

Cenomanian rotaliids (Foraminiferida) from Oman and Morocco

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Received: 14 September 2012 / Accepted: 6 March 2013 / Published online: 25 July 2013
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Abstract The small rotaliids (Foraminiferida) found in Cenomanian rock thin sections of Oman and Morocco are diversified. A continuum of morphotypes is divided within 3 taxa described as subspecies of *Rotorbinella mesogeensis* Tronchetti 1981 from which they share many morphological characteristics. According to features, including shell shape and size, and spiral thickening of the wall, they are named *R. m. microformis* ssp. nov., *R. m. medioformis* ssp. nov. and *R. m. mesogeensis* ssp. nov., the latter being the typical form of Tronchetti 1981. The subspecies *mesogeensis* is a biostratigraphical marker of the Cenomanian while *microformis* is known since the Late Albian up to the Late Cenomanian (possibly Early Turonian). *Pararotalia boixae* sp. nov. comprises specimens previously attributed to *P. tuberculifera* Reuss 1862 pro parte. This Cenomanian new species (with Campanian affinis forms) is characterized by morphological features that clearly distinct it from the type of Reuss. We found it in the Cenomanian of Oman, but not in contemporaneous Moroccan sediments.

Keywords *Rotorbinella* · *R. mesogeensis* · *Pararotalia* · *P. boixae* · *P. tuberculifera* · Cretaceous · Tethys

Introduction

As part of a micropalaeontological study of Cenomanian—earliest Turonian sediments from the South and Southwest Tethys in Morocco and Oman (Cavin et al. 2010 and other

papers in prep.), numerous very small rotaliids were evidenced in rock thin sections. *Rotorbinella mesogeensis* (Tronchetti 1981) and *Pararotalia* cf. *tuberculifera* (Reuss 1862) closely resembling those of Boix et al. (2009) were first recognized. Within the abundant population, various specimens, very different from the typical forms, remained, however, unattributed.

Variants of *R. mesogeensis* with distinctive morphological features and decreasing size display a morphological gradational series evidenced on the base of four hundred fifty photographs from thin sections. Three different morphological groups are clearly differentiable (taxon) and form a remarkable continuum with outstanding morphological difference between both end members of the series.

On the other hand, sections resembling to *P. tuberculifera* sensu Boix et al. (2009) are homogenous in our Omani samples (not recognized in Morocco). There is considerable confusion with this species which is, according to the literature, morphologically highly variable (especially since the Maastrichtian) and ranges from the Late Santonian (Boix et al. 2009) up to the Montian (Szczechura and Pozaryska 1972). Our Cenomanian specimens are older, smaller, and significantly differ from the type species description of *P. tuberculifera*. The aim of this paper is then to describe, illustrate and determine the most common rotaliids found in Cenomanian Moroccan and Omani sediments. Our specimens are actually among the oldest known foraminifera with rotaliid structures. Their occurrence in the Cenomanian makes them possible root-stock for the further diversification of the rotaliines that will expand during the Late Cretaceous and Paleogene (see Boix et al. 2009 cum biblio). Revets (2001), however, state that it is unlikely that *Rotorbinella* (massive plug) has any direct or indirect relation with the immediate ancestor of

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Rotalia (multiple pillars) or any of the other rotaliacean genera with strongly sculptured umbilical sides. This can only be clarified by an extensive study of Cretaceous rotaliid genera and species, what is not the aim of this work. The main characteristics of the family and genus we will get onto are summarized as follows:

The family Rotaliidae Ehrenberg 1839 is characterized by a hyaline lamellar-perforated wall, trochospiral chamber arrangement, single foramen to multiple foramina, septa with open interocular space or canal, folia present with additional structures (plates) delimiting and restricting an umbilical space (Boix et al. 2009 cum biblio). The genus *Rotorbinella* Bandy 1944, emended by Revets (2001), is characterized by a smooth convex spiral side and a smooth convex to flat umbilical side with a single central massive plug; an interiomarginal aperture, a well-developed free folia separated by an open fissure (intraseptal interocular space) and marked by a faint notch; an umbilical plate, and an umbilical intraseptal interocular space remaining open as a long sutural slit. Umbilical interocular space is transformed into simple spiral canal in earlier whorls. The subfamily Pararotaliinae Reiss 1963 emended by Hottinger et al. (1991) includes trochospiral test with single interiomarginal main aperture into which a toothplate protrudes with a free edge; irregular supplementary apertures may be present; canal system composed of intraseptal interocular spaces, of a spiral umbilical canal formed by interconnected toothplates, and in some genera of enveloping canals produced by secondary lamination. The genus *Pararotalia* LeCalvez 1949, following Loeblich and Tappan (1988) and Hottinger et al. (1991), is defined by a low trochospire with a smooth to pustulose surface, umbilicus with prominent umbilical shoulder surrounding a solid umbilical plug, open undivided umbilical sutural interocular spaces, a spiral canal system, an areal foramen with a lower lip that is the edge of an element called toothplate by Hottinger et al. (1991) and Loeblich and Tappan (1988) but not by Revets (1993) (see below). Folia are inexistent following Hottinger et al. 1991 (see also Revets 1993).

Locality, stratigraphy and associated microfauna

Figure 1 gives the geographic location and three synthetic field sections representative of the studied areas with a provisional stratigraphic repartition of the taxa considered in this paper (other sections are actually under study). The samples involved in this study have been collected in eighteen field sections and the stratigraphic location of every important (holotypes and paratypes) samples is reported in the field sections of Fig. 1. Together with the GPS coordinates given in the type locality below, sample position can be easily located.

The main part of the Moroccan and Omani series is dated Cenomanian by ammonites. The Albian—Cenomanian boundary was not sampled as it was not outcropping in the studied localities. The Cenomanian—Turonian boundary is situated between two ammonite levels, one dated as Late Cenomanian (*Neolobites* beds, which can be used for correlation from Moroccan to Omani sections), and the uppermost one as upper Early Turonian (*Vascoceratidae* beds in the eastern Adam foothills synthetic section). As no sharp lithological change was noticed within this interval, this stage boundary cannot be located more precisely.

Morocco

Southeast Moroccan field sections (published in Cavin et al. 2010) give precise sample location as well as lithology, stratigraphy, ammonites and other macrofossils. Figure 1 gives a synthetic section of the Tazougart Belkassam—Tizi Momrad area. Samples concerned in this study were collected in the Cenomanian/Turonian Akrabou formation which is precisely dated by two ammonite bioevents. The first one with the *Neolobites vibrayeanus* bioevent (Fig. 1) characterizes the lower part of the *Calyptoceras guerangeri* Zone (lower Late Cenomanian) and the second (see Cavin et al. 2010) with the *Mammites nodosoides* bioevent correspond to the *Mammites nodosoides* Zone (upper Early Turonian).

Associated microfauna: The Upper Cenomanian transgression is characterized, during the *Neolobites* bioevent, by very scarce benthos, but common calcispheres and abundant, simple, little evolved (no keel) and very small morphotypes (70–100 µm, max 150 µm) planktonic foraminifers most of which are attributed to *Hedbergella* (*Asterohedbergella*) *asterospinosa* Hamaoui 1964 together with various primitive type adults, known to be opportunistic species that rapidly colonize shallow, newly opened areas during transgressive periods (Hart and Bailey 1979; Caron 1983; Caron and Homewood 1983; Hart 1999). Above the *Neolobites* bioevent, various benthic (and rare planktic) foraminiferas as well as stromatoporoids, selenoporaceae, corals, algae, bryozoans, bivalves, ostracods, serpulids, calcispheres, gastropods and echinoderms gradually colonize the shelf. Amongst the sections of benthic foraminiferas associated with our rotaliids, we recognized alveolinids (*Cisalveolina*?, *Prealveolina* sp.), *Biconcava bentori*, *Ammobaculites* sp., *Biplanata peneropliformis*, bolivinids, buliminids, *Chrysalidina gradata*, *Cuneolina* sp., *Dicyclina schlumbergeri*, discorbids, epistominids, *Haplophragmoides* sp., various miliolids (*Quinqueloculina* spp.), *Montcharmontia appeninica*, *Nezzazata* spp., *Nezzazatinella picardi*, *Nummofallotia apula*, *Peneroplis* sp., *Pseudolituonella reicheli*, *Pseudorhapydionina dubia*,

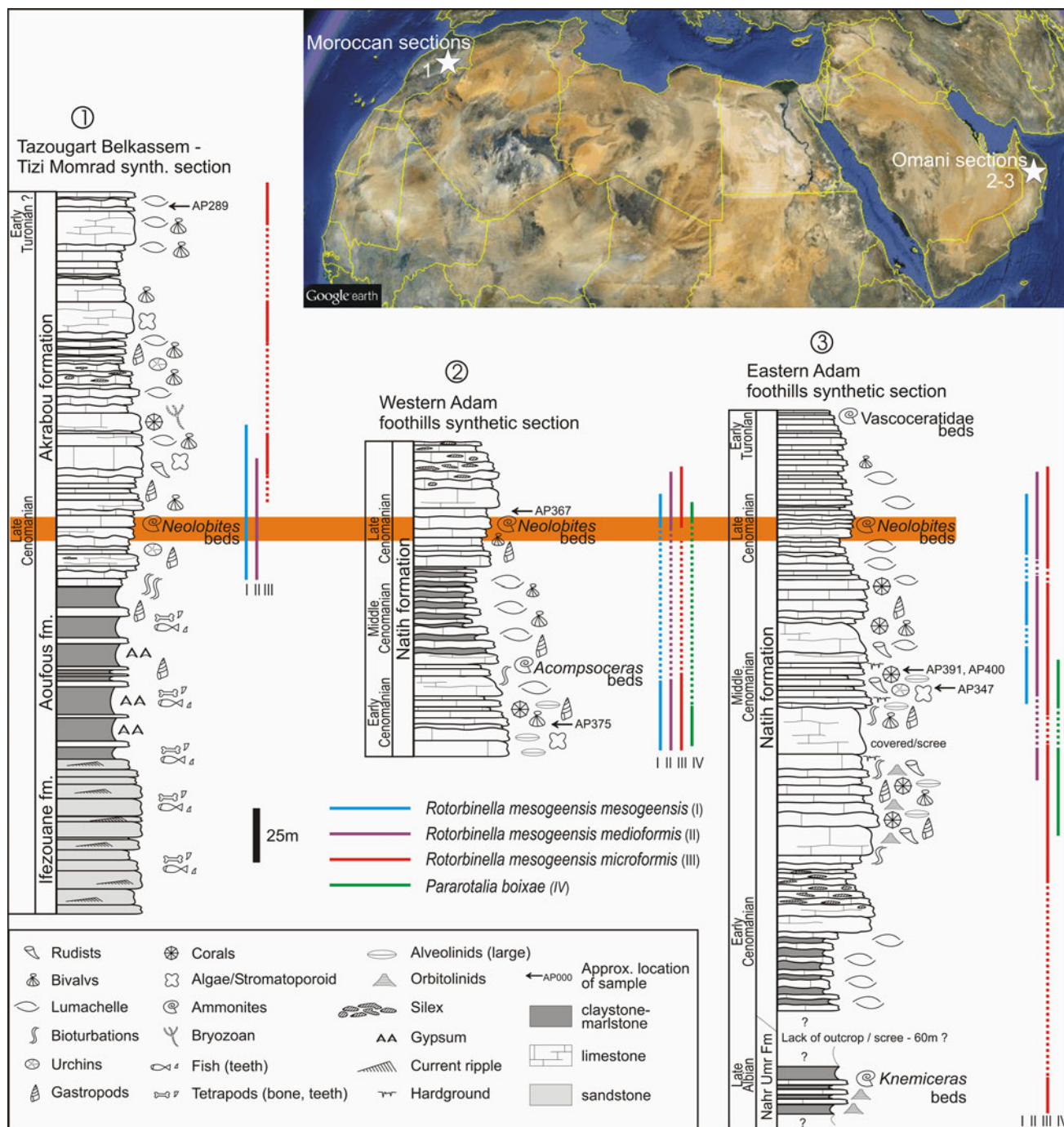


Fig. 1 Localization and synthetic sections of the studied localities with the (provisional) repartition of the four rotaliid taxa considered in this study. See Cavin et al. (2010) for detailed sections of Morocco.

