



# Latest Oligocene to earliest Pliocene deep-sea benthic foraminifera from Ocean Drilling Program (ODP) Sites 752, 1168 and 1139, southern Indian Ocean

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**Abstract.** Deep-sea benthic foraminifera provide important markers of environmental conditions in the deep-ocean basins where their assemblage composition and test chemistry are influenced by ambient physical and chemical conditions in bottom-water masses. However, all foraminiferal studies must be underpinned by robust taxonomic approaches. Although many parts of the world's oceans have been examined, over a range of geological timescales, the Neogene benthic foraminifera from the southern Indian Ocean have only been recorded from a few isolated sites. In this study, we have examined 97 samples from Neogene sediments recovered from three ODP sites in the southern Indian Ocean (Sites 752, Broken Ridge; 1139, Kerguelan Plateau; 1168, west Tasmania). These data cover a range of palaeolatitudes and water depths during the Miocene. More than 200 species of benthic foraminifera were recorded at each site and, despite their geographic and bathymetric separation, the most abundant taxa were similar at all three sites. Many of these species range from late Oligocene to early Pliocene demonstrating relatively little faunal turnover of the most abundant taxa during the key palaeoclimatic shifts of the Miocene. We illustrate and document the occurrence of the 52 most abundant species (i.e. those with > 1 % abundance) encountered across the three study sites.

## 1 Introduction

The Neogene can be informally subdivided into an early warm interval and late cool interval (Flower and Kennett, 1993). Superimposed on this long-term cooling is the Mid-Miocene climatic optimum (MMCO) between ~ 15 and 17 Ma, marking the warmest interval of the Neogene (Zachos et al., 2001). Cooling following the MMCO culminated at ~ 13–14 Ma in major growth of the East Antarctic Ice Sheet (EAIS). Further cooling coincided with increasing intensification of Antarctic deep-water formation and growth of the AIS and Greenland ice sheet (Flower and Kennett, 1993, 1994, 1995).

Profound palaeoclimatic and palaeoceanographic changes in the Neogene drove progressive and significant turnover of deep-sea benthic foraminiferal communities from the so-called transitional fauna characterising the late Oligocene–early Miocene to the late Neogene fauna of the late Miocene

and finally the establishment of recognisably modern assemblages in the mid-Pleistocene (Jones, 1994; Kaiho, 1994). The first major transitional interval occurred in the early-to-middle Miocene, between ~ 13–17 Ma (Kaiho, 1994), spanning the onset of the MMCO, subsequent East Antarctic Ice Sheet growth, and associated changes in water mass character and upwelling intensity (Woodruff, 1985). Further changes in assemblages that occur in the late Miocene, ~ 8–10 Ma, relate to global cooling and expansion of the Antarctic ice sheet (Gupta et al., 2004). Finally, the last global extinction of benthic foraminifera (~ 20 % of deep-sea genera) occurred in the late Pliocene–mid-Pleistocene (Hayward et al., 2012) and is variously attributed to increasing ocean productivity and intensification of low-oxygen zones and changes in the food type and supply, due to the expansion of the Antarctic and later Northern Hemisphere ice sheets and global cooling (Hermoyian and Owen, 2001; Gupta et al., 2004; Smart et al., 2007).

Superimposed on this long-term global pattern of benthic foraminifer assemblage change are distinct basinal and latitudinal differences in the timing of certain biotic events. For instance, the global decline in deep-sea benthic foraminifer species abundance and richness occurs much earlier (late Oligocene–Miocene) in the Southern Ocean than in the Indian Ocean (late Miocene; Hayward et al., 2012). However, the response of deep-sea benthic fauna in the Indian Ocean to these global changes remains relatively poorly constrained.

Previous records of Miocene benthic foraminifera from the central and southern Indian Ocean are largely single-site reports with a focus on palaeoceanographical interpretations, though some provide useful illustration for comparison with the present study. Boersma (1990) reported benthic foraminifera from 12 ODP sites from leg 115 across the central Indian Ocean, where quantitative studies of the benthic foraminifera indicated faunal separation at intermediate, deep and abyssal water depths from the late Oligocene onwards, and hence the development of a more strongly vertically stratified ocean. Nomura (1991) systematically described the most abundant Oligocene-to-Pleistocene benthic foraminifera species and assemblage changes at ODP Sites 754 (Broken Ridge) and 756 (Ninetyeast Ridge) in the eastern Indian Ocean, linking them with palaeoceanographic changes.

There have been two studies focussing on the Kerguelen Plateau. Schroder-Adams (1991) investigated middle-Eocene-to-Holocene benthic foraminifera from Sites 736, 738 and 744 on the Kerguelen Plateau (Fig. 1), describing and illustrating many species. Significant faunal changes (and species replacements) were noted in the middle Eocene, late-Eocene–early-Oligocene, middle Miocene and late Miocene. Mackensen (1992) quantitatively studied benthic foraminiferal assemblages from the lower Miocene through to upper Pleistocene interval from ODP Site 747 (Central Kerguelen Plateau) and Sites 748 and 751 (Southern Kerguelen Plateau).

Gupta and Satapathy (2000) studied abyssal benthic foraminifera from 31 samples of the latest Miocene to Pleistocene from Deep Sea Drilling Project (DSDP) Site 236, north of the Mascarene Plateau. This study investigated the link between benthic foraminifera distribution, productivity and deep-ocean thermohaline circulation in the west-central Indian Ocean during that period.

The main aim of this work is to provide a taxonomic and stratigraphic reference for the most common Miocene benthic foraminifera encountered in the southern Indian Ocean, supported by scanning electron microscopy (SEM) images. The study deals with foraminifera encountered in ODP Holes 752A, 1139A and 1168A, all in the southern part of the Indian Ocean (Fig. 1). Of these, the latter two have not previously been investigated for benthic foraminiferal assemblages; whilst Neogene benthic foraminifera assemblages have been used for palaeoceanographic reconstructions in Hole 752A (Singh et al., 2012), no systematic species

description or reference images were provided. The present study expands our understanding of the spatial and temporal distribution of the most abundant benthic foraminifera from the deep-sea Miocene sediments of this region.

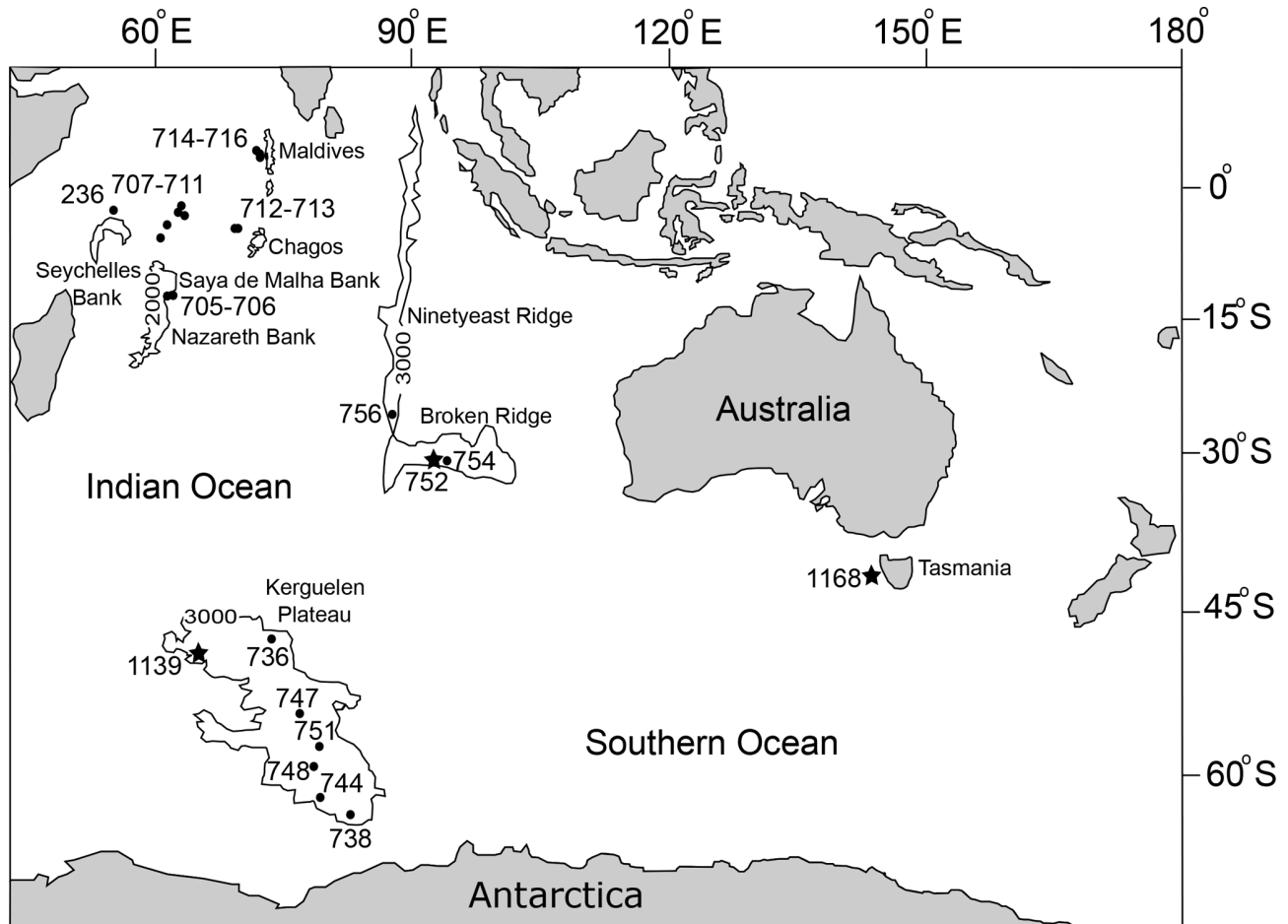
## 2 Materials and methods

ODP Site 752 is situated on the Broken Ridge in the south-eastern Indian Ocean ( $30^{\circ}53.475''$  S,  $93^{\circ}34.652''$  E; Fig. 1) at a current water depth of 1086 m (Shipboard Scientific Party, 1989). The palaeodepth reconstruction for the site is upper bathyal in the late Oligocene shallowing to mid-lower bathyal in the Miocene (Shipboard Scientific Party, 1989). The current study covered a 79.7 m interval of sediments from Hole 752A, which includes the latest Oligocene through to early Pliocene ages; the average core recovery is 70.6 %, composed mainly of foraminifer and nannofossil ooze. An age model for Hole 752A was developed using the calcareous nannofossil datums from the initial report (Shipboard Scientific Party, 1989), with revised ages from the Astronomically Tuned Neogene Time Scale (ATNT2012) in GTS2012 (Hilgen et al., 2012).

ODP Site 1139 is located west of Kerguelen Island ( $50^{\circ}11'20''$  S,  $63^{\circ}55'40''$  E; Fig. 1) with a modern water depth of 1415 m consistent with a bathyal palaeodepth throughout the late Oligocene to earliest late Miocene (Shipboard Scientific Party, 2000). The late Oligocene to earliest late Miocene interval was sampled from Hole 1139A, comprising 167.3 m with average core recovery of 62 %. The sediments are foraminifera-bearing nannofossil ooze, nannofossil-bearing clay, and claystone and nannofossil-bearing ooze and chalk. An age model has been established using planktic foraminifera (Shipboard Scientific Party, 2000) and calcareous nannofossil datums (Persico et al., 2003) with ages revised using ATNT2012 in GTS2012 (Hilgen et al., 2012).

ODP Site 1168 is situated at a middle bathyal water depth (2463 m) on the western margin of Tasmania ( $42^{\circ}38'40''$  S,  $144^{\circ}25'30''$  E; Fig. 1) (Shipboard Scientific Party, 2001). The sedimentary interval studied in Hole 1168A covers 422.8 m with an average recovery of 98 %. This interval covers the latest Oligocene through to early Pliocene, which is mainly composed of nannofossil ooze, silty clay and claystone. The age model for Hole 1168A uses planktic foraminifera, calcareous nannofossils and geomagnetic polarity datums calculated by Stickley et al. (2004) with revised ages from ATNT2012 in GTS2012 (Hilgen et al., 2012).

In total, 97 samples were selected from the study sites (30, 25 and 42 samples at ODP Sites 752, 1139 and 1168, respectively). Sediment samples were processed by first disaggregating them in water and then wet sieving at  $63\ \mu\text{m}$ . Samples were then dried overnight in an oven at  $40^{\circ}\text{C}$ , the dry  $> 63\ \mu\text{m}$  sieved size fraction was then split until an aliquot of  $> 300$  benthic foraminifer specimens was achieved



**Figure 1.** Location map of the study area. Studied ODP sites are marked as stars (752, 1168 and 1139), additional sites referred to in the text are located by dots (after Weatherall et al., 2015). Sites 752, 754 and 756 (leg 121), Site 1168 (leg 189), Site 1139 (leg 183), Sites 705–716 (leg 115) and Deep Sea Drilling Project (DSDP) Site 236 (leg 24). The isobath adjacent to the Kerguelen Plateau, Broken Ridge and Ninetyeast Ridge is 3000 m, while the isobath near the Maldives, Chagos, Saya de Malha, Nazareth and Seychelles banks is 2000 m.

and subsequently picked clean of all benthic foraminifer. The 52 most abundant species encountered (of more than 500 species provisionally determined across all three sites) were selected for this work as they represent ~ 79 % of the total benthic foraminifera specimens found across all sites. Scanning electron microscope images of representative (uncoated) specimens of each selected species were taken on a Phenom Desktop SEM at the University of Birmingham. The total size range of specimens observed within the study was also recorded by measuring the longest axis of the specimens using a reticle on a stereo microscope.

### 3 Foraminiferal assemblages

In the current study the generic and suprageneric classification of the foraminifera follows Loeblich and Tappan (1988, 1994). The classification of Loeblich and Tappan (1994) is broadly the same as that of Loeblich and Tappan (1988) with some modification of high-level categories as given in Loeblich and Tappan (1992).

Specifically, the elevation of the foraminifera to a higher taxonomic rank by Lee (1990) to the class Foraminifera was accepted by Loeblich and Tappan (1992) and Kaminski (2004). The key sources for species identification are Wright (1978), Hayward (2002), Hayward et al. (2012) and Holbourn et al. (2013). Descriptions are based on existing literature with additional observations from this study.

Benthic foraminifer assemblages are relatively well-preserved with specimens largely complete and surficial details preserved. Assemblages are diverse with more than 200 species identified in total in each site (500 within the entire study) and are dominated by calcareous benthic foraminifera. This diversity is higher than previously documented in the Indian Ocean (e.g. Boersma, 1990; Nomura, 1991; Mackensen, 1992; Schroder-Adams, 1991). The 52 selected species described here are assigned to 33 different genera and are subdivided into four orders, 15 superfamilies, 20 families and 16 subfamilies. Four recorded species are left in open nomen-

clature, two each from *Bolivina* and *Gyroidinoides*. All taxa described are calcareous hyaline forms with the exception of one agglutinated species. Representatives of the Buliminida (31 species) constitute the majority of those recorded, especially in ODP Hole 752A, but they are also both abundant and diverse in Holes 1139A and 1168A. Species of the Rotaliida are the next most important components of the benthic foraminifer assemblages.

#### 4 Taxonomy

Class **Foraminifera** J. J. Lee, 1990

Order **Buliminida** Fursenko, 1958

Superfamily **Bolivinoidea** Glaessner, 1937

Family **Bolivinidae** Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839b

*Bolivina dilatata* Reuss 1850

Figure 3: 1a–b

1850 *Bolivina dilatata* Reuss: p. 381, pl. 48, fig. 15a–c

1949 *Bolivina subspatulata* Boomgaard, p. 112, pl. 12, fig. 4

2016 *Bolivina dilatata* Reuss; Lei and Li, p. 202, pl. 2, figs. a–h

#### Description

The test is biserial elongate, has perforate hyaline wall, the shape of the chambers is triangular to trapezoidal. The sutures are depressed. The aperture is a slit-like to arcuate opening with a thin tooth plate in the middle. The aperture location is terminal.

#### Dimensions

The species length ranges from 125 to 250 µm in the current study.

#### Stratigraphic range

This species is recorded in the Aquitanian of 1139 (ODP Site 1139) and late Oligocene (Chattian) to early Pliocene (Zanclan) at 1168. This species is not recorded at 752, consistent with earlier studies (Nomura, 1995).

#### Remarks

This is considered a cosmopolitan species (Lei and Li, 2016) but to the best of our knowledge this is the first time it has been recorded in the Indian Ocean.

*Bolivina huneri* Howe, 1939

Figure 3: 2a–b

1939 *Bolivina huneri* Howe: p. 66, pl. 9, figs. 3, 4

1983 *Bolivina huneri* Howe; Tjalsma and Lohmann, p. 23, pl. 11, fig. 5

1987 *Bolivina huneri* Howe; Miller and Katz, p. 124, pl. 1, figs. 7a–b

2013 *Bolivina huneri* Howe; Holbourn et al., p. 68, figs. 1–3

#### Description

Very densely ornamented biserial species with tapered test. The test surface has a reticulate ornamentation largely obscuring sutures with the exception of the final chamber. The inflated chambers are elongated. The aperture is situated at the base of the last chamber and is arcuate with wide aperture view and tooth plate.

#### Dimensions

The species length ranges from 175 to 250 µm in the current study.

#### Stratigraphic range

This species is recorded from the Chattian through to early Burdigalian of 752. At 1168 the species is confined to the Miocene and ranges from Burdigalian to Tortonian; the species is not recorded at 1139. These ranges fall within the middle-Eocene–late-Miocene (Tortonian) range determined by Holbourn et al. (2013).

#### Remarks

The distribution is cosmopolitan (Holbourn et al., 2013) and has previously been recorded on the Kerguelen Plateau, southern Indian Ocean, at ODP Sites 748 and 751 (Mackensen, 1992) and 736, 738 and 744 (Schroder-Adams, 1991).

