



# Late Miocene to Early Pliocene benthic foraminifera from the Tasman Sea (International Ocean Discovery Program Site U1506)

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**Abstract.** Modern and fossil benthic foraminifera have been widely documented from New Zealand, but detailed studies of material collected from drilling expeditions in the Tasman Sea are scarcer. This study aims to provide an updated taxonomic study for the Late Miocene–Early Pliocene benthic foraminifera in the Tasman Sea, with a specific focus on the paleoceanographic phenomenon known as the Biogenic Bloom. To achieve these goals, we analysed 66 samples from International Ocean Discovery Program (IODP) Site U1506 located in the Tasman Sea and identified a total of 98 taxa. Benthic foraminifera exhibit good preservation, allowing for accurate taxonomic identification. The resulting dataset serves as a reliable and precise framework for the identification and classification of the common deep-water benthic foraminifera in the region. The paleobathymetric analysis based on depth-dependent species indicates deposition at lower bathyal depths. Additionally, the quantitative analysis of the benthic foraminiferal assemblages allowed us to explore their response to the Biogenic Bloom at Site U1506. The paleoenvironmental analysis, focused on the Early Pliocene part of the Biogenic Bloom, points to high-productivity conditions driven by phytoplankton blooms and intensified vertical mixing of the ocean waters. These results provide valuable insights into the paleoceanographic events in the Tasman Sea, particularly the Biogenic Bloom, highlighting the significance of benthic foraminifera as reliable proxies for deciphering paleoenvironmental conditions. The taxonomic identifications and paleoenvironmental interpretations presented herein will aid in future paleoceanographic studies and facilitate comparisons with other deep-sea regions.

## 1 Introduction

Multiple studies have focused on recent (e.g. Vella, 1957; Eade, 1967; Hayward et al., 1999; Kawagata, 2001; Hayward et al., 2010, and references therein; Martin et al., 2010; Hayward et al., 2013) and fossil benthic foraminifera in New Zealand (e.g. Boersma, 1984a; Hornibrook et al., 1989; Nees, 1994, 1997; Kawagata, 1999; Nees et al., 1999; Hayward, 2002, and references therein; Hayward, 2004; Hayward et al., 2004; Mancin et al., 2013); however, fewer studies have dealt with material collected during ocean drilling expeditions in the Tasman Sea (Boersma, 1986; Kurihara and Ken-

nett, 1986, 1988, 1992; Hayward, 2002; Kender et al., 2016; Kawagata and Kamahashi, 2016; Alegret et al., 2021).

The Tasman Sea has been the focus of three drilling expeditions since the 1970s, namely Deep Sea Drilling Project (DSDP) Leg 21, DSDP Leg 29, and International Ocean Discovery Program (IODP) Expedition 371. Hayward and Buzas (1979) documented the taxonomy and paleoecology of Early Miocene benthic foraminifera from DSDP Site 206 in the New Caledonia Basin. Kurihara and Kennett (1986, 1988, 1992) reported Miocene to recent benthic foraminifera from DSDP Site 206, along with DSDP Sites 588, 590, and 591 in the Lord Howe Rise, to evaluate the paleoceanography of the Tasman Sea (Fig. 1). Boersma (1986) studied Eocene

to Pliocene benthic foraminifera from seven DSDP sites from Leg 90 (586B, 587, 588, 589, 590, 591, and 594). Kender et al. (2016) documented the benthic foraminiferal extinction and paleoenvironmental changes during the Middle Pleistocene at DSDP Site 593 in the Challenger Plateau. More recently, benthic foraminifera recovered during IODP Expedition 371 in the Tasman Sea were documented in the expedition reports (Sutherland et al., 2019b). Their paleodepth interpretation was summarised by Sutherland et al. (2020), and their assemblages are being currently studied in detail, with two quantitative studies published so far on Eocene (Alegret et al., 2021) and Miocene–Pliocene benthic foraminifera (Gastaldello et al., 2023a).