Detailed sections of Oman are in preparation. GPS coordinates of main sections are given in text

Pseudorhipidionina casertana, *Pseudotextulariella* sp., *Spiroloculina*? sp., *Spiroplectamina* sp., *Textularia* spp., *Trochammina* sp., and *Trochospira avnimelechi*. The stromatoporoid are attributed to *Actinostomaria stellata* and the solenoporaceae to *Parachaetetes asvapatii*. See Cavin et al. (2010) for associated algae.

Oman

The material used in this study was collected in 8 field sections along the Adam foothills (south of the Oman mountain), named from east to west, Jabal Madar, Jabal Madmar, Jabal Khaydalah, Jabal Salakh, Jabal Nadah and

Jabal Fitri. Two synthetic field sections are given in Fig. 1 illustrating the two main series encountered in the Cenomanian of the area. Western Adam foothills field sections are encountered west of Jabal Salakh, and Eastern Adam foothill field sections east of Jabal Salakh. Detailed field sections will be presented in a paper in preparation, giving precise stratigraphic location of all samples, ammonites, and detailed repartition of associated microfauna. Cenomanian/Turonian Natih formation is subdivided into 7 members locally dated by ammonite bearing levels. Ammonites (under study) give an age (Fig. 1) from Late Albian (for the *Knemiceras* species found in the Nahr Umr formation) to the upper Early Cenomanian/lower Middle Cenomanian, and Early Turonian (*Watinoceras coloradoense* Zone) for the Natih formation.

Associated microfauna: The ramp limestone facies (see Philip et al. 1995, van Buchem et al. 1996, 2002; Home-wood et al. 2008, for sedimentology, stratigraphy, stratonomy, paleoenvironments) reveals, together with our rotraliids, an association mainly made up of *Biconcava bentori*, *Biplanata peneropliformis*, *Cisalveolina* sp, *Praealveolina* gr *cretacea*, *Dukhanina conica*, *Chrysalidina gradata*, *Cuneolina* gr *pavonia*, *Dicyclina schlumbergeri*, *Epistomina* sp, *Glomospira* sp, *Haplophragmoides* sp, *Montcharmontia compressa*, *Nezzazata* spp (*N. gr simplex*,

N. gr gyra, *N. gr isabellae*), *Nezzazatinella* cf. *picardi*, various Orbitolinids (*Orbitolina conica*, *Orbitolina* sp A, *Heterocoskinolina ruskei*), *Praebulimina* sp, *Pseudonummoloculina* sp, *Pseudorhapidionina* cf. *laurinensis*, diverse and abundant miliolids (*Quinqueloculina* spp.), *Pseudolituonella reicheli*, *Spiroloculina* spp, *Spiroplectammina* sp, *Trochospira avnimelechi*, *Trocholima* spp (*T. altispira*, *T. arabica*, *T. lenticularis*), textularidae, various algae, ostracods, microbivalvs shells. The intrashelf basin facies has a typical association composed of various small hedbergellids (*Asterohedbergella asterospinosa*, *Muricohedbergella*?), *Macroglobigerinelloides ultramicrus*, *Heterohelix moremani*, *Epistomina* sp., *Praebulimina* sp., oligosteginids (mostly *Pithonella spaerica* with possible *Calcisphaerula innominata*), *Saccocoma*, microbivalvs shells and ostracods.

Materials and methods

The material of this study results from two fields trip, the first in 2008 in Morocco (Cavin et al. 2010), and the second in 2010 in Oman (papers in prep.). Hard limestone samples imply working with thin section. All characteristics are then deducted from sections as no extracted specimens

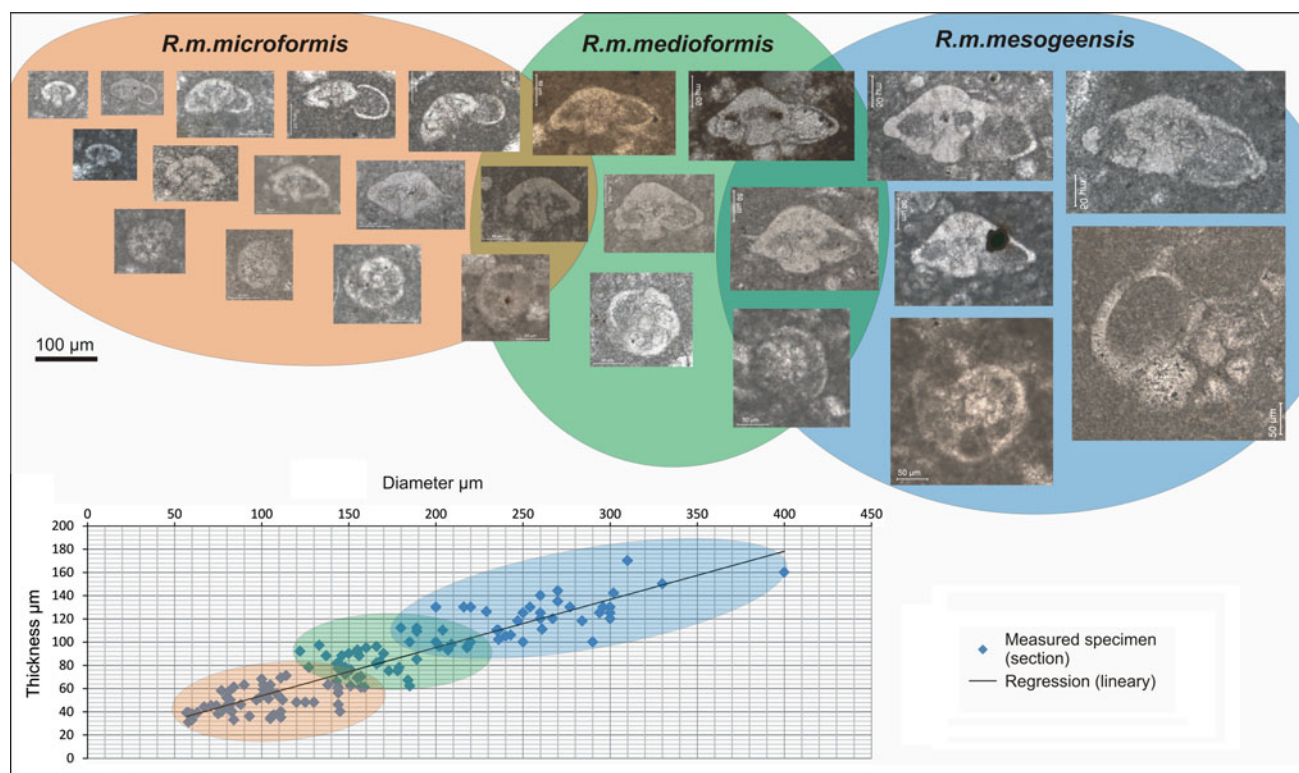


Fig. 2 The three subspecies of *Rotorbinella mesogeensis* (Tronchetti 1981): *R. m. microformis*, *R. m. medioformis* and *R. m. mesogeensis*. Note the obvious morphological differences (a upper part of the

figure) of the three subspecies (with transition forms) along the diameter vs. thickness continuum shown in the graphic (b lower part of the figure). See text for explanations

were available. Optical microscopy (magnification up to 1,000 \times) is the main tool. About seven hundred sections of rotaliids have been photographed and compared (size, morphology). From the 450 shell sections, photographs attributed below to subspecies of *R. mesogeensis*, morphological variation (Fig. 2a) and measurement (width, thickness, Fig. 2b) of the 130 better centered axial and sub-axial sections from populations of Morocco, Oman, as well as Spain (Boix 2007), and France (Tronchetti 1981) were considered. The largest diameter versus largest thickness was measured on these (sub) axial sections (i.e. centered enough to pass through the umbilical plug, the latter being about 25 % of the width of the test of the holotype of Tronchetti 1981, Pl. 26 Fig. 6). Spread within every shell sizes, these 130 centered sections are representative of the population. Graphics of Fig. 2 show the remarkable morphological and size continuum between the different taxa. Three morphological groups can be distinctly evidenced and clearly differentiated based on morphological features and size. The continuum implies the boundaries between taxa are obviously faint and subjective (unless there is no continuum), and intermediate forms exist. In our opinion, the paleontological exploration pursued in this work involve splitting as first essential stage of the taxonomic process to maximize information about taxa variability, a precious tool for further studies about stratigraphy, phylogeny, paleoecology, paleobiogeography. At this first stage, lumping (i.e. these three obviously different taxa in *R. mesogeensis*) can just be an unfortunate loss of information adding nomenclatural confusion and blocking further potential findings like distinct stratigraphic range and/or paleoecological and/or paleogeographical significance as well as phylogeny of the different taxa.

Systematic palaeontology

Superfamily Rotaliacea Ehrenberg 1839.

