongly marked, easily identified as very typical infold in both
49 axial and transverse sections.
50
51

52
53 *Remarks.* The specimens of *Rt. cf. jacobi* illustrated by Sander (1962) in the original description
54 appear to show dissimilar external features. The author himself admitted that “ornamentation
55 is variable” (see Sander 1962, p. 15) among specimens. Whether these external differences
56 observed are a consequence of differential preservation or the result of grouping different
57 morphotypes is a question that cannot be resolved here, but for now we favour the latter
58 hypothesis. A detailed analysis of external features of the type population shows that two
59
60

1
2
3 morphotypes can be distinguished. One of these seems to have a more delicate chamber wall
4 with dorsal ornamentation and fine sculpture on pronounced spiral and chamber sutures (see
5 Sander 1962, pl. 3, figs. 13–15). This morphotype also reveals a flat ventral side with an
6 umbilical structure composed of folia fused at their adaxial tips, which suggests a columellar
7 structure. The other form shows a smooth dorsal side, lacking any ornamentation, and an
8 umbilical structure based on free-standing piles (see Sander 1962, pl. 3, figs. 16–18). This
9 umbilical structure extends towards the direction of growth giving it a marked degree of
10 convexity. We agree with Sander (1962) in identifying the first morphotype as a species of
11 *Rotalia*, but we have serious doubts about the generic placement of the second, which is
12 externally closer to *Rotospirella conica* or *Praelockhartia neoakbari* gen. nov., sp. nov. than to a
13 true member of *Rotalia*. This issue is even more difficult to resolve because Sander did not
14 designate a holotype. More material, a designation of a lectotype and a proper description of
15 the internal characteristics are needed in order to confirm or reject identifications. We
16 tentatively ascribe our specimens of *Rotalia* to *Rt. cf. jacobi* on account of their similar
17 features such as external ornamentation and size.
18
19
20
21
22
23
24

25 Praelockhartiinae subfam. nov.

26
27 *LSID.* urn:lsid:zoobank.org:act:B8AB164F-7268-4C60-AA3A-69A71BBCA488

28
29 *Type genus.* *Praelockhartia* gen. nov.

30
31 *Diagnosis.* Rotaliid with coarse perforated test. Dorsal side smooth or showing slight to
32 thickened spiral suture due to inflational ornamentation of chamber margin. Ventral side flat
33 to slightly concave with piles. Umbilical structure based on folia differentiated from chamber
34 wall by marked notch. Folia fused at adaxial tips forming piles. Secondary lamellation producing
35 two types of umbilical cavities: one located irregularly among piles (i.e., interpilic umbilical
36 cavities) and other produced by folium foldings at peripheral part of umbilical zone,
37 between chamber wall and piles (i.e., umbilical peripheral cavities). Second type forming
38 complex structure of irregular cavities consisting of both well-developed foliar chamberlets
39 and cavity produced by notch suture when covered by outer lamella of following chambers.
40
41
42
43

44 *Differential diagnosis.* The new subfamily differs from representatives of other rotaliid
45 subfamilies by the combination of umbilical piles and the complex and irregular structure of
46 peripheral umbilical cavities.
47

48
49 *Remarks.* In addition to the new genus *Praelockhartia* (see below), we assign the genus
50 *Rotospirella* Hottinger, 2014 to the Praelockhartiinae subfam. nov. We also include *Rotalispira*
51 Hottinger, 2014 because its type species, *R. scarsellai* (Torre, 1966), shows some poorly
52 developed umbilical cavities (see Hottinger 2014, pl. 5.1, figs. 9, 16, 20 and 21) and *R.*
53 *pyrenaica* Hottinger, 2014 has slender umbilical piles. In our opinion, the recently described
54 Cretaceous species *Rotalispira vitigliana* Consorti, Frijia & Caus, 2017 and *R. maxima* Consorti,
55 Frijia & Caus, 2017 should be restudied and their generic attribution re-evaluated as they
56 appear to show an umbilical structure that is dissimilar to the one of the type species of the
57 genus; both seem to lack any kind of umbilical cavity. The genus *Rotalispira* Consorti,
58
59
60

Villalonga & Caus, 2017 could also be included in the new subfamily, because of the presence of thin umbilical piles and poorly developed interpilae cavities (see Hottinger 2014, figs. 5.13 and 5.25). However, the architecture of this genus should be addressed because the main traits are not detailed in the original description. *Rotalispira acuta* Consorti, Villalonga & Caus, 2017 shows architectural features that are similar to those of *R. scarsellai*; for example, see the incipient double-keeled test in Hottinger 2014, fig. 5.1–22.

PRAELOCKHARTIA gen. nov.

LSID. urn:lsid:zoobank.org:act:F2752076-39D0-45CB-AE96-6D3B52ED78A3

Type species. Praelockhartia neoakbari sp. nov.

Etymology. Prae-, Latin for 'before', and *Lockhartia*; gender feminine.

Diagnosis. Test coarsely perforated, conical to hemispherical. Aperture simple, consisting of slit in interomarginal position. Embryo composed of three subspherical chambers (triconch) followed by chambers arranged trochospirally. Chambers with rounded periphery and thick wall. Dorsal side convex, evolute and smooth, lacking ornamentation. Spiral suture visible by absence of coarse perforation. Ventral side flat to slightly convex, ornamented with piles. Strongly marked notch extending into internal infold or furrow in lateral-ventral chamber wall (foliar suture), separating main chamber lumen from foliar chamberlet. Irregular peripheral umbilical cavities present. Long folia fused at adaxial part of umbilicus, forming piles separated by very narrow funnels. Poorly developed umbilical cavities present between piles. Main chamber lumen and umbilical spiral canal separated by umbilical plate (see architectural model in Fig. 5).

Differential diagnosis. Praelockhartia gen. nov. differs from other genera included in the Lockhartiinae by Hottinger (2014) by its more massive umbilical structure (based on strong piles and an absence of regular interpilae umbilical cavities) and by its smooth dorsal surface. *Rotospirella* and *Rotalispira* differ from *Praelockhartia* gen. nov. by the absence of strong piles, by their thinner and more delicate folia and slightly smaller notches.

Praelockhartia neoakbari sp. nov.

Figures 6–8

LSID. urn:lsid:zoobank.org:act:E9D9E46D-13DA-4374-BA23-FE27A4ECDAE7

(?)1978 *Lockhartia* n. sp.; Rahaghi, pl. 12, figs. 5–6.

1983 *Rotalia* aff. *trochidiformis*; Rahaghi, p. 36, fig. 10.

Etymology. From the Greek *neo*, meaning new, and *akbari*, the species formerly considered a biomarker of SBZ 2 (see below).

1
2
3 *Ttypes*. The holotype is MGB 59865 LP2.95 (Fig. 6M); axial height 560 μm , equatorial diameter
4 790 μm . The other specimens illustrated in Figures 6–8 are paratypes.

6
7 *Diagnosis*. Lamellar-perforated wall with coarse pores. Test conical to hemispherical. Simple,
8 slit-shaped aperture in interomarginal position. Rounded periphery with imperforate margin.
9 Dorsal side evolute and smooth, lacking ornamentation; spiral suture slightly marked. Ventral
10 side flat to slightly convex, ornamented with piles. No dimorphism observed. Protoconch
11 diameter 85–115 μm . Embryo followed by chambers arranged trochospirally, composed of up
12 to 2.5–3 whorls. Adult shells with diameter of around 1 mm (0.9–1.2 mm, minimum and
13 maximum observed) and height of about 0.6 mm, with H/D ratio of conical shell around 0.6–
14 0.7. Main chamber lumen separated from umbilical spiral canal and foliar chamberlet by
15 umbilical plate. Chambers increasing in size during growth. Spiral suture visible by absence of
16 coarse perforation. Notch strongly marked extending into internal infold or furrow in lateral-
17 ventral chamber wall forming kind of foliar suture separating ventral part of chamber from
18 folia at umbilical zone. Notch covered by secondary lamellation forming irregular peripheral
19 umbilical cavities. Long folia fused at adaxial tips, forming piles separated by very narrow
20 vertical spaces or funnels. Primitive, poorly developed umbilical cavities appearing in umbilical
21 zone.
22
23
24
25
26
27
28

29 Genus ROTOSPIRELLA Hottinger, 2014

30
31 *Type species*. *Lockhartia conica* Smout, 1954.

32
33 *Previous remarks*. This genus was described by Hottinger (2014) to accommodate the rare
34 original material of *Lockhartia conica*, a species described by Smout (1954) from the Paleocene
35 of Qatar, and other specimens from the Zagros Mountains, Iran (no age given for the latter).
36 Hottinger (2014) presented only a brief description of *Rotospirella*, not a true diagnosis, failing
37 to provide a full explanation of all basic architectural traits. In order to avoid any future
38 controversy, we consider it of importance to complete the generic and specific diagnoses by
39 describing other diagnostic key traits not considered by Hottinger. In order to do so, we have
40 re-examined high resolution pictures of the type series of *R. conica* (paratypes are available
41 online through the webpage of the Natural History Museum, London) and of the material from
42 Iran figured by Hottinger (2014).
43
44
45

46
47 *Diagnosis (emended)*. Lamellar-perforated, conical shell with trochospiral chamber
48 arrangement and rounded periphery. Very thick, coarsely perforated wall. Dorsal side evolute
49 with smooth surface. Ventral side slightly ornamented with rounded protuberances produced
50 by umbilical piles. Single aperture in interomarginal position. Main chamber lumen and
51 umbilical spiral canal separated by umbilical plate. Long and delicate folia extending and fusing
52 at adaxial part forming piles and funnels. Two types of cavities appearing in umbilicus:
53 umbilical interpile cavities and umbilical peripheral cavities. Dimorphism not observed.
54
55

56
57 *Differential diagnosis*. *Rotospirella* differs from all other genera included in the subfamilies
58 Rotaliinae Ehrenberg, 1839 and Lockhartiinae Hottinger, 2014 by having an umbilical structure
59 based on piles and two types of umbilical cavities.
60

Rotospirella conica (Smout, 1954)

Figure 9

1954 *Lockhartia conica* Smout, p. 53, pl. 4, figs. 1–3.

1991 *Lockhartia conica* Smout; Wan, p. 162, pl. 1, figs. 28, 29.

2011 *Lockhartia conica* Smout; Boukhary *et al.*, p. 44, pl. 4, figs. 1–4.

2014 *Rotospirella conica* (Smout); Hottinger, p. 31, fig. 3.6.

Diagnosis (emended). Lamellar-perforated and high conical shells with rounded apex and periphery. Very thick, coarsely perforated wall. Dorsal side evolute with smooth surface. Ventral side flat, slightly concave and ornamented with rounded protuberances produced by umbilical piles. Single aperture in interomarginal position. Dimorphism not observed. Megalospheric generation starting with large proloculus of around 150 μm , followed by chambers arranged trochospirally. Umbilical spiral canal connecting all chambers at umbilical zone. Long and delicate folia extending and fusing in their adaxial part forming piles and funnels. Umbilical cavities appearing in peripheral part of umbilicus and between piles. Axial diameter for adult specimens around 1–1.5 mm (mean 1.3 mm) and 2–3 whorls. H/D ratio around 0.8.

Remarks. We refer some of our material to this species on account of their general architecture and delicate folia.

Subfamily LOCKHARTIINAE Hottinger, 2014

Genus LOCKHARTIA Davies, 1932

Lockhartia aff. *conditi* (Nuttall, 1926)

Figure 10

Description. The rare material collected shows a conical test with rounded periphery; axial section with an oval outline. Dorsal side evolute with slight ornamentation. Aperture as a slit, located in interomarginal position. Folia very long and fusing to form piles and funnels. Regular umbilical cavities appearing among piles; typical of genus. Maximum diameter observed around 1.1 mm and H/D ratio around 0.6, with proloculus of about 55 μm .

Differences and similarities. Our specimens seem to be architecturally close to *Lockhartia conditi*, but are smaller. We have left them in open nomenclature in view of the paucity of the material.

ROTALIOIDEA indeterminate

Genus ROTALIIDIUM nov.

LSID. urn:lsid:zoobank.org:act:6A8B4458-C1AE-4810-A73B-8D24EFC7DC86

Type species. Rotaliidium parvum sp. nov.

Etymology. From the rotaliform shape and the Latin suffix *-idium*, a diminutive form in reference to its small size; gender neuter.

Diagnosis. Lamellar-perforated test with low to very low trochospiral chamber arrangement. Dimorphism not observed, but presumably restricted to early stages of growth. Aperture slit in interomarginal position. Advolute chambers with rounded periphery. Umbilicus filled with fused folia forming small and massive plug. Dorsal and ventral sides slightly convex. Supplementary spiral apertures along spiral suture connecting main chamber lumen with dorsal supplementary spaces or chamberlets. Umbilical spiral canal and main chamber lumen separated by umbilical plate.

Differential diagnosis. This new genus is closely related to *Rotorbinella*, the umbilical structure based on fused folia forming a massive plug being similar in both genera. However, the former differs from the latter in having dorsal sutural apertures that connect the main chamber lumen with the small dorsal supplementary spaces or chamberlets. The combination of these two features, i.e., the umbilical plug and dorsal supplementary chamberlets, in the same morphotype, differentiate the new genus from all other rotaliids described to date.

Rotaliidium parvum sp. nov.

Figures 11–12

LSID. urn:lsid:zoobank.org:act:5630898A-6760-4C04-B322-7510F23F1D87

Etymology. From the Latin *parvum*, meaning small, in reference to its size.

Types. The holotype is MGB 59865 LP6.134 (Fig. 11D), axial height 175 μm , equatorial diameter 300 μm . The other specimens illustrated in Figures 11 and 12 are considered paratypes.