*Bolivina reticulata* Hantken, 1875

Figure 3: 3a–b

1875 *Bolivina reticulata* Hantken: p. 65, pl. 15, fig. 6

1978 *Bolivina reticulata* Hantken; Wright, p. 711, pl. 2, figs. 8–10

### Description

Broad biserial test with wide, slightly inflated, elongate chambers, characteristically covered by narrow anastomosing ribs. The test is slightly perforated and has a narrow keel around the periphery. Depressed and limbate sutures are observed. The aperture is sub-rounded and located at the base of the last chamber with an internal tooth plate. The species is characterised by its sub-rounded shape in side view and slightly compressed in cross section.

### Dimensions

The species length ranged from 150 to 375 µm in the current study.

### Stratigraphic range

The species is recorded at 752 from the Chattian to Serravalian, from the Miocene and early Pliocene (Zanclean) at 1168 and Langhian–Tortonian at 1139.

### Remarks

This species is recorded in the Mediterranean (Wright, 1978), South Atlantic Ocean (Tjalsma, 1983). This species has a highly variable morphology both in terms of test shape and ornamentation (Wright, 1978). This species is included by some authors as a junior synonym of *Latibolivina subreticulata* (Parr, 1932) by Loeblich and Tappan (1994) and Holbourn et al. (2013), and it is primarily recorded from the tropical Indian Ocean and Pacific Ocean (Holbourn et al., 2013). Thus, this species likely has a global distribution.

*Bolivina* cf. *reticulata* Hantken, 1875

Figure 3: 5a–b

cf. 1875 *Bolivina reticulata* Hantken: p. 65, pl. 15, fig. 6

cf. 1978 *Bolivina reticulata* Hantken; Wright, p. 711, pl. 2, figs. 8–10

cf. 2013 *Latibolivina subreticulata* (Parr); Holbourn et al., p. 327, figs. 1–4

### Description

The test is biserial, with hyaline wall composition. The chamber shape is elongate to trapezoid. The suture is depressed and limbate. The ornamentation is of anastomosing ribs. The aperture is basal and rounded with a tooth plate.

### Dimensions

The species length ranges from 125 to 375 µm in the current study.

### Stratigraphic range

The species is only observed at 752 through the Miocene and early Pliocene (Zanclean). This species is highly abundant in the mid-to-late Miocene.

### Remarks

This species is similar to *Bolivina reticulata* (Hantken, 1875) but *B. reticulata* has a broader (particularly towards the base) and relatively more elongate test, with a more compressed periphery in apertural view. According to Wright (1978), *Bolivina reticulata* varies in shape from an elongate form with limbate sutures to specimens with little ornamentation. This species is also similar to *Bolivina viennensis* (Marks, 1951) reported in the Polish Carpathian Foredeep Basin (Central Paratethys) by Peryt (2013). This form has so far only recorded in the Indian Ocean.

*Bolivina* sp. 3

Figure 3: 4a–c

### Description

The test is biserial and elongate with smooth surface. Some specimens are highly perforated. The chambers are elongate to trapezoid in shape. The sutures are slightly depressed. The aperture is sub-rounded and located at the base of the last chamber.

### Dimensions

The species length ranged from 150 to 250 µm in the current study.

### Stratigraphic range

The species is only observed in the late Oligocene (Chattian) of 752. At 1139 it occurs between the Chattian and Serravalian. At 1168 the species ranges throughout the Miocene and into the early Pliocene (Zanclean).

### Remarks

This species differs from *Bolivina dilatata* (Reuss, 1850), by having a longer test relative to its width (2.5 times long as wide rather than 2 : 1); the sutures are extremely shallow. The current species is similar to the *Bolivina* cf. *dilatata maxima* (p. 148, fig. 7, pl. k) recorded in the Central Paratethys (Peryt, 2013) but the latter has more depressed sutures. The current species differs from *Bolivina spathulata* (Williamson, 1858), which has sharp edge in the apertural view, whereas specimens here have a sub-rounded edge in apertural view. Also, specimens from the China seas (Lei and Li, 2016) have an anastomosing imperforate costae ornamentation, and they

are much larger  $\sim 550\ \mu\text{m}$  (2 times longer than those observed here). This species is so far only been recorded in the southern Indian Ocean (current study).

*Bolivina* sp. 9

Figure 3: 6a–b

### Description

The test is finely perforated, smooth and elongate, with a hyaline wall composition. Chambers are broad, trapezoid and biserially arranged, with a depressed suture between chambers. Aperture is loop-shaped with basal position. The test length is nearly 3 times longer than the width. Test is tapered at both ends.

### Dimensions

The species length ranges from 125 to 250  $\mu\text{m}$  in the current study.

### Stratigraphic range

The species occurs through the Miocene and into the early Pliocene (Zanclean) at 752. The species is very abundant in the early Burdigalian at 752. Only very few specimens have been recorded at 1168, mainly in the Chattian and between the Burdigalian to Serravallian with a very few records in the early Pliocene (Zanclean). This species is not recorded at 1139.

### Remarks

This species is similar to *Bolivinellina pseudopunctata* (Alve and Murray, 2001) recorded in intertidal environments from southern England (*Ibid*; pl. 2, figs. 7–9). The current species has a wider loop-shaped aperture with the last chamber slightly irregular, while *B. pseudopunctata* has a narrower, slightly compressed aperture and the shape of the chambers are consistently trapezoidal. This species differs from *Bolivina spathulata* (Williamson, 1858) by having a big and rounded (loop-shaped) aperture on the apertural face rather than a small and narrow loop-shaped aperture. Also, *Bolivina spathulata* specimens from the China seas (Lei and Li, 2016) have an anastomosing imperforate costae ornamentation, not been observed in the current study.

*Bolivina viennensis* Marks, 1951

Figure 3: 7a–b

1951 *Bolivina viennensis* Marks: p. 60, pl. 7, fig. 1

1991 *Brizalina albatrossi* (Cushman); Nomura, p. 53, pl. 1, fig. 3

2005 *Bolivina viennensis* Marks; Popescu and Crihan, p. 380, pl. 1, figs. 14–16

2008 *Bolivina viennensis* Marks; Baldi and Hohenegger, p. 2, fig. 3.a

### Description

The test is biserial, elongated. Chambers elongated to trapezoid, sutures depressed. Surface ornamentation reticulate showing an anastomosing pattern. Aperture rounded, terminal. Normal pores are relatively few and concentrated near the margin of the chambers.

### Dimensions

The species length ranges from 175 to 575  $\mu\text{m}$  in the current study.

### Stratigraphic range

This species is only present at 752 and ranges from the Burdigalian to Messinian, reappearing in the early Pliocene (Zanclean).

### Remarks

This species is similar to *Bolivina* cf. *reticulata* but the length of *Bolivina viennensis* is nearly 3 times longer than the width, and the test has a sharp end near the proloculus, while *Bolivina* cf. *reticulata* is shorter and is sub-rounded near the proloculus. This species is recorded as *Bolivina viennensis* in the southern Vienna Basin (Austria) (Baldi and Hohenegger, 2008) and in Romania (Popescu and Crihan, 2005). Similar specimens are recorded as *Brizalina albatrossi* in the eastern Indian Ocean at Site 754 in the Broken Ridge (Nomura, 1991).

Genus *Bolivinellina* Saidova, 1975

*Bolivinellina* cf. *B. translucens* (Phleger & Parker, 1951)

Figure 3: 8a–c

cf. 1951 *Bolivina translucens* Phleger & Parker: p. 15, pl. 7, figs. 13, 14

cf. 1988 *Bolivinellina translucens* (Phleger & Parker); Loeblich and Tappan: pl. 547, figs. 6, 7

cf. 1999 *Bolivina translucens* (Phleger & Parker); Ohkushi et al., p. 139, pl. 2, figs. 11, 12

### Description

Test is elongate, triserial to biserial, narrow and oval in section. Chambers are narrow and moderately inflated; sutures are depressed and oblique. Wall calcareous, hyaline and smooth; a few pores apparent near the sutures. Aperture is basal and slit-to-loop-shaped with a tooth plate at the base of the aperture. Test nearly 3–4 times longer than wide.

### Dimensions

The species length ranges from 175 to 475 µm in this study.

### Stratigraphic range

The species is only found at Site 752 where it is distributed throughout the succession, with the greatest abundance in the late Miocene (Messinian) and early Pliocene (Zanclean).

### Remarks

The chambers appear triserially arranged in the initial part of the test, with inflated chambers which become less inflated later towards the aperture. *Bolivinellina translucens* is widely distributed in Gulf of Mexico (Phleger and Parker, 1951) and, more locally, has been recorded along the central West Coast of India (Mazumder et al., 2003) and throughout the Indian Ocean (current study).

Superfamily **Bolivinitoidea** Cushman, 1927

Family **Bolivinittidae** Cushman, 1927

Genus *Abditodentrix* Patterson, 1985

*Abditodentrix pseudothalmanni* (Boltovskoy & de Kahn, 1981)

Figure 3: 9a–b

1981 *Bolivinitta pseudothalmanni* Boltovskoy & de Kahn: p. 44–46, pl. 1, figs. 1–5

1985 *Abditodentrix asketocomptella* Patterson, p. 139, pl. 1, figs. 1–9

1988 *Abditodentrix pseudothalmanni* (Boltovskoy & de Kahn); Loeblich and Tappan, p. 503, pl. 554, figs. 1–5

cf. 1991 *Brizalina thalmanni* (Renz, 1948), Nomura, p. 53, pl. 1, fig. 4

### Description

Test elongate, biserial and sagittate. The test is flattened in side view with a distinctive truncate margin giving it a rectangular appearance in section. Chambers are elongated to trapezoid. The sutures are depressed. Aperture is in a basal position and elliptical in shape with tooth plate infolded on one side. The surface is densely covered with elevated reticulate ornamentation.

### Dimensions

The species length ranges from 100 to 425 µm in this study.

### Stratigraphic range

Occurs in the late Oligocene (Chattian) in all study sites, ranging into the early late Miocene (early Tortonian) in 1139 and the early Pliocene (Zanclean) at 752 and 1168.

### Remarks

Most of the observed specimens are highly compressed in cross section and densely ornamented in the initial portion, near the proloculus, with simple reticulation or no ornamentation near the aperture. This species is recorded in the south-west Pacific Ocean (Hayward et al., 2002) and the south-west Atlantic Ocean (Loeblich and Tappan, 1988). It is recorded as *Brizalina* cf. *thalmanni* in the eastern Indian Ocean (Nomura, 1991).

Superfamily **Buliminoidea** Jones in Griffith and Henfrey, 1875

Family **Buliminidae** Jones, 1875

Genus *Bulimina* d'Orbigny, 1826

*Bulimina truncana* Gümbel, 1868

Figure 3: 10a–b

1868 *Bulimina truncana* Gümbel: p. 727, pl. 2, figs. 77a, b

1884 *Bulimina rostrata* Brady: p. 408, pl. 5, figs. 14, 15

1927 *Bulimina alazanensis* Cushman: p. 161, pl. 25, fig. 4

1940 *Bulimina bremneri* Finlay: p. 455, pl. 64, figs. 84–86

1991 *Bulimina alazanensis* Cushman: Schroder-Adams, p. 624, pl. 1, fig. 5

1991 *Bulimina truncana* Gümbel: Hermelin, p. 65, pl. 1, figs. 10, 16

2002 *Bulimina truncana* Gümbel: Hayward et al., pl. 1, figs. 9, 10

### Description

Test is triserial, elongate and sub-triangular in cross section, tapered in outline. Rounded to sub-rounded in the apertural end and pointed in the apical end. The chambers are inflated with obscured sutures. The longitudinal costae occur on all chambers (although the upper portion of the final three chambers is smooth) and join together to form a spinose protrusion from the earliest chambers. The aperture is loop-shaped with internal tooth plate and surrounded by apertural lip. The greatest width of the test is towards the apertural end.

### Dimensions

The species length ranges from 125 to 625 µm in the current study.

### Stratigraphic range

The species is recorded from the late Oligocene to Pliocene at 752 and 1168, whereas it is confined to the Miocene (Aquitanian to Serravallian) at 1139.

### Remarks

Boersma (1986) noted that *Bulimina truncana* has a highly variable morphology and thus multiple synonyms are based on differences in the number and extent of costae, their height and orientation. Of these, small forms with fewer costae that almost completely cover the final chamber have been often been attributed to *Bulimina rostrata*, whereas those with more costae, that also tend to be wavy, are assigned to *Bulimina alazanensis*. Furthermore, *B. rostrata* also achieves its maximum width towards the middle of the test and is overall sub-circular in cross section compared to *B. alazanensis* where the maximum test width occurs closer to the apertural end and the test has a more sub-triangular cross section. *B. truncana* is very similar to *B. alazanaensis* but was separated out based on having fewer, straighter costae that begin on the first or second chambers rather than the third (Boersma, 1986). Ultimately overlapping species occurrences at the same sites, difficulties in consistently differentiating taxa and missing holotype specimens (*B. alazanensis*) have led to them being synonymised (Hayward et al., 2019a) in the World Register of Marine Species (WoRMS). Here, tests are usually sub-triangular in cross section, having parallel, regularly formed costae with the largest width of the test towards that apertural end rather than the middle, and hence they are closest to the forms included in *B. truncana*. This species is considered to be cosmopolitan and has been recorded in Southwest Pacific Ocean (Hayward et al., 2002), Tasman sea, Coral Sea (Boersma, 1986) and Indian Ocean (Nomura, 1995).

*Bulimina* cf. *B. elongata* d'Orbigny, 1846

Figure 3: 11a–b

cf. 1846 *Bulimina elongata* d'Orbigny: p. 187, pl. 11, figs. 19, 20

cf. 1826 *Bulimina elongata* d'Orbigny: (Nomen nudum), p. 269

cf. 2004 *Bulimina elongata* d'Orbigny: De Man et al., p. 187, pl. 2, fig. 9

cf. 2008 *Bulimina elongata* d'Orbigny: Kender et al., p. 513, pl. 17, figs. 4, 5

### Description

Elongate, narrow (3 times as long as wide), triserial test becoming nearly biserial in final whorl. Little tapering of test. Chambers are flattened and broad. Sutures are depressed. The aperture is basal and rounded. The surface is mainly smooth with very few perforations.

### Dimensions

The species length ranges from 150 to 400 µm in this study.

### Stratigraphic range

This species ranges from the late Oligocene (Chattian) to mid-Burdigalian at 1168, extending into the early Tortonian at 1168. This supports the range (mid-Eocene to Pleistocene) identified by Thomas (1990). This species is not present at 752.

### Remarks

This species differs from *Bulimina elongata* sensu stricto (see Holbourn et al., 2013) in that the chambers are less inflated (have a nearly polygonal outline) and a much slower rate of chamber enlargement. Holbourn et al. (2013) consider *Bulimina elongata* a cosmopolitan species.

*Bulimina gibba* Fornasini, 1902

Figure 3: 12

1902 *Bulimina gibba* Fornasini: p. 378, pl. O, figs. 32–34

2005 *Bulimina gibba* Fornasini; Rasmussen, p. 86, pl. 11, fig. 5

2013 *Bulimina gibba* Fornasini; Holbourn et al., p. 97, figs. 1–3

### Description

Triserial, elongate, fusiform shape. Nearly circular in cross section with narrow apical tip. Chambers are inflated with clearly depressed sutures and strongly overlapping. The aperture is loop-shaped, located at the base of the last chamber with apertural lip merging with an internal tooth plate. The test surface is relatively smooth with perforation distributed across the chambers.

### Dimensions

The species length ranges from 125 to 300 µm in the current study.



### Stratigraphic range

This species occurs from the late Oligocene (Chattian) to early Tortonian at 1139. This species is not recorded at either 752 or 1168.

### Remarks

This species is commonly found and described (e.g. Holbourn et al., 2013) as having an apical protrusion from the proloculus; however, in this study, no spinose protrusions are observed in any specimen. This absence cannot be explained by preservation. This species has previously only been reported from the Atlantic (Holbourn et al., 2013), but the authors noted that it may well range further, which is confirmed in this study. Holbourn et al. (2013) report this species from the Miocene to Holocene but this work suggests it may occur earlier in the Indian Ocean.

*Bulimina striata* d'Orbigny in Guérin-Méneville, 1832

Figure 3: 13

1832 *Bulimina striata* d'Orbigny in Guérin-Méneville: p. 18, pl. 3, fig. 16

1852 *Bulimina costata* d'Orbigny: p. 194

1922 *Bulimina inflata* var. *mexicana* Cushman: p. 95, pl. 21, fig. 2

1953 *Bulimina mexicana* Cushman; Phleger and others, p. 33, pl. 6, fig. 27

1954 *Bulimina striata mexicana* Cushman; Parker, p. 511, pl. 6, fig. 24

1957 *Bulimina australis* Vella: p. 32, pl. 8, figs. 168–169

1992 *Bulimina striata* d'Orbigny in Guérin-Méneville: Mackensen, p. 668, pl. 1, fig. 5

2003 *Bulimina striata* d'Orbigny in Guérin-Méneville: Hayward et al., p. 517

2011 *Bulimina striata* d'Orbigny in Guérin-Méneville: Kuppusamy et al., p. 46, pl. 2, figs. 7, 8

2013 *Bulimina striata* d'Orbigny in Guérin-Méneville: Mancin et al., p. 64, pl. 2, fig. 3

### Description

Test is conical, triserial, and semicircular in cross section; the initial part of the test (near proloculus) is acute. Chambers are inflated overhanging previous chambers, becoming broader and less ornamented near the aperture. The sutures are depressed but largely obscured by ornamentation in the earlier portion of the test. Longitudinal costae extend from

the lower half of the chambers to overhang preceding chambers ending in acute points. The aperture is loop-shaped and bordered by a lip with an internal tooth plate.

### Dimensions

The species length ranges from 100 to 500 µm in this study.

### Stratigraphic range

The species is recorded throughout the whole succession (late Oligocene–Pliocene) at 752. At 1139 and 1168 this species occurs from the late Oligocene (Chattian) disappearing from 1139 in the Langhian and early Tortonian at 1168.

### Remarks

This species is cosmopolitan. This species is identified around New Zealand (Debenay, 2012; Hayward et al., 2003) and by Kuppusamy et al. (2011) in north-west Atlantic Ocean. Many older Indian Ocean publications report this species as *B. mexicana* (e.g. Nomura, 1995), which does have a global distribution (Holbourn et al., 2013). Holbourn et al. (2013) consider the range of this species to be Miocene–Holocene; here it is found in the late Oligocene.