Family Rotaliidae Ehrenberg 1839

Genus *Rotorbinella* Bandy 1944

Type species: *Rotorbinella colliculus* Bandy 1944

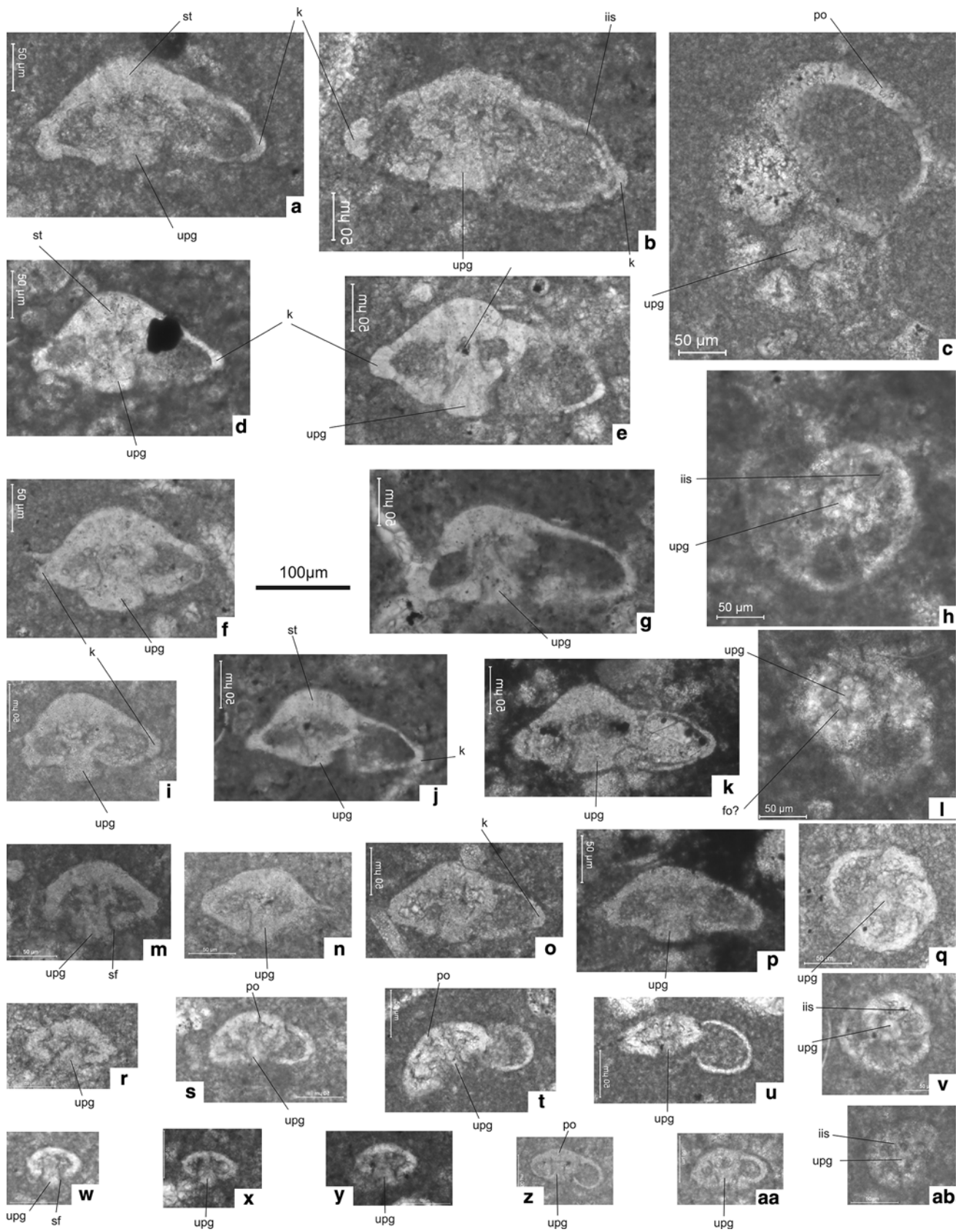
The history of this genus is proposed in Levy et al. (1979) and Revets (2001). Following Boix et al. (2009), the shell is small to medium size, lamellar perforate trochospiral shell, no evident generational dimorphism, spiral side convex, smooth, without ornamentation, umbilical side convex to flat, smooth, with a single massive umbilical plug, aperture in interiomarginal position, pores of small to medium size on spiral side, slightly larger on umbilical side, folium is small, imperforate, slightly oblique and free and with a suture marked by a faint notch. Umbilical plate

(or coverplate, see Revets 2001) clearly present and intraseptal interocular space open (uncovered) with no feathering (ornamentation by series of grooves perpendicular to the slit produced by the sunken chamber suture), umbilical interocular space open in last whorl, but possibly covered in earlier whorls and thus be transformed into a simple spiral canal.

Following Revets (2001), the presence of coverplate confirms the rotaliacean nature of the taxon and the presence of a well-developed primary umbilical plug (very different from the multiple lamellar pillars characteristic of *Rotalia*) differentiates the taxon from most of the other rotaline or discorbine. The aperture, folia, and nature of the plate are the main differences between *Rotorbinella* and *Pararotalia*, and the presence in *Neorotalia* of an enveloping canal system (cover of interocular space with canal openings) and a compound plug with canals is discriminant.

Remarks about *Rotorbinella mesogeensis* (Tronchetti 1981)

Numerous and diverse sections with close morphological characteristics are put together with *R. mesogeensis* in a morphological (Fig. 2a) and size (diameter/thickness ratio, Fig. 2b) continuum of showing very different end members. Generational dimorphism cannot be excluded, but is currently impossible to demonstrate as no evidence of various sizes of proloculus and/or juvenile stage has been noticed. The continuum illustrated in Fig. 2 implies the boundaries between taxa are faint and subjective and suggests considering the morphotypes as subspecies. Sharp boundaries would have clearly indicated different species, and morphological deviation is much higher than what is generally considered as intra-specific variation (e.g. in Haynes and Whittaker 1990 about *Rotalia trochidiformis*) or as forma (e.g. in Miller et al. 1982; Haynes 1992). Based on more than 450 photographs of shells in thin sections, and considering the evident morphological differences, we separate the specie *mesogeensis* in the subspecies *mesogeensis* nov.ssp., *medioformis* nov.ssp. and *microformis* nov.ssp. Note that intermediate forms exist between these subspecies (Figs. 2a, 3). The major differences concern the size (the biggest specimen can be up to 5–10 times the smallest), shape (i.e. rugged—slim with various height of spire and thickness of the wall), ornamentation (i.e. size of the umbilical plug, presence/absence of a keel), and number of chambers in the last whorl. As noted Tronchetti (1993) the last chamber are fragile and possess a very thin wall, only visible on some rare sections (e.g. Fig. 3a–b, e, g, j–k, o–p, t–u, z–aa), implying the diameter is not the most decisive criterion for attribution of the section.



◀**Fig. 3** *Rotorbinella mesogeensis mesogeensis* ssp. nov. (a–h); intermediate forms between *R. m. mesogeensis* and *R. m. medioformis* (i–l); *R. m. medioformis* ssp. nov. (m–q); *R. m. microformis* ssp. nov. (r–ab). Axial and subaxial sections a–b, d–g, i–k, m–p, r–u, w–aa; equatorial and subequatorial sections c, h, l, q, v, ab. a Sample ap346 (Natih C formation, Jabal Madar, Oman); b, h sample ap391 (Natih C formation, Jabal Khaydalah, Oman); c sample ap276 (Akrabou formation, Tizi Momrad, Morocco, see Cavin et al. 2010); d sample ap363 (Natih B/A formation boundary, Jabal Salakh, Oman); e, n (paratype) sample ap367 (Natih A formation, Jabal Madar, Oman); f sample ap379 (Natih A formation, Jabal Nadah, Oman); g, j sample ap369 (Natih A formation, Jabal Salakh, Oman); i sample ap408 (Natih C formation, Jabal Salakh, Oman); k, o, p (holotype) sample ap375 (Natih C formation, Jabal Nadah, Oman); l, q, t (holotype), u (paratype), v, ab sample ap289 (Akrabou formation, Tazougart-Belkassam, Morocco, see Cavin et al. 2010), m (paratype) sample ap400 (Natih C formation, Jabal Madmar, Oman); r sample ap331 (Natih E formation, Jabal Madar, Oman); s (paratype), w (paratype) sample ap327 (Natih E, Jabal Madar, Oman); x, y (paratypes) sample ap325 (Natih E formation, Jabal Madar, Oman); z, aa sample ap367 (Natih A formation, Jabal Salakh, Oman). *st* spiral thickening, *k* keel, *upg* umbilical plug, *iis* intraseptal interocular space, *fo* folium, *po* pore, *sf* spiral fissure

Rotorbinella mesogeensis (Tronchetti 1981)
mesogeensis ssp. nov., Fig. 3a–h

1981 *Rotalia mesogeensis* nsp. Tronchetti, Pl. 26 Figs. 6–12, Pl. 27, Figs. 1–8, Pl. 28, Figs. 1–7

1993 *Rotalia mesogeensis* Tronchetti, p. 46 Pl. 1, Figs. 1–10 (1–4, 6 from Tronchetti 1981)

2007 *Rotorbinella mesogeensis* Boix, Pl. XVI, Figs. 2–5, 7a,d,e (7 from Tronchetti 1981); Pl. XVII Figs. 4–7; Pl. XVIII Figs. 1–8.

2008 *Rotalia mesogeensis* Ettachfini Pl. 20, Figs. 12–15

2009 *Rotorbinella mesogeensis* Boix et al. Fig. 3. 1–9 (from Boix 2007)

Holotype: One specimen n. HFC 2 (Tronchetti 1981, Pl. 26 Fig. 6, Tronchetti 1993, Pl. 1 Fig. 1) deposited in the laboratoire de Géologie Historique et de Paléontologie de l'Université de Provence, Centre Saint-Charles, Marseille, France (Tronchetti 1981, 1993).

Type locality: Les Renardières (Près Lussant), E.N.E. de Rochefort (Charente-maritime), France (Tronchetti 1981, 1993).

Description: Dissymmetric lenticular test with a clearly convex spiral side and convex to flat umbilical face, smooth on both sides, periphery subacute to rounded always marked by an imperforated keel, massive free plug in the center of the umbilicus, bordered by a furrow (umbilical interocular space) with diverticulum between chambers, these intercameral furrows (interocular intraseptal space) do not reach the periphery, thin umbilico spiral canal, spiral chamber walls finely perforated, wider pores on umbilical face, lacking in the foliar walls, three whorls in the adult test, 6–8 (up to 10 following

Boix et al. 2009, 6 in Tronchetti 1993) chambers in the last whorl, double septa with intraseptal canals straight to slightly arched, chamber lumen with foliar chamberlet separated from the main chamber lumen by an umbilical plate.

Differences: These are the typical tall forms of *R. mesogeensis* as described by Tronchetti (1981) (some of his confer specimens correspond then to the *medioformis* subspecies, see below). This subspecies regroups here the tallest specimens, morphologically well corresponding to the original description, with a diameter higher than 200 µm and thickness higher than 100 µm. Note that Tronchetti (1993) proposed a diameter of 200 µm and thickness of 150 µm as lower limit of *R. mesogeensis*.