Diagnosis. Lamellar-perforated test with low to very low trochospiral chamber arrangement and rounded periphery. Single, slit-shaped aperture in interomarginal position. Advolute chambers. Umbilicus filled with small massive plug. Dorsal and ventral sides slightly convex, smooth surface, lacking ornamentation. Small proloculus of around 4 μm in diameter. Maximum diameter of adult specimens around 300–340 μm . H/D ratio of around 0.6. Spiral apertures connect main chamber lumen with dorsal supplementary chamberlets. Umbilical spiral canal separated from main chamber lumen by umbilical plate.

THE K/Pg INTERVAL IN THE OMAN MOUNTAINS: DROP AND INCREASE OF THE LARGER FORAMINIFERAL DIVERSITY

1
2
3 When considering 'a community' to be a group of species living together in a certain area and
4 delimited by discontinuities (Hottinger 2001), the different populations of larger benthic
5 foraminifera observed across the K/Pg interval in the Oman Mountains represent different
6 states of equilibrium between species and environment. The K/Pg boundary represented a
7 negative turning point for K-strategists among foraminifera, the vast majority of Late
8 Cretaceous species going extinct. Based on our observations at Jabal Ja'alan, it seems that it
9 took millions of years for the larger foraminiferal community to reach a peak of maturation
10 again that was characterised by a rich and diverse assemblage of species (see distribution
11 chart; Fig. 13).

15 *The latest Cretaceous representatives*

16
17 The mature larger foraminiferal community, documented by a great abundance and diversity
18 of species, during the Late Cretaceous is represented in the Oman Mountains by populations
19 in the Qhalah and Simsima formations (Roger *et al.* 1998; Abdelghany 2003, 2006). At Jabal
20 Ja'alan, the uppermost strata of the Simsima Formation contain an assemblage of larger
21 foraminifera that comprises *Broeckina* cf. *dufrenoyi* (d'Archiac & Haime, in d'Archiac, 1854),
22 *Fissoelphidium operculiferum* Smout, 1954, *Loftusia morgani* Douvillé, 1904, *Omphalocyclus*
23 *macroporus* (Lamarck, 1816), *Pseudomphalocyclus blumenthali*? Meriç, 1980, *Siderolites*
24 *calcitrapoides*? Lamarck, 1801, *Stomatorbina binkhorsti* (Reuss, 1862) and the dasycladacean
25 alga *Trinocladus radoicicae* Elliott, 1968 (Fig. 14). This assemblage, which can also be observed
26 in several other sections exposed in the Abat region and the remainder of the Oman
27 Mountains, is of Maastrichtian age and its members can be considered to be the latest
28 representatives of the Cretaceous in the study area. These abundant and diverse Omani
29 Cretaceous populations deserve detailed taxonomic studies in the future, as they show
30 architectural differences with respect to their western Tethyan relatives. Such is the case with
31 siderolitids, which have dissimilar structural traits in respect to the forms described to date.

37 38 39 *The earliest Paleogene representatives*

40
41 The palaeoecological conditions that allowed the development and spread of such a high
42 diversity during the Late Cretaceous subsequently changed. The assemblage of the Murka
43 Formation is composed mainly of the larger rotaliid species *Praelockhartia neoakbari* gen.
44 nov., sp. nov., *Rotaliidium parvum* gen. nov., sp. nov., *Rotalia* cf. *jacobi*, *Rotospirella conica*,
45 *Lockhartia* aff. *conditi* and *Rotorbinella hensoni*. In some samples, other taxa co-occur,
46 including *Idalina* sp., *Valvulina triangularis* d'Orbigny, 1826, *Gyroidina* sp., *Quinqueloculina* sp.
47 and *Stomatorbina binkhorsti* (Reuss, 1862) (Fig. 14). At Jabal Ja'alan the K/Pg boundary was
48 difficult to identify as it is restricted to a minor sedimentary discontinuity, as pointed out by
49 Roger *et al.* (1998, p. 267). The presence of the dasycladaceans *Halimeda* sp., *Jodotella* sp.,
50 *Cymopolia* sp., *Indopolia satyavanti* Pia, in Rao & Pia, 1936, *Clypeina* sp., *Neomeris* sp. and
51 Bryopsidales indet. (Fig. 15) in association with the larger rotaliids suggest that the deposits
52 are of Paleocene age (see Schlüter *et al.* 2008, for a similar Paleocene assemblage). The
53 absence of biomarkers of SBZ 3, which appear higher in the succession (see below) and
54 correlation of the Murka Formation with the planktonic biozones P1 to P3 in neighbouring
55 areas (see Roger *et al.* 1998; Serra-Kiel *et al.* 2016), allows us to suggest that the rotaliid
56
57
58
59
60

1
2
3 assemblage belongs to SBZ 1 or 2, of Danian age. Concerning these two SBZs, it is fairly well
4 known that there is no clear biomarker for SBZ 1, with the exception of *Bangiana hanseni*
5 Drobne, Ogorelec & Riccamboni, 2007, because *Laffitteina bibensis* Marie, 1946, also recorded
6 to be characteristic of this biozone, has a longer range (Inan *et al.* 2005). On the basis of our
7 observations at Jabal Ja'alan, the SBZ 1 seems to be restricted to a thin interval with no
8 significant foraminiferal benthic biomarkers, as observed in lowermost Paleocene deposits
9 outcropping in other regions such as the western Pyrenees (Serra-Kiel, J., Vicedo, V., Baceta,
10 J.I., Bernaola, G. and Robador, A., unpublished data) and other areas in the Neo-Tethys (Zhang
11 *et al.* 2013). At Jabal Ja'alan, this lowermost short interval of the Murka Formation should be
12 resampled and restudied in much more detail in future in order to discard definitively any
13 hiatus due to erosion or non-deposition in the lowermost Danian.
14
15
16

17 *The overlying Selandian to early Thanetian assemblage*

18
19
20 The rotaliids of the Murka Formation are followed by another rich larger foraminiferal
21 assemblage of the Abat Formation, comprising *Keramospherinopsis* sp., *Kathina* cf. *major*
22 Smout, 1954, *Daviesina* sp., *Periloculina?* spp., *Lockhartia retiata* Sander, 1962, *L. diversa*
23 Smout, 1954, *L. cf. altispira* Smout, 1954 and *L. praehaimeii* Smout, 1954. This assemblage can
24 be attributed to SBZ 3, indicating a Selandian to early Thanetian age (Fig. 16). The Abat
25 Formation is equivalent, according to Roger *et al.* (1998), to the lower part of the Jafnayn
26 Formation. This rich assemblage, which also calls for further research because of its
27 extraordinary diversity, seems to mark the total recovery in this area of the palaeoecological
28 conditions of shallow-water platforms.
29
30
31
32
33
34

35 **ROTALIIDS IN THE OMANI "CRETACEOUS-PALEOGENE TRANSITION"**

36
37 The near-exclusive presence of rotaliids in the Murka Formation also appears to be in
38 accordance with other findings in the K/Pg transition in Oman and surrounding areas.
39 Micropalaeontological baseline studies for the Arabian Peninsula, such as the monographs by
40 Sander (1952) and Smout (1954), dealt essentially with rotaliids as the most representative
41 group of larger foraminifera of the early Paleocene. However, this pattern can also be found in
42 other locations of the Neo-Tethys Ocean, such as the Indus Basin, where larger rotaliids are
43 commonly reported from SBZs 1 and 2 (Afzal 2011; Afzal *et al.* 2011; Zhang *et al.* 2013;
44 Kahsnitz *et al.* 2016, among others). The presence of rotaliids across the K/Pg transition at Jabal
45 Ja'alan was also noted in a reference study by Roger *et al.* (1998). According to those authors,
46 the upper part of the "basal sequence" of the Murka Formation contained "rotaliinés" such as
47 *Rotalia* cf. *trochidiformis* and a "poorly evolved form" of *Lockhartia diversa* (Roger *et al.* 1998,
48 p. 265). They considered this assemblage to be typical of the "Cretaceous-Paleogene
49 transition" in restricted platform facies of the Arabian Peninsula. Despite the fact that they
50 sampled the Murka Formation along the eastern flank of Jabal Ja'alan and in other
51 neighbouring areas (see Roger *et al.* 1998, p. 264, figs. 8-9), it is very likely that their rotaliid
52 morphotypes are the same as ours. Similar to Smout (1954), they distinguished two
53 morphotypes, yet probably provided erroneous identifications. For instance, their *Rotalia* cf.
54 *trochidiformis* could in fact be *Rt. cf. jacobi* and *Lockhartia diversa* might be a misidentification
55 of some lockhartiform, such as *Rotospirella conica* or *Praelockhartia neoakbari* gen. nov., sp.
56
57
58
59
60

1
2
3 nov. If the latter, the confusion could be rooted in the resemblance of *Rll. conica* to
4 lockhartiines (see below). Further, other findings support the idea of such a misidentification,
5 especially in the latter case, as recent studies have confirmed that *Lockhartia diversa* is
6 younger, more complex and more evolved than *Rll. conica* (see Hottinger 2014, p. 10, range
7 chart) and *P. neoakbari* gen. nov., sp. nov. Therefore, it is highly improbable to find *L. diversa*
8 in the middle part of the Murka Formation, considering that the age is constrained by the
9 upper and lower larger foraminiferal assemblages. In any case, it seems clear that larger
10 rotaliids played a dominant role in the shallow-water carbonate platform environments after
11 the Cretaceous-Paleogene biotic crisis on a regional or even global scale.
12
13
14
15
16
17

18 **THE SPECIES *LOCKHARTIA* *AKBARI* AS A BIOMARKER FOR SBZ2**

19
20 Among all taxa considered in the literature as markers for SBZ 2, the current status of
21 *Lockhartia akbari* and *Paralockhartia eos* is in need of some brief comments. These species
22 were first mentioned in a reference paper by Serra-Kiel et al. (1998) as biomarkers of SBZ 2,
23 together with *Miscellanites globularis* (Rahaghi, 1978) and *Ornatononion minutus* (Rahaghi,
24 1983). The former were cited as follows: “*akbari* Hottinger & Tambareau in press, *Lockhartia*
25 [pl. 12, fig. 1-7: Rahaghi, 1978]
26 [...]”
27
28
29 *eos* Hottinger & Tambareau in press, *Paralockhartia* [pl. 1, fig. 1-8: Hottinger & Tambareau, in
30 press]”
31

32 Since then, these species have been mentioned as characteristic of SBZ 2 (Tambareau
33 et al. 1997; Inan & Inan 2008; Khasnitz, 2017, among others), although they were not formally
34 described. They were even included as biomarkers in the descriptive tables of SBZs included in
35 successive editions of the Geological Time Scale (Gradstein et al. 2004, 2012). Eventually, the
36 species *Paralockhartia eos* was validly published by Hottinger (2014). In contrast, *Lockhartia*
37 *akbari* currently is a *nomen nudum* (Pignatti 1998; Kahstniz 2017). As a matter of a fact,
38 Hottinger (2014) did not even mention this latter species in his monograph of the Paleogene
39 rotaliids, and synonymised Rahaghi’s specimens (cited in Serra-Kiel et al. 1998 as *L. akbari*)
40 with *Lockhartia retiata* Sander, 1962. Judging from the architecture of Rahaghi’s specimens
41 and that of *L. retiata*, we disagree with the synonymy proposed by Hottinger. Some of
42 Rahaghi’s specimens, described in 1978 as *Lockhartia* n. sp., are, in our opinion, architecturally
43 closer to our specimens of *Praelockhartia neoakbari* gen. nov., sp. nov. than to *L. retiata* (in
44 particular, the specimen of Hottinger’s 2014, pl. 12, figs. 5–6). Rahaghi’s specimens seem to
45 show a smooth dorsal side and an umbilicus with central pillars and peripheral umbilical
46 cavities, which differs from the well-developed umbilical cavities of lockhartiines.
47
48
49
50
51
52

53 **THE MURKA ROTALIIDS: A KEY TO UNDERSTANDING THE ORIGIN OF THE *LOCKHARTIA* SEA**

54
55 The so-called *Lockhartia* Sea is a palaeogeographical area in which the group of *Lockhartia*
56 communities spread and diversified during the Paleogene, becoming an important group of
57 index fossils. According to Hottinger (2014, p. 3), the *Lockhartia* Sea was “a part of the
58 Paleogene Neotethys, reaching in Asia from Tibet to Pakistan, Afghanistan, Iran and southern
59 Turkey, in Africa from Somalia to Egypt and all over the Arabian Peninsula”.
60

1
2
3 The larger foraminifera found in the Murka Formation, especially the Praelockhartiinae
4 subfam. nov., can be considered to be crucial elements in the analysis and understanding of
5 the evolution of Paleogene rotaliids. The architectural traits of some species identified in the
6 present paper suggest the existence of some kind of phylogenetic relationship between these
7 older forms and the younger and successful *Lockhartia* morphotypes. Following the extinction
8 at the K/Pg boundary, *Praelockhartia neoakbari* gen. nov., sp. nov. was the first larger rotaliid
9 that was architecturally close to species of *Lockhartia* appearing in our samples from Jabal
10 Ja'alan. These specimens show a more primitive architecture, as based on thick folia and
11 strong pillars and peripheral umbilical cavities. The dorsal ornamentation is also simpler,
12 comprising merely a slightly marked spiral suture, contrasting with the highly ornamented
13 dorsal side of lockhartiids.
14
15
16
17