Superfamily **Turrilinoidea** Cushman, 1927

Family **Turriliniidae** Cushman, 1927

Subfamily **Turrilininae** Cushman, 1927

Genus *Eubuliminella* Revets, 1993

*Eubuliminella exilis* (Brady, 1884)

Figure 4: 1

1884 *Bulimina elegans* var. *exilis* Brady: p. 399, pl. 50, figs. 5, 6

1927 *Buliminella subfusiformis* var. *tenuata* Cushman: p. 149, pl. 2, fig. 9

1930 *Buliminella subfusiformis* (Cushman); Cushman and Moyer, p. 56, pl. 7, fig. 20

1947 *Bulimina exilis* Brady; Cushman and Parker, p. 123, pl. 28, figs. 27, 28

1947 *Bulimina subfusiformis* var. *tenuata* (Cushman); Cushman and Parker, p. 124, pl. 28, fig. 29

1993 *Eubuliminella exilis* (Brady); Revets, p. 141, pl. 1, figs. 1–7

2015 *Eubuliminella exilis* (Brady); Setoyama & Kaminiski, p. 8, figs. 4.2, 8.7

### Description

Elongate, narrow test that is triserial in the latter part. The test length is about 4 times as long as it is wide. Ovate and little inflated chambers separated by curved and depressed sutures. The aperture is basal and loop-shaped, but from the apertural opening the tooth plate is not clear.

### Dimensions

The species length ranges from 150 to 550 µm in the current study.

### Stratigraphic range

The stratigraphic range of the species at 1168 is early Miocene (Burdigalian) to the early Pliocene (Zanclean); Holbourn et al. (2013) suggested a range from the late Miocene; the present study therefore extends the known stratigraphic range.

### Remarks

The specimens in the current study lack the spine in the initial whorl and have more weakly inflated chambers. According to Revets (1993) and Holbourn et al. (2013), this species can be found worldwide.

Superfamily **Cassidulinoidea** d'Orbigny, 1839a

Family **Cassidulinidae** D'Orbigny, 1839a

Subfamily **Cassidulininae** d'Orbigny, 1839a

Genus *Globocassidulina* Voloshinova, 1960

*Globocassidulina subglobosa* (Brady, 1881)

Figure 4: 2

1881 *Cassidulina subglobosa* Brady: p. 60, illustrated in Brady, 1884, pl. 54, fig. 17

1884 *Cassidulina subglobosa* Brady; Brady, p. 430, pl. 54, fig. 17

1983 *Globocassidulina subglobosa* (Brady); Tjalsma and Lohmann, p. 31, pl. 16, fig. 9

1991 *Globocassidulina subglobosa* (Brady); Nomura, p. 55, pl. 5, fig. 8

2013 *Globocassidulina subglobosa* (Brady); Holbourn et al., p. 264, figs. 1, 2

### Description

Test is biserial and sub-globular, with a sub-circular shape in cross section. Chambers are inflated and separated by depressed, curved sutures. The test wall is smooth and only finely perforate. The aperture is slit-like, straight or curved.

### Dimensions

The species length ranges from 100 to 925 µm in this study.

### Stratigraphic range

This is a long-ranging species, recorded from late Oligocene to early Pliocene at both 752 and 1168 and late Oligocene to the top of the studied interval (early Tortonian) at 1139.

### Remarks

This species is very well-preserved in all studied sites. This is a cosmopolitan species (Jones, 1994) that is very long-ranging (Paleocene–Holocene; Tjalsma and Lohmann, 1983).

Genus *Paracassidulina* Nomura, 1983b

*Paracassidulina minuta* (Cushman, 1933b)

Figure 4: 3a–b

1933b *Cassidulina minuta* Cushman: p. 92, pl. 10, figs. 3a–c

1951 *Cassidulina crassa* d'Orbigny; Phleger and Parker, p. 26, pl. 14, figs. 4a–b

1954 *Cassidulina* aff. *crassa* d'Orbigny; Parker, p. 535, pl. 11, fig. 1

1983b *Paracassidulina minuta* Cushman; Nomura, p. 66, pl. 5, figs. 16a–c

1991 *Paracassidulina minuta* Cushman; Nomura, p. 55, pl. 5, figs. 2a–b

### Description

Biserial test with slightly depressed sutures. Surface is smooth and finely perforated. Chambers are strongly curved. Aperture is long, curved and has an apertural ridge parallel to the chamber periphery.

### Dimensions

The species length ranges from 125 to 300 µm in the current study.

### Stratigraphic range

The species ranges from Chattian to early Tortonian at 752, Chattian to mid-Serravallian at 1139. The stratigraphic distribution of the species at 1168 is early Aquitanian to Zanclean.

## Remarks

The chambers of the specimens found here are only slightly inflated, this differs from *Globocassidulina minuta* (Cushman, 1933b) described from the Paumotu Islands (also called Tuamotu Islands) in the Southern Pacific Ocean in that the latter has more globular chambers. This species is recorded by Nomura (1991) at Broken Ridge (Site 754) in eastern Indian Ocean and in the Gulf of Mexico (Poag, 2015).

Subfamily **Ehrenberginae** Cushman, 1927

Genus *Ehrenbergina* Reuss, 1850

*Ehrenbergina carinata* Eade, 1967

Figure 4: 4a–b

1967 *Ehrenbergina carinata* Eade: p. 448, pl. 9, figs. 1–4

1991 *Ehrenbergina carinata* Eade; Nomura, p. 55, pl. 5, fig. 13

2013 *Ehrenbergina carinata* Eade; Hayward et al., p. 442, pl. 6, figs. 12, 13

## Description

Test triangular in both dorsal view and cross section. Early chambers are not inflated, while the later chambers are slightly inflated. Well-developed peripheral keel and a spine extending from each chamber. Dorsal view is compressed. The sutures are flush but towards the periphery become raised. The ventral view is characterised by central keel. Aperture is slit-like and curved, with a narrow lip in the ventral side.

## Dimensions

The species length ranges from 150 to 725 µm in the current study.

## Stratigraphic range

The species range at 752 is late Miocene (Messinian) to early Zanclean. At 1168 the species is very rare and only recorded in the early and late Miocene (Tortonian). This species is not recorded at 1139.

## Remarks

This species is well-preserved at 752 and reaches very large size (up to 725 µm) in some intervals, especially in the late Miocene (Messinian). According to Eade (1967) the current species is recorded in the Kermadec Islands, Fiji, Norfolk Island, Tonga, and northern New Zealand. This species is also recorded by Nomura (1991) at Broken Ridge (Site 754) and New Zealand (Hayward et al., 2013).

Genus *Burseolina* Seguenza, 1880

*Burseolina pacifica* (Cushman, 1925)

Figure 4: 5a–b

1925 *Cassidulina pacifica* Cushman: p. 53, figs. 14–16

1925 *Globocassidulina pacifica* (Cushman), pl. 2, fig. 16

1983a *Burseolina pacifica* (Cushman); Nomura, pl. 6, fig. 2, pl. 21, figs. 6–10

1983b *Burseolina pacifica* (Cushman); Nomura, pp. 57–60, pl. 5, figs. 1–4

1991 *Burseolina* cf. *pacifica* (Cushman); Nomura, p. 53, pl. 5, figs. 14a–b

## Description

Enrolled biserial test with rounded periphery. Sutures are flush to the surface and thus almost indistinguishable. The apertural face is flattened and the aperture is elongate, curved, and with apertural flap in the lower apertural margin.

## Dimensions

The species length ranges from 175 to 600 µm in this study.

## Stratigraphic range

The distribution of the species at 752 ranges from the late Oligocene (Chattian), where it is rare, with later Miocene records from the Burdigalian to mid-Messinian. The species is rare at 1168 in the Chattian and only appears in the late Burdigalian in the Miocene. This species is not recorded at 1139.

## Remarks

According to Cushman (1925) this species is widely distributed in deep or cool waters and it has been recorded in the Pacific Ocean. It has also been reported from subtropical regions, along the Pacific coast of Japan (Nomura, 1983a) and in the Indian Ocean (Nomura, 1991). Notably the specimens here are more spherical in outline than *B. pacifica* reported by Nomura (1991). *Burseolina* is most abundant from the Miocene to the present.

*Burseolina* cf. *pacifica* (Cushman, 1925)

Figure 4: 6

cf. 1925 *Cassidulina pacifica* Cushman: p. 53, figs. 14–16

cf. 1925 *Globocassidulina pacifica* (Cushman), pl. 2, fig. 16

cf. 1983a *Burseolina pacifica* (Cushman); Nomura, pl. 6, fig. 2, pl. 21, figs. 6–10

cf. 1983b *Burseolina pacifica* (Cushman); Nomura, pp. 57–60, pl. 5, figs. 1–4

cf. 1991 *Burseolina pacifica* (Cushman); Nomura, p. 53, pl. 5, figs. 4a–b

### Description

Test is biserial and sub-spherical. The surface is smooth. Flush to slightly depressed sutures. The aperture is elongated, curved and with apertural flap in the lower apertural margin.

### Dimensions

The species length ranges from 100 to 425 µm in this study.

### Stratigraphic range

The range of the species at 752 is early Miocene (Aquitanian) to early Pliocene (Zanclean). At 1139 it is very rare in the late Oligocene (Chattian) and also in the Miocene, except for Seravallian where it has its greatest abundance. The distribution at 1168 is mid-Burdigalian to Zanclean.

### Remarks

This species differs from *Burseolina pacifica* by having a relatively larger and wider aperture and broader flap. The last chambers in this species are also usually separated from the preceding chambers by clearly depressed sutures. This species has a limited geographic distribution and is also observed in tropical to subtropical regions, along the Pacific coast of Japan (Nomura, 1983a) and in the Indian Ocean on the Ninetyeast Ridge (Site 756) (Nomura, 1991).

Superfamily **Pleurostomelloidea** Reuss, 1860

Family **Pleurostomellidae** Reuss, 1860

Subfamily **Pleurostomellinae** Reuss, 1860

Genus *Pleurostomella* Reuss, 1860

*Pleurostomella acuminata* Cushman, 1922

Figure 4: 7a–b

1922 *Pleurostomella acuminata* Cushman: p. 50, pl. 19, fig. 6

1866 *Pleurostomella alternans* Schwager: p. 238, pl. 6, fig. 80

1934 *Pleurostomella alternans* var. *telostoma* Schubert; Cushman, pl. 16, fig. 6

1978 *Pleurostomella acuta* Hantken; Boltovskoy, pl. 5, fig. 42

1978 *Pleurostomella dominicana* Bermúdez; Boltovskoy, pl. 6, figs. 2, 3

2011 *Pleurostomella acuminata* (Cushman); Kuppusamy et al., p. 60, pl. 9, figs. 7, 8

### Description

Test is smooth, elongate and biserial, with slightly depressed sutures. Chambers are elongate and oval. Wide terminal aperture, with projecting hood on one side and two triangular or bifid teeth on opposite side. Prolocular spine is present.

### Dimensions

The species length ranges from 150 to 725 µm in the current study.

### Stratigraphic range

At 752 and 1168 it ranges from Chattian to early Zanclean and at 1139 from Chattian to early Tortonian.

### Remarks

A prolocular spine is present in most specimens but in others it is either broken or missing. This species is cosmopolitan and recorded throughout the Indian Ocean (Hayward, 2002).

Superfamily **Stilostomelloidea** Finlay, 1947

Family **Stilostomellidae** Finlay, 1947

Genus *Orthomorphina* Stainforth, 1952

*Orthomorphina perversa* (Schwager, 1866)

Figure 4: 8a–c

1866 *Nodosaria perversa* Schwager: p. 212, pl. 5, fig. 29

1872 *Nodosaria pupoides* Silvestri: p. 65, pl. 6, figs. 148–158

1937 *Nodogenerina challengeriana* Thalmann: p. 341, pl. 64, figs. 25–27

1949 *Nodogenerina aminaensis* Bermúdez: p. 178, pl. 11, fig. 57

1978 *Orthomorphina challengeriana* (Thalmann); Boltovskoy, pl. 5, figs. 16–17

1978 *Orthomorphina perversa* (Schwager); Boltovskoy, pl. 5, figs. 23–24

1992 *Stilostomella* sp. G. Kaiho: p. 307, pl. 5, fig. 23

2002 *Orthomorphina perversa* (Schwager); Hayward, pl. 1, figs. 50–52

### Description

Test uniserial, rectilinear. Chambers are ovoid in outline and increase in height towards the last chamber. The surface is striate with ribs perpendicularly arranged. The sutures are straight and depressed. The aperture is rounded and terminal with rim.

### Dimensions

The species length ranges from 200 to 975 µm in the current study.

### Stratigraphic range

The species ranges from Chattian to early Zanclean at 752 and 1168 but only extends into the mid-Serravallian (mid-Miocene) at 1139.

### Remarks

The largest chamber is usually in the middle part of the test and the last chamber is smaller than the penultimate one. Sometimes this difference is very pronounced. This species is cosmopolitan (Hayward, 2002).

Genus *Siphonodosaria* Silvestri, 1924

*Siphonodosaria lepidula* Schwager, 1866

Figure 4: 9a–b

1866 *Nodosaria lepidula* Schwager: p. 210, pl. 5, figs. 27, 28

1978 *Stilostomella* ex.gr. *lepidula* (Schwager). Boltovskoy, pl. 7, figs. 33–36

1980 *Stilostomella lepidula* (Schwager); Srinivasan and Sharma, p. 46, pl. 7, figs. 1–6

1993 *Stilostomella lepidula* (Schwager); Gupta, 1993, figs. 2, 1–2

1994 *Nodogenerina lepidula* (Schwager); Loeblich and Tappan, p. 133, pl. 261, figs. 18–20

2002 *Siphonodosaria lepidula* f. *lepidula* (Schwager); Hayward, p. 305, pl. 3, figs. 25–32

2012 *Siphonodosaria lepidula* (Schwager); Hayward et al., p. 174, pl. 18, figs. 6–20

### Description

Elongate, uniserial test, slightly arcuate shape, with chambers gradually increasing in size. Chambers are spherical (campanulate or pyriform) and typically become more widely spaced later with pronounced depressed sutures. A ring of small spines, annularly arranged, surrounds the base of each otherwise relatively smooth-walled chamber. Aperture is terminal with a broad neck and phialine lip; there is small tooth in the middle of the aperture giving a v-shaped appearance to aperture.

### Dimensions

The species length ranges from 200 to 1350 µm in this study.

### Stratigraphic range

The distribution at 752 and 1168 is Chattian to early Zanclean and at 1139 is Chattian to early Tortonian.

### Remarks

This species is abundant, with a cosmopolitan distribution (Hayward et al., 2012; Holbourn et al., 2013). It is also highly morphologically variable showing considerable variation in ornamentation, chamber shape and the presence or absence of a prolocular spine, and hence has been frequently recorded under a number of different names (Hayward et al., 2012). After detailed population level investigations, Hayward et al. (2012) group the different morphotypes under *S. lepidula* is known from the Late Cretaceous to Pleistocene, reports of recent occurrences are considered reworked (Hayward et al., 2012).

*Siphonodosaria subspinososa* (Cushman, 1943)

Figure 4: 10a–d

1934 *Ellipsonodosaria* sp. Cushman and Jarvis: pl. 10, figs. 4, 5

1943 *Ellipsonodosaria subspinososa* Cushman: p. 92, pl. 16, figs. 6, 7b

1983 *Stilostomella subspinososa* (Cushman); Tjalsma and Lohmann, p. 36, pl. 14, figs. 16, 17

1998 *Siphonodosaria subspinososa* (Cushman); Robertson, p. 180, pl. 67, fig. 3

2010 *Siphonodosaria subspinososa* (Cushman); Hayward et al., p. 129, pl. 14, figs. 20, 21

### Description

Test elongate, uniserial, straight to slightly arcuate shape, circular in cross section. Chambers are spherical, separated by

strongly depressed sutures. Short spines cover the surface. Chambers show a relatively rapid increase in size towards the aperture creating a tapered test outline. The aperture is terminal with broad neck and phialine lip.

### Dimensions

The species length ranges from 200 to 1125 µm in the current study.

### Stratigraphic range

The distribution at 752 and 1168 is Chattian to early Zanclean, and at 1139 Chattian to early Tortonian.

### Remarks

Specimens are very well-preserved and abundant at Site 752. Holbourn et al. (2013) comment that this species shows large variability in the size and ornamentation of the test, with short spines commonly found on the test sometimes converging to form fine costae in the lower portion of the test. This is consistent with observations in this study. Distribution is worldwide (Holbourn et al., 2013).

Genus *Stilostomella* Guppy, 1894

*Stilostomella* cf. *S. annulifera* Cushman and Bermúdez, 1936

Figure 4: 11a–b

cf. 1936 *Ellipsonodosaria annulifera* Cushman and Bermúdez: p. 28, pl. 5, figs. 8, 9

1978 *Stilostomella* cf. *S. annulifera* Wright: p. 717, pl. 8, fig. 2

cf. 1990 *Stilostomella annulifera* (Cushman and Bermúdez); Thomas, 1990, p. 590, pl. 1, fig. 4

cf. 1998 *Siphonodosaria annulifera* (Cushman and Bermúdez); Robertson, p. 178, pl. 66, figs. 1, 2

### Description

Test elongate, rectilinear, arcuate in overall shape with a smooth wall texture. Chambers are inflated to sub-spherical. Sutures are limbate and shallow. Chambers become bigger and more elongated towards apertural end. Aperture is terminal with phialine lip.

### Dimensions

The species length ranges from 225 to 1250 µm in this study.

### Stratigraphic range

The distribution of the species at 1139 is Chattian to early Tortonian and at 1168 and 752 from Chattian to early Zanclean.