Geographic and stratigraphic distribution: Since its description in 1981, *R. mesogeensis* is progressively better and more often recognized. Now often cited it is found in numerous localities summarized below, completing the data of Tronchetti (1993). In France, it is known in (Tronchetti 1993 cum biblio) : south-west France in Charente-Maritime in Early Cenomanian sediments; south-east France in the Gard department in the Early Cenomanian; in Provence in middle to Late Cenomanian; in the Pyrenees in the Cenomanian. Bilotte et al. (2008) cite possible *R. mesogeensis* or *R. algeriana* in Languedoc. Chiocchini (2008) and Chiocchini et al. (1994) found it in the Late Cenomanian of central Italy. In Spain it is known along of the Pyrenean chain, Boix (2007) and Boix et al. (2009) detail the distribution of various rotaliids, including *R. mesogeensis* they find from middle to Late Cenomanian in shallow-water facies. In Morocco, Ettachfini (1993); Ettachfini and Andreu (2004); Ettachfini (2008); Cavin et al. (2010) found *R. mesogeensis* in the Late Cenomanian of the “Haut Atlas occidental” (Essaouira basin), “High Atlas”, and the “Sillon Préafricain” (Goulmima—Erfoud area). In the Karst dinarides, Velic (2007) mention the presence of *R. mesogeensis* in Cenomanian sediments. In Croatia, Crumiere-Airaud (unpublished phd, 1991, see Tronchetti 1993) found it in southern Istria (Premantura field section) Late Cenomanian sediments dated by ammonites and benthic foraminifers (Tronchetti 1993). In southern Serbia-Montenegro, Golubic et al. (2006) mention *R. mesogeensis* in Early Cenomanian. In Greece, Mermighis (unpublished phd 1989, see Tronchetti 1993) found *R. mesogeensis* in the Trapezona area in middle and Late Cenomanian sediments dated by rudists and benthic foraminifers (Tronchetti 1993). In Turkey, Masse et al. (2010) found *R. mesogeensis* in association with *Favusella washitaensis*, indicating a Early Cenomanian (or earlier) age. In Tunisia, Bessaïs (unpublished phd 1989, see Tronchetti 1993) in the S-E of Kasserine city (Jabal Selloum) in Early to middle

Cenomanian sediments dated by ammonites, rudists, benthic foraminifers and ostracodes (Tronchetti 1993).

Paleoenvironment: Following our observations, *R. m. mesogeensis* is present in the shallow shelf/ramp environments, but absent from the deeper Omani intrashelf basins. This is in accordance with Tronchetti (1993), for whom *R. mesogeensis* is known from inner/median shelf environments with some tolerance to the nature of the substrate.

Rotorbinella mesogeensis (Tronchetti 1981) subsp. *medioformis* ssp. nov., Fig. 3m–q

1981 cf. *Rotalia mesogeensis* nsp Tronchetti, Pl. 27 Fig. 9, Pl. 28 Fig. 8

2007 *Rotorbinella mesogeensis* Boix, Pl. XVI Fig. 1 (same figure as Boix et al. 2009 Fig. 3.2, intermediate form between *R.m. mesogeensis* and *R.m. medioformis*), Pl. XVII Figs. 1, 2

Holotype: Specimen figured in Fig. 3p, sample ap375 deposited in the micropaleontological collection of the Natural history Museum of Geneva, n°MHNG2013-1.

Paratypes: Specimens figured in Fig. 3m (sample ap400), Fig. 3n (sample ap367) deposited in the micropaleontological collection of the Natural history Museum of Geneva, n°MHNG 2013-2 and MHNG 2013-3.

Type locality: Jabal Nadah, Adam Foothills, Oman, coordinates N22°29.409 E057°09.893

Type horizon: Natih C formation, Cenomanian.

Etymology: From medium, for its middle position in the series of subspecies.

Type description: Dissymmetric lenticular test with a clearly convex spiral side and convex to flat umbilical face, smooth on both sides, periphery subacute to rounded sometimes marked by an imperforated keel, massive free plug in the center of the umbilicus, bordered by a furrow (umbilical interocular space), spiral chamber walls finely perforated, 6–7 chambers in the last whorl, double septa with interocular intraseptal space, straight to slightly arched, foliar chamberlet (not clearly evidenced in our sections), separated by main chamber lumen by an umbilical plate. This subspecies can be considered as a “small *R.mesogeensis mesogeensis*” progressively losing its morphological characters (see Fig. 2). Many characteristics of *R. m. mesogeensis* are although still recognizable in this subspecies, and intermediate forms can be difficult to attribute.

Differences: The main differences with other subspecies are the more robust shape of the test, the scarcity of the keel, and the smaller size with a diameter between 120 and

220 µm and thickness between 50 and 120 µm. *R. m. mesogeensis* is bigger (200 µm and more diameter, 100 µm and more thickness) with an often thicker spiral wall, and *R.m. microformis* (see below) is always smaller (50 to 140 µm diameter, 30 to 70 µm thickness) with a thinner wall of the same thickness on both faces of the test (no spiral thickening) and never keeled.

Geographic and stratigraphic distribution: *R.m.medioformis* is known in France (Tronchetti 1981), Spain (Boix 2007; Boix et al. 2009), Morocco and Oman in Middle to Late Cenomanian sediments.

Paleoenvironment: It is not possible at the moment to propose a definite paleoecological significance for this subspecies, although it seem (as for *R. m. mesogeensis*) restricted to shallow shelf environment (absent of the intrashelf basins of Oman), it may have a slightly higher tolerance to environmental changes than *R. m. mesogeensis*.

Rotorbinella mesogeensis (Tronchetti 1981) subsp. *microformis* ssp.nov., Fig. 3r–ab

cf. : 2008 Microfacies à discorbidae Ettachfini Pl. 21 Fig. 13.

Holotype: Specimen figured in Fig. 3t, sample ap289 deposited in the micropaleontological collection of the Natural history Museum of Geneva, n°MHNG2013-4.

Paratypes: Specimens figured in Fig. 3u, sample ap289, Fig. 3s, w sample ap327, and Fig. 3x, y sample ap325 (Jabal Madar, Adam Foothills, Oman, Natih E formation, Cenomanian), deposited in the micropaleontological collection of the Natural history Museum of Geneva, n°MHNG2013-5 and MHNG2013-6.

Type locality: Tazougart Belkassem field section of Cavin et al. (2010) coordinates N32°05.231—W003°46.198

Type horizon: Upper part of Akrabou formation, Late Cenomanian—possibly Early Turonian.

Etymology: From micro, for the very small size of this subspecies.

Type description: The shell shows a smooth convex spiral side with no ornamentation, pores are discernible. The chambers are arranged in a low trochospire, the chambers are ovate in axial section and keel is absent. The shape of the umbilical side varies from slightly convex to plane or even concave if section passes through the last chamber. A single massive plug occupies the center of the unornamented umbilical face. The plug is surrounded by a narrow spiral fissure (umbilical interocular space) possibly giving rise to a spiral umbilical canal (not evidenced in our pictures). The very small size of the specimen make tough the recognition of internal shell structure and the possible

presence of a small folia and notch are suspected, but not clearly identified. The slightly arched septum is bilamellar with interocular intraseptal space. The trochospire show two spiral whorls with 6–7 chambers in the last one. The size is small to very small with a diameter between 50 and 140 μm and a thickness between 30 and 70 μm . Note that the very small size of the shell means it could easily be omitted by micropaleontologists working with unconsolidated sediments, and possibly also by the ones working in thin sections.

Differences: As internal shell structures cannot be currently certified, attribution of *microformis* to *Rotorbinella* and *mesogeensis* is proposed here based on morphological affinities and continuum with *R. m. medioformis* and *R. m. mesogeensis*. This subspecies is characterized by its very small size, axial sections reveal ovate chambers, absence of keel, absence of spiral thickening of the test (contrarily to *medioformis* and *mesogeensis*), and possible concave umbilical face. *R. m. mesogeensis* and *R. m. medioformis* have always bigger size with a different shape (see Fig. 2).

Geographic and stratigraphic distribution: In Oman is observed the oldest occurrence of *R. m. microformis* with a Late Albian (*Diploceras cristatum* ammonite Zone, Nahr Umr Formation) age, up to the Late Cenomanian (Natih A formation). In Morocco, it is observed in the Middle to Late Cenomanian, possibly Early Turonian (high Mouloya, Ettachfni 2008, and Kem–Kem area, south-eastern mountains). The older age of this subspecies makes it the possible ancestor of *medioformis* and *mesogeensis*.

Paleoenvironment: *R. m. microformis* is actually only known from shallow marine environment of Morocco and Oman (not found in the intrashelf basins of Oman). *R. m. microformis* worth interest as it surely has a paleoecological signification with a wide tolerance to various shallow environment including peculiar (restricted) ones. It can be the only foraminifer found in some sample (e.g. in ap289 where found together with abundant dasyclads and various echinoderm and other shell fragments). The cited above “discorbid microfacies” of Ettachfni 2008 (sample Mib75, p. 62) is most probably another typical example of these peculiar environment.

Differences with discorbids and other nearby taxa: In the micropaleontological works dealing with thin section (note that the taxa cited below are almost only known as extracted specimens), the small low trochospiral shells with hyaline optically radiate wall are often named “discorbids” or “rotalines” (i.e. by Sartoni and Crescenti 1960). The (Albian/Cenomanian up to the Paleocene) “Rotaline” of the latter authors correspond in part to the *Rotalina cayeuxi* of Agip (1959) which do not correspond to the original

illustrations of Lapparent (as noted by Sartoni and Crescenti 1960). Anyway, the fact that all these shells do not have the single central massive umbilical plug and are much bigger ($>220 \mu\text{m}$) than *R. m. microformis* ($<140 \mu\text{m}$) is here sufficient for differentiation. The well-developed massive primary umbilical plug (not the coalescence of the umbilical-most parts of the successive folia) encountered in *Rotorbinella* is never encountered in *D. vesicularis* (type species of *Discorbis*), *D. turbo* (type species of *Discorbina*), *L. dimidiatus* (type species of *Lamellodiscorbis*), *R. auberii* (type species of *Rotorbis*) (Revets 2001). As well the compound plug of *N. mexicana* (type species of *Neorotalia*) (Hottinger et al. 1991), multiple pillars of *R. trochidiformis* (type species of *Rotalia*) (Haynes and Whittaker 1990; Levy et al. 1982) are not homologous with the umbilical plug found in *Rotorbinella* (Revets 2001). Also *Rosalina globularis* (type species of *Rosalina*) do not show any umbilical plug (see Levy et al. 1979, Hansen and Revets 1992). Note that well-developed umbilical plugs are only found in few taxa among which *A. norrisi* (Albian type species of *Albertainopsis*), *B. monterelensis* (Campanian type species of *Brotzenella*), *R. colliculus* (Eocene type species of *Rotorbinella*), *P. inermis* (Eocene type species of *Pararotalia*) (Hottinger et al. 1991), *G. praegeri* (Recent type species of *Gavelinopsis*), *A. beccarii* (Recent type species of *Ammonia*) (Levy et al. 1986; Revets 1996, 2001, 2002a, b).

Regarding internal chamber structures (difficult to evidence with certainty in *R. m. microformis*), the presence of umbilical plate (Boix et al. 2009) or coverplates (Revets 2001) in *R. colliculus* confirms the rotaliacean nature of *Rotorbinella*. Also, following Hansen and Revets (1992), *D. vesicularis* (type species of *Discorbis*) has coverplates and is structurally a rotaliid; it is then proposed to be reclassified (together with *Ammonia*, *Discorbina*, *Lamellodiscorbis*, *Rotorbis*, *Rotorboides*, *Streblodes*, *Gavelinopsis*) in the Ammoniinae, Rotaliidae, Rotaliacea. The original concept of *Discorbis* is then well represented by *Rosalina* (no umbilical plug), which has chambers with no internal structures (Hansen and Revets 1992 but see discussion in Revets 2002a).