18 *Rotospirella conica* appears to have been the next step in the increasing complexity
19 between praelockhartiines and lockhartiines, showing affinities to the latter group with regard
20 to the umbilical structure and the distribution of piles. The folia of *Rll. conica* are thinner and
21 longer than those of *P. neoakbari* gen. nov., sp. nov. The morphostructural similarities of *Rll.*
22 *Conica* with lockhartiines are likely to be the main reason why Smout originally ascribed it to
23 the genus *Lockhartia*. Although Hottinger (2014) suggested that the origin of the group of
24 lockhartiines could be found in the older forms ascribed to the genus *Rotalispira*, ruling out
25 any type of relationship with *Rll. conica*, we believe, as Smout did, that this latter species is
26 indeed phylogenetically related as based on architectural similarities of the test. The presence
27 of umbilical cavities and their coarsely perforated tests are the main factors that support this
28 hypothesis. In our opinion, the absence of heavy ornamentation is not a sufficient difference
29 to warrant ruling out any kind of phylogenetic relationship between *Rll. conica* and
30 lockhartiines. Generally speaking, the ornamentation is a structural pattern that is difficult to
31 categorise in terms of phylogeny. Relatively high variability in ornamentation may be observed
32 when looking closely at representatives of a population. For instance, we may refer to the thin
33 sections of *L. roeae* (Davies, 1930) and *L. conditi* (Nuttall, 1926) as illustrated by Hottinger
34 (2014, pl. 5.13 and pl. 5.14-15, respectively): all of these specimens seem to show relatively
35 smooth dorsal sides in thin section.
36
37
38
39
40
41

42 Therefore, in general terms, we consider the Praelockhartiinae subfam. nov. to be a
43 group of larger rotaliid foraminifera with a primitive architecture with respect to the younger
44 and more evolved Lockhartiinae. *Rotospirella conica* could be considered as the link between
45 the primitive *Praelockhartia neoakbari* gen. nov., sp. nov. and the more evolved forms of
46 *Lockhartia (sensu lato)*. This would mean that *Praelockhartia neoakbari* gen. nov., sp. nov. is a
47 strong candidate for the true root in the Paleocene of lockhartiines and, therefore, potentially
48 the origin of the later diversity in the *Lockhartia* Sea.
49
50
51
52
53

54 DISCUSSION

55
56 The most significant biotic communities, in terms of diversity and abundance, found in strata
57 of the Murka Formation are rotaliids and green algae. This assemblage has been dated as early
58 Paleocene (late Danian) and ascribed to SBZ 2. The rotaliids can be considered key to
59 understanding the origin and evolution of the later Paleogene rotaliid populations, playing a
60

crucial role in the shallow-water carbonate platforms of the region during the K/Pg interval. It seems that rotaliids recovered more rapidly than other larger foraminifera after the massive extinction across the K/Pg boundary, or that they were more resistant to certain palaeoecological conditions that likely had yet to become favourable for other larger benthic foraminifera. The origin of one of the main groups of Paleogene larger rotaliids, the lockhartiines, seems to be rooted early in the Paleocene with representatives of the Praelockhartiinae subfam. nov., on the basis of their closely related architectures. The simple structure of 'rotorbinellas', which originated in the Cenomanian, seems to be the most successful or biologically advantageous in terms of functionality as it was replicated after two global biotic crises, i.e., the Cenomanian–Turonian and K/Pg boundaries.

CONCLUSIONS

A detailed revision of the larger rotaliids found in the K/Pg interval outcropping along the western flank of Jabal Ja'alan has allowed us to:

- Describe two new genera and two new species, i.e., *Praelockhartia neoakbari* and *Rotaliidium parvum*.
- Emend the diagnosis of both the genus *Rotospirella* and its type species, *R. conica*.
- Create a new subfamily, Praelockhartiinae, to accommodate primitive forms closely related to *Lockhartia*.
- Formulate a new hypothesis concerning the origin of the lockhartiines, one of the most diverse groups among Paleogene shallow-water benthics. This hypothesis revolves around considering the Murka Formation rotaliids the root of this group, being key to understanding the origin of the diversity found later in the *Lockhartia* Sea.
- Define the new rotaliid assemblage of SBZ 2 for this area, namely, *Praelockhartia neoakbari* gen. nov., sp. nov., *Rotaliidium parvum* gen. nov., sp. nov., *Rotalia* cf. *jacobi*, *Rotospirella conica*, *Lockhartia* sp. and *Rotorbinella hensoni*. Other benthic foraminifera found in the assemblage are: *Idalina* sp., *Valvulina triangularis*, *Gyroidina* sp., *Quinqueloculina* sp. and *Stomatorbina*.
- Present a detailed discussion of the state of the unavailable name *Lockhartia akbari*, considered a biomarker of SBZ 2.

Acknowledgements. Financial support for the present study was received within the framework of the research and collections projects of the Museu de Ciències Naturals de Barcelona (MCNB). Many thanks are due to the technicians of the Documentation Centre, for supplying references, and to preparator Dr Gerard Lucena of the Geo-Palaeo Preparation Lab of the MCNB, for his work in producing the excellent thin sections of carbonate rocks. Many thanks are also due to Professors M. Parente (University of Naples "Federico II", Italy) and B. Granier (University of Brest, France) for their very useful comments on calcareous algae. The present study was also conducted within the framework of the research project CGL2015-69805-P of the Spanish Ministry of Economy and Competitiveness. In addition, we are grateful

to Professors Johannes Pignatti and Mariano Parente and to the handling editor for pertinent comments on an earlier version of the typescript.

REFERENCES

- ALEGRET, L. and THOMAS, E. 2005. Cretaceous/Paleogene boundary bathyal paleo-environments in the central North Pacific (DSDP Site 465), the northwestern Atlantic (ODP Site 1049), the Gulf of Mexico and the Tethys: the benthic foraminiferal record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **224**, 53–82.
- — 2013. Benthic foraminifera across the Cretaceous/Paleogene boundary in the Southern Ocean (ODP Site 690): diversity, food and carbonate saturation. *Marine Micropaleontology*, **105**, 40–51.
- ABDELGHANY, O. 2003. Late Campanian-Maastrichtian foraminifera from the Simsim Formation on the western side of the northern Oman Mountains. *Cretaceous Research*, **24**, 391–405.
- 2006. Early Maastrichtian larger foraminifera of the Qahlah Formation, United Arab Emirates and Sultanate of Oman border region. *Cretaceous Research*, **27**, 898–906.
- AFZAL, J. 2011. Evolution of larger benthic foraminifera during the Paleocene-Early Eocene interval in the east Tethys (Indus Basin, Pakistan). Unpublished PhD thesis, University of Leicester, 291 pp.
- WILLIAMS, M., LENG, M. J., ALDRIDGE, R. J. and STEPHENSON, M. H. 2011. Evolution of Paleocene to Early Eocene larger benthic foraminifer assemblages of the Indus Basin, Pakistan. *Lethaia*, **44**, 299–320.
- ARCHIAC, E. J. A. D. d'. 1854. Coupe géologique des environs des Bains de Rennes (Aude), suivie de la description de quelques fossiles de cette localité. *Bulletin de la Société géologique de France* (2)**11**, 185–204.
- BANDY, O. L. 1944. Eocene foraminifera from Cape Blanco, Oregon. *Journal of Paleontology*, **18**, 366–377.
- BOUKHARY, M., HEWAIDY, A. G., LUTERBACHER, H., EL-AMIN BASSIOUNI, M. and AL-HITMI, H. 2011. Foraminifera and ostracodes of Early Eocene Umm er Radhuma Formation, Dukhan Oil Field, Qatar. *Micropaleontology*, **57**, 37–60.
- CONSORTI, L., FRIJIA, G. and CAUS, E. 2017a. Rotaloidean foraminifera from the Upper Cretaceous carbonates of central and southern Italy and their chronostratigraphic age. *Cretaceous Research*, **70**, 226–243.
- CONSORTI, L., VILLALONGA, R. and CAUS, E. 2017b. New rotaliids (benthic foraminifera) from the Late Cretaceous of the Pyrenees in northeastern Spain. *Journal of Foraminiferal Research*, **47**, 284–293.

- 1
2
3 DAVIES, L. M. 1930. The fossil fauna of the Samana Range and some neighbouring areas: Part
4 6. The Palaeocene Foraminifera. *Memoirs of the Geological Survey of India*, **15**, 67–79.
5
6 DAVIES, L. M. 1932. The genera *Dictyoconooides* Nutall, *Lockhartia* nov., and *Rotalia* Lamark:
7 their species, generic differences, and fundamental distinction from the *Dictyoconus*
8 group of forms. *Transactions of the Royal Society of Edinburgh*, 57, part II (13). 397–
9 428, 4 pls.
10
11
12 DELAGE, Y. and HÉROUARD, E., 1896. *Traité de Zoologie concrète*, vol. 1. La cellule et les
13 protozoaires. Schleicher Frères, Paris, 584 pp.
14
15
16 DOUVILLÉ, H. 1904. Mollusques fossiles. In: MORGAN, J. DE, Mission scientifique en Perse.
17 Etudes géologiques ; Paléontologie, **3**(2), 191–380.
18
19
20 DROBNE, K., OGORELEC, B. and RICCAMBONI, R. 2007. *Bangiana hanseni* n. gen. n. sp.
21 (Foraminifera), an index species of Danian age (Lower Paleocene) from the Adriatic
22 carbonate platform (SW Slovenia, NE Italy, Herzegovina). *Razprave 4.razr. SAZU*, **45**, 5–
23 71.
24
25
26 EHRENBERG, C. G. 1839. Über die Bildung der Kreidefelsen und des Kreidemergels durch
27 unsichtbare Organismen. *Physikalische Abhandlungen der Königlichen Akademie der*
28 *Wissenschaften zu Berlin*, **1838**, 59–147.
29
30
31 ELLIOTT, G.F. 1968. Permian to Paleocene calcareous algae (Dasycladaceae) of the Middle
32 East. *Bulletin of the British Museum (Natural History)*, Geology, Supplement 4: 1–111.
33
34
35 FILBRANDT, J. B., NOLAN, S. C. and RIES, A. C. 1990. Late Cretaceous and early Tertiary
36 evolution of Jebel Ja'alan and adjacent areas, NE Oman. In ROBERTSON, A. H. F.,
37 SEARLE, M. P. and RIES, A. C. (eds). The geology and tectonics of the Oman region.
38 *Geological Society, Special Publication*, **49**, 697–714.
39
40
41 FOURNIER, M., LEPVRIER, C., RAZIN, P. And JOLIVET, L. 2006. Postobduction extension in the
42 Oman Mountains and subsequent compression. *GeoArabia*, **11**, 17–40.
43
44
45 GLENNIE, K. W., BOEUF, M. G. S., HUGHES-CLARKE, M. W., MOODY-STUART, M., PILAAR, W. F.
46 H. and REINHARDT, M. 1974. Geology of the Oman Mountains. *Royal Dutch Geological*
47 *and Mining Society Transactions*, **31**, 1–423.
48
49
50 GOLDBECK, E. J. and LANGER, M. R. 2009. Biogeographic provinces and patterns of diversity in
51 selected Upper Cretaceous (Santonian-Maastrichtian) larger Foraminifera. 187–232. In
52 DEMCHUK, T. D. and GARYA, A.C. (eds.), *Geologic problem solving with microfossils: a*
53 *volume in Honor of Garry D. Jones*. SEPM Special Publication, **93**, 347 pp.
54
55
56 GRADSTEIN, F. M., OGG, J. G. and SMITH, A. G. 2004. *A geologic time scale 2004*. Cambridge
57 University Press, Cambridge, 589 pp.
58
59
60 GRADSTEIN, F. M., OGG, J. G., SCHMIDTZ, M. D. and OGG, G. B. 2012. *The geologic time scale*
2012. Elsevier, Amsterdam, 1176 pp.

- 1
2
3 GRÉLAUD, C., RAZIN, P. and HOMEWOOD, P. W. 2010. Channelized systems in an inner
4 carbonate platform setting: differentiation between incisions and tidal channels (Natih
5 Formation, Late Cretaceous, Oman). *Geological Society of London, Special Publication*,
6 **329**, 163–186.
7
8
9 HALLOCK, P. 1988. Diversification in algal symbiont-bearing foraminifera: a response to
10 oligotrophy? *Revue de Paléobiologie*, volume spécial **2**, 789–797.
11
12 HOHENEGGER, J. 1995. Depth estimation by proportions of living larger Foraminifera. *Marine*
13 *Micropaleontology*, **26**, 31–47.
14
15
16 HOTTINGER, L. 2001. Learning from the past?. 449–477. In LEVI-MONTALCINI, R. (ed.)
17 *Frontiers of Life*, Volume 4, part 2: Discovery and spoliation of the biosphere. Academic
18 Press, London/San Diego, 520 pp.
19
20
21 HOTTINGER, L. 2006. The “face” of benthic foraminifera. *Bollettino della Società Paleontologica*
22 *Italiana*, **45** (1), 75–89.
23
24
25 HOTTINGER, L. 2014. *Paleogene larger rotaliid foraminifera from the western and central*
26 *Neotethys*. Springer International Publishing, Cham, Switzerland, 196 pp.
27
28
29 HUGHES CLARKE, M. W. 1988. Stratigraphy and rock-unit nomenclature in the oil producing
30 area of interior Oman. *Journal of Petroleum Geology*, **11**, 5–60.
31
32
33 INAN, N. and INAN, S. 2008. Selandian (Upper Paleocene) benthic foraminiferal assemblages
34 and their stratigraphic ranges in the northeastern part of Turkey. *Yerbilimleri*, **29**, 147–
35 158.
36
37
38 INAN, N., TASLI, K. and INAN, S. 2005. *Laffitteina* from the Maastrichtian-Paleocene shallow
39 marine carbonate successions of the Eastern Pontides (NE Turkey): biozonation and
40 microfacies. *Journal of Asian Earth Sciences*, **25**, 367–378.
41
42
43 KAHSNITZ, M. 2017. Paleocene to Lower Eocene sediments of the eastern Neo-Tethyan Ocean:
44 sedimentary and geodynamic evolution as well as biostratigraphy of the larger benthic
45 foraminifera *Lockhartia* and the genesis of nodular limestones. Unpublished PhD
46 thesis, University of Bremen, Bremen, 139 pp.
47
48
49 KAHSNITZ, M., ZHANG, Q. and WILLEMS, H. 2016. Stratigraphic distribution of larger benthic
50 foraminifera *Lockhartia* in South Tibet (China). *Journal of foraminiferal Research*, **46**:
51 34–47.
52
53
54 LAMARCK, J. B. P. A. de. 1801. *Système des animaux sans vertèbres*. Paris, The author, 432 pp.
55
56
57 LAMARCK, J. B. P. A. de. 1804. Suite des mémoires sur les fossiles des environs de Paris.
58 *Annales du Muséum national d'Histoire naturelle*, **5**, 349–357.
59
60
61 LAMARCK, J. B. P. A. de. 1816. *Histoire naturelle des animaux sans vertèbres*. Tome second.
62 Paris, Verdière, 568 pp.