### Remarks

Specimens here largely lack the prolocular spine because of preservation (see Fig. 4: 11a). This species is similar to *Strictocostella scharbergana* Neugeboren, 1856, but the last chamber of *S. annulifera* is slightly bigger and more inflated with a shorter neck. Some publications (e.g. Hayward et al., 2012) synonymise these two species and use *S. scharbergana*. *S. consobrina* differs from this species by having sutures which are flusher to the test, as shown in Holbourn et al. (2013). It has also been observed that the chambers of this species are particularly large in those specimens recorded in Mediterranean Sea (Wright, 1978). *S. cf. S. annulifera* has a cosmopolitan distribution (Holbourn et al., 2013) including records in the Mediterranean Sea (Wright, 1978) and Antarctica (Thomas, 1990). *S. annulifera* ranges from the early Eocene to middle Miocene (Holbourn et al., 2013), but *S. scharbergana* is considered to range from the early Paleocene to mid-Pleistocene (Hayward et al., 2012), more consistent with this extended younger occurrence.

Genus *Strictocostella* Patterson, 1987

*Strictocostella matanzana* (Palmer & Bermúdez, 1936)

Figure 4: 12a–c

1936 *Ellipsonodosaria? matanzana* Palmer & Bermúdez: p. 298, pl. 18, fig. 12

1940 *Ellipsonodosaria matanzana* Palmer and Bermúdez; Palmer, pl. 15, fig. 1

1957 *Siphonodosaria cf. matanzana* (Palmer and Bermúdez); Todd, pl. 67, fig. 7

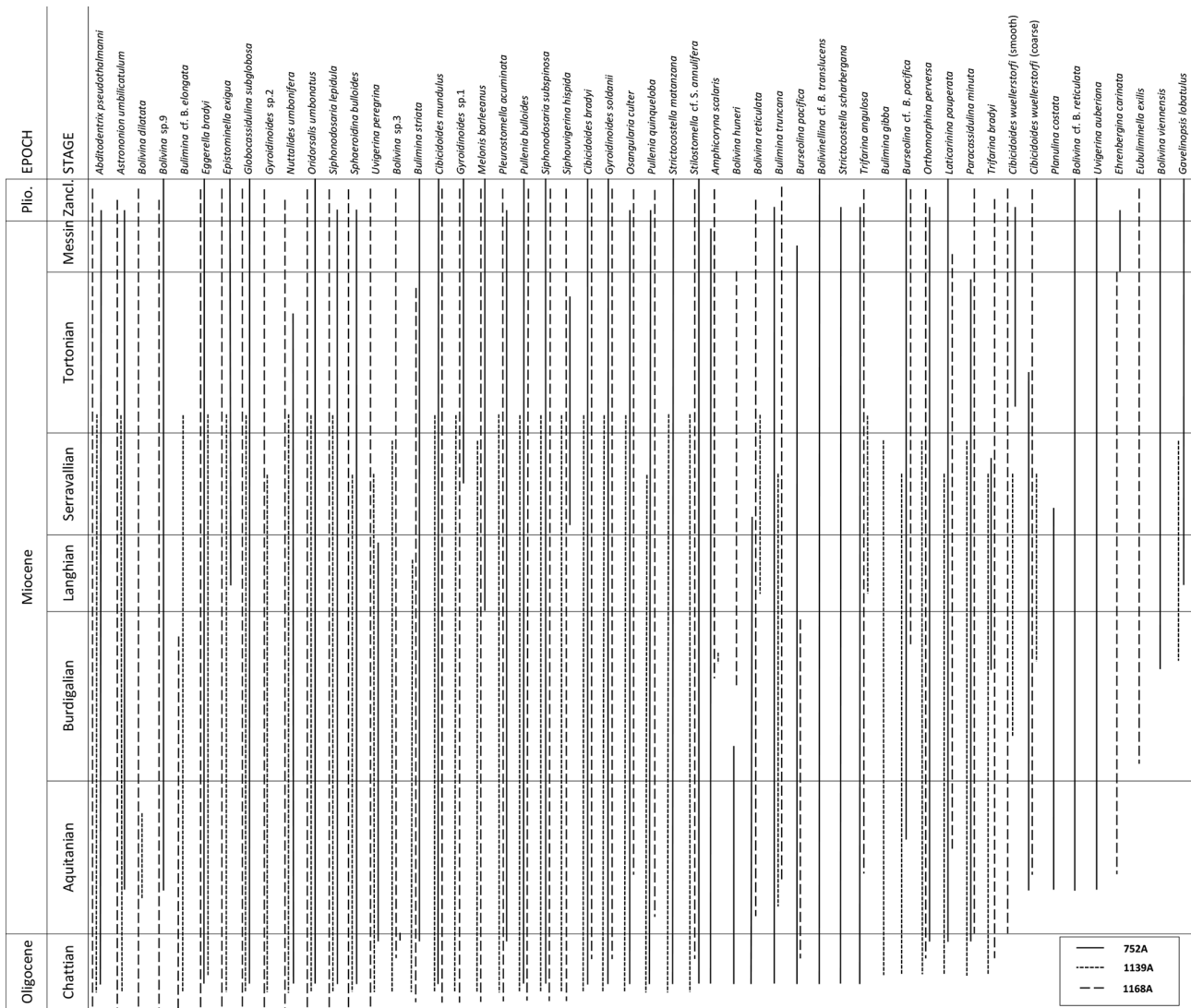
1975 *Stilostomella lepidula* Saidova: p. 315, pl. 87, fig. 6

1998 *Siphonodosaria matanzana* (Palmer and Bermúdez); Robertson, pl. 67, fig. 2

2007 *Myllostomella matanzana* (Palmer and Bermúdez); O'Neill et al., p. 1085, pl. 1, figs. 22–23

2010 *Strictocostella matanzana* (Palmer and Bermúdez); Hayward et al., p. 128, figs. 14, 27–28

2012 *Strictocostella matanzana* (Palmer and Bermúdez); Hayward et al., p. 190, pl. 22, figs. 10–20



**Figure 2.** Range chart of the 52 most abundant benthic foraminifera species encountered at Ocean Drilling Program (ODP) Holes 752A, 1139A and 1168A.

**Description**

Test elongate, uniserial, rectilinear. The base is composed of few small, spherical chambers which become larger and more elongate towards the aperture. Sutures are straight and depressed. There are small spines forming a ring towards the base of each chamber. The aperture is terminal with a phialine lip and short, broad neck ornamented by pustular spines.

**Dimensions**

The species length ranges from 200 to 750 µm in the current study.

**Stratigraphic range**

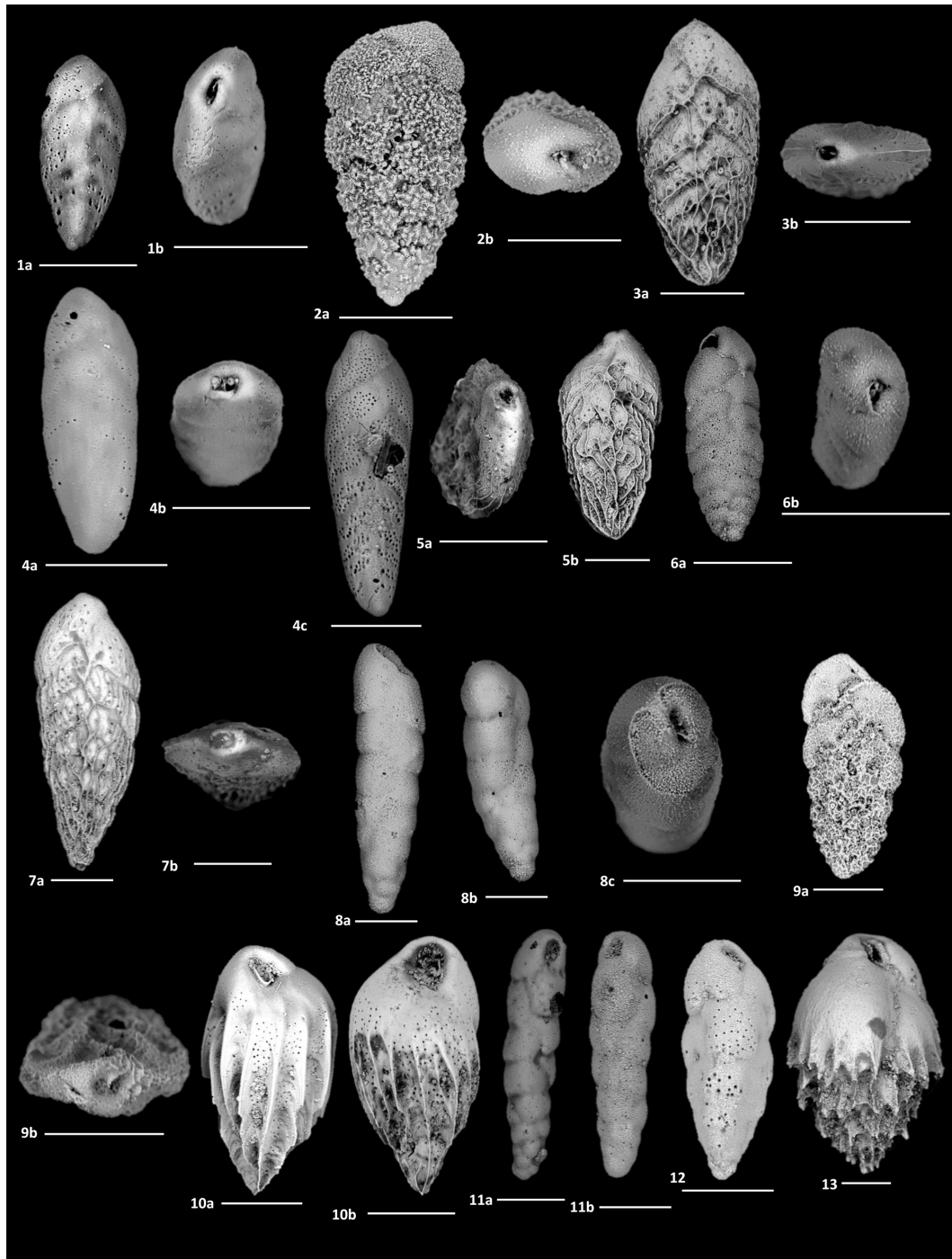
The species occurs rarely in the Chattian at Site 752 and it is not recorded in Aquitanian–Langhian, but appears again from early Serravallian to Zanclean. At 1139 the distribution of the species is from Chattian to early Tortonian; it is not recorded at 1168.

**Remarks**

The wall of the neck is folded, giving an undulation to the phialine lip. *S. matanzana* has a cosmopolitan distribution; sister species tend to be more prevalent in the Indian Ocean (Hayward et al., 2012).

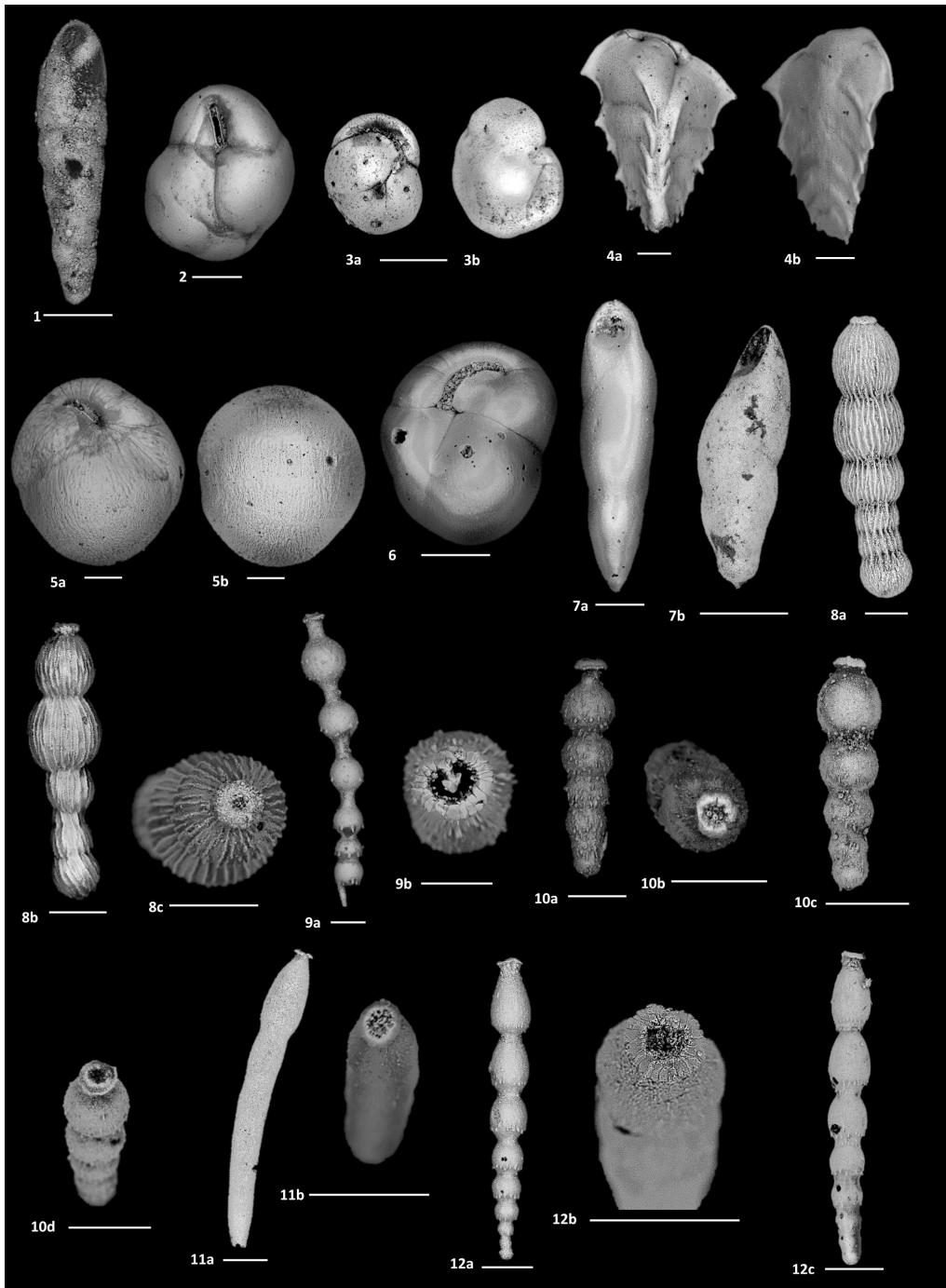
*Strictocostella scharbergana* (Neugeboren, 1856)

Figure 5: 1a–b

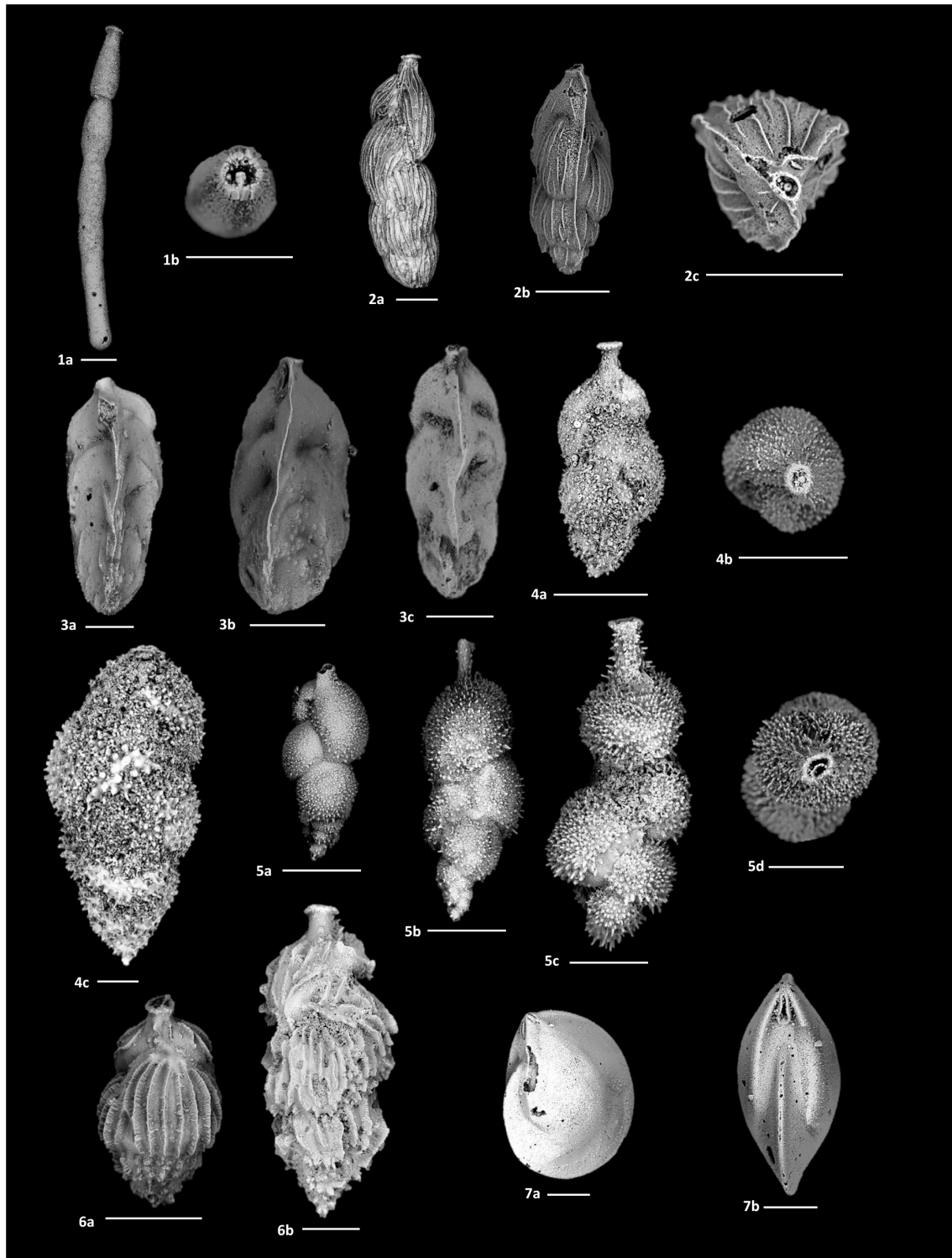


**Figure 3.** Scale bar is 100  $\mu\text{m}$ . **(1a–b)** *Bolivina dilatata*, ODP Hole 1168A, 37X-6, 75–79 cm: **(1a)** side view; **(1b)** apertural view. **(2a–b)** *Bolivina huneri*, ODP Hole 752A, 10H-5, 77–81 cm. **(2a)** side view; **(2b)** apertural view. **(3a–b)** *Bolivina reticulata*, ODP Hole 1168A, 15X-2, 76–80 cm: **(3a)** side view; **(3b)** apertural view. **(4a–b)** *Bolivina* sp. 3, ODP Hole 1168A, **(4a–b)** 26X-2, 73–77 cm: **(4a)** side view; **(4b)** apertural view. **(4c)** 37X-6, 75–79 cm: side view. **(5a–b)** *Bolivina* cf. *reticulata*, ODP Hole 752A, **(5a)** 5H-1, 65–70 cm: apertural view. **(5b)** 3H-5, 62–67 cm: side view. **(6a–b)** *Bolivina* sp. 9, ODP Hole 752A, 9H-2, 104–109 cm: **(6a)** side view; **(6b)** apertural view. **(7a–b)** *Bolivina viennensis*, ODP Hole 752A, 5H-1, 65–70 cm: **(7a)** side view; **(7b)** apertural view. **(8a–c)** *Bolivinelina* cf. *B. translucens*, ODP Hole 752A, 3H-1, 50–55 cm: **(8a–b)** side view; **(8c)** apertural view. **(9a–b)** *Abditodentrix pseudothalmanni*, ODP Hole 1139A, 19R-2, 60.5–64.5 cm: **(9a)** side view; **(9b)** apertural view. **(10a–b)** *Bulimina truncana*, **(10a)** ODP Hole 752A, 9H-5, 65–70 cm: lateral view. **(10b)** ODP Hole 1168A, 37X-6, 75–79 cm: apertural side view. **(11a–b)** *Bulimina* cf. *B. elongata*, **(11a)** ODP Hole 1168A, 23X-3, 74–78 cm: apertural side view. **(11b)** ODP Hole 1139A, 18R-1, 96–100 cm: apertural side view. **(12)** *Bulimina gibba*, ODP Hole 1139A, 19R-2, 60.5–64.5 cm: lateral view. **(13)** *Bulimina striata*, ODP Hole 752A, 5H-1, 65–70 cm: apertural side view.