Morphological forms close to *R. m. mesogeensis*

Consulting literature for the above study, we looked for cretaceous rotaliids morphologically resembling our *rotorbinellas*, i.e. with open intraseptal and umbilical interocular space and free massive umbilical plug, as well as umbilical plate and folia when visible. Old rarely cited species and more recent ones but just as much cited are most often only seldom (and sometimes partially) illustrated. A lengthy future objective would then be the revision of the type species of *Rotalia algeriana* Magniez and

Sigal (1953), *Rotalia saxorum* D'Orbigny (1850), *Rotalia sigali* Drooger (1952), *Rotalia minuta* Martin (1964), *Rotalia hemisphaerica* (Reuss 1862), *Rotalia pisana* Michelotti (1841), *Rotalia reticulata* Reuss (1863), *Rotalia perovalis* Terquem (1882), *Rotalia germanica* Kiesel (1970), *Rotalia corbarica* Massieux (1973), *Rotalia lecalvezeae* Guillemin (1977), *Rotorbinella hensoni* (Smout 1954), *Rotalia cushmani* Applin and Jordan (1945), *Rotorbinella skourensis* (Pfender 1938), *Rotalia bandyi* Martin (1964), *Rotalia marginata* D'Orbigny (1850) to compare them with the well-defined *R. mesogeensis mesogeensis* and *R. campaniola* Boix et al. (2009), different species being probably conspecific, while others may have been lumped in one.

Genus *Pararotalia* LeCalvez 1949

Type species: *Rotalia inermis* Terquem 1882

The genus *Pararotalia* is defined by a planoconvex to biconvex test in a low trochospiral coil with an imperforated keel, umbilicus with a single massive plug, areal aperture with a lower lip representing the serrated edge of the spiral umbilical element separating the chamber lumen from the umbilical interocular space. This element is called toothplate by Hottinger et al. (1991) and Loeblich and Tappan (1988) while Revets (1993) has a more restrictive view of the term toothplate and rather refer to foraminiferal coverplate concept for the internal structures in rotaliids. For Hottinger et al. (1991), the presence of this toothplate with a free edge in *Pararotalia*, and the absence of such features as umbilical plate, foramenal plate connected to a cover plate or a folia, set the *Pararotaliinae* Reiss 1963 well apart from the *Rotaliinae* Ehrenberg 1839, *Cuvillierininae* Loeblich and Tappan 1964, and *Ammoniinae* Saidova 1981, and the open and undivided ventral sutural interocular spaces separates it from *Neorotalia*.

The Early to Late Cenomanian (possibly Earliest Turonian) of Oman contains a homogenous population of small rotaliid specimen which is (although a bit smaller) very similar to the Late Santonian—Early Campanian *P. tuberculifera* illustrated by Boix (2007); Boix et al. (2009). Comparison with the original description and drawings of Reuss (1862), however, generated the research and discussion below.

History and remarks on *Pararotalia tuberculifera* (Reuss 1862)

Literature: In 1862, *Rotalia tuberculifera* Reuss is described in isolated form in Cretaceous sediments from Maasticht, The Netherlands. Following the German text (here translated), it is characterized by its diameter (around 875 µm for tall specimens), its rounded flattened shell with a keel interrupted by the suture reaching the periphery, the spiral side with only half of the last whorl recognizable (the

rest of the surface being hidden/covered by rather bigger rounded beaded grains); umbilical face with 10 chambers in the last whorl, narrow center of umbilicus hidden by some bigger grains, shallow and narrow umbilical sutures getting deeper near the umbilicus; whole surface of umbilical and spiral faces covered by small grains with discernible pores in-between; spiral face more bulged than umbilical face, opening as a slit on the umbilical face below dorsal margin. In 1949, Hofker (1949) illustrate *Nonion tuberculifera* (Reuss) from the Late Senonian of south Limburg (Maastrichtian) with irregularly placed large knobs on the surface centre (and often near the periphery too) of both faces the test. The drawings of Hofker are different from those of Reuss by the much larger tubercles and the evidence of a “canal system” on both sides of the shell. These observations make Hofker state that the figures of Reuss are incorrect, but that his specimens correspond to Reuss's description. In 1950, Visser (1950) states that *Rotalia tuberculifera* is one of the most common foraminifera in the type maastrichtian (following Reuss 1862 it is rare). His text state the presence of an umbilical plug, but it is neither visible on his drawings nor evidenced on his pictures. In 1951, Hofker (1951) attribute *R. tuberculifera* to the genus *Parella*. He discusses this attribution with different morphological arguments including a canal system between the knobs on both faces, the presence of a typical spine at each of the chambers, and the somewhat areal aperture. In 1957, Hofker (1957) attribute *P. tuberculifera* to the genus *Pararotalia* in a consequent study with abundant illustration. According to Hofker (ibid), *P. tuberculifera* is the oldest (Maastrichtian—Montian) species of the genus and a highly variable species with trimorphism (A1, A2 and B forms), the forms at the beginning of the evolution (Maastrichtian b) being very different (size is particularly increasing with time) from those at the end of the series (Montian). In 1957 Brown and Broennimann (1957) propose that *P. tuberculifera* probably includes *Siderolites skourensis*. In 1958, Reiss and Merling (1958) detail internal structures (e.g. toothplates, septal flaps) of various rotaliids (characterized by their double septa) among which feature *Pararotalia*, with illustrations of *P. tuberculifera*. Hofker (1959) study the evolution of the species with time and include a large list of synonyms. In 1960, Hofker (1960) cite the presence of *P. tuberculifera* in the Late Santonian of the Aquitaine basin (France), detail the areal loop-shaped aperture with a typical lamella over it and a thin toothplate (lip sensu Hottinger 2006) protruding from the apertural face, and resume the characters of *Pararotalia*. In 1963 Hofker (1963) detail again *P. tuberculifera* with a simple septa (contrarily to the observations of Reiss and Merling 1958), and with at the areal aperture a curled part forming the border of the aperture with the toothplate (apertural lip

sensu Hottinger 2006), and at the axial wall of the foramen, a short dent protruding at the distal side of the foramen (most probably toothplate sensu Hottinger 2006). Hofker (1966), in his extensive work on Maastrichtian, Danian and Palaeocene foraminifera, illustrates numerous drawings of *P. tuberculifera* with an important morphological diversity. Pozaryska and Szczechura (1968) illustrate (drawings) this common form of the Palaeocene of Poland for which they note the considerable variation of shape, size and ornamentation; wall surface seems smooth, central plug can be single or divided into several small knob-like plugs, protuberances around central plug, if present, are formed by older raised parts of chambers (tena). Szczechura and Pozaryska (1972) illustrate their work with SEM images pointing out again the variability of the Montian *P. tuberculifera* of Crimea. Villain (1977) gives SEM views of one Maastrichtian *P. tuberculifera* shell from south Limburg, Netherland. Luperto Sinni (1978) illustrates thin sections of tall Senonian *P. tuberculifera* with detailed description and synonymy list attesting to the variable morphology. The remarkable works of Boix (2007) and Boix et al. (2009) on several Late Cretaceous rotaliids give very good description and abundant illustrations of sections of *P. tuberculifera* from the Late Santonian—Early Campanian, specimens that resemble very much our Cenomanian forms (see below).

Discussion about *P. tuberculifera*: Comparing the illustrations (drawings and pictures) attributed to *P. tuberculifera* by Reuss (1862); Egger (1899); Hofker (1949, 1951, 1957, 1959, 1960, 1963, 1966); Visser (1950); Reiss and Merling (1958); Hottinger (1966); Pozaryska and Szczechura (1968), Sprechmann (1981), Szczechura and Pozaryska (1972); Villain (1977); Petters (1978, 1979); Luperto Sinni (1978); Salaj and Nairn (1987); Doppert and Neele (1983); Witte and Schuurman (1996); Boix (2007); Boix et al. (2009), a very high morphological variability is evidenced. Main differences are noticed in terms of shape and size (diameter from 280 to 1460 μm) of the test, presence/absence of a single salient massive umbilical plug, surrounded or not by spiral fissure, with or without bigger tubercles at the umbilical end of the chambers, with varying ornamentation (e.g. size and disposition of tubercles, beaded/smooth sutures, striated/pustuled/smooth chamber walls, presence/absence of peripheral keel and/or spines), number of chambers in the last whorl, and age (Santonian to Montian).

Hofker (1957) explains the large morphological differences within *R. tuberculifera* with test trimorphism, based on various arguments including test and proloculum size, more or less distinct umbilical plug, shape and ornamentation of the test. But although characteristics are discussed in the text and 3 drawings are respectively attributed to A1, A2 and B, this trimorphism is arduous to acknowledge

regarding the accessible drawings and pictures. His figure referred as a B form (Hofker 1957 Fig. 17 firstly described as *Rotalia choctawensis* by Van Bellen 1946, non Cushman and McGlamery 1938), is almost planispiral with an aperture in a different location, and cannot be conspecific with *R. tuberculifera* (Szczechura and Pozaryska 1972). Hofker (1963) also refers to micro and macrospheres, but the two sections he uses for demonstration have almost the same shell diameter and thickness (although one is a bit flatter), and the different sizes of the proloculus can then easily result of different centering of the sections; and if the two other specimens he refers to (isolated forms in Hofker 1957) are more different, their proloculus are not visible. Then, if cases of dimorphism are known within rotaliids (see Boix et al. 2009; Billman et al. 1980) it however, has to be revised for *P. tuberculifera* sensu Hofker (ibid), while it seem to lack for *P. tuberculifera* sensu Boix et al. (2009) as well as for our specimens from Oman.

Concerning revision of the holotype, Reuss's complete collection of foraminifera (collection that disappeared for a long period of time and was rediscovered in the 1970s, see Papp et al. 1977), made up of 1839 slides, is now deposited in the Naturhistorisches Museum in Vienna. The related catalogue is however, still missing, and as Reuss did not have any direct link between his publications and his specimens/samples, any work with this collection is now very difficult. During their revision of the work of Reuss (1863); Meyn and Vespermann (1989, 1994), made an unpublished temporary catalogue of the complete collection they left with the collection. Some specimens from the Maastrichtian work of Reuss (1862) had also been identified, but there is no mention of *R. tuberculifera* (F. Rögl pers. comm.). Although about 65 original glass vials of Reuss were empty (Meyn and Vespermann, ibid.), there is chances that the type species of *R. tuberculifera* is still somewhere within the 1839 slides. A review of all the samples of the Reuss collection may then be necessary to find the type, or confirm it is definitely lost, but is not conceivable in this study. Meyn and Vespermann (1989) noted that "some of the drawings of Reuss are highly accurate and some are schematic or somewhat idealized but showing all important features of the species". But Reuss's original description cite the presence of some bigger grains hiding the umbilicus, and of bigger rounded beaded grains hiding the first whorls of the spiral side, characters that do not appear on his drawings which may then be inaccurate as noted Hofker (1949). The drawings of Hofker (1949) are then probably more realistic, but show a spinose periphery which is not reported neither in the text nor in the drawing of Reuss, and do not show the "deepening of the umbilical sutures approaching the umbilicus" stated by Reuss. Moreover, the presence of a single central massive umbilical plug is at first not mentioned, neither in the text

nor on the drawings of Reuss (1862), or in the centered (visible proloculum) sections of Hofker (1949) (Fig. H, 1951 Figs. 16–18). This feature appears with the text of Visser (1950) but is not visible on his drawings although it can possibly be conceived in his (then highly oblique) section of Fig. 10; and then with Hofker (1957). Since then, this “highly variable species” most probably regroup different species with the various morphological characteristics cited above.