- 1
2
3 LEUTENEGGER, S. 1984. Symbiosis in benthic Foraminifera: specificity and host adaptations.
4 *Journal of foraminiferal Research*, **14**, 16–35.
5
- 6 MARIE, P. 1946. Sur *Laffitteina bibensis* et *Laffitteina monody*, nouveau genre et nouvelles
7 espèces de Foraminifères du Montien. *Bulletin de la Société géologique de France*,
8 (5)**15**, 419–434.
9
- 10
11 MERIÇ, E. 1980. *Pseudomphalocyclus blumenthali*, a new genus and species from the Upper
12 Maastrichtian of southern Turkey. *Micropaleontology*, **26**, 84–89.
13
- 14 NUTTALL, W. L. F. 1926. The Larger Foraminifera of the Upper Ranikot Series (Lower Eocene) of
15 Sind, India. *Geological Magazine*, **63**, 112–121.
16
17
- 18 ORBIGNY, A. D. d'. 1826. Tableau méthodique de la classe des Céphalopodes. *Annales des*
19 *Sciences naturelles*, **7**, 96–169, 245–314.
20
- 21 PAWLOWSKI, J., HOLZMANN, M. and TYSZKA, J. 2013. New supraordinal classification of
22 Foraminifera: molecules meet morphology. *Marine Micropaleontology*, **100**, 1–10.
23
24
- 25 PIGNATTI, J. 1998. Paleogene larger Foraminifera reference list. In DROBNE, K. and
26 HOTTINGER, L. (eds.) *Paleogene shallow benthos of the Tethys*, **1**. Slovenska akademija
27 znanosti in umetnosti, Ljubljana, 296 pp.
28
- 29 RAHAGHI, A. 1978. *Paleogene biostratigraphy of some parts of Iran*. Teheran, National Iranian
30 Oil Company, Geological Laboratories, **7**, 167 pp.
31
32
- 33 RAHAGHI, A. 1983. *Stratigraphy and faunal assemblage of Paleocene-Lower Eocene in Iran*.
34 Teheran, National Iranian Oil Company, Geological laboratories, **10**, 73 pp.
35
- 36 RAO, L. R. and PIA, J. 1936. Fossil algae from the uppermost Cretaceous beds (the Niniyur
37 Group) of the Trichinopoly district, S. India. *Memoirs of the Geological Survey of India*,
38 *Palaeontologia Indica* (new series), **21** (4), 49 pp.
39
40
- 41 REUSS, A. E. 1862. Entwurf einer systematischen Zusammenstellung der Foraminiferen.
42 Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien,
43 mathematisch-naturwissenschaftliche Classe, **44** (1), 355–396.
44
45
- 46 ROGER, J., BOURDILLON, C., RAZIN, P., Le CALLONNEC, L., RENARD, M., AUBRY, M.-P., PHILIP,
47 J., PLATEL, J.-P., WYNS, R. and BONNEMAISON, M. 1998. Modifications des
48 paléoenvironnements et des associations biologiques autour de la limite Crétacé-
49 Tertiaire dans les montagnes d'Oman. *Bulletin de la Société géologique de France*,
50 **169**(2), 255–270.
51
52
- 53 SAMUEL, O., BORZA, K. and KÖHLER, E. 1972. *Microfauna and lithostratigraphy of the*
54 *Paleogene and adjacent Cretaceous of the Middle Váh Valley (West*
55 *Carpathians)*. Geologický ústav Dionýza Stúra, Bratislava, 246 pp.
56
57
- 58 SANDER, N. J. 1962. Aperçu paléontologique et stratigraphique du Paléogène en Arabie
59 Séoudite orientale. *Revue de Micropaléontologie*, **5**(9), 3–40.
60

- 1
2
3 SCHLÜTER, M., STEUBER, T., PARENTE, M. and MUTTERLOSE, J. 2008. Evolution of a
4 Maastrichtian-Paleocene tropical shallow-water carbonate platform (Qalhat, NE
5 Oman). *Facies*, **45**, 513–527.
6
7
8 SERRA-KIEL, J., HOTTINGER, L., CAUS, E., DROBNE, K., FERNÁNDEZ, C., JAUHRI, A.K., LESS, G.,
9 PAVLOVEC, R., PIGNATTI, J., SAMSÒ, J. M., SCHAUB, H., SIREL, E., STROUGO, A.,
10 TAMBAREAU, Y., TOSQUELLA, J. and ZAKREVSAYA, E. 1998. Larger foraminiferal
11 biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Société géologique*
12 *de France*, **169**, 281–299.
13
14
15 SERRA-KIEL, J., VICEDO, V., RAZIN, P. And GRÉLAUD, C. 2016. Selandian-Thanelian larger
16 foraminifera from the lower Jafnayn Formation in the Sayq area (eastern Oman
17 Mountains). *Geologica Acta*, **14**, 315–333.
18
19
20 SCOTT, R. W. 1990. Chronostratigraphy of the Cretaceous carbonate shelf, southeastern
21 Arabia. *Geological Society of London, Special Publication*, **49**, 89–108.
22
23
24 SMOUT, A. H. 1954. Lower Tertiary foraminifera of the Qatar peninsula. London, British
25 Museum (Natural History), 96 pp.
26
27 TAMBAREAU, Y., HOTTINGER, L., RODRÍGUEZ-LÁZARO, J., VILLATTE, J., BABINOT, J.F., COLIN,
28 J.P., GARCIA-ZARAGA, E., ROCCHIA, R. and GUERRERO, N. 1997. Communautés
29 benthiques fossiles aux alentours de la limite Crétacé-Tertiaire dans les Pyrénées.
30 *Bulletin de la Société géologique de France*, **168**(6), 795–804.
31
32
33 TORRE, M. 1966. Alcuni foraminiferi del Cretacico superior della Penisola Sorrentina. *Bolletino*
34 *della Società dei Naturalisti in Napoli*, **75**, 409–431.
35
36 VAN BUCHEM, F. S. P., RAZIN, P., HOMEWOOD, P. W., PHILIP, J. M., EBERLI, G. P., PLATER, J. P.,
37 ROGER, J., ESCHARD, R., DESAUBLIAUX, G. M. J., BOISSEAU, T., LEDUC, J. P.,
38 LABOURDETTE, R. And CATALOUBE, S. 1996. High resolution sequence stratigraphy of
39 the Natih Formation (Cenomanian/Turonian) in northern Oman: distribution of source
40 rocks and reservoir facies. *GeoArabia*, **1**(1), 65–91.
41
42
43 WAN, X. 1991. Paleocene larger foraminifera from southern Tibet. *Revista Española de*
44 *Micropaleontología*, **23**(2), 7–28.
45
46
47 ZHANG, Q., WILLEMS, H., & DING, L. 2013. Evolution of the Paleocene-early Eocene larger
48 benthic foraminifera in the Tethyan Himalaya of Tibet, China. *International Journal of*
49 *Earth Science (Geologische Rundschau)*, **102**, 1427–1445.
50
51
52

53 Captions

54
55 **FIG. 1.** Geographical location of the stratigraphical section studied at Jabal Ja'alan (Oman
56 Mountains). 17, 23, 35: roads. Scale bar represents 10 km.

57
58
59 **FIG. 2.** Lithostratigraphy of the Murka Formation at Jabal Ja'alan (Oman Mountains) and
60 position of the samples studied.

FIG. 3. *Rotorbinella hensoni* (Smout, 1954) from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A–C, E–F, H–S, U–AI**, MGB 59865, from sample 6: A, LP16.24; B, LP17.11; C, LP19.8; E, LP2.56; F, LP6.93; H, LP18.13; I, LP2.3; J, LP11.114; K, LP9.10; L, LP5.8; M, LP1.88; N, LP12.22; O, LP6.76; P, LP11.96; Q, LP11.130; R, LP2.39; S, LP19.13; U, LP4.4; V, LP6.109; W, LP8.1; X, LP7.7; Y, LP12.89; Z, LP12.140; AA, LP21.3; AB, 21.4; AC, LP15.18; AD, LP6.28; AE, LP2.65; AF, LP1.33; AG, LP11.101; AH, LP18.26; AI, LP12.72; **D**, MGB 59867 LP1.20, from sample J2; **G**, MGB 84538 LP1.51, from sample J3 and **T**, MGB 84538 LP14.1, from sample J7. A–AA, axial sections. AB–AG, oblique sections. AH–AI35, transverse sections. Scale bar represents 500 µm. Abbreviations: E: embryo; f: foramen; foc: foliar cavity or chamberlet; fpil: foliar pile; ilsp: intraseptal interocular space; k: keel; n: notch; p: pore; s: septum; spc: spiral canal; up: umbilical plate; upil: umbilical pile or plug.

FIG. 4. *Rotalia cf. jacobi* Sander, 1962 from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A, C–D, V**, MGB 84538, from sample J7: A, LP14.9; C, LP14.5; D, LP10.4; V, LP4.2; Specimens **B, E–F, H–K, M–U, W–X**, MGB 59865, from sample 6: B, LP1.93; E, LP15.19; F, LP13.7; H, LP21.12; I, LP17.29; J, LP16.28; K, LP1.87; M, 59865 LP17.6; N, LP17.32; O, LP6.105; P, LP18.27; Q, LP18.19; R, LP18.28; S, LP11.67; T, LP18.8; U, LP6.68; Specimen L, MGB 59867 LP1.15, from sample J2. A–O, axial sections. P–U oblique sections. V–X transverse sections. Scale bar represents 500 µm. Abbreviations: col: columella; E: embryo; fol: folium; foc: foliar cavity or chamberlet; fpil: foliar pile; n: notch; s: septum; spc: spiral canal; spsut: spiral suture; up: umbilical plate; upil: umbilical pile or plug.

FIG. 5. Basic structural model of *Praelockhartia* gen. nov. Transverse section of the last whorl (not to scale).

FIG. 6. *Praelockhartia neoakbari* gen. nov., sp. nov. from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A, P** and **R**, MGB 59867, from sample J2: A, LP1.3; P, LP1.22; R, LP1.29; Specimens **T**, MGB 84538 LP10.1, from sample J7 and **B–O, Q** and **S, U–V**, MGB 59865, from sample 6: B, LP17.7; C, LP12.68; D, LP2.98; E, LP13.11; F, LP6.92; G, LP15.21; H, LP11.17; I, LP13.9; J, MGB 59865 LP17.16; K, LP17.26; L, LP17.24; M, LP2.95 (holotype); N, LP17.28; O, LP18.5; Q, LP12.28; S, LP16.31; U, LP18.23; V, LP18.22. Axial sections. Scale bar represents 500 µm. Abbreviations: E: embryo; fol: folium; fpil: foliar pile; fu: funnel; lh: loop-hole; n: notch; p: pore; spc: spiral canal; spsut: spiral suture; uc: umbilical cavity; up: umbilical plate; upc: umbilical cavity; upil: umbilical pile.

FIG. 7. *Praelockhartia neoakbari* gen. nov., sp. nov. from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens from sample 6, MGB 59865: A, LP18.16; B, LP1.8; C, LP1.50; D, LP15.13; E, LP18.10; F, LP11.71; G, LP1.92; H, LP18.2; I, LP17.31; J, LP15.2; K, LP17.23; L, LP11.124; M, LP12.76; N, LP12.135. Oblique sections. Scale bar represents 500 µm. Abbreviations: f: foramen; foa: foliar aperture;

foc: foliar cavity or chamberlet; ilsp: intraseptal interocular space; p: pore; uc: umbilical cavity; up: umbilical plate; upc: umbilical peripheral cavity; upil: umbilical pile; s: septum; spc: spiral canal.

FIG. 8. *Praelockhartia neoakbari* gen. nov., sp. nov. from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A–F**, **H–Q**, MGB 59865, from sample 6: A, LP16.36; B, LP12.127; C, LP11.72; D, LP6.90; E, LP19.13; F, LP6.99; H, LP16.22; I, LP11.7; J, LP18.1; K, LP18.6; L, LP17.17; M, LP17.22; N, LP18.21; O, LP18.3; P, LP17.25; Q, LP17.3; and specimen **G**, MGB 59867 LP1.11, from sample J2. Oblique sections. Scale bar represents 500 µm. Abbreviations: E: embryo; f: foramen; fo: folia; ilsp: intraseptal interocular space; n: notch; p: pore; s: septum; spc: spiral canal; uc: umbilical cavity; up: umbilical plate; upc: umbilical peripheral cavity; upil: umbilical pile.

FIG. 9. *Rotospirella conica* (Smut, 1954) from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A–F**, MGB 84538, from sample J7: A, LP11.3; B, LP11.7; C, LP8.1; D, LP10.3; E, LP9.6; F, LP8.6. Scale bar represents 500 µm. Abbreviations: E: embryo; f: foramen; fol: folium; spc: spiral canal; spsut: spiral suture; uc: umbilical cavity; up: umbilical plate.

FIG. 10. *Lockhartia* aff. *conditi* (Nuttall, 1926) from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A–E**, MGB 84538, from sample J7: A, LP11.2; B, LP12.5; C, LP9.19; D, LP14.10; E, LP9.15. Scale bar represents 500 µm. Abbreviations: f: foramen; fol: folium; fu: funnel; ilsp: intraseptal interocular space; s: septum; spc: umbilical spiral canal; uc: umbilical cavities.