Gastaldello et al. (2023a) focused on the record of the Late Miocene–Early Pliocene Biogenic Bloom at Site U1506 in the Tasman Sea. This paleoceanographic phenomenon occurred between 9 and 3.5 Ma (Farrell et al., 1995; Dickens and Owen, 1999; Diester-Haass et al., 2005) and is characterised by a substantial increase in marine primary productivity, primarily observed in upwelling regions of the Indian and Pacific oceans (Peterson et al., 1992; Berger et al., 1993; Dickens and Owen, 1999; Grant and Dickens, 2002; Lyle et al., 2019). It is important to acknowledge that most quantitative studies on benthic foraminifera in the Tasman Sea (e.g. Hayward and Buzas, 1979; Boersma, 1986; Kurihara and Kennett, 1986, 1988, 1992) pre-date the concept of the Biogenic Bloom, which was first described by Farrell et al. (1995); thus the changes observed in benthic foraminiferal assemblages in these works were not linked to the Biogenic Bloom. This phenomenon has been identified and studied in the Tasman Sea at DSDP Site 590 (Grant and Dickens, 2002), at Ocean Drilling Project (ODP) Site 1172 (Diester-Haass et al., 2006), and at IODP Site U1506 (Sutherland et al., 2022; Gastaldello et al., 2023a). However, there is still much to discover about the regional imprint of the Biogenic Bloom (Farrell et al., 1995; Dickens and Owen, 1999; Grant and Dickens, 2002; Diester-Haass et al., 2005; Drury et al., 2021), and despite the extensive documentation of this event globally (Pillot et al., 2023), our understanding of its driving mechanisms, consequences, and biotic response remains limited.

The study of benthic foraminifera provides a valuable tool for deciphering the evolution of paleoenvironmental conditions at the seafloor (Murray, 2006). Many environmental factors, including bottom water oxygenation, the flux of organic matter to the seafloor, the type and quality of organic matter, and bottom current velocity, influence the abundance of benthic foraminiferal taxa and the composition of their assemblages (Jorissen et al., 2007). These factors, in turn, are shaped by complex local and regional physical, chemical, and biological parameters (Jorissen et al., 2007). In-depth studies of benthic foraminifera have the potential to unveil crucial information about paleoceanographic events such as the Biogenic Bloom, and a strong taxonomic framework and correct species identification are critical for paleoenviron-

mental interpretations and for comparison with other locations.

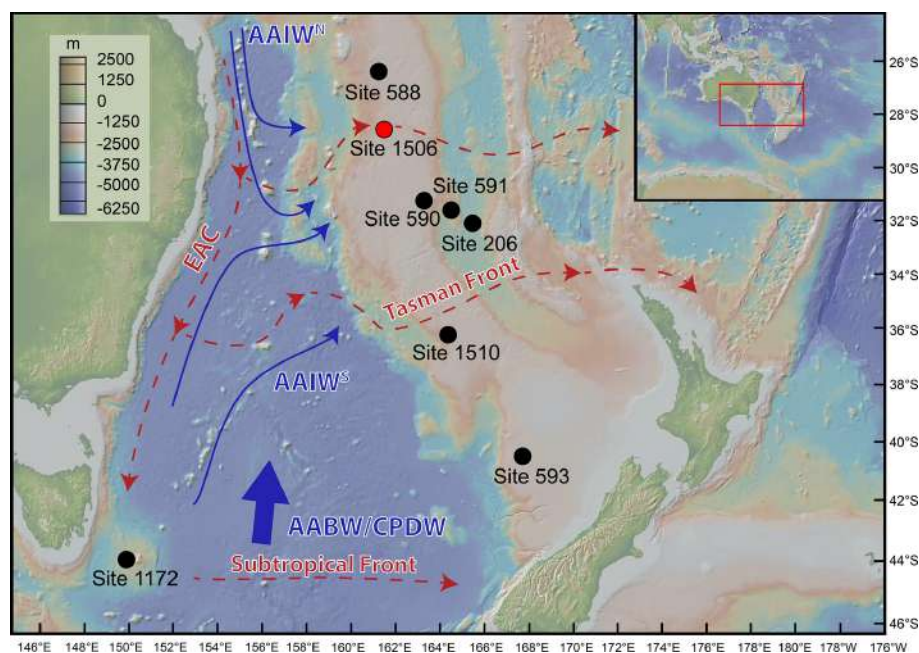
The main objectives of this study are twofold. First, we aim to provide an updated taxonomic assessment for the most common benthic foraminifera found in the Tasman Sea during the Late Miocene–Early Pliocene. This includes examining their distribution in terms of biogeography and temporal patterns. Secondly, we aim to refine the quantitative studies on benthic foraminifera at Site U1506 and to improve the previously made paleoenvironmental and paleoceanographic interpretations from Gastaldello et al. (2023a) to provide new insight into the Biogenic Bloom phenomenon in this region.