In their recent and abundantly illustrated work, Boix (2007); Boix et al. (2009) show morphologically homogeneous and rather small specimens they attribute to *P. tuberculifera*. The centered axial sections of Boix et al. 2009 (Fig. 12.1, 2, 7, 12, 15, 18–20), very close to our sections of Oman (Fig. 4a–j, l–m, o), always display an umbilical face with a large single central massive and prominent umbilical plug surrounded by a spiral fissure and a heavy pustule at the umbilical shoulder of every chamber; a spiral face with raised (possibly beaded) sutures, and smooth wall with possible rare pustules in the center of the spire. Considering these morphological characteristics, and their age (Early to Late Cenomanian of Oman, Late Santonian to Early Campanian of Spain), older than most *R. tuberculifera* cited above, and as neither the Campanian (Hofker 1959 Figs. 132–134) and Santonian (Hottinger 1966 Fig. 9b) drawings attributed to *R. tuberculifera*, nor Reuss’s specimens or text, do clearly describe/show the characteristics cited above, the specimens found in Oman and Spain (Boix 2007; Boix et al. 2009) are considered as species different from *R. tuberculifera* and described as follows:

Pararotalia boixae sp. nov., Fig. 4a–u

aff. : 2007 *Pararotalia tuberculifera* (Reuss), Boix, Pl. 23 Figs. 1–7, Pl. 24 Figs. 1–8

aff. : 2009 *Pararotalia tuberculifera* (Reuss), Boix et al. p. 221 Figs. 12.1–21 (without synonyms)

Holotype: Specimen figured in Fig. 4f, sample ap400 deposited in the micropaleontological collection of the Natural history Museum of Geneva, n°MHNG2013-7

Paratypes: Specimens figured in Fig. 4a–e, samples ap367, ap347, ap391, Fig. 4g, sample ap400, deposited in the micropaleontological collection of the Natural history Museum of Geneva, n° MHNG2013-8 to MHNG2013-11.

Type locality: North-West end of Jabal Salakh, Adam foothills, coordinates: N22°24.251 E057°12.027

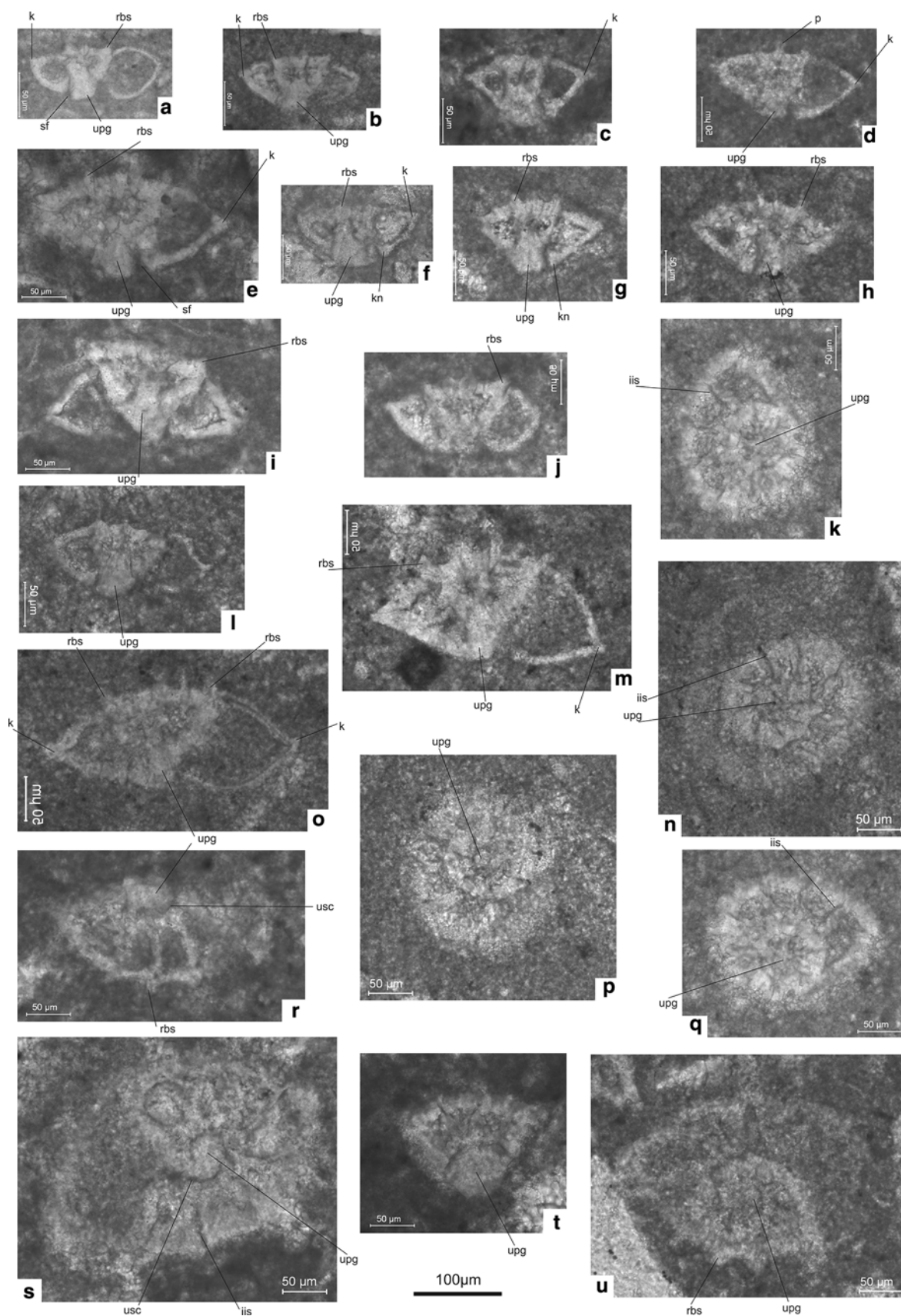
Type horizon: Natih C formation, Cenomanian.

Etymology: Dedicated to C. Boix for her work on cretaceous rotaliids.

Fig. 4 a–u *Pararotalia boixae* sp. nov.; axial and subaxial sections a–h, j, l–m, o; equatorial and subequatorial sections k, n, p–s, u; oblique subequatorial section r, t; oblique subaxial section i; a (paratype) sample ap367 (Natih A formation, Jabal Salakh, Oman); b (paratype) sample ap347 (Natih C formation, Jabal Madar, Oman); c–e (paratypes), i–k, n–u sample ap391 (Natih C formation, Jabal Khaydalah, Oman); f (holotype), g (paratype), l sample ap400 (Natih C formation, Jabal Madmar, Oman); h sample ap325 (Natih E formation, Jabal Madar, Oman); m sample ap382 (Natih E formation, Jabal Khaydalah, Oman). *st* spiral thickening, *k* keel, *upg* umbilical plug, *iis* intraseptal interocular space, *kn* knob, *po* pore, *sf* spiral fissure, *rbs* raised beaded suture, *usc* umbilical spiral canal

Type description: This species is characterized by a trochospiral plano-convex to biconvex shell with an acute periphery marked by an imperforated keel. The spiral side is flat to slightly convex with a smooth wall and raised (possibly beaded) suture giving in thin sections the aspect of pustules, which, in some sections (e.g. Fig. 4a, d, m), show a dark median line absent from the specimens of Boix et al. (2009) that resemble a pore, but that has not been studied in detail. These raised/beaded sutures concentrate around the apex (as a result of the suture of the first whorls) where additional tubercles (present on the spiral side only) can also be present. Umbilical side is more convex and wall is smooth with umbilical shoulders of spiral chambers bearing each a heavy knob that forms a circle around the single free-standing massive umbilical plug. About 10 chambers are present in the last of 2–3 whorls. The massive umbilical plug stands free in the center of the umbilicus, separated from the adaxial chamber walls by a deep open furrow (umbilical interocular space). The septa are straight and radial. The intraseptal interocular space is restricted to the umbilical part of the septum (in the specimens of Boix et al. 2009) and is undivided (no feathering). The opening is present on the umbilical face as a radial sutural slit that reaches the periphery (Boix et al. 2009). The areal foramen is bordered by an upper lip and a lower protruding element forming the serrated edge of the toothplate (not clearly recognizable in our sections but see Boix et al. 2009, Fig. 12.17). Proloculus is less than 15 microns in diameter (Boix et al. 2009). The lack of suitable transverse sections do not allow to precise the presence (or not) of a folia. No evident dimorphism of generation is evidenced, and Cenomanian specimens are smaller (maximum diameter of 300 µm) than the Late Santonian– Early Campanian affinis specimens of Boix et al. (2009) which reach 500 µm in equatorial diameter.

Remarks and differences: *P. boixae* show a low intraspecific morphological variability. The raised (possibly beaded) sutures of *P. boixae*, giving the characteristic tuberculate aspect in thin sections, plus its somewhat planoconvex shell (rather plane spiral face and convex umbilical face), distinctly separate this species from the smooth faced *R. mesogeensis mesogeensis*, *R. mesogeensis*



medioformis, *R. saxorum*, *R. corbarica*, *R. hensoni*, *R. algeriana*, *R. skourensis*. The presence of a single large massive prominent umbilical plug surrounded by a deep furrow, the presence of a knob on the umbilical shoulder of the chambers, the raised/beaded sutures and the smooth chamber walls separates it from *P. tuberculifera* sensu Reuss (1862). Reliable attribution of most drawings of the *P. tuberculifera* sensu Hofker (op.cit.) to *P. boixae* cannot be done without looking back to the original specimens. The figures from Villain 1977 (Pl. 6 Figs. 7–9), Hofker 1959 (Figs. 132–133, 1960 Fig. 7, 1966 Pl. 24 Fig. 137, Pl. 28 Figs. 40–41, Pl. 33 Fig. 73), Hottinger 1966 (Fig. 9b), Visser 1950 (Pl. 5 Fig. 14) are probably to be referred to *P. tuberculifera* sensu Reuss (1862).

Geographic and stratigraphic distribution: Middle to Late Cenomanian (Natih E to Natih A formation) in Oman (not found in contemporaneous sediments of Morocco), Late Santonian to Early Campanian in the south Central Pyrenees for the affinis forms of Boix et al. (2009).