FIG. 11. *Rotaliidium parvum* gen. nov., sp. nov. from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens, MGB 59865, from sample 6: A, LP2.17; B, LP1.34; C, LP1.17; D, LP6.134 (holotype); E, LP12.99; F, LP16.14; G, LP18.4; H, LP6.54; I, LP16.25; J, LP16.19; K, LP18.7. Axial, subaxial and oblique sections. Scale bar represents 200 µm. Abbreviations: sch: supplementary chamberlets; sap: f: foramen; fol: folia; s: septum; up: umbilical plate; upil: umbilical pile or plug.

FIG. 12. *Rotaliidium parvum* gen. nov., sp. nov. from the lower Paleocene (upper Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens **A–F** and **H**, MGB 59865, from sample 6: A, LP21.6; B, LP20.5; C, LP21.2; D, LP19.6; E, LP19.4; F, LP19.1; Specimen **G**, MGB 59867 LP1.14, from sample J2. Scale bar represents 200 µm. Axial, oblique and transverse sections. Abbreviations: sch: supplementary chamberlets; E: embryo; n: notch; spc: spiral canal; up: umbilical plate; upil: umbilical pile or plug.

FIG. 13. Larger foraminiferal and green algae biostratigraphy along the western flank of Jabal Ja'alan (Oman Mountains) (data on planktic foraminifera are from Roger *et al.* 1998 and Serra-Kiel *et al.* 2016).

1
2
3 **FIG. 14.** Larger benthic foraminifera and dasycladalean algae from the Upper Cretaceous
4 Simsim Formation. **A**, *Omphalocyclus macroporus* (Lamarck, 1816), MGB 59861 LP3.4, sample
5 2; **B**, *Loftusia morgani* Douvillé, 1904, MGB 59860 LP4.1, from sample 1; **C**, *Trinocladus*
6 *radoicicae* Elliott, 1968, MGB 59861 LP6.4, from sample 2; **D**, *Siderolites calcitrapoides*?
7 Lamarck, 1801, MGB 59861 LP7.1, from sample 2; **E**, *Pseudomphalocyclus blumenthali*? Meriç,
8 1980, MGB 59861 LP1.5, from sample 2; **F**, *Broeckina* cf. *dufrenoyi* (d'Archiac & Haime, in
9 d'Archiac, 1854), MGB 59861 LP5.1, from sample 2; **G**, *Stomatorbina binkhorsti* (Reuss, 1862),
10 MGB 59862 LP3.4, from sample 3; **H**, *Fissoelphidium operculiferum* Smout, 1954, MGB 59860
11 LP5.6, from sample 1. Scale bars represent 2 mm (A–B); 1 mm (D–E); 500 µm (C, F–H).

12
13
14
15 **FIG. 15.** Foraminifera and green algae associated with rotaliids from the upper Danian of the
16 Murka Formation: **A**, *Halimeda* sp., MGB 59870 LP1.3, from sample J5; **B**, *Jodotella* sp., MGB
17 59870 LP1.1, from sample J5; **C**, **K**, *Idalina* sp., MGB 84538 LP9.1, from sample J7; **D**,
18 *Stomatorbina binkhorsti* (Reuss, 1862), MGB 84538 LP10.6 and MGB 84538 LP1.11, from
19 samples 7 and J3, respectively; **E**, *Indopolia satyavanti* Pia, in Rao & Pia, 1936, MGB 59870
20 LP1.4, from sample J5; **F**, Bryopsidales indet., MGB 59865 LP5.31, from sample 6; **G**, *Valvulina*
21 *triangularis* d'Orbigny, 1826, MGB 84538 LP5.25, from sample J7; **H**, *Gyroidina* sp., MGB 59868
22 LP1.8, from sample J3; **I**, Dasycladales indet., MGB 84538 LP14.15, from sample J7; **J**, *Neomeris*
23 sp., MGB 59868 LP1.1, from sample J3; **L**, *Clypeina* sp., MGB 84538 LP1.11, from sample J7.
24 Scale bars represent 1 mm (A, E), 500 µm (B–D and F–L).

25
26
27
28 **FIG. 16.** Selandian?–early Thanetian larger foraminifera and green algae of the Abat Formation,
29 MGB 84539, from sample 8. **A**, *Periloculina*? sp., MGB 84539 LP1.4; **B**, *Keramosphaerinopsis*
30 sp., MGB 84539 LP1.5; **C**, *Sakesaria* sp., MGB 84539 LP1.7; **D**, *Lockhartia retiata* Sander, 1962,
31 MGB 84539 LP1.6; **E**, *Lockhartia praehaime* Smout, 1954, MGB 84539 LP2.1; **F**, *Kathina* cf.
32 *major* Smout, 1954, MGB 84539 LP1.9; **G**, *Daviesina* sp., MGB 84539 LP1.8; **H**, *Cymopolia* sp.,
33 MGB 84539 LP1.3; **I**, *Periloculina*? sp. (a) and *Clypeina* sp. (b), MGB 84539 LP2.4. Scale bars
34 represent: 1 mm (A–C, H) and 500 µm (D–G, I).



Figure 1. Geographical location of the stratigraphic section studied in Jabal Ja'alan (Oman). 17, 23, 35: roads. Scale bar represents 10 Km

75x77mm (300 x 300 DPI)

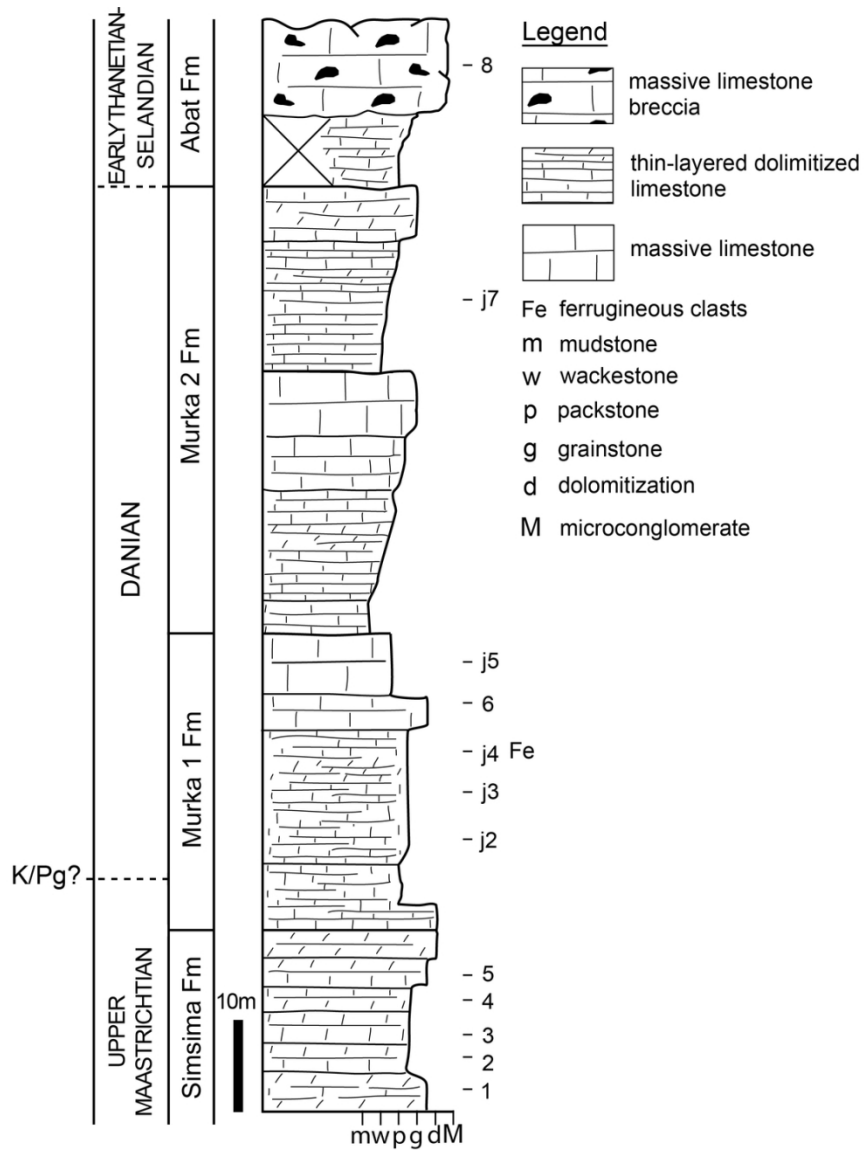


Figure 2. Lithostratigraphy of the Murka Formation in Jabal Ja'alan (Oman Mountains) and position of the samples studied.

109x125mm (300 x 300 DPI)

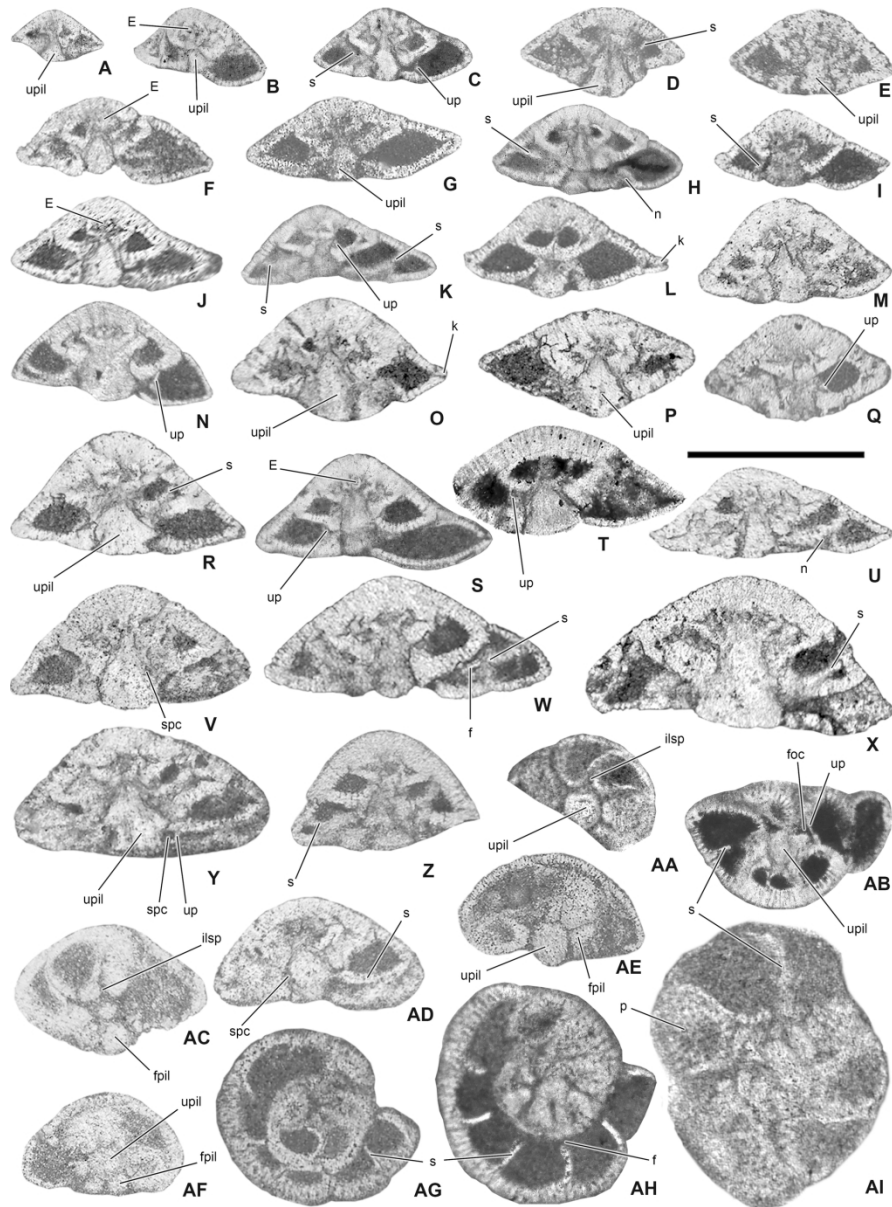


Figure 3. *Rotorbinella hensoni* (Smout, 1954) from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens A-C, E-F, H-S, U-AI from sample 6 (MGB 59865); D from sample J2 (MGB 59867); G from sample J3; and T from sample J7 (MGB 84538). A-AA, axial sections. AB-AG, oblique sections. AH-AI35, transverse sections. Scale bar represents 500 μ m. Abbreviations: E: embryo; f: foramen; foc: foliar cavity or chamberlet; fpil: foliar pile; ilsp: intraseptal interloocular space; k: keel; n: notch; p: pore; s: septum; spc: spiral canal; up: umbilical plate; upil: umbilical pile or plug.