**Figure 4.** Scale bar is 100  $\mu\text{m}$ . (1) *Eubuliminella exilis*, ODP Hole 1168A, 42X-3, 70–74 cm: apertural side view. (2) *Globocassidulina subglobosa*, ODP Hole 752A, 4H-1, 70–75 cm: apertural side view. (3a–b) *Paracassidulina minuta*, ODP Hole 1168A, (3a) 42X-3, 70–74 cm: apertural side view. (3b) 37X-6, 75–79, 0–1 cm: side view. (4a–b) *Ehrenbergina carinata*, ODP Hole 752A, 3H-1, 50–55 cm: (4a) apertural side view; (4b) side view. (5a–b) *Burseolina pacifica*, ODP Hole 752A, 6H-1, 70–75 cm: (5a) apertural side view; (5b) side view. (6) *Burseolina* cf. *pacifica*, ODP Hole 752A, 6H-1, 70–75 cm: apertural side view. (7a–b) *Pleurostomella acuminata*, (7a) ODP Hole 752A, 7H-1, 63–68 cm: apertural side view. (7b) ODP Hole 1168A, 22X-2, 45–49 cm: lateral view. (8a–c) *Orthomorphina perversa*, (8a) ODP Hole 1139A, 14R-4, 65–69 cm: side view. (8b, c) ODP Hole 752A, 3H-1, 50–55 cm: (8b) side view; (8c) apertural view. (9a–b) *Siphonodosaria lepidula*, (9a) 7H-2, 73–78 cm: side view. (9b) ODP Hole 8H-1, 100–105 cm: apertural view. (10a–d) *Siphonodosaria subspinoso*, (10a–b) ODP Hole 752A, 8H-6, 70–75 cm: (10a) side view; (10b) apertural view. (10c) ODP Hole 1168A, 18X-5, 80–84 cm: side view. (10d) ODP Hole 1168A, 15X-2, 76–80 cm: apertural view. (11a–b) *Stilostomella* cf. *S. annulifera*, ODP Hole 1139A, 15R-4, 41–45 cm: (11a) side view; (11b) apertural view. (12a–c) *Strictocostella matanzana*, (12a–b) ODP Hole 752A, 3H-5, 62–67 cm: (12a) side view; (12b) apertural view. (12c) ODP Hole 1139A, 18R-1, 96–100 cm: side view.



**Figure 5.** Scale bar is 100  $\mu\text{m}$ . **(1a–b)** *Strictocostella scharbergana*, ODP Hole 752A, 4H-1, 70–75 cm: **(1a)** side view; **(1b)** apertural view. **(2a–c)** *Trifarina angulosa*, **(2a)** ODP Hole 752A, 6H-1, 70–75 cm: side view. **(2b, c)** ODP Hole 1168A, 23X-3, 74–78 cm: **(2b)** side view; **(2c)** apertural view. **(3a–c)** *Trifarina bradyi*, **(3a)** ODP Hole 752A, 8H-6, 70–75 cm: side view. **(3b)** ODP Hole 1168A, 15X-2, 76–80 cm: side view. **(3c)** ODP Hole 1139A, 5R-1, 121–125 cm: side view. **(4a–c)** *Siphouvigerina hispida*, **(4a–b)** ODP Hole 1168A, 20X-3, 100–104 cm: **(4a)** side view; **(4b)** apertural view. **(4c)** ODP Hole 1139A, 7R-1, 111–115 cm: side view. **(5a–d)** *Uvigerina auberiana*, ODP Hole 752A, **(5a)** 10H-2, 60–65 cm: side view. **(5b)** 3H-5, 62–67 cm: side view. **(5c, d)** 4H-2, 81–85 cm: **(5c)** side view; **(5d)** apertural view. **(6a–b)** *Uvigerina peregrina*, **(6a)** ODP Hole 752A, 9H-5, 65–70 cm: side view. **(6b)** ODP Hole 1168A, 22X-2, 45–49 cm: side view. **(7a–b)** *Lenticulina cultrata*, ODP Hole 752A, 10H-5, 77–81 cm; **(7a)** side view; **(7b)** edge view.

1856 *Dentalina scharbergana* Neugeboren: p. 87, pl. 4, figs. 1–4

1856 *Strictocostella scharbergana* Neugeboren, p. 87, pl. 4, figs. 1–4

1866 *Dentalina costai* Schwager: p. 229, pl. 6, fig. 62

1884 *Nodosaria consobrina* (d'Orbigny); Brady, pl. 62, figs. 23, 24

1936 *Ellipsonodosaria annulifera* Cushman and Bermúdez: p. 28, pl. 5, figs. 8, 9

1960 *Stilostomella consobrina* (d'Orbigny); Barker, pl. 62, figs. 23, 24

1977 *Siphonodosaria consobrina* (d'Orbigny); Nishimura et al., pl. 4, figs. 16, 17

1994 *Stilostomella consobrina* (d'Orbigny); Jones, 1994, pl. 62, figs. 23, 24

2000 *Stilostomella scharbergana* (Neugeboren); Sztràkos, pl. 5, fig. 19

2005 *Mylostomella costai* (Schwager); Hayward and Kawagata, pl. 1, figs. 17, 18

2007 *Strictocostella costai* (Schwager); Hayward et al., fig. 2

2010 *Strictocostella scharbergana* (Neugeboren); Hayward et al., p. 128, figs. 14, 28–29

2012 *Strictocostella scharbergana* (Neugeboren); Hayward et al., p. 192, pl. 23, figs. 8–19

### Description

Test arcuate, uniserial, slender. Proloculus spherical but chambers become more ovate towards the aperture. Surface is smooth. Sutures flush or slightly incised. Aperture is terminal with a short neck and phialine lip, internal apertural rim consists of a long, simple tooth and multiple long, fine denticles.

### Dimensions

The species length ranges from 200 to 1400 µm in the current study.

### Stratigraphic range

The species range at 752A is Chattian to early Zanclean. This species is not recorded at 1168 and 1139.

### Remarks

Wall smooth throughout, occasionally with one pustular spine near the base of the proloculus. Hayward et al. (2012) consider *S. scharbergana* conspecific with *Stilostomella consobrina*, and in many works it is identified as *S. scharbergana* (e.g. Sztràkos, 2000; Hayward et al., 2010, 2012). Cosmopolitan distribution (Hayward et al., 2012).

Family **Uvigerinidae** Haeckel, 1894

Subfamily **Angulogerinae** Galloway, 1933

Genus *Trifarina* Cushman, 1923

*Trifarina angulosa* (Williamson, 1858)

Figure 5: 2a–c

1858 *Uvigerina angulosa* Williamson: p. 67, pl. 5, fig. 140

1960 *Angulogerina angulosa* (Williamson); Barker, pl. 74, figs. 15, 16

1994 *Trifarina angulosa* (Williamson); Jones, p. 86, pl. 74, figs. 15, 16

2013 *Trifarina angulosa* (Williamson); Holbourn et al., p. 559, figs. 1–4

### Description

The test is triserial in the early portion, becoming uniserial later. Test cross section is triangular with acute periphery. The chambers are moderately inflated and increase in size towards the apertural end. The sutures are curved and depressed. Wall ornamented by discontinuous longitudinal costae. The aperture is terminal, with a rounded opening atop a short neck, with lip and internal tooth plate.

### Dimensions

The species length ranges from 150 to 775 µm in the current study.

### Stratigraphic range

This species shows a staggered appearance; first appearing sporadically at Site 752 in the Chattian then in the Aquitanian at 1168, followed by the mid-Langhian at 1139. The last appearance is in the Tortonian at 1139 and in the Zanclean at 1168 and 752.

## Remarks

Specimens from 1168 usually have the typical triangular cross section with acute periphery but those from 1139 and particularly 752 often appear nearly rounded in cross section and lack the acute margin. This species is typically recorded from the mid-Miocene to Holocene (Jones, 1994). Thus, this study extends the species range back into the latest Oligocene. The species is found worldwide (Holbourn et al., 2013).

*Trifarina bradyi* Cushman, 1923

Figure 5: 3a–c

1923 *Trifarina bradyi* Cushman: p. 99, pl. 22, figs. 3, 9

1884 *Rhabdognium tricarinatum* d'Orbigny; Brady, p. 525, pl. 67, figs. 1, 3

1960 *Trifarina bradyi* Cushman; Barker, pl. 67, figs. 1, 3

1988 *Trifarina bradyi* Cushman; Loeblich and Tappan, p. 526, pl. 574, figs. 10–13

2013 *Trifarina bradyi* Cushman; Holbourn et al., p. 560, figs. 1, 2

## Description

Test initially triserial becoming rectilinear and uniserial later. Test tapered at both ends and relatively smooth, later chambers. Distinctive triangular cross section with acute peripheral keel. Chambers are moderately inflated and increase in size towards the aperture, separated by thick, strongly curved, depressed sutures. The aperture is terminal with short neck, lip and tooth plate.

## Dimensions

The species length ranges from 125 to 575 µm in this study.

## Stratigraphic range

At 1139 and 1168 the species is rare in the Chattian, but is more consistently present from the Aquitanian disappearing in the mid-Serravallian at 1139 and early Zanclean at 1169. The species at 752 is restricted to the Burdigalian through to Serravallian (mid-Miocene).

## Remarks

Inter-site differences are observed within this species in the Indian Ocean. Specimens from 752 and 1139 are quite similar, with the lower half of the test having longitudinal striations, while at 1168 there are denticles or small nodes (see Fig. 5: 3a and b). Distribution is worldwide according to

Holbourn et al. (2013) and it has previously been recorded from the eastern Indian Ocean by Nomura (1991). As with *T. angulosa*, a much earlier late Oligocene occurrence for this species is found in the eastern Indian Ocean than previously reported (Jones, 1994).

Subfamily **Uvigerininae** Haeckel, 1894

Genus *Siphouvigerina* Parr, 1950

*Siphouvigerina hispida* (Schwager, 1866)

Figure 5: 4a–c

1866 *Uvigerina hispida* Schwager: p. 249, pl. 7, fig. 95

1938 *Uvigerina rustica* Cushman and Edwards: p. 83, pl. 14, fig. 6

1980 *Euvigerina hispida* (Schwager); Srinivasan and Sharma, pl. 7, figs. 14, 15

2002 *Neouvigerina hispida* (Schwager); Hayward, p. 301, pl. 1, fig. 14

2013 *Siphouvigerina hispida* (Schwager); Patarroyo and Martínez, p. 41

2013 *Uvigerina hispida* Schwager; Holbourn et al. p. 592, fig. 1

## Description

Triserial, elongate, nearly fusiform-shaped test with a basal spine. Nearly circular in cross section. Chambers are inflated to sub-globular, gradually increasing in size towards the aperture and separated by depressed sutures. The surface is densely ornamented by acicular to coarse papillae or spines. The aperture is terminal and rounded, with a short neck, a phialine lip and internal tooth plate.

## Dimensions

The species length ranges from 175 to 875 µm in the current study.

## Stratigraphic range

The species distribution at 752 is from early Serravallian to late Tortonian. At 1139 the species distribution is from Chattian to early Tortonian. At 1168, this species is very rare in the Chattian but it is consistently present from the Aquitanian to early Zanclean.

## Remarks

This species is generally larger at Site 1139 than at the other study sites. This species is cosmopolitan (Hayward, 2002; Holbourn et al., 2013) and known from the early Miocene (Aquitanian) to recent. However, it occurs earlier (latest Oligocene) here in the eastern sector of the Indian Ocean.

Genus *Uvigerina* d'Orbigny, 1826

*Uvigerina auberiana* d'Orbigny, 1839a

Figure 5: 5a–d

1839 *Uvigerina auberiana* d'Orbigny: p. 106, pl. 2, figs. 23, 24

1884 *Uvigerina asperula* Czjzek; Brady, p. 578, pl. 75, figs. 6, 8

1884 *Uvigerina asperula* var. *auberiana* Brady, p. 579, pl. 75, fig. 9

1978 *Uvigerina auberiana* (d'Orbigny): Wright, p. 717, pl. 8, fig. 10

1984 *Uvigerina auberiana* (d'Orbigny): Lamb and Miller, p. 26, pl. 4, figs. 1–6

2011 *Uvigerina auberiana* (d'Orbigny): Kuppusamy, p. 69, pl. 13, fig. 9

2013 *Uvigerina auberiana* (d'Orbigny): Holbourn et al., p. 584, figs. 1–3

## Description

Test elongate, triserial, fusiform shape. Circular in cross section. Depressed sutures and inflated chambers that gradually increase in size. Small spines usually cover the whole test. Aperture is terminal and rounded, with tubular neck, phialine lip and internal tooth plate.

## Dimensions

The species length ranges from 200 to 525 µm in the current study.

## Stratigraphic range

The species is only recorded at 752, from Aquitanian to early Zanclean.

## Remarks

Some specimens are very densely covered in short spines, ranging all over the test and extending to cover the neck as well. The specimens in this study are relatively elongate (~2.5–3 times long as broad) similar to the type material rather than the 2:1 ratio described by Holbourn et

al. (2013). Cosmopolitan distribution according to Holbourn et al. (2013).

*Uvigerina peregrina* Cushman, 1923

Figure 5: 6a–b

1923 *Uvigerina peregrina* Cushman: p. 166, pl. 42, figs. 7–10

1926 *Uvigerina gardnerae* Cushman and Applin: p. 175, pl. 8, figs. 16, 17

1984 *Uvigerina peregrina* Cushman; Lamb and Miller, p. 36–37, pl. 8, figs. 1–3; pl. 9, figs. 1–5

1991 *Uvigerina peregrina* Cushman; Nomura, p. 55, pl. 1, fig. 10

2013 *Uvigerina peregrina* Cushman; Hayward et al., p. 442, pl. 6, fig. 20

## Description

Test elongate, triserial. Chambers inflated, separated by depressed sutures. The test is ornamented by parallel, longitudinal costae. Aperture terminal, with phialine lip and short narrow neck.

## Dimensions

The species length ranges from 175 to 700 µm in the current study.

## Stratigraphic range

The range at 752 and 1139 is Chattian to Tortonian, while at 1168 it ranges from Chattian to early Zanclean.

## Remarks

The surface costae are usually non-continuous and parallel. The lower portion of the test is covered in isolated spines, which are randomly oriented; there are also in specimens shown in Lamb and Miller (1984) (pl. 34–37, 8, 9). This species is cosmopolitan (Lamb and Miller, 1984) with records including the Indian Ocean (Nomura, 1991) and New Zealand (Hayward et al., 2013).

Order **Lagenida** Lankester, 1885

Superfamily **Nodosarioidea** Ehrenberg, 1838

Family **Vaginulinidae** Reuss, 1862

Subfamily **Lenticulininae** Chapman, Parr, and Collins, 1934

Genus *Lenticulina* Lamarck, 1804

*Lenticulina cultrata* (de Montfort, 1808)

Figure 5: 7a–b

1808 *Robulus cultratus* de Montfort: p. 214

1839 *Robulina canariensis* d'Orbigny: p. 127, pl. 3, figs. 3, 4

1846 *Robulina similis* d'Orbigny: pl. 4, figs. 14, 15

2013 *Lenticulina cultrata* de Montfort; Hewaidy et al., p. 132, pl. 1, figs. 3a, b

2016 *Lenticulina cultrata* de Montfort; Amakrane et al., p. 103, pl. 6, fig. 27

### Description

Test planispiral, involute, with peripheral keel. Lenticular-shaped smooth test, circular in outline, biconvex in cross section. Chambers are slightly inflated. Sutures are curved and flush to the test. The primary aperture is radiate and terminal.

### Dimensions

The species length ranges from 150 to 1000 µm in the current study.

### Stratigraphic range

The species distribution at 752 is Chattian to late Messinian. The species is only present in the early-to-mid Burdigalian at 1139 and it is not recorded at all at 1168.