Conclusions

As a part of an analysis of Cenomanian sediments of Morocco and Oman, this study details an abundant microfauna of small rotaliids. Some of these, still unknown, are described as subspecies of *Rotorbinella mesogeensis* (Tronchetti 1981). A gradational series (continuum) of three morphological groups with clearly differentiated morphology and (obviously) faint boundaries are split within *R. mesogeensis mesogeensis* ssp. nov., *R. m. medioformis* ssp. nov. and *R. m. microformis* ssp. nov. Although it is at the moment not possible to propose a definite palaeoecological significance for each taxon, shallow shelf/ramp environments show the most significant abundance of these taxa, while some of the shallowest (restricted?) environments reveal *R. m. microformis* as the only foraminifer. All these taxa are absent from deeper (intrashelf basins) environments. *R. mesogeensis* and subspecies are the earliest representative of the genus *Rotorbinella* that persists at least throughout the Palaeogene (Boix et al. 2009). The occurrence of *R. mesogeensis microformis* in the Late Albian (*Diploceras cristatum* ammonite Zone) of Oman makes it a probable ancestor of *R. m. medioformis* and *R. m. mesogeensis* and lets it possibly (internal structure can still be debated) be one of the oldest known rotaliid foraminifers. The *medioformis* and *mesogeensis* subspecies are abundant since the Early Cenomanian (ante *Mantelliceras dixonii* ammonite Zone) and last up to the Late Cenomanian (possibly basal Early Turonian, ante *Mammites nodosoides* ammonite Zone). The Cenomanian—Turonian boundary cannot be located very precisely and the disappearance of

the rotaliids around the boundary in Morocco and Oman is most probably due to facies change (deepening environment). *R. m. microformis* may be present in the Early Turonian. The Moroccan and Omani data confirm that, as noted by Tronchetti (1981, 1993) and Boix et al. (2009), *R. mesogeensis mesogeensis* is restricted to the Cenomanian and can be considered as a marker. The latter is considered by Boix et al. (2009) as the progenitor of all rotorbinellas, which will diversify into *Rotorbinella campaniola* Boix et al. 2009, *Pyrenerotalia longifolia* Boix et al. 2009, and *Iberorotalia reicheli* Hottinger 1966, since Early Santonian by modifications of the umbilical structure and size increase.

Pararotalia boixae sp. nov. regroups specimens that were previously included in the variability of *P. tuberculifera* (Reuss 1862). Bibliographic research revealed much confusion within this presumed highly variable species (probably containing different morphotypes/species), whose original description was complicated by probable inaccuracies of the original drawings. Seeking the (possibly lost) holotype within the huge Reuss's collection was not feasible as part of this work. *P. boixae* has shallow water environment affinities and a clearly distinct morphology and different age (Cenomanian with affinis forms in the Early Campanian) when compared with what we report to *P. tuberculifera* sensu Reuss (1862). *R. m. microformis*, *R. m. medioformis*, *R. m. mesogeensis* and *P. boixae* are the oldest reported occurrences of rotaliid foraminifers. These taxa are the rootstock of this family that will start its extensive diversification since the Late Coniacian—Early Santonian (see Boix et al. 2009).

Acknowledgments Best thanks to F. Rögl for his kind answers about the search of *R. tuberculifera* in the Reuss's collection of the Naturhistorisches Museum of Vienna; P.A. Proz (Museum, Geneva) for the confection of the numerous thin sections; R. Wernli (University of Geneva) for his numerous advices, our discussions and his comments that greatly improved this paper; and two anonymous reviewers for their stimulating comments, remarks and questions. Salim Omar Al-Ibrahim, Director General of Minerals (Ministry of Commerce and Industry of Oman) and Ali Al Rajhi, Director of Survey and Research are thanked for their logistic support.

References

- Agip, M. (1959). Microfacies italiane (dal Carbonifero al Miocene medio) (pp. 1–35), tt. I–CXLV, S. Donato Milanese.
- Applin, E. R., & Jordan, L. (1945). Lockhartia cushmani Applin and Jordan and notes on two previously described foraminifera from tertiary rocks in Florida. *J Paleontol*, 24(4), 474–478.
- Bandy, O. L. (1944). Eocene foraminifera from Cape Blanco, Oregon. *J Paleontol*, 18, 366–377.
- Billman, H., Hottinger, L., & Oesterle, H. (1980). Neogene to recent Rotaliid foraminifera from the Indopacific Ocean; their Canal system, their classification and their stratigraphic use. *Schweizerische Paläontologische Abhandlungen*, 101, 71–113.

- Bilotte, M., Bruxelles, L., Canérot, J., Laumonier, B., & Coinçon, R. S. (2008). Comment to "latest-Cretaceous/Paleocene karsts with marine infillings from Languedoc (South of France); paleogeographic, hydrogeologic and geodynamic implications by P.J. Combes et al.". *Geodinamica Acta*, 20(6), 403–413.
- Boix, C. (2007). *Foraminiferos rotalidos del Cretacico superior de la cuenca Pirenaica*. PhD. Thesis, Universitat Autònoma de Barcelona (pp. 1–139). <http://hdl.handle.net/10803/3442>.
- Boix, C., Villalonga, R., Caus, E., & Hottinger, L. (2009). Late Cretaceous rotaliids (Foraminiferida) from the Western Tethys. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen*, 253(2–3), 197–227.
- Brown, N. K., & Broennimann, P. (1957). Some Late Cretaceous rotaliids from the Caribbean region. *Micropaleontology*, 3(1), 29–38.
- Caron, M. (1983). La spéciation chez les Foraminifères planctiques, une réponse adaptée aux contraintes de l'environnement. *Zitteliana*, 10, 671–676.
- Caron, M., & Homewood, P. (1983). Evolution of early planktic foraminifers. *Marine Micropaleontology*, 7, 453–462.
- Cavin, L., Tong, H., Boudad, L., Meister, C., Piuze, A., & Tabouelle, J. et al. (2010). Vertebrate assemblages from the Early Late Cretaceous of southeastern Morocco: an overview. *J Afr Earth Sci*, 57, 391–412.
- Chiocchini, M. (2008). The new genus *Palaeocornuloculina* (Foraminiferida, Cornuspiracea) and its species from Cenomanian limestones of Southern Latium (Central Italy). *Memorie Descrittive della Carta Geologica d'Italia, LXXXIV*, 203–224.
- Chiocchini, M., Farinacci, A., Mancinelli, A., Molinari, V., & Potetti, M. (1994). *Biostratigrafia a foraminiferi, dasicladali e calpionelle delle successioni carbonatiche mesozoiche dell'appennino centrale (Italia)*. Studi Geologici Camerti volume speciale, 1994, Biostratigrafia dell'Italia centrale (pp. 9–129).
- Doppert, J. W. C., & Neele, N. G. (1983). Biostratigraphy of marine Paleogene deposits in the Netherlands and Adjacent areas. *Mededelingen. Rijks Geologische Dienst*, 37(2), 1–79.
- Drooger, C. W. (1952). *Foraminifera from Cretaceous-Tertiary-transitional strata of the Hodna Mountains, Algeria*. (3(2), pp. 89–103). Washington, DC: Cushman Foundation for Foraminiferal Research Contr.
- Egger, J. G. (1899). Foraminiferen und Ostrakoden aus den Dreideckern der Oberbayerischen Alpen. *Abhandlungen der Mathematisch-Physikalischen Classe der Königlich Bayerischen Akademie der Wissenschaften XXI. Band, I*, 1–230.
- Ehrenberg, C. G. (1839). Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. *Physikalische Abhandlungen der Königlich Akademie der Wissenschaften zu Berlin, 1838* (1840: separate 1839), 59–147.
- Ettachfini, El M., & Andreu, B. (2004). Le Cénomanien et le Turonien de la Plate-forme Préafricaine du Maroc. *Cretaceous Res*, 25, 277–302.
- Ettachfini, El M. (1993). Le Vraconien, Cenomanien et Turonien du Bassin d'Essaouira (Haut Atlas occidental, Maroc). Analyses lithologique, biostratigraphique et sédimentologique, Stratigraphie séquentielle. Thèse de Doctorat de l'Université Paul Sabatier. Toulouse. *Strata série II*, 18, 1–247.
- Ettachfini, El M. (2008). La transgression au passage du Cénomanien au Turonien sur le domaine atlasique marocain, Stratigraphie intégrée et relations avec l'événement océanique global. Thèse de doctorat d'Etat es Sciences de l'Université Chouaib Doukkali, El Jadida. *Strata série II*, 45, 1–299.
- Golubic, S., Radoicic, R., & Seong-Joo, L. (2006). *Decastronema katori* gen. nov., comb. nov.: a mat-forming cyanobacterium on Cretaceous carbonate platforms and its modern counterparts. *Carnets de Géologie, 2006–02*(CG2006_A02), 1–17.
- Guillemin, Y. (1977). Contribution à l'étude des foraminifères du Montien du bassin de Paris. *Cahiers de micropaléontologie*, 4, 1–79.
- Hamaoui, M. (1964). On a new subgenus of Hedbergella (Foraminiferida). *Israel J Earth Sci*, 13, 133–142.
- Hansen, H. J., & Revets, S. A. (1992). A revision and reclassification of the Discorbidae, Rosalinidae and Rotaliidae. *J Foraminiferal Res*, 22, 166–180.
- Hart, M. B. (1999). The evolution and biodiversity of Cretaceous planktonic Foraminiferida. *Geobios*, 32(2), 247–255.
- Hart, M. B., & Bailey, H. W. (1979). The distribution of planktonic Foraminiferida in the mid-Cretaceous of N.W. Europe. *Aspekte der Kreide Europas IUGS Ser A*, 6, 527–542.
- Haynes, J. R. (1992). Supposed pronounced ecophenotypy in foraminifera. *J Micropaleontology*, 11, 59–63.
- Haynes, J. R., & Whittaker, J. E. (1990). The status of *Rotalia* Lamarck (Foraminifera) and of the Rotaliidae Ehrenberg. *J Micropaleontology*, 9(1), 95–106.
- Hofker, J. (1949). On Foraminifera from the Late Senonian of South Limburg (Maestrichtian). *Institut royal des sciences naturelles de Belgique, mémoires*, 112, 1–69.
- Hofker, J. (1951). On foraminifera from the Dutch Cretaceous. *Publicaties van het Natuurhistorisch genootschap in Limburg*, 4, 1–47.
- Hofker, J. (1957). Foraminifera from the Cretaceous of southern Limburg, Netherlands XXIV, the development of *Pararotalia tuberculifera* (Reuss). *Natuurhistorisch Maandblad*, 46, 32–39.
- Hofker, J. (1959). Les foraminifères des craies tuffoïdes de Charente et Dordogne de l'Aquitaine, France du sud-ouest. Comptes rendus du 84ème congrès national des Sociétés Savantes, Dijon, 1959, Colloque Crétacé supérieur, pp. 253–368.
- Hofker, J. (1960). Foraminifera from the Cretaceous of south-limburg, Netherlands I, the aperture of *Pararotalia tuberculifera* (Reuss). *Natuurhistorisch Maandblad*, 49, 79–83.
- Hofker, J. (1963). Once again *Pararotalia tuberculifera*. *Natuurhistorisch Maandblad*, 52, 80–82.
- Hofker, J. (1966). Maestrichtian, Danian and Paleocene Foraminifera. *Palaeontographica supplement*, 10, 1–376.
- Homewood, P., Razin, P., Grélaud, C., Droste, H., Vahrenkamp, V., Mettraux, M., et al. (2008). Outcrop sedimentology of the Natih Formation, northern Oman: a field guide to selected outcrops in the Adam foothills and Al jabal al Akhdar areas. *Geoarabia*, 13(3), 39–120.
- Hottinger, L. (1966). Foraminifères rotaliformes et orbitoïdes du Sénonien inférieur pyrénéen. *Eclogae Geologicae Helvetiae*, 59(1), 277–315.
- Hottinger, L. (2006). *Illustrated glossary of terms used in foraminiferal research*. Notebooks on Geology, Memoir 2, pp. 1–126. http://paleopolis.rediris.es/cg/CG2006_M02/.
- Hottinger, L., Halicz, E., & Reiss, Z. (1991). The foraminiferal genera *Pararotalia*, *Neorotalia* and *Calcarina*: taxonomic revision. *J Paleontology*, 65(1), 18–33.
- Kiesel, Y. (1970). Die Foraminiferenfauna de paläozänen und eozänen Schichtenfolge der Deutschen Demokratischen Republik. *Paläontologische Abhandlungen Abteilung A, IV*(2), 163–394.
- LeCalvez, Y. (1949). Révision des foraminifères Lutétiens du Bassin de Paris. II Rotaliidae et familles affines. Mémoires du service de la Carte Géologique détaillée de la France (pp. 1–54).
- Levy, A., Mathieu, R., Poignant, A., & Rosset-Moulinier, M. (1986). Discorbidae and Rotaliidae: a classification to be revised. *J Foraminiferal Res*, 16(1), 63–70.
- Levy, A., Mathieu, R., Poignant, A., Rosset-Moulinier, M., & Rouvillois, A. (1982). Données nouvelles sur *Rotalia trochidiformis* Lamarck (Foraminiferida). Emendation du genre *Rotalia* Lamarck 1804. *Géologie Méditerranéenne*, 9(1), 33–41.