165x224mm (300 x 300 DPI)

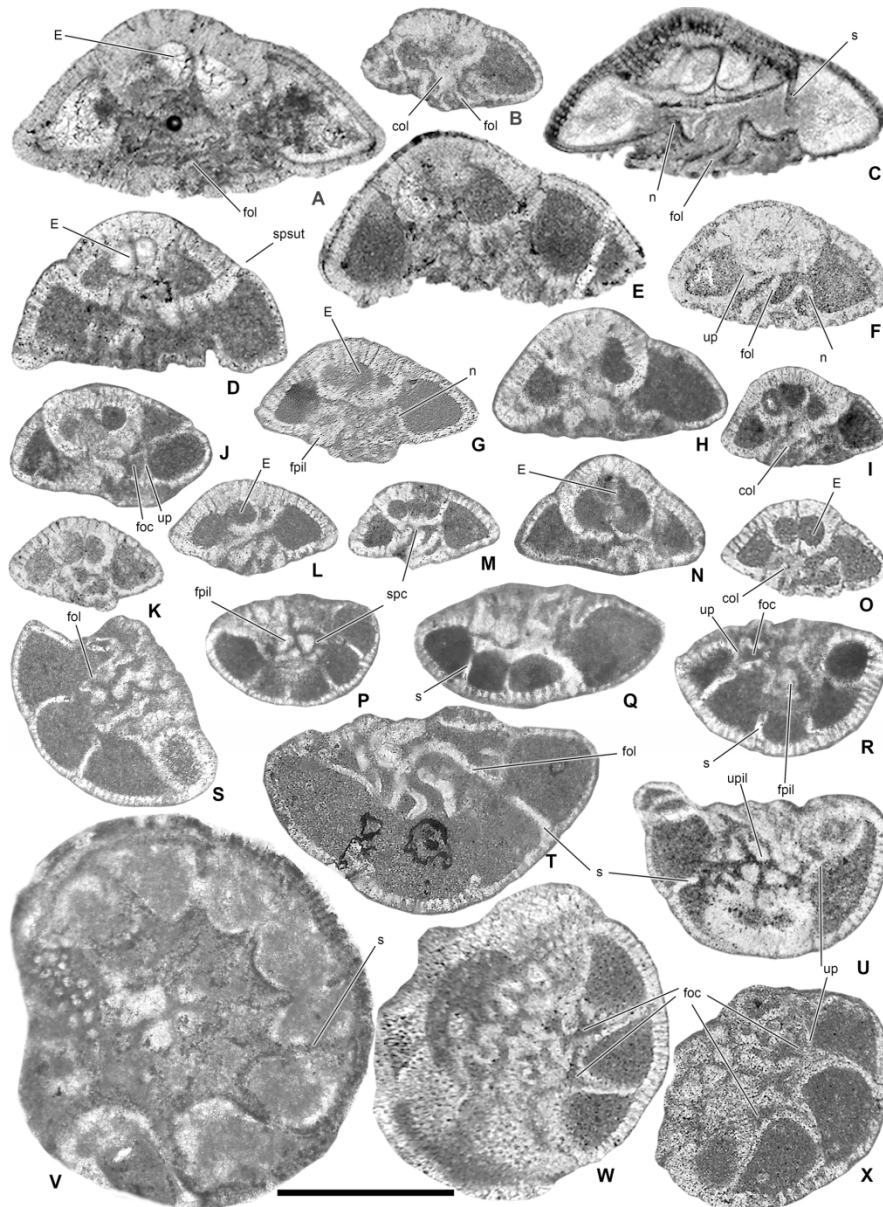


Figure 4. *Rotalia cf. jacobi* Sander, 1952 from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens A, C-D, V from sample J7 (MGB 84538); B, E-F, H-K, M-U, W-X from sample 6 (MGB 59865); and 7, L from sample J2 (MGB 59867). A-O, axial sections. P-U oblique sections. V-X transverse sections. Scale bar represents 500 μ m. Abbreviations: col: columella; E: embryo; fol: folium; foc: foliar cavity or chamberlet; fpil: foliar pile; n: nocht; s: septum; spc: spiral canal; spsut: spiral suture; up: umbilical plate; upil: umbilical pile or plug.

165x224mm (300 x 300 DPI)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

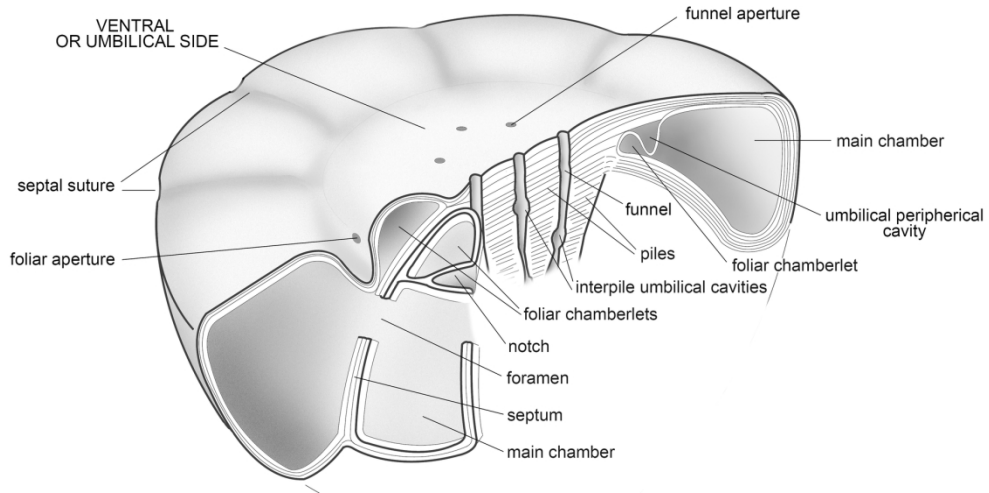


Figure 5. Basic structural model of *Praelockhartia* gen. nov. Transverse section of the last whorl, not to scale.

165x82mm (300 x 300 DPI)

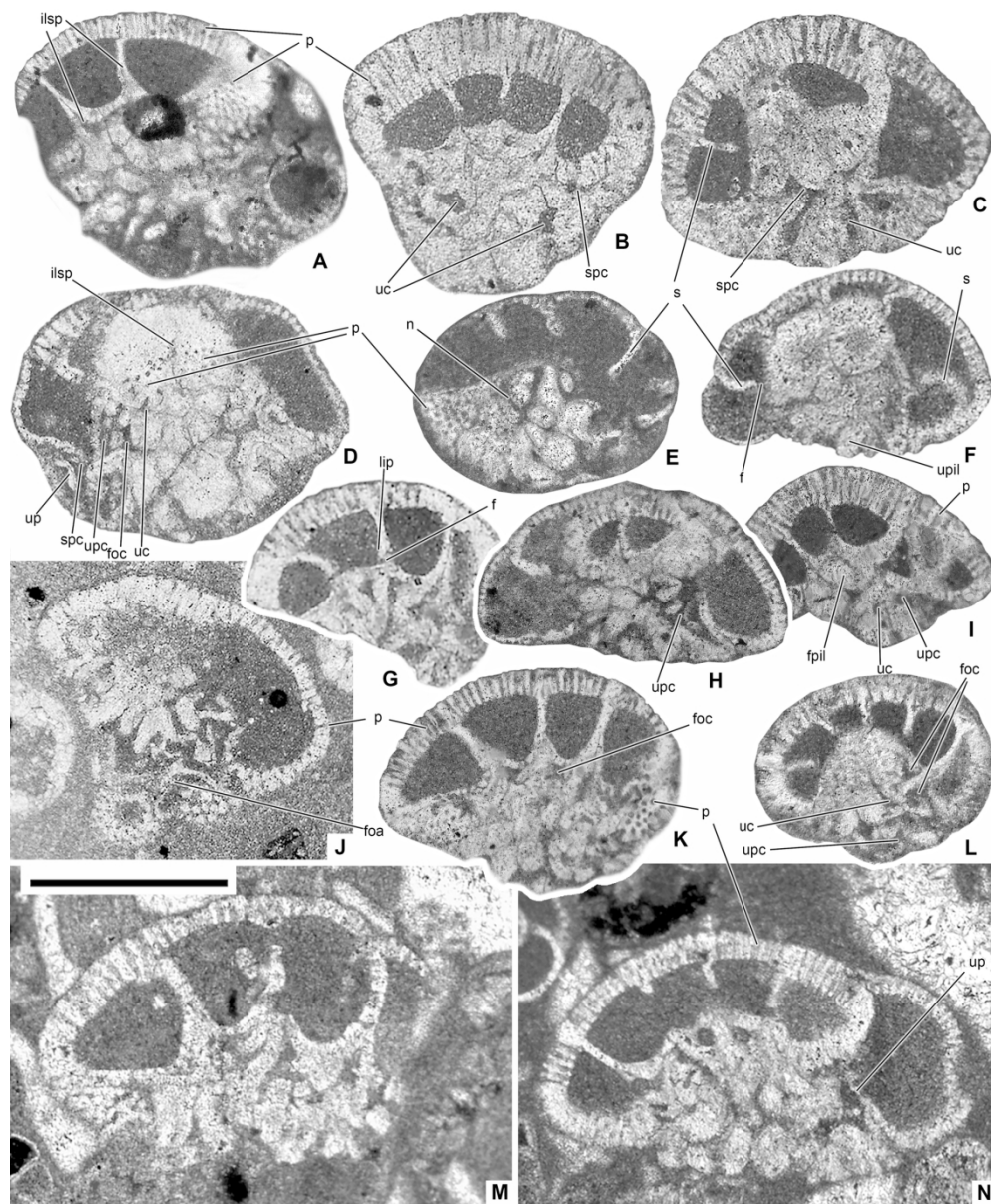


Figure 7. *Praelockhartia neoakbari* gen. nov. sp. nov. from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens from sample 6 (MGB 59865). Oblique sections. Scale bar represents 500 μ m. Abbreviations: f: foramen; fca: foliar aperture; fca: foliar cavity or chamberlet; ilsp: intraseptal interloocular space; p: pore; uc: umbilical cavity; up: umbilical plate; upc: umbilical peripheral cavity; upil: umbilical pile; s: septum; spc: spiral canal.

165x200mm (300 x 300 DPI)

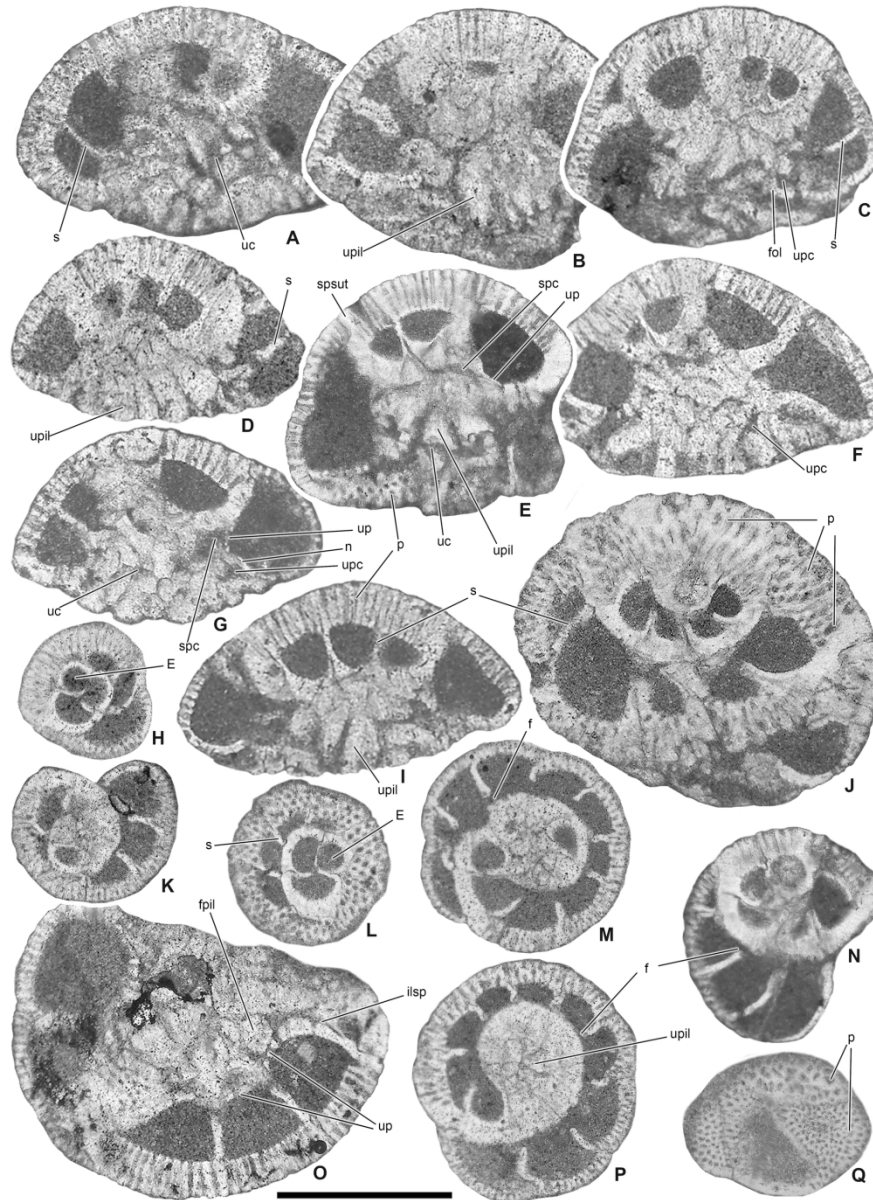
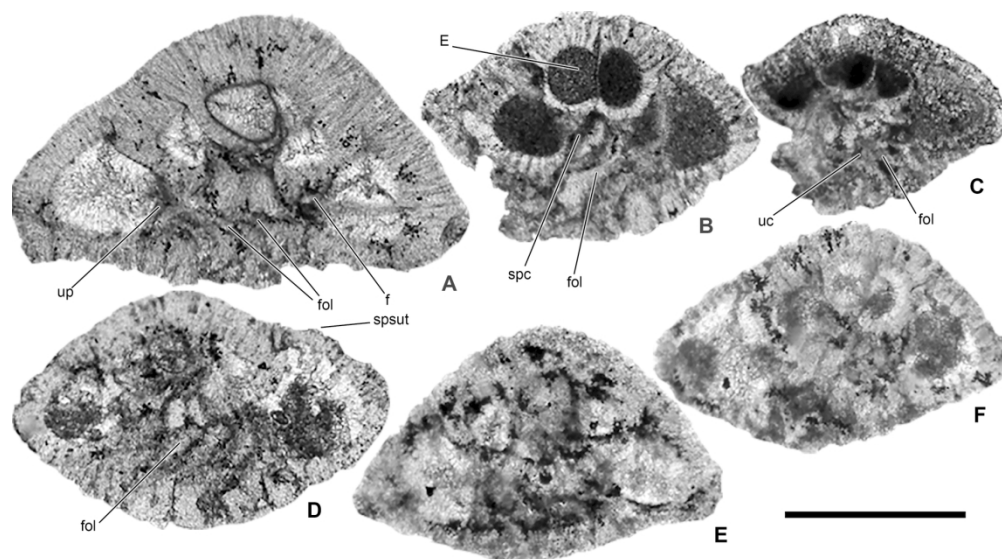


Figure 8. *Praelockhartia neoakbari* gen. nov. sp. nov. from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens A-F, H-Q from sample 6 (MGB 59865); and specimen G from sample J2 (MGB 59867). Oblique sections. Scale bar represents 500 μ m. Abbreviations: E: embryo; f: foramen; fo: folia; ilsp: intraseptal interloocular space; n: notch; p: pore; s: septum; spc: spiral canal; uc: umbilical cavity; up: umbilical plate; upc: umbilical peripheral cavity; upil: umbilical pile.