### Remarks

This species is well-preserved and abundant at 752. It is known from the Indian Ocean (current study) and was noted from the west Pacific (Hanagata and Nobuhara, 2015) so could be considered to have a limited distribution.

Subfamily **Marginulininae** Wedekind, 1937

Genus *Amphicoryna* Schlumberger, in Milne-Edwards, 1881

*Amphicoryna scalaris* (Batsch, 1791)

Figure 6: 1a–b

1791 *Nautilus (Orthoceras) scalaris* Batsch: pp. 1, 4, pl. 2, fig. 4a, b

1826 *Nodosaria longicauda* d'Orbigny: p. 254

1860 *Marginulina falx* Jones and Parker: p. 302

1884 *Nodosaria scalaris* (Batsch); Brady, p. 510, pl. 63, figs. 28–31

1960 *Amphicoryna scalaris* (Batsch); Barker, p. 134, pl. 63, figs. 28–31

2013 *Amphicoryna scalaris* (Batsch); Holbourn et al., p. 42, fig. 1

### Description

Test elongate, rectilinear, with pronounced basal spine. Chambers are inflated, gradually increasing in size and separated by straight, depressed sutures. The wall is ornamented by long striations or fine ribs many of which are parallel and continuous in appearance. Aperture is terminal and radiate with ring-like ridges around the neck.

### Dimensions

The species length ranges from 200 to 750 µm in this study.

### Stratigraphic range

At 752 the species ranges from Chattian to Messinian. At 1139 and 1168 this species is very rare, occurring in the mid-Burdigalian at 1139, extending to the early Zanclean at 1168.

### Remarks

This species is very well-preserved and recorded in highest abundance at 752. This species occurs worldwide according to Holbourn et al. (2013) and is commonly found in the Indian Ocean.

Order **Rotaliida** Lankester, 1885

Superfamily **Asterigerinoidea** d'Orbigny, 1839a

Family **Epistomariidae** Hofker, 1954

Subfamily **Nuttallidinae** Saidova, 1981

Genus *Nuttallides* Finlay, 1939

*Nuttallides umbonifera* (Cushman, 1933a)

Figure 6: 2a–e

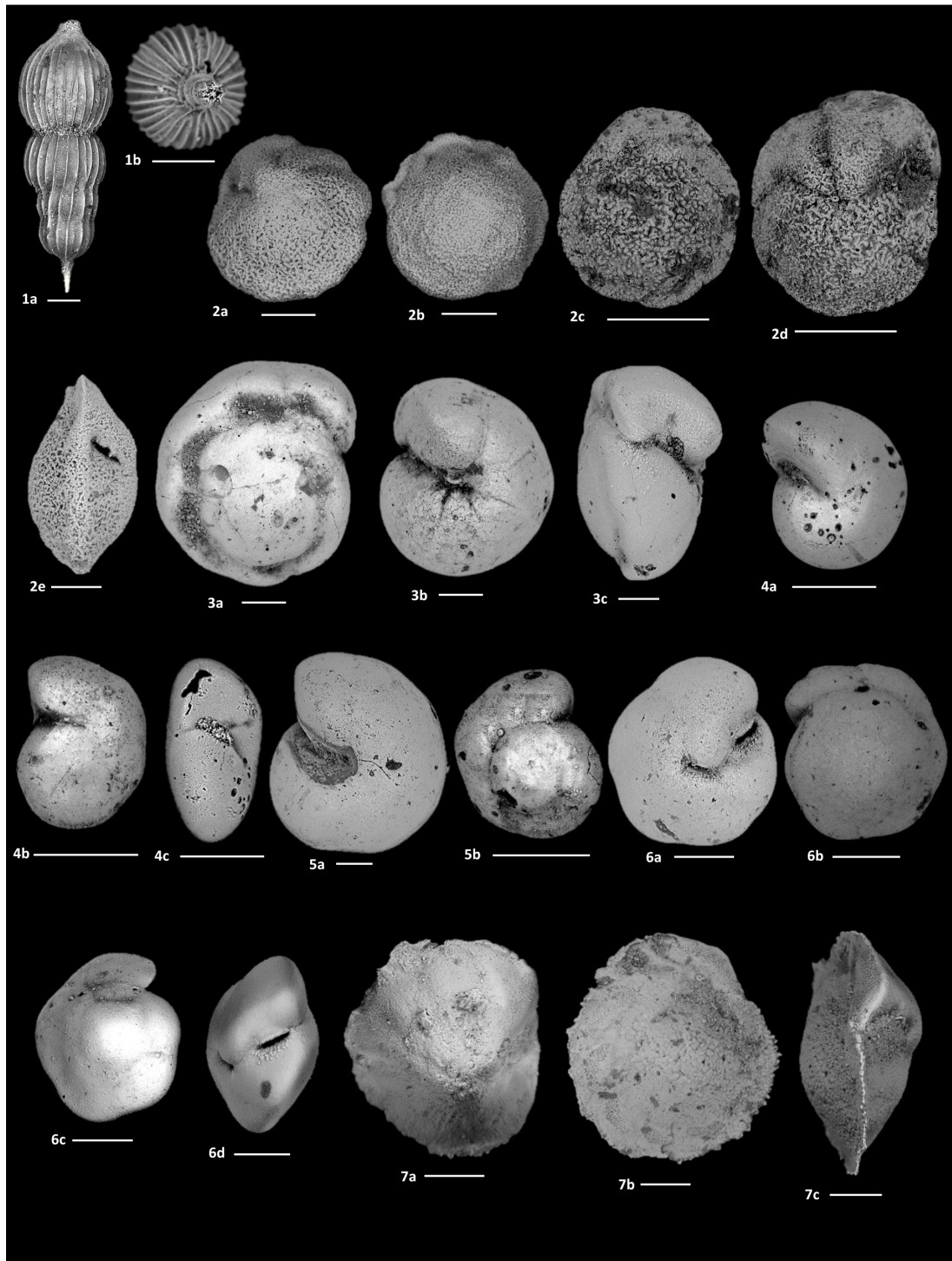
1933a *Pulvinulinella umbonifera* Cushman: p. 90, pl. 9, fig. 9

1884 *Truncatulina pygmaea* Hantken; Brady, p. 666, pl. 95, figs. 9, 10

1933a *Pulvinulinella umbonifera* Cushman: p. 90, pl. 9, fig. 9

1960 *Eponides bradyi* Earland; Barker, pl. 95, figs. 9, 10

1987 *Nuttallides umbonifera* (Cushman); Miller and Katz, p. 136, pl. 5, fig. 5



**Figure 6.** Scale bar is 100  $\mu\text{m}$ . **(1a–b)** *Amphicoryna scalaris*, ODP Hole 752A, **(1a)** 10H-5, 77–81 cm: side view. **(1b)** 8H-1, 100–105 cm: apertural view. **(2a–e)** *Nuttallides umbonifera*, **(2a, e)** ODP Hole 752A, 4H-5, 64–69 cm: **(2a)** umbilical view; **(2e)** edge view. **(2b)** ODP Hole 752A, 9H-5, 65–70 cm: spiral view. **(2c)** ODP Hole 1168A, 13X-1, 40–44 cm: spiral view. **(2d)** ODP Hole 1168A, 14X-4, 45–49 cm: umbilical view. **(3a–c)** *Gyroidinoides soldanii*, ODP Hole 1139A, 3R-4, 32–36 cm: **(3a)** spiral view; **(3b)** umbilical view; **(3c)** edge view. **(4a–c)** *Gyroidinoides* sp. 1, ODP Hole 1139A, **(4a, c)** 19R-2, 60.5–64.5 cm: **(4a)** spiral view; **(4c)** edge view. **(4b)** 17R-3, 91–95 cm: umbilical view. **(5a–b)** *Gyroidinoides* sp. 2, **(5a)** ODP Hole 1168A, 32X-4, 80–84 cm: umbilical view. **(5b)** ODP Hole 1139A, 15R-4, 41–45 cm: spiral view. **(6a–d)** *Oridorsalis umbonatus*, **(6a–b)** ODP Hole 1168A, 8H-1, 100–104 cm: **(6a)** umbilical view; **(6b)** spiral view. **(6c)** ODP Hole 752A, 5H-1, 65–70 cm: spiral view. **(6d)** ODP Hole 1168A, 8H-1, 100–104 cm: edge view. **(7a–c)** *Osangularia culter*, ODP Hole 1168A, 28X-3, 75–79 cm: **(7a)** umbilical view; **(7b)** spiral view; **(7c)** edge view.

1994 *Osangulariella umbonifera* (Cushman); Jones, p. 99, pl. 95, figs. 9, 10

1995 *Nuttallides umboniferus* (Cushman); Nomura, p. 276, pl. 3, fig. 2

### Description

Lenticular, trochospiral form. Unequally biconvex test with a sub-acute peripheral keel. About 12 crescentic chambers in the final whorl, separated by slightly depressed, arcuate to sinuous sutures on the umbilical side and oblique sutures on the spiral side. Aperture is an interiomarginal slit extending from the umbilical boss towards periphery.

### Dimensions

The species length ranges from 100 to 750 µm in the current study.

### Stratigraphic range

The range of the species is Chattian to Tortonian at 1139 and 752. At 1168 it ranges from Chattian to early Zanclean.

### Remarks

This species is characterised by an imperforate umbilical boss. *Nuttallides umbonifera* (Cushman) is often employed as an indicator of Antarctic Bottom Water (AABW) in the Pacific Ocean and Indian Ocean (Corliss, 1979). This species is long-ranging and distributed worldwide. Mackensen et al. (1990) believed that the species is associated with carbonate corrosive bottom water masses in the Weddell Sea. Distribution worldwide according to Holbourn et al. (2013) and found throughout the Indian Ocean and Southern Ocean (Mackensen, 1992; Nomura, 1995).

Superfamily **Chilostomelloidea** Brady, 1881

Family **Gavelinellidae** Hofker, 1956

Subfamily **Gavelinellinae** Hofker, 1956

Genus *Gyroidinoides* Brotzen, 1942

*Gyroidinoides soldanii* (d'Orbigny, 1826)

Figure 6: 3a–c

1826 *Gyroidina soldanii* d'Orbigny: p. 278

1846 *Gyroidina soldanii* d'Orbigny; d'Orbigny, pl. 8, figs. 10–12

1978 *Gyroidina soldanii* d'Orbigny; Wright, p. 715, pl. 5, figs. 7–9

1992 *Gyroidinoides soldanii* d'Orbigny; Mackensen, p. 668, pl. 5, figs. 9, 10

1994 *Gyroidinoides soldanii* d'Orbigny; Jones, p. 106, pl. 107, figs. 6, 7

### Description

Test is trochospiral and planoconvex. Umbilical side is involute and convex, and the spiral side is flat and evolute. Rounded periphery. Chambers are inflated and separated by slightly depressed sutures that are straight on umbilical side but curved on spiral side. The surface is smooth. The aperture is a narrow interiomarginal slit, extending from umbilicus to the periphery. The umbilicus is open.

### Dimensions

The species length ranges from 100 to 750 µm in this study.

### Stratigraphic range

This species occurs in the Chattian at all three sites, ranging to the early Zanclean at 752 and 1168, and the early Tortonian at 1139.

### Remarks

Most of the specimens observed in this study have a planar or slightly convex spiral side, and relatively small chambers in the last whorl on the spiral side. Distribution worldwide according to Holbourn et al. (2013). This species is now considered a junior synonym of *Hansenisca soldanii* (Hayward et al., 2019b) in the World Register of Marine Species (WoRMS).

*Gyroidinoides* sp. 1

Figure 6: 4a–c

### Description

Test is trochospiral, plano-convex. The spiral side is flat and evolute, while the umbilical side is convex and involute. Chambers are generally inflated separated by slightly depressed sutures on both umbilical and spiral sides. The aperture is an interiomarginal slit extending from umbilicus to periphery. The surface is smooth.

### Dimensions

The species length ranges from 100 to 550 µm in this study.

### Stratigraphic range

The species is rare at 752 only occurring in the mid-Serravallian and early Zanclean. At 1139 the species ranges from Chattian to early Tortonian. At 1168 it is very rare in the Chattian, with a more common range from early Burdigalian to early Zanclean.



### Remarks

The chambers are more elongate and larger on the spiral side than in *Gyroidinoides soldanii* and it lacks the open, narrow umbilicus of *G. soldanii* and *G. sp. 2*. The distribution of the species may be restricted to the current study (southern Indian Ocean). The stratigraphic range overlaps with that of *G. soldanii*.

*Gyroidinoides sp. 2*

Figure 6: 5a–b

### Description

The test is trochospiral and planoconvex. Sutures flush to slightly depressed on spiral side, while slightly depressed on umbilical side. Aperture is slit-like extending from umbilicus to periphery. The aperture has a long crescentic flap covering the umbilicus.

### Dimensions

The species length ranges from 100 to 400 µm in the current study.

### Stratigraphic range

Species ranges from Chattian to mid-Serravallian at 1139 and Chattian to early Zanclean at 1168. This species is not recorded at 752.

### Remarks

This species differs from *Gyroidinoides soldanii* by having larger chambers on the spiral side, which is also more convex. *Gyroidinoides sp. 1* has slightly more inflated chambers on the spiral side and a shorter, more curved apertural slit than this species. This species may be restricted to the current study area (southern Indian Ocean).

Family **Oridorsalidae** Loeblich and Tappan, 1984

Genus *Oridorsalis* Andersen, 1961

*Oridorsalis umbonatus* (Reuss, 1851)

Figure 6: 6a–d

1851 *Rotalina umbonata* Reuss: p. 75, pl. 5, fig. 35

1884 *Pulvinulina umbonata* (Reuss); Brady, p. 695, pl. 105, fig. 2

1884 *Truncatulina tenera* Brady: p. 665, pl. 95, fig. 11

1932 *Eponides umbonata* (Reuss); Nuttall, p. 26, pl. 6, figs. 4, 5

1983 *Oridorsalis umbonatus* (Reuss); Tjalsma and Lohmann, p. 18, pl. 6, fig. 8

1988 *Oridorsalis umbonata* (Reuss); Whittaker, p. 137, pl. 19, figs. 1–3

2011 *Oridorsalis umbonatus* (Reuss); Kuppusamy et al., p. 59, pl. 8, figs. 23, 24

### Description

Test trochospiral, lenticular, unequally biconvex, and nearly circular in outline. The convexity of spiral side is greater than the umbilical side. Involute in umbilical and evolute in spiral side. Six nearly inflated chambers in the last whorl. Sutures usually slightly depressed, curved on umbilical side and radial on spiral side. The test is smooth. The aperture is an interiomarginal slit, extending from periphery to umbilicus.

### Dimensions

The species length ranges from 100 to 750 µm in this study.

### Stratigraphic range

The stratigraphic distribution of the species is Chattian to early Zanclean at 752 and 1168, Chattian to early Tortonian at 1139.

### Remarks

This species generally has six chambers, some specimens possess seven chambers, in the last whorl. This species is easily identifiable and long-ranging from the Paleocene to Holocene, and is common worldwide Holbourn et al. (2013).

Genus *Osangularia* Brotzen, 1940

*Osangularia culter* (Parker & Jones, 1865)

Figure 6: 7a–c

1865 *Planorbulina farcta* var. *ungeriana* subvar. *culter* Parker and Jones: pp. 382, 421, pl. 19, fig. 1

1866 *Anomalina bengalensis* Schwager, p. 259, pl. 7, fig. 111

1884 *Truncatulina culter* (Parker and Jones); Brady, p. 668, pl. 96, fig. 3

1953 *Osangularia culter* (Parker and Jones); Phleger et al., p. 42, pl. 9, figs. 11–16

1960 *Osangularia bengalensis* (Schwager); Barker, pl. 96, fig. 3

1994 *Osangularia bengalensis* (Schwager); Jones, p. 100, pl. 96, fig. 3

### Description

Test is trochospiral, lenticular and unequally biconvex; the umbilical side is more convex than spiral side. The umbilical side is involute, while the spiral side is evolute. Acute periphery with a serrated keel. The slightly inflated nearly 10 chambers, separated by slightly elevated, curved sutures on the spiral side, and straight with slightly depressed sutures on umbilical side. The test is smooth with some perforation in the chambers on spiral side. Aperture is slit-like interiomarginal, extending from umbilicus to periphery.

### Dimensions

The species length ranges from 125 to 1000 µm in the current study.

### Stratigraphic range

The range of the species is Chattian to early Zanclean at 752, Chattian to early Tortonian at 1139. At 1168 it ranges from Aquitanian to Langhian, and then mid-Tortonian to early Zanclean.

### Remarks

*Osangularia culter* is one of several species dominating intermediate water assemblages in the Miocene (Woodruff, 1985). Distribution cosmopolitan (Holbourn et al., 2013).

Superfamily **Discorboidea** Ehrenberg, 1838

Family **Rosalinidae** Reiss, 1963

Genus *Gavelinopsis* Hofker, 1951

*Gavelinopsis lobatulus* (Parr, 1950)

Figure 7: 1

1913 *Discorbina praegeri* (Heron-Allen and Earland): p. 122, pl. 10, figs. 8–10

1950 *Discorbis lobatulus* Parr: p. 354, pl. 13, figs. 23–25

1960 *Gavelinopsis lobatulus* (Parr); Barker, p. 182, pl. 88, figs. 1a–c

2011 *Gavelinopsis lobatulus* (Parr); Kuppusamy et al., p. 52, pl. 5, figs. 2, 3

### Description

Test trochoid. The periphery is thickened and keeled. Five slightly inflated chambers in the last whorl. Nearly flush sutures on spiral side, with slightly depressed sutures on umbilical side. The aperture is an interiomarginal slit extending from umbilicus to periphery, having a narrow lip.

### Dimensions

The species length ranges from 125 to 375 µm in the current study.

### Stratigraphic range

The stratigraphic distribution is early Langhian to early Zanclean at 752 and mid-Burdigalian to Mid-Serravallian at 1139. This species is not recorded at 1168.

### Remarks

Most of the specimens of this species are characterised by an umbilical plug and sharp periphery. Recorded from the Indian Ocean and Southern ocean including the Kerguelen Plateau (Mackensen, 1992) and eastern Indian Ocean (Nomura, 1991). This species is considered a subjective junior synonymy of *Gavelinopsis praegeri* (Hayward et al., (2019c) in WoRMS).