- Levy, A., Mathieu, R., Poignant, A., Rosset-Noulinier, M., & Rouvillois, A. (1979). Révision de quelques genres de la famille Discorbidae (Foraminifera) fondée sur l'observation de leur architecture interne. *Revue de Micropaléontologie*, 22, 66–88.
- Loeblich, A. R., & Tappan, H. (1964). Sarcodina chiefly "thecamoebians" and Foraminifera, (pp. C1–C900). In R. C. Moore (Ed.), *Treatise on Invertebrate Paleontology*, Pt. C., Protista 2. Lawrence: Geological Society of America and University of Kansas Press.
- Loeblich, R., & Tappan, H. (1988). *Foraminiferal Genera and their Classification*. Kluwer, pp. 1–1728.
- Luperto Sinni, E. (1978). Microfossili senoniani delle Murge. *Rivista Italiana di Paleontologia e Stratigrafia*, 82, 293–416.
- Magniez, J., & Sigal, J. (1953). Description des espèces nouvelles; 1-Foraminifères. In G. Cheylan, J. Magné, J. Sigal, & N. Grekoff (Eds.), *Résultats géologiques et micropaléontologiques du sondage d'El Krachem (Hauts Plateaux algérois)*. (série 6, 3(4–6), pp. 471–492). Paris: Société Géologique de France
- Martin, L. (1964). Upper Cretaceous and Lower Tertiary foraminifera from Fresno County, California. *Jahrbuch der Geologischen Bundesanstalt Sonderband*, 9, 1–128.
- Masse, J. P., Fenerci-Masse, M., Isintek, I., & Güngör, T. (2010). Albian Rudist Fauna from the Karaburun Peninsula, İzmir Region, Western Turkey. *Turkish J Earth Sci*, 19, 671–683.
- Massieux, M. (1973). *Micropaléontologie stratigraphique de l'Eocène des Corbières septentrionales (Aude)* XXIV (pp. 1–146). Paris: Ed. du Centre national de la recherche scientifique, Cahiers de paléontologie.
- Meyn, H., & Vespermann, J. (1989). The Reuss collection (Cretaceous foraminifera) in Vienna. *J Paleontol*, 63, 388.
- Meyn, H., & Vespermann, J. (1994). Taxonomische Revision von Foraminiferen der Unterkreide SE-Niedersachsens nach Roemer 1839. 1841, 1842, Koch 1851 und Reuss 1863. *Senckenbergiana Lethaea*, 74(1–2), 49–272.
- Michelotti, G. (1841). Saggio storico dei Rizopodi caratteristici dei terreni sopracretacei. *Soc Ital Sci Modena Mem Fis*, 22, 253–302.
- Miller, A. A. L., Scott, D. B., & Medioli, F. S. (1982). *Elphidium excavatum* (Terquem); ecophenotypic versus subspecific variation. *J Foraminiferal Res*, 12, 116–144.
- Orbigny, A. (1850). *Prodrome de Paléontologie stratigraphique universelle des animaux mollusques et rayonnés* (2, pp. 1–428). Paris, France: V. Masson.
- Papp, A., Rögl, F., & Schmid, M. E. (1977). Zur Kenntnis des Originalmaterials Hauer—d'Orbigny 1846. *Verhandlungen der Geologischen Bundesanstalt*, 1977(2), 69–77.
- Petters, S. W. (1978). Maastrichtian—Paleocene Foraminifera from NW Nigeria and their Paleogeography. *Acta Palaeontologica Polonica*, 23(2), 131–153.
- Petters, S. W. (1979). Nigerian Paleocene benthonic foraminifera biostratigraphy, paleoecology and paleobiogeography. *Marine Micropaleontology*, 4, 85–99.
- Pfender, J. (1938). Etude micrographique des calcaires Crétacés et Eocènes de l'Imini, de Tamdakht et de Skoura. In L. Moret (Ed.), *Contribution à la paléontologie des couches Crétacées et Eocènes du versant sud de l'Atlas de Marrakech* (49, pp. 57–71). Morocco, Serv. Mines, Notes et Mém., Rabat.
- Philip, J., Borgomano, J., & Al-Maskiry, S. (1995). Cenomanian—Early Turonian carbonate platform of Northern Oman: stratigraphy and palaeo-environments. *Palaeogeogr Palaeoclimatol Palaeoecol*, 119, 77–92.
- Pozaryska, K., & Szczuchura, J. (1968). Foraminifera from the Paleocene of Poland, their ecological and biostratigraphical meaning. *Paleontologia polonica*, 20, 1–104.
- Reiss, Z. (1963). Reclassification of perforate foraminifera. *Bull State Israel Geol Surv*, 35, 1–111.
- Reiss, Z., & Merling, P. (1958). Structure of some Rotaliidea. *State of Israel Ministry of Development geological survey bulletin*, 21, 1–29.
- Reuss, A. E. (1862). Paläontologische Beiträge—Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche classe, Vol. 44(1), pp. 301–342.
- Reuss, A. E. (1863). Paläontologische Beiträge. *K Akad Wiss Wien Math-Naturw Cl Sitzber*, 44(1), 301–342.
- Revs, S. A. (1993). The foraminiferal toothplate, a review. *J Micropaleontology*, 12(2), 155–168.
- Revs, S. A. (1996). The generic revision of the Anomaliniidae, Alabaminidae, Cancrisidae and Gavelinellidae. *Cushman Foundation Special Publication*, 34, 57–113.
- Revs, S. A. (2001). The genus *Rotorbinella* Bandi, 1944 and its classification. *J Foraminiferal Res*, 31(4), 315–318.
- Revs, S. A. (2002a). The genus *Albertinopsis*, gen. nov. and the relations between Gavelinellidae and Rosalinidae. *J Foraminiferal Res*, 32(1), 51–56.
- Revs, S. A. (2002b). On the rotaline nature of *Gavellinopsis* Hofker, 1951. *J Foraminiferal Res*, 32(1), 61–67.
- Saidova, K. H. (1981). *O sovremennom sostoyanii sistemy nadvidovykh taksonov Kaynozoyksikh bentosnykh foraminifer (On an up-to-date system of supraspecific taxonomy of Cenozoic benthonic foraminifera)*. (pp. 1–73). Moscow: Institut Okeanologii P. P. Shirshova, akademiya Nauk SSSR.
- Salaj, J., & Nairn, A. E. M. (1987). Age and depositional environment of the lower Tar « member » of the Zimam formation (Late Senonian) in the northern Hamada Al Hamra, Libya. *Palaeogeogr Palaeoclimatol Palaeoecol*, 61, 121–143.
- Sartoni, S., Crescenti, U. (1960). Ricerche biostratigrafiche nel Mesozoico dell'Appennino meridionale. *Annali del Museo Geologico di Bologna*, XXIX(2a), 161–388.
- Smoot, A. H. (1954). *Lower Tertiary foraminifera of the Qatar Peninsula* (pp. 1–96). London: British Museum (Natural History).
- Sprechmann, S. J. (1981). Paleocommunities and paleobathymetry of Maastrichtian sublittoral benthonic foraminifera from Western Europe. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 162(2), 188–230.
- Szczuchura, J., & Pozaryska, K. (1972). The Montian warm-water foraminifera in the meridional province of Europe. *Acta Palaeontologica Polonica*, 16(4), 345–388.
- Terquem, O. (1882). Les foraminifères de l'Eocène des environs de Paris. *Soc Geol France Mém*, 2(3), 1–193.
- Tronchetti, G. (1981). Les foraminifères crétacés de Provence (Aptien-Santonien). Systématique—biostratigraphie—Paléocéologie—Paléogéographie. Thèse Doctorat Etat Université de Provence, Marseille, pp. 1–559.
- Tronchetti, G. (1993). *Rotalia mesogeensis* Tronchetti 1981 (foraminifera): importance biostratigraphique, paléocéologique et paléobiogéographique pour le Cénomane téthysien. *Géologie Méditerranéenne*, 20(1), 45–51.
- Van Bellen, R. C. (1946). Foraminifera from the Middle Eocene in the southern part of the Netherlands, Province of Limbourg. Mededeelingen Van De Geologische Stichting—Serie C—V—No.4, pp. 1–145.
- van Buchem, F. S. P., Razin, P., Homewood, P. W., Oterdoom, H., & Philip, J. (2002). Stratigraphic organization of carbonate ramps and organic-rich intra-shelf basins: Natih formation (middle Cretaceous) of northern Oman. *Am Assoc Petroleum Geol Bull*, 86(1), 21–54.
- van Buchem, F. S. P., Razin, P., Homewood, P. W., Philip, J. M., Eberli, G. P., Platel, J.-P., et al. (1996). High resolution sequence stratigraphy of the Natih formation (Cenomanian/Turonian) in Northern Oman: distribution of source rocks and reservoir facies. *GeoArabia*, 1(1), 65–91.

- Velic, I. (2007). Stratigraphy and Palaeobiogeography of Mesozoic Benthic Foraminifera of the Karst Dinarides (SE Europe). *Geologica Croatica*, 60(1), 1–113.
- Villain, J.-M. (1977). Le Maastrichtien dans sa region type (Limbourg, Pays-Bas). Etude stratigraphique et micropaléontologique. *Palaeontogr Abteilung A*, 157, 1–87.
- Visser, A. M. (1950). Monograph on the Foraminifera of the type-locality of the Maestrichtian (south-Limburg, Netherlands). *Leidse Geologische Mededelingen*, 16, 197–359.
- Witte, L., & Schuurman, H. (1996). Calcareous benthic foraminifera across the Cretaceous/Tertiary boundary in the Geulhemmergerg (SE Netherlands). *Geologie en Mijnbouw*, 75(2), 173–185.