165x226mm (300 x 300 DPI)



umbilical plate; upc: umbilical peripheral cavity; upil: umbilical pile.
 Figure 9. *Rotospirella conica* (Smout, 1954) from the lower Paleocene (Danian) of the Murka 2 Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens A-F from sample J7 (MGB 84538). Scale bar represents 500 μ m. Abbreviations: E: embryo; f: foramen; fol: folium; spc: spiral canal; spsut: spiral suture; uc: umbilical cavity; up: umbilical plate.

165x91mm (300 x 300 DPI)

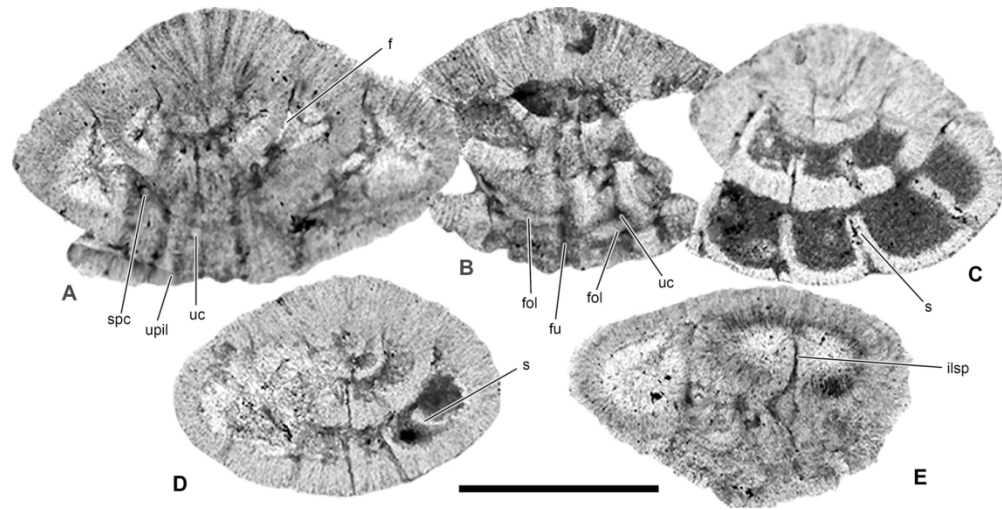


Figure 10. *Lockhartia* aff. *conditi* (Nuttall, 1926) from the lower Paleocene (Danian) of the Murka 2 Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens A-E from sample J7 (MGB 84538). Scale bar represents 500 μ m. Abbreviations: f: foramen; fol: folium; fu: funnel; ilsp: intraseptal interloocular space; s: septum; spc: umbilical spiral canal; uc: umbilical cavities.

165x82mm (300 x 300 DPI)

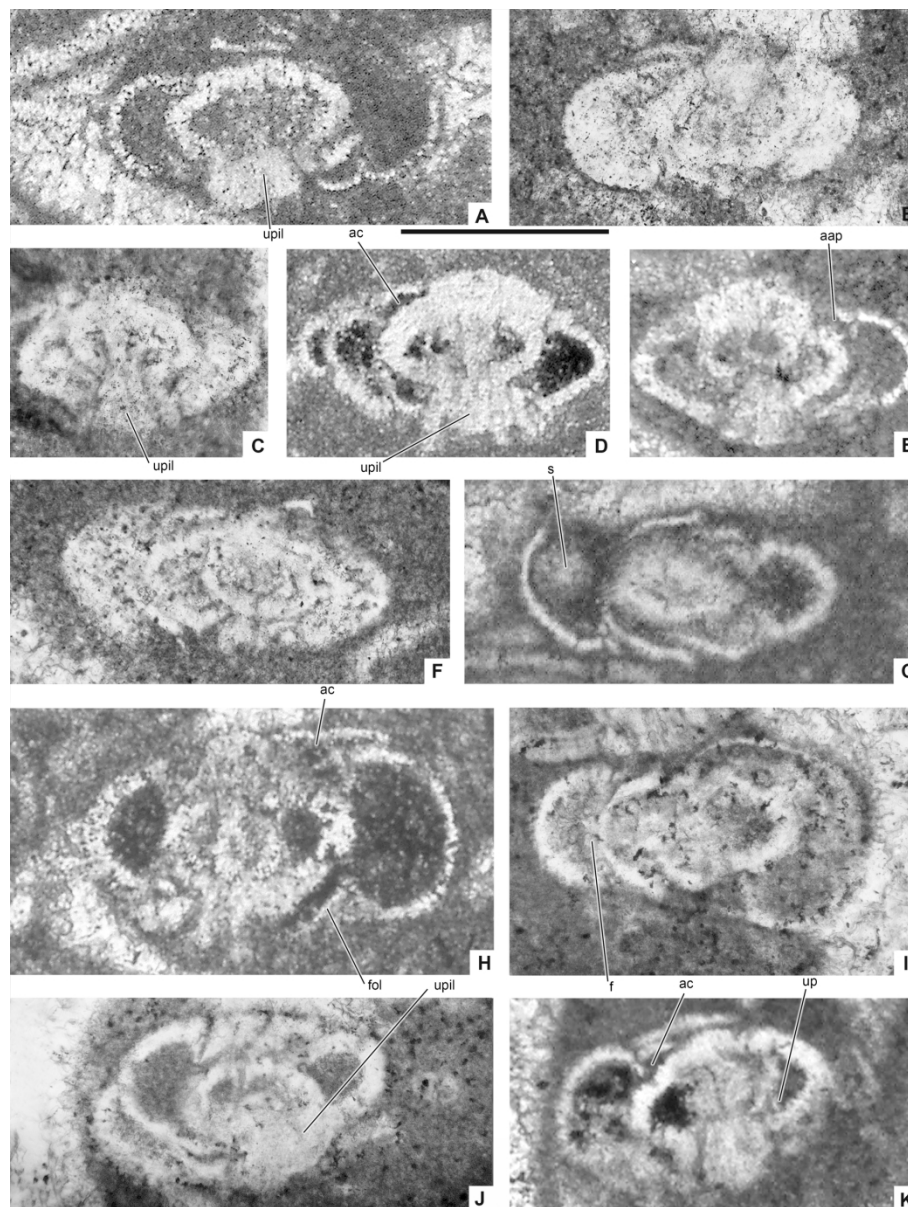


Figure 11. *Rotaliidium parvum*, gen. nov. sp. nov. from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens from sample 6 (MGB 59865). Holotype: specimen D (MGB 59865 LP6.134). Axial, subaxial and oblique sections. Scale bar represents 200 μ m. Abbreviations: sch: supplementary chamberlets; sap: f: foramen; fol: folia; s: septum; up: umbilical plate; upil: umbilical pile or plug.

165x218mm (300 x 300 DPI)

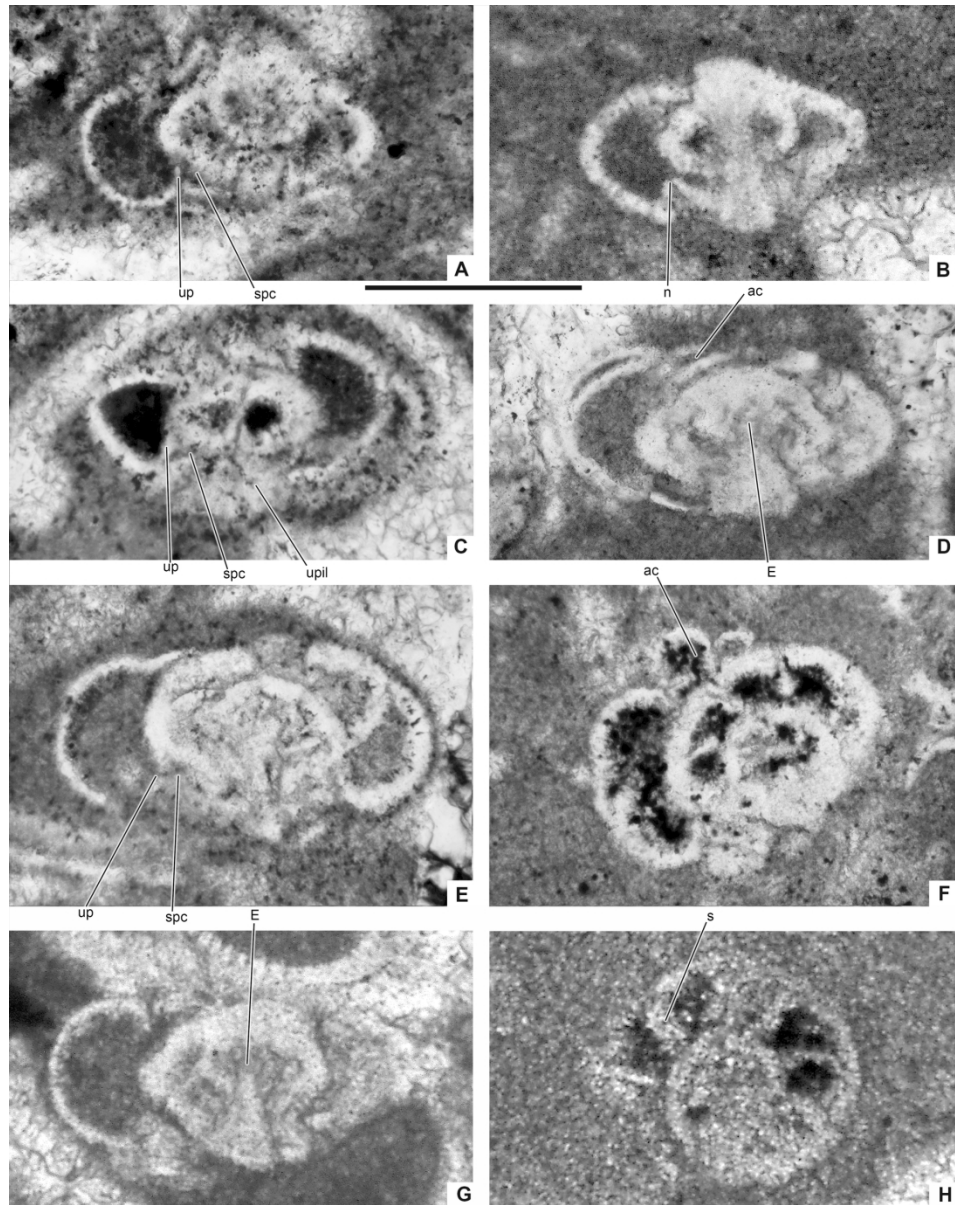


Figure 12. *Rotaliidium parvum*, gen. nov. sp. nov. from the lower Paleocene (Danian) of the Murka Formation, Jabal Ja'alan, Oman Mountains. Megalospheric generation. Transmitted light photographs of thin sections of cemented carbonate rocks. Specimens from sample 6 (MGB 59865). Scale bar represents 200 μ m. Axial, oblique and transverse sections. Abbreviations: sch: supplementary chamberlets; E: embryo; n: notch; spc: spiral canal; up: umbilical plate; upil: umbilical pile or plug.

165x209mm (300 x 300 DPI)

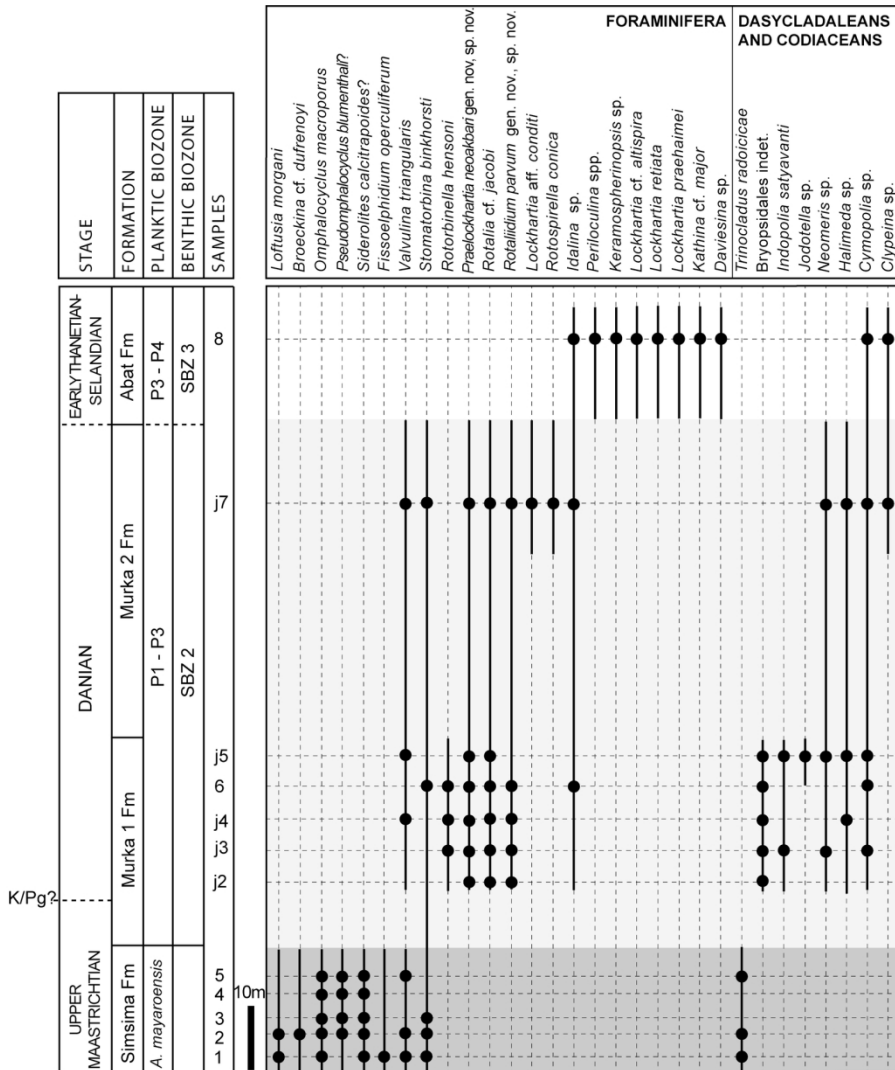


Figure 13. Larger foraminiferal and green algae biostratigraphy in the west flank of Jabal Ja'alan (Oman Mountains) (data of planktic foraminifera extracted from Roger et al. 1998 and Serra-Kiel et al. 2016).