Family **Sphaeroidinidae** Cushman, 1927

Genus *Sphaeroidina* d'Orbigny, 1826

*Sphaeroidina bulloides* d'Orbigny, 1828 in Deshayes, 1828

Figure 7: 2a–c

1828 *Sphaeroidina bulloides* d'Orbigny in Deshayes: p. 267

1846 *Sphaeroidina austriaca* d'Orbigny: p. 284, pl. 20, figs. 19–21

1848 *Sexloculina haueri* Czjzek: p. 149, pl. 13, figs. 35–38

1884 *Sphaeroidina bulloides* d'Orbigny; Brady, p. 620, pl. 84, figs. 1, 2

1949 *Sphaeroidina ciperana* Cushman and Todd: p. 67, pl. 12, fig. 14

1949 *Sphaeroidina compacta* Cushman and Todd: p. 19, pl. 4, fig. 14

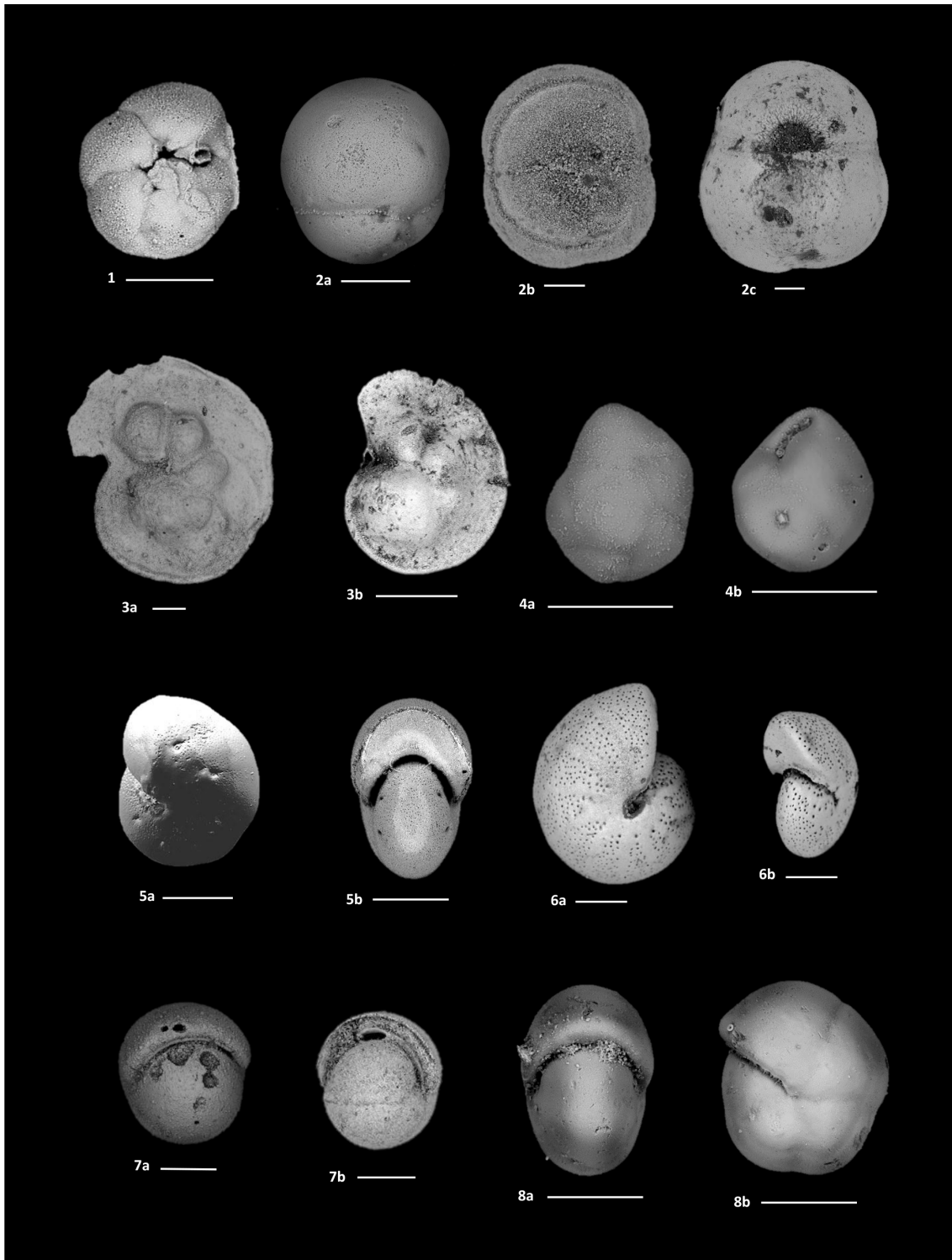
1949 *Sphaeroidina compressa* Cushman and Todd: p. 20, pl. 4, figs. 15, 16

1949 *Sphaeroidina nitida* Cushman and Todd: p. 20, pl. 4, fig. 13

1953 *Sphaeroidina japonica* Asano: p. 19, pl. 2, figs. 43–44

1985 *Sphaeroidina bulloides* d'Orbigny; Papp and Schmid, p. 96, pl. 90, figs. 7–12

2013 *Sphaeroidina bulloides* d'Orbigny; Holbourn et al., p. 520, figs. 1–3



**Figure 7.** Scale bar is 100  $\mu\text{m}$ . **(1)** *Gavelinopsis lobatulus*, ODP Hole 752A, 3H-5, 62–67 cm: umbilical view. **(2a–c)** *Sphaeroidina bulloides*, **(2a)** ODP Hole 752A, 8H-1, 100–105 cm: side view. **(2b)** ODP Hole 1139A, 8R-1, 45–49 cm: apertural side view. **(2c)** ODP Hole 1168A, 26X-2, 73–77 cm: apertural side view. **(3a–b)** *Laticarinina pauperata*, **(3a)** ODP Hole 752A, 7H-2, 73–78 cm: umbilical view. **(3b)** ODP Hole 1139A, 18R-1, 96–100 cm: umbilical view. **(4a–b)** *Epistominella exigua*, ODP Hole 1168A, 36X-6, 62.5–66.5 cm: **(4a)** spiral view; **(4b)** umbilical view. **(5a–b)** *Astrononion umbilicatum*, ODP Hole 1139A, **(5a)** 19R-2, 60.5–64.5 cm: umbilical view. **(5b)** 17R-3, 91–95 cm: edge view. **(6a–b)** *Melonis barleeanus*, ODP Hole 1139A, **(6a)** 4R-2, 105–109 cm: umbilical? view. **(6b)** 19R-2, 60.5–64.5 cm: edge view. **(7a–b)** *Pullenia bulloides*, **(7a)** ODP Hole 752A, 9H-5, 65–70 cm: edge view. **(7b)** ODP Hole 1139A, 16R-2, 55–59 cm: edge view. **(8a–b)** *Pullenia quinqueloba*, ODP Hole 1168A, 35X-1, 65–69 cm: **(8a)** edge view; **(8b)** umbilical view.

### Description

Test is sub-globular, usually three chambers in the final whorl. The test is variably coiled. Chambers are globular to hemispherical, separated by slightly depressed sutures. The wall is calcareous, imperforate and smooth. The aperture is a crescentic opening, bordered by a lip, occurring where the three last chambers meet.

### Dimensions

The species length ranges from 125 to 725 µm in the current study.

### Stratigraphic range

The stratigraphic distribution is Chattian to Zanclean at 752 and 1168, and Chattian to Serravallian at 1139.

### Remarks

The larger specimens in the current study have a thick and opaque wall; smaller specimens are thinner-walled and appear translucent. Worldwide distribution according to Holbourn et al. (2013) including previous reports from the eastern Indian Ocean (Nomura, 1991).

Superfamily **Discorbinelloidea** Sigal in Piveteau, 1952

Family **Discorbinellidae** Sigal in Piveteau, 1952

Subfamily **Discorbinellinae** Sigal in Piveteau, 1952

Genus *Laticarinina* Galloway and Wissler, 1927

*Laticarinina pauperata* (Parker & Jones, 1865)

Figure 7: 3a–b

1865 *Pulvinulina repanda* Fichtell and Moll var. *menardii* d'Orbigny, subvar. *pauperata* Parker and Jones: p. 395, pl. 16, figs. 50–51

1884 *Pulvinulina pauperata* (Parker and Jones); Brady, p. 696, pl. 104, figs. 3–11

1942 *Laticarinina bulbrookii* Cushman and Todd: p. 19, pl. 4, figs. 8, 9

1942 *Laticarinina crassicarinata* Cushman and Todd: p. 18, pl. 4, figs. 11, 12

1949 *Laticarinina pauperata* (Parker and Jones); Bermúdez, p. 309, pl. 23, figs. 43–45

1953 *Laticarinina pauperata* (Parker and Jones); Phleger et al., p. 49, pl. 11, figs. 5, 6

1991 *Laticarinina pauperata* (Parker and Jones); Nomura, p. 55, pl. 1, fig. 6

1992 *Laticarinina pauperata* (Parker and Jones); Mackensen, p. 668, pl. 2, figs. 1, 2

2011 *Laticarinina pauperata* (Parker and Jones); Kuppusamy et al., p. 57, pl. 7, fig. 8

### Description

Test planoconvex, slightly trochoid. The spiral side is flat; the umbilical side is slightly convex. Chambers are inflated but becoming progressively more loosely coiled with modest rate of enlargement. Chambers are cuneiform on the umbilical side and reniform on the spiral side, and they are separated by radial and slightly depressed sutures. Chambers on the ventral side are radial, while in the dorsal side is more separated. Large, transparent peripheral keel around whole test, projecting in front of final chamber. Aperture is on the inner margin of last formed chamber.

### Dimensions

The species length ranges from 175 to 1300 µm in the current study.

### Stratigraphic range

The range of the species at 752 is Chattian to early Burdigalian and then again late Langhian to early Zanclean. At 1139 the species appears in the Chattian and later from the mid-Aquitania to mid-Serravallian. At 1168, it is recorded from the mid-Aquitania to mid-Messinian.

### Remarks

Most specimens are easily distinguished by the presence of a very broad, transparent keel on the periphery.

### Biogeography

This species has previously been reported from the eastern Indian Ocean (Nomura, 1991) and Kerguelen Plateau (Mackensen, 1992) but can be found worldwide (Holbourn et al., 2013).

Family **Pseudoparrellidae** Voloshinova, 1952

Subfamily **Pseudoparrellinae** Voloshinova, 1952

Genus *Epistominella* Husezima and Maruhasi, 1944

*Epistominella exigua* (Brady, 1884)

Figure 7: 4a–b

1884 *Pulvinulina exigua* Brady: p. 696, pl. 103, figs. 13–14

1951 *Pseudoparrella exigua* (Brady); Phleger and Parker, p. 28, pl. 15, fig. 6

1994 *Pseudoparrella exigua* (Brady); Loeblich and Tappan, p. 146, pl. 307, figs. 1–7

1951 *Pulvinulinella exigua* (Brady); Hofker, p. 322, figs. 219–221

1960 *Epistominella exigua* (Brady); Barker, pl. 103, figs. 13, 14

1992 *Epistominella exigua* (Brady); Mackensen, p. 668, pl. 4, figs. 5, 6

1994 *Alabaminoides exiguus* (Brady); Jones, p. 103, pl. 103, figs. 13, 14

2011 *Epistominella exigua* (Brady); Kuppusamy et al., p. 50, pl. 4, figs. 11, 12

2013 *Epistominella exigua* (Brady); Holbourn et al., p. 240, figs. 1–6

### Description

Test trochoid, unequally biconvex. Slightly convex spiral side, convex umbilical side. The periphery is acute. Five to six moderately inflated chambers in the last whorl, separated by curved, flush sutures on spiral side and curved, depressed sutures on umbilical side. Aperture is an interiomarginal slit on umbilical side extending to the face of the final and largest chamber.

### Dimensions

The species length ranges from 100 to 275  $\mu\text{m}$  in the current study.

### Stratigraphic range

The species is rare at 752 ranging from early Langhian to early Zanclean. The range is Chattian to early Tortonian at 1139 and to early Zanclean at 1168.

### Remarks

The abundance of this species is employed as a proxy for constraining the flux of pulsed organic matter (Holbourn et al., 2013). This species is found worldwide including local to this study in the Timor Sea (Loeblich and Tappan, 1994), Kerguelen Plateau (Mackensen, 1992) and Weddell Sea, Antarctic (Thomas, 1990).

Superfamily **Nonionoidea** Schultze, 1854

Family **Nonionidae** Schultze, 1854

Subfamily **Astrononioninae** Saidova, 1981

Genus *Astrononion* Cushman & Edwards, 1937

*Astrononion umbilicatum* Uchio, 1952

Figure 7: 5a–b

1952 *Astrononion umbilicatum* Uchio: p. 36, pl. 32, fig. 1

1978 *Astrononion umbilicatum* Uchio; Wright, p. 710, pl. 1, fig. 12

2011 *Astrononion umbilicatum* Uchio; Kuppusamy et al., p. 44, pl. 1, figs. 7–9

### Description

Planispiral involute test. Periphery rounded, elliptical in lateral view. Chambers large and increasing gradually in size. Approximately seven to eight chambers in the last whorl, separated by curved, thickened radial sutures. Aperture is a narrow interiomarginal, crescentic slit, extending across the periphery to the umbilicus.

### Dimensions

The species length ranges from 100 to 350  $\mu\text{m}$  in the current study.

### Stratigraphic range

The distribution of the species at 752 is early Aquitanian to early Zanclean and Chattian to early Zanclean at 1168. The range is Chattian to early Tortonian at 1139.

### Remarks

The flaps that partially cover the sutures in the last whorl leave a small cavity beneath, which look like secondary chamberlets. This species was originally described from the lower Pleistocene of Japan (Uchio, 1952) but has not been widely reported from elsewhere. It is known from the Indian Ocean (current study), ODP Site 757 (Singh and Gupta, 2004), north-west Atlantic Ocean (Kuppusamy et al., 2011) and the Mediterranean (Wright, 1978).

Subfamily **Pulleniinae** Schwager, 1877

Genus *Melonis* de Montfort, 1808

*Melonis barleeanus* (Williamson, 1858)

Figure 7: 6a–b

1858 *Nonionina barleeana* Williamson: p. 32, pl. 3, figs. 68, 69

1930 *Nonion barleeenum* (Williamson); Cushman, p. 11, pl. 4, fig. 5

1953 *Nonion barleeenum* (Williamson); Phleger et al., p. 30, pl. 6, fig. 4

1979 *Melonis barleeaanum* (Williamson); Corliss, p. 10, pl. 5, fig. 78

1988 *Melonis barleeaanum* (Williamson); Loeblich and Tappan, pl. 696, figs. 5, 6

1992 *Melonis barleeaanus* (Williamson); Mackensen, p. 668, pl. 5, fig. 2

1997 *Melonis barleeaanus* Williamson, 1858; Bergamin et al., p. 38, pl. 2, figs. 1–9

### Description

Test planispiral, bi-umbilicate, involute, compressed test. The umbilicus is open. The test is elliptical, elongated in lateral view, rounded periphery. Ten to 11 flattened chambers, separated by broad, flush sutures. The test is smooth and perforated. The aperture is an interiomarginal slit extending to the umbilicus, possessing an apertural lip.

### Dimensions

The species length ranges from 150 to 600 µm in this study.

### Stratigraphic range

The stratigraphic distribution of the species at 752 is split into two phases, early Langhian to mid-Serravallian and then again late Messinian to Zanclean. At 1139 it ranges from Chattian to mid-Tortonian, while at 1168 it ranges from Chattian to Zanclean.

### Remarks

Forms identified here have a prominent apertural lip distinguishing them from morphologically similar *Melonis affinis* separated out by some authors (see details in Holbourn et al., 2013). However, we consider the morphologically similar *Melonis affinis* synonymous with *M. barleeaanus* following molecular analyses by Schweizer (2006).

### Biogeography

The species is found worldwide, but Holbourn et al. (2013) suggest that it is not present at very high latitudes. The highest southern-recorded occurrence is on the Kerguelen Plateau by Mackensen (1992), which is supported by the current study observations.

Genus *Pullenia* Parker & Jones in Carpenter et al., 1862

*Pullenia bulloides* (d'Orbigny, 1846)

Figure 7: 7a–b

1826 *Nonionina bulloides* d'Orbigny; p. 293

1884 *Pullenia sphaeroides* (d'Orbigny); Brady, p. 615, pl. 84, figs. 12, 13

1945 *Pullenia bulloides* (d'Orbigny); Cushman and Todd, p. 64, pl. 11, fig. 5

1949 *Pullenia bulloides* (d'Orbigny); Bermúdez, p. 276, pl. 21, figs. 28–29

1978 *Pullenia bulloides* (d'Orbigny); Wright, p. 716, pl. 7, fig. 7

2011 *Pullenia bulloides* (d'Orbigny); Kuppasamy et al., p. 62, pl. 9, figs. 18, 19

### Description

Test planispiral, involute, globular, sub-circular in outline. Four to five inflated chambers in the last whorl, separated by flush to slightly depressed sutures. Very compact test. Aperture is a narrow interiomarginal, crescentic slit, extending from the periphery to umbilicus.

### Dimensions

The species length ranges from 125 to 425 µm in this study.

### Stratigraphic range

The stratigraphic distribution of the species at 752 and 1168 is Chattian to Zanclean. At 1139 the species ranges from Chattian to mid-Tortonian.

### Remarks

This species usually has a broad periphery and a smooth surface. Up to five chambers are present in the final whorl compared to four or five in the holotype and topotype specimens. Distribution is worldwide (Holbourn et al., 2013) including previous reports from the Indian Ocean by Nomura (1991) and (Singh and Gupta, 2004).