156x167mm (300 x 300 DPI)

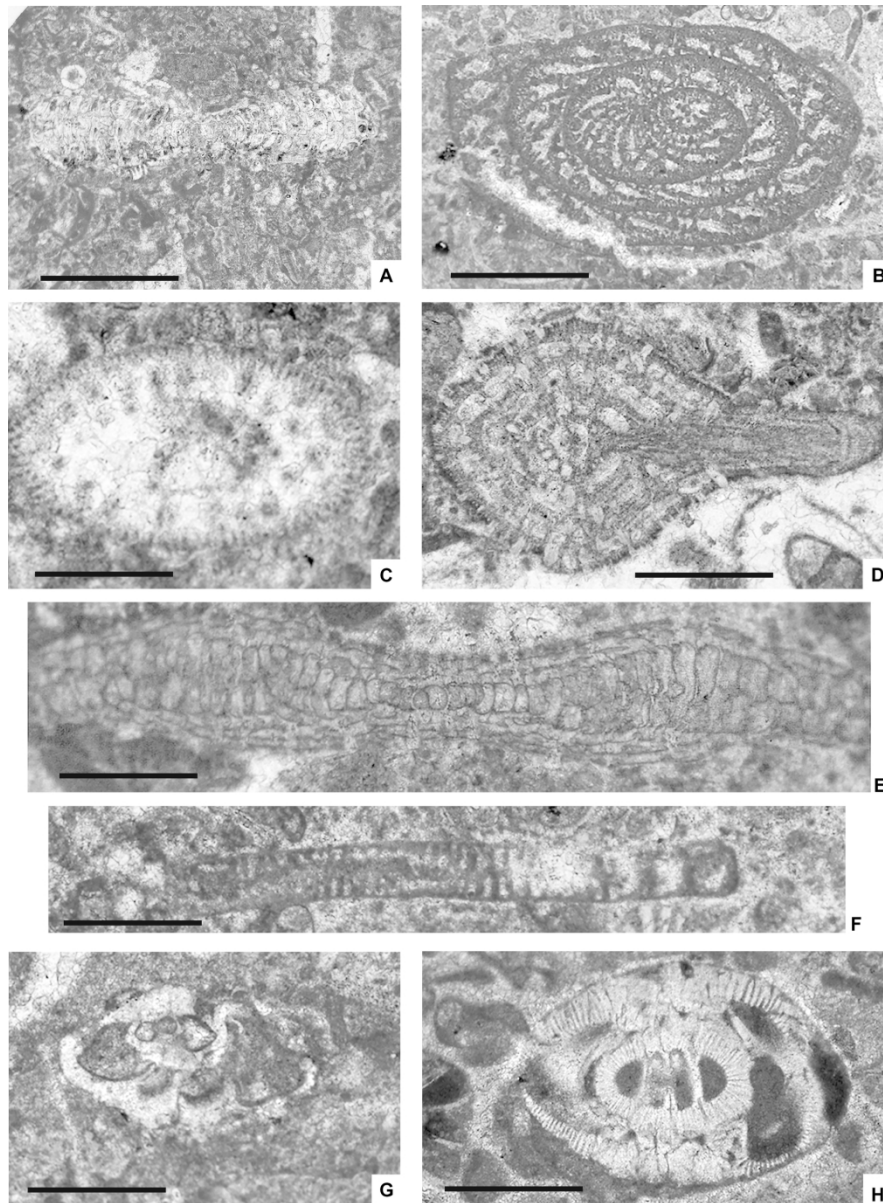


Figure 14. Larger benthic foraminifera and dasycladales algae from the Upper Cretaceous of Simsim Formation. A, *Omphalocyclus macroporus* (Lamarck, 1816); B, *Loftusia morgani* Douvillé, 1904; C, *Trinocladus radoicicae* Elliott, 1968; D, *Siderolites calcitrapoides?* Lamarck, 1801; E, *Pseudomphalocyclus blumenthali?* Meriç, 1980; F, *Broeckina cf. dufrenoyi* (d'Archiac & Haime in d'Archiac, 1854); G, *Stomatorbina binkhorsti* (Reuss, 1862); H, *Fissoelphidium operculiferum* Smout, 1955. Scale bars represent 2 mm (A-B); 1 mm (D-E); 500 µm (C, F-H).

165x225mm (300 x 300 DPI)

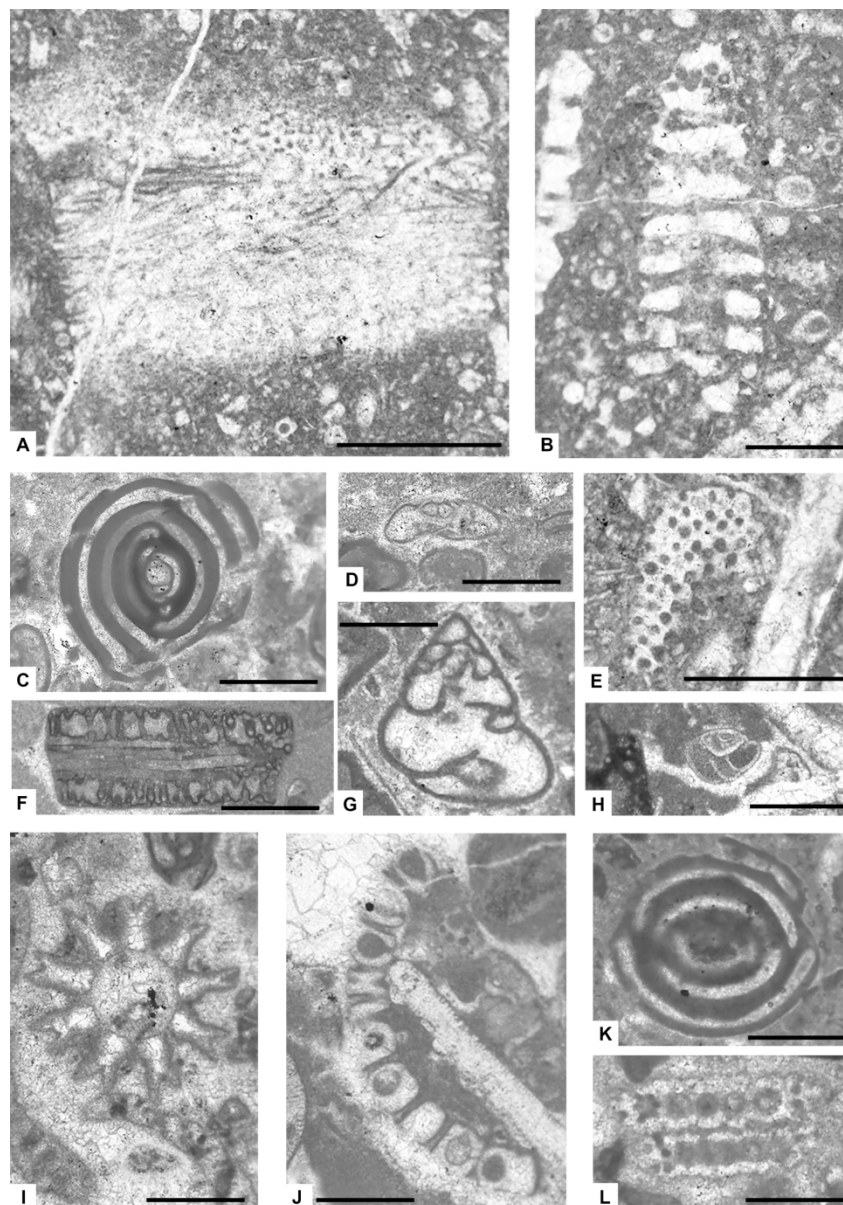


Figure 15. Foraminifera and green algae associated with rotaliids from the Danian of Murka Formation: A, *Halimeda* sp.; B, *Jodotella* sp.; C and K, *Idalina* sp.; D, *Stomatorbina binkhorsti* (Reuss, 1862); E, *Indopolia satyavanti* Pia in Rao & Pia, 1936; F, Bryopsidales indet.; G, *Valvulina triangularis* d'Orbigny, 1826; H, *Gyroidina* sp.; I, Dasycladales indet.; J, *Neomeris* sp.; K, *Clypeina* sp. Scale bars represent 1 mm (A and E), 500 μ m (B-D and F-L).

158x225mm (300 x 300 DPI)

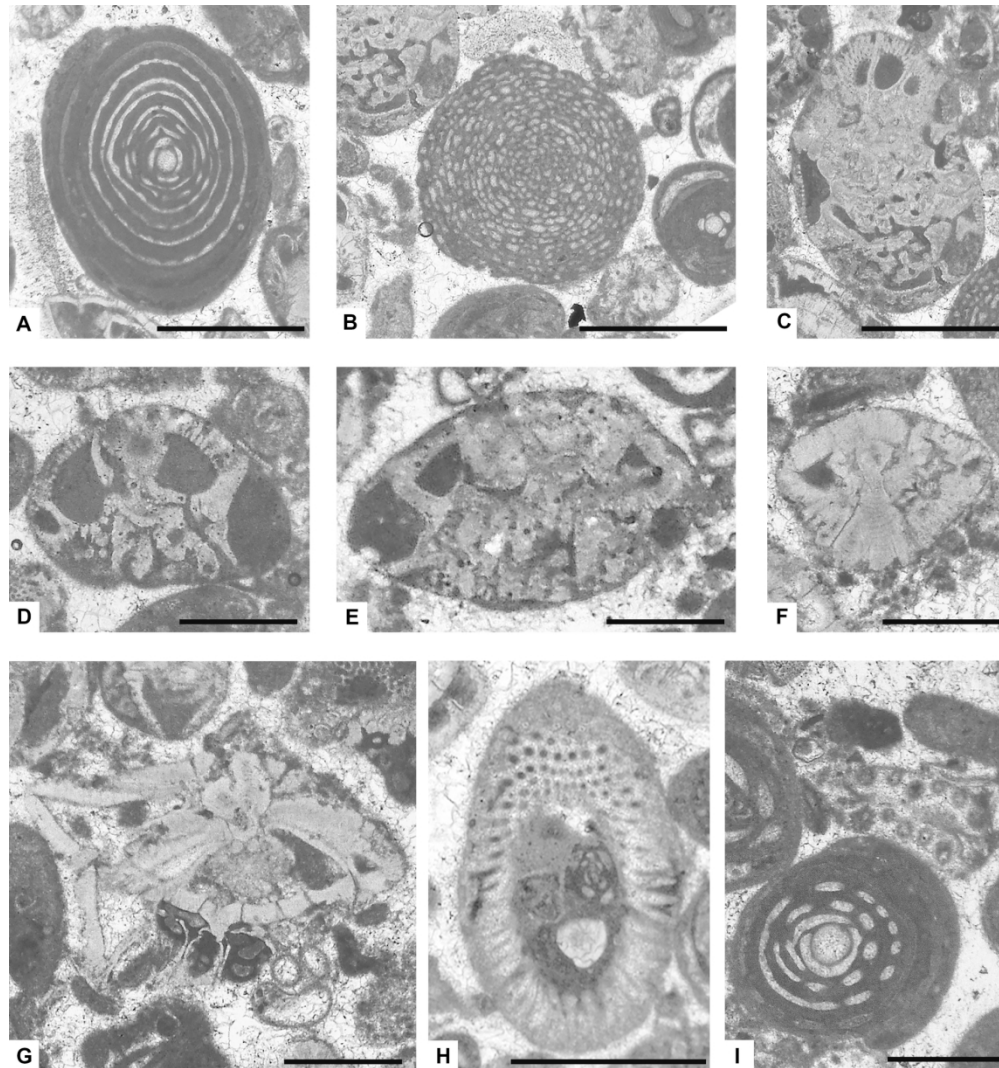


Figure 16. Selandian?-early Thanetian larger foraminifera and green algae of the Abat Formation. A, *Periloculina?* sp.; B, *Keramospherinopsis* sp.; C, *Lockhartia* cf. *altispira* Smout, 1954; D, *Lockhartia retiata* Sander, 1962; E, *Lockhartia praeahaimi* Smout, 1954; F, *Kathina* cf. *major* Smout, 1954; G, *Daviesina* sp.; H, *Cymopolia* sp.; I, *Periloculina?* sp. (a) and *Clypeina* sp. (b). Scale bars represent: 1 mm (A-C, H) and 500 μ m (D-G, I).

165x176mm (300 x 300 DPI)