*Pullenia quinqueloba* (Reuss, 1851)

Figure 7: 8a–b

1851 *Nonionina quinqueloba* Reuss: p. 71, pl. 5, fig. 31a, b

1960 *Pullenia subcarinata* (d'Orbigny); Barker, pl. 84, figs. 14, 15

1949 *Pullenia quinqueloba* (Reuss); Bermúdez, p. 276, pl. 21, figs. 32, 33

1983 *Pullenia quinqueloba* (Reuss); Tjalsma and Lohmann, p. 36, pl. 16, fig. 2

1987 *Pullenia quinqueloba* (Reuss); Miller and Katz, p. 138, pl. 4, figs. 2a–b

### Description

Test planispiral, involute. Sub-globular, slightly compressed test, rounded periphery. Chambers are triangular and inflated. Five chambers present in the final whorl, separated by depressed and radial sutures. Aperture is a narrow, crescentic, interiomarginal slit, extending from periphery to umbilicus.

### Dimensions

The species length ranges from 125 to 500 µm in the current study.

### Stratigraphic range

The range of the species at 752 is Chattian to Zanclean at 1139 Chattian to mid-Serravallian and at 1168 early Aquitanian to Zanclean.

### Remarks

This species is distinguished from five-chambered forms of *P. bulloides* by the more open coiling and less circular outline. This species is recorded worldwide (Holbourn et al., 2013) but is common in the continental shelf sediments of the Yellow Sea and the East China Sea (Lei and Li, 2016) and in the Indian Ocean (Nomura, 1991; Singh and Gupta, 2004).

Superfamily **Planorbuloidea** Schwager, 1877

Family **Cibicididae** Cushman, 1927

Subfamily **Cibicidinae** Cushman, 1927

Genus *Cibicidoides* Saidova, 1975

*Cibicidoides bradyi* (Trauth, 1918)

Figure 8: 1a–b

1918 *Truncatulina bradyi* Trauth, p. 235

1884 *Truncatulina dutemplei* (d'Orbigny); Brady, p. 665, pl. 95, fig. 5

1976 *Cibicidoides bradyi* (Trauth); Pflum and Frerichs, pl. 3, figs. 6, 7

1994 *Gyroidina bradyi* (Trauth); Jones, p. 99, pl. 95, fig. 5

2013 *Cibicidoides bradyi* (Trauth); Holbourn et al., p. 162, figs. 1–6

### Description

Test trochospiral, unequally biconvex. The umbilical side is involute, and the spiral side is evolute, more convex. Nine inflated chambers in the last whorl, separated by radial curved sutures in umbilical side, and oblique sutures in the spiral side. The aperture is a slit-like opening with lip extending from periphery to spiral side.

### Dimensions

The species length ranges from 100 to 450 µm in this study.

### Stratigraphic range

The species first appears in the Chattian and ranges to the Zanclean at 752 and 1168; at 1139 it ranges from Chattian to early Tortonian.

### Remarks

Distinguished from *Cibicidoides robertsonianus* (Brady, 1881), with which it can be confused (Holbourn et al., 2013), by having fewer chambers (typically < 10) in the last whorl, smaller test and a more rounded periphery. Recorded worldwide (Holbourn et al., 2013), including from the central Indian Ocean by Boersma (1990). Whilst this species is perhaps most commonly referred to as *C. bradyi* in the literature (e.g. Holbourn et al., 2013), accepted alternate names include *Parrelloides bradyi* and *Heterolepa bradyi* (Hayward et al., 2019d, in WoRMS database).

*Cibicidoides mundulus* (Brady, Parker & Jones, 1888)

Figure 8: 2a–c

1888 *Truncatulina mundula* Brady, Parker and Jones: p. 228, pl. 45, fig. 25a–c

1953 *Cibicides kullenbergi* Parker in Phleger et al.: p. 49, pl. 11, figs. 7, 8

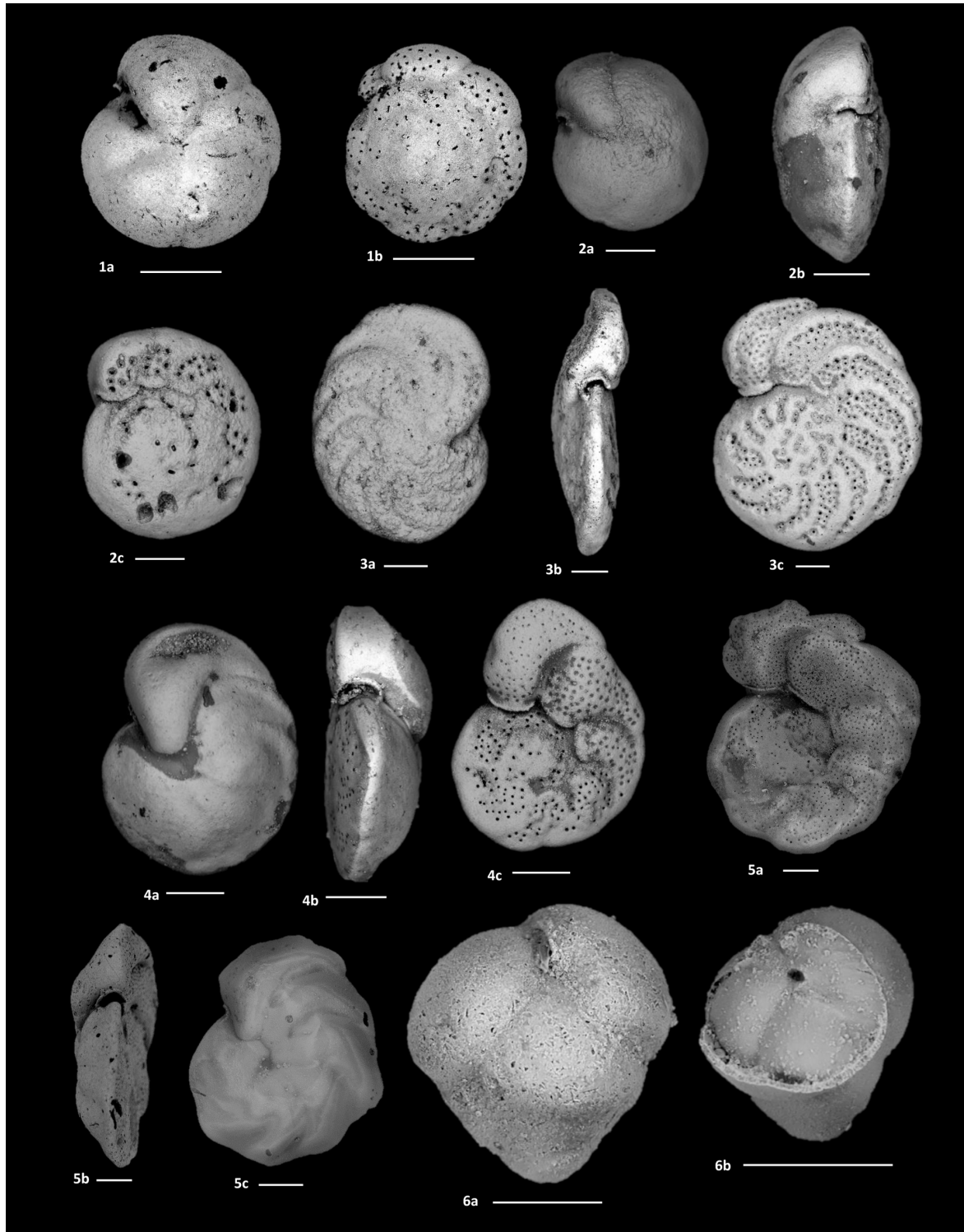
1955 *Cibicidoides mundulus* (Brady, Parker and Jones); Loeblich and Tappan, p. 25, fig. 4a–c

1960 *Cibicidoides mundulus* (Brady, Parker and Jones); Barker, pl. 95, fig. 6

1992 *Cibicidoides mundulus* (Brady, Parker and Jones); Mackensen, p. 668, pl. 3, figs. 5–7

### Description

Unequally biconvex test, trochospiral. The umbilical side is more convex than the spiral side. Chambers are low, inflated, 10 to 12 chambers in the last whorl, separated by curved sutures. The primary aperture is a long, narrow interiomarginal slit, extending from periphery to spiral side. The test is smooth on the umbilical side and highly perforated on the spiral side.



**Figure 8.** Scale bar is 100  $\mu\text{m}$ . **(1a–b)** *Cibicoides bradyi*, ODP Hole 1139A, **(1a)** 9R-4, 105–110 cm: umbilical view. **(1b)** 8R-1, 45–49 cm: spiral view. **(2a–c)** *Cibicoides mundulus*, ODP Hole 752A, 3H-1, 50–55 cm: **(2a)** umbilical view; **(2b)** edge view; **(2c)** spiral view. **(3a–c)** *Cibicoides wuellerstorfi*, (normal) ODP Hole 752A, 7H-2, 73–78 cm: **(3a)** umbilical view; **(3b)** edge view; **(3c)** spiral view. **(4a–c)** *Cibicoides wuellerstorfi*, (smooth) ODP Hole 752A, 5H-1, 65–70 cm: **(4a)** umbilical view; **(4b)** edge view; **(4c)** spiral view. **(5a–c)** *Planulina costata*, ODP Hole 752A, 7H-2, 73–78 cm: **(5a)** spiral view; **(5b)** edge view; **(5c)** umbilical view. **(6a–b)** *Eggerella bradyi*, ODP Hole 1168A; **(6a)** 42X-3, 70–74 cm: side view. **(6b)** 10H-2, 80–84 cm: apertural view.



### Dimensions

The species length ranges from 125 to 800 µm in this study.

### Stratigraphic range

The stratigraphic distribution of the species at 752 and 1168 is Chattian to Zanclean. At 1139A it ranges from the Chattian to early Tortonian.

### Remarks

The specimens here all show a pronounced umbilical boss, as also illustrated by Holbourn et al. (2013, p. 196, pl. 1–8) and (Setoyama and Kaminski, 2015, p. 14, fig. 5, pl. 4a–c). Common species found worldwide (Holbourn et al., 2013), including in the eastern Indian Ocean (Nomura, 1991) and Kerguelen Plateau (Mackensen, 1992).

*Cibicidoides wuellerstorfi* (Schwager, 1866)

Figure 8: 3a–c

1866 *Anomalina wuellerstorfi* Schwager: p. 258, pl. 7, figs. 105, 107

1884 *Truncatulina wuellerstorfi* (Schwager); Brady, pp. 627, 662, pl. 93, figs. 8, 9

1960 *Planulina wuellerstorfi* (Schwager); Barker, pl. 93, fig. 9

1976 *Cibicides wuellerstorfi* (Schwager); Pflum and Frerichs, p. 116, pl. 4, figs. 2–4

1994 *Cibicidoides wuellerstorfi* (Schwager); Jones, p. 98, pl. 93, figs. 8, 9

2015 *Cibicidoides wuellerstorfi* (Schwager); Setoyama and Kaminski, p. 14, fig. 5, pl. 10a–c

### Description

Planispiral to low trochospiral and plano-convex test. Up to 12 elongated and curved chambers in the last whorl; increasing rapidly in size. Peripheral keel so acute periphery. The sutures are depressed and strongly curved. The wall is coarsely perforated on the spiral side. The aperture is a narrow slit, having a narrow lip extending from the periphery to the spiral side.

### Dimensions

The species length ranges from 125 to 1000 µm in the current study.

### Stratigraphic range

The stratigraphic distribution of the coarse type at 752 is early Aquitanian to Tortonian and mid-Aquitanian to Zanclean at 1168. At 1139 it ranges from mid-Burdigalian to mid-Serravallian. The smooth type ranges from early Tortonian to Zanclean at 752. At 1139 it ranges from Burdigalian to Serravallian, while at 1168 it ranges from Aquitanian to Zanclean.

### Remarks

This species has two different styles of test ornamentation as noted by Nomura (1991) in the eastern Indian Ocean (ODP Hole 754A) – a “smooth” and a “coarse” type. The smooth type (pl. 6, fig. 4a–c) has a smooth umbilical side and is relatively inflated in side view compared to the coarse type, which is highly adorned with nodes on the umbilical side and is more compressed in side view. The smooth type is recorded at all three localities in the current study. The coarse type *Cibicidoides wuellerstorfi* has previously been assigned to three different genera; *Fontobia* (Schwager), *Planulina* Revets (1996) and *Cibicidoides*. Following the molecular phylogenetic studies of Schweizer (2006) and Schweizer et al. (2009, 2011) the latter genus has now been accepted and applied in the literature (Setoyama and Kaminski, 2015). Worldwide distribution (Holbourn et al., 2013), widely reported in the Indian Ocean (e.g. Boersma, 1990; Nomura, 1991).

Family **Planulinidae** Bermúdez, 1952

Genus *Planulina* d’Orbigny, 1826

*Planulina costata* (Hantken, 1875)

Figure 8: 5a–c

1875 *Truncatulina costata* Hantken: p. 73, pl. 9, fig. 2a–c

1932 *Planulina wuellerstorfi* Schwager; Nuttall, p. 31, pl. 4, figs. 14, 15

1979 *Planulina wuellerstorfi* Schwager; Sztrákos, p. 86, pl. 26, fig. 4

1934 *Planulina marialana* Hadley: p. 27, pl. 4, figs. 4–7

1941 *Planulina palmerae* van Bellen: in van Bellen et al., 1941, p. 1144, figs. 7–9

1986 *Planulina costata* (Hantken); van Morkhoven et al., p. 212, pl. 72

1991 *Planulina costata* (Hantken); Nomura, p. 55, pl. 4, fig. 5a–c

### Description

Low trochoid test. Spiral side is evolute and flattened, while the umbilical side is involute and slightly convex. Chambers number 10 to 12, with a low inflated shape, separated by slightly to highly curved sutures. The test is smooth on the umbilical side and highly perforated with small pores on the spiral side. Aperture is slit-like, peripheral, with a small lip extending towards the umbilicus.

### Dimensions

The species length ranges from 150 to 1150  $\mu\text{m}$  in the current study.

### Stratigraphic range

This species only occurs at 752 where it ranges from early Aquitanian to early Serravallian.

### Remarks

Van Morkhoven et al. (1986) considered that this species may have evolved from *Planulina cocoaensis* and that *P. costata* and *Planulina renzi* may have evolved separately through the Oligocene and early Miocene. The current species is similar to the smooth form of *C. wuellerstorfi* in overall test shape and by having a smooth umbilical surface, but differs by having a smaller apertural opening, more compressed test and more irregular periphery. It is similar to *Planulina karsteni* (Petters and Sarmiento, 1956), but the spiral side of *P. karsteni* is slightly convex, while in *Planulina costata* it is plano-convex. Species is widely distributed (van Morkhoven et al., 1986) and has previously been recorded from the eastern Indian Ocean (Nomura, 1991).

Order **Textulariida** Lankester, 1885

Superfamily **Eggerelloidea** Ehrenberg, 1838

Family **Eggerellidae** Cushman, 1937

Subfamily **Eggerellinae** Cushman, 1937

Genus *Eggerella* Cushman, 1933a

*Eggerella bradyi* (Cushman, 1911)

Figure 8: 6a–b

1911 *Verneuilina bradyi* Cushman: p. 54, fig. 87

1937 *Eggerella bradyi* (Cushman); Cushman, p. 52, pl. 5, fig. 19

1951 *Eggerella bradyi* (Cushman); Phleger and Parker, p. 6, pl. 3, figs. 1, 2

1960 *Eggerella bradyi* (Cushman); Barker, pl. 47, figs. 4–7

1988 *Eggerella bradyi* (Cushman); Loeblich and Tappan, p. 170, pl. 189, figs. 1, 2

1991 *Eggerella bradyi* (Cushman); Nomura, p. 55, pl. 1, fig. 12a, b

### Description

The test is trochoid in the initial portion, subsequently changing to a triserial arrangement. The test is nearly conical. Chambers are highly inflated, separated by depressed sutures. The wall is agglutinated, with a calcareous cement. The aperture is a semicircular slit, with narrow lip, located at the base of the last biggest chamber.

### Dimensions

The species length ranges from 125 to 550  $\mu\text{m}$  in the current study.

### Stratigraphic range

The species ranges from the Chattian to Zanclean at 752 and 1168. At 1139 it ranges from Chattian to early Tortonian.

### Remarks

This species is considered cosmopolitan (Kender et al., 2008) and has previously been recorded in the Miocene of the east Indian Ocean by Nomura (1991) and on the Kerguelen Plateau (Mackensen, 1992).

## 5 Discussion and summary

Benthic foraminiferal assemblages from ODP Sites 752, 1139 and 1168 were identified from the  $> 63 \mu\text{m}$  fraction for the late Oligocene through to Pliocene. Assemblages are highly diverse comprising more than 200 species at each individual site with between 41 % and 57 % of taxa at any one site, not recorded at the other two, but these taxa represent very low proportions of the overall assemblages. Although there is some faunal similarity between the three sites, in terms of species occurrence, the faunal composition at each site differs through the studied interval and each site responds differently to climatic events through the Miocene. Hole 752A yielded 268 species, of which 143 do not occur at the other two sites; at Hole 1139A 224 species were recorded, 92 of which are only recorded at this site and in Hole 1168A, 331 species are recorded with 189 taxa not present at the two other sites. However, the most abundant taxa in this study occur at all sites, with just a few exceptions. Notably, there appear to be environmentally-cued distributions. For example, *Bolivina huneri* only occurs at Hole 752 and 1168 but does not occur at 1139. *Bolivina dilatata* is recorded at 1139 and 1168 but not at 752. *Bolivina* cf. *reticulata* and *Bolivina viennensis* are recorded at 752 but not at the

other two sites. *Bulimina gibba* is recorded at 1139 but not at either 1168 or 752. A full discussion of the assemblage data and palaeoceanographic implications are deferred to a later contribution. Here we selected the 52 most abundant species, each representing at least 1 % of the total fauna encountered in this study, to describe and illustrate providing an important reference work for foraminiferal studies in the southern Indian Ocean.

**Data availability.** The data used to compile this paper are available at the University of Birmingham eData repository and can be accessed at <https://doi.org/10.25500/edata.bham.00000411> (Ridha et al., 2019).

**Author contributions.** DR has undertaken all sample processing, data collection and analyses under the supervision of IB and KME. All authors have contributed to the writing of the paper.

**Competing interests.** The authors declare that they have no conflict of interest.

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