## 2 Material and methods

Site U1506 (28.66° S, 161.74° E; 1505 m water depth) was drilled during IODP Expedition 371 in the Tasman Sea (Fig. 1). The drilling operations took place on the northern part of the Lord Howe Rise in the south-western Pacific Ocean (Sutherland et al., 2019a). The paleodepth at Site U1506 from the late Oligocene to the Pleistocene is inferred to have been consistently lower bathyal, 1000–2000 m (Sutherland et al., 2019b). Our study spans a ~140 m thick succession of foraminiferal-bearing nannofossil ooze/chalk from Hole 1506A, covering the Late Miocene to Early Pliocene time interval. Data are plotted on the CSF-A depth scale (core depth below sea floor A; m CSF-A from here on referred to as m). The age model for Site U1506 was developed using orbital tuning of the natural gamma radiation, benthic foraminiferal oxygen isotopes, and calcareous nannofossil biostratigraphy (Gastaldello et al., 2023a).

In this study, benthic foraminifera were analysed in a total of 66 samples from Core U1506A-24R-5W, 64–66 cm (221.75 m) to Core U1506A-10R-1W, 100–102 cm (82.01 m) (Supplement Table S1). The average sampling resolution is 2.2 m, which equals about 40 kyr. The limited recovery of Core 15 results in the lowest sampling resolution between 130 and 140 m (core recovery ~7%; Sutherland et al., 2019b). We revised the taxonomic identifications of the benthic foraminifera analysed in Gastaldello et al. (2023a), and we re-analysed the already-examined residues and the benthic assemblages of five samples between 144.17 and 82.01 m (U1506A-10R-1W, 100–102 cm; U1506A-11R-1W, 105–107 cm; U1506A-11R-3W, 130–132 cm; U1506A-12R-1W, 110–112 cm; U1506A-16R-4W, 126–128 cm). Two additional samples from Site U1506 were prepared and analysed for this study (U1506A-11R-4W, 80–82 cm at 96.05 m and U1506A-11R-3W, 30–32 cm at 94.05 m).

Samples were dried in an oven at 40 °C and weighed to obtain bulk dry sample weight. Subsequently, the samples were disaggregated in water with diluted (NaPO<sub>3</sub>)<sub>6</sub>, sieved to separate the fraction larger than 63 µm, and dried at 40 °C. For each sample, approximately 300 specimens of benthic foraminifera larger than 63 µm were picked and mounted



**Figure 1.** Map of ODP sites where benthic foraminifera assemblages have been studied in the Tasman Sea: DSDP Site 206 (Hayward and Buzas, 1979; Kurihara and Kennett, 1986, 1988, 1992); DSDP Sites 588, 590, and 591 (Kurihara and Kennett, 1986, 1988, 1992); DSDP Site 593 (Kender et al., 2016); IODP Site U1506 (Gastaldello et al., 2023a); and IODP Site U1510 (Alegret et al., 2021). Arrows represent present-day circulation patterns in the Tasman Sea (modified after Gastaldello et al., 2023a). Surface water circulation (dotted red arrows) includes the East Australian Current, the Tasman Front, and the Subtropical Front; intermediate waters (thin blue arrows) include the north (AAIW<sup>N</sup>) and the south (AAIW<sup>S</sup>) Antarctic Intermediate Water. Deep waters (thick blue arrow) include the Antarctic Bottom Water and the Circumpolar Deep Water. Figure made with GeoMapApp (<http://www.geomapp.org>, last access: 3 January 2024).

on microslides for permanent record stored at the University of Zaragoza. A total of 98 taxa (84 calcareous and 14 agglutinated) were recognised at the species or higher taxonomic level. Species identification follows Van Morkhoven et al. (1986), Hermelin (1989), Hayward and Buzas (1979), Hayward et al. (2010, 2013), Kaminski and Gradstein (2005), and Holbourn et al. (2013).

All taxa were allocated to epifaunal or infaunal morphogroups based on their morphology following Corliss (1991), Jones and Charnock (1985), and Corliss and Chen (1988) (Fig. 2). The epifaunal–infaunal ratio was used as a proxy for oxygen levels and trophic conditions on the sea bed, with high relative abundances of infaunal morphogroups associated with eutrophic and/or low oxygen paleoenvironments and oligotrophic conditions and/or high oxygen availability commonly linked to assemblages dominated by epifaunal morphogroups (Jorissen et al., 1995, 2007). The percentage of agglutinated and calcareous taxa was calculated (Fig. 2). To interpret shifts in paleoenvironmental conditions, species with specific paleoecological preferences were categorised as suboxic–dysoxic species (Bernhard, 1986; Kaiho, 1991), opportunistic species (Smart et al., 1994; Erbacher et al., 1999; Fontanier et al., 2002; Hayward et al., 2005; Boscolo Galazzo et al., 2015; Dias et al., 2018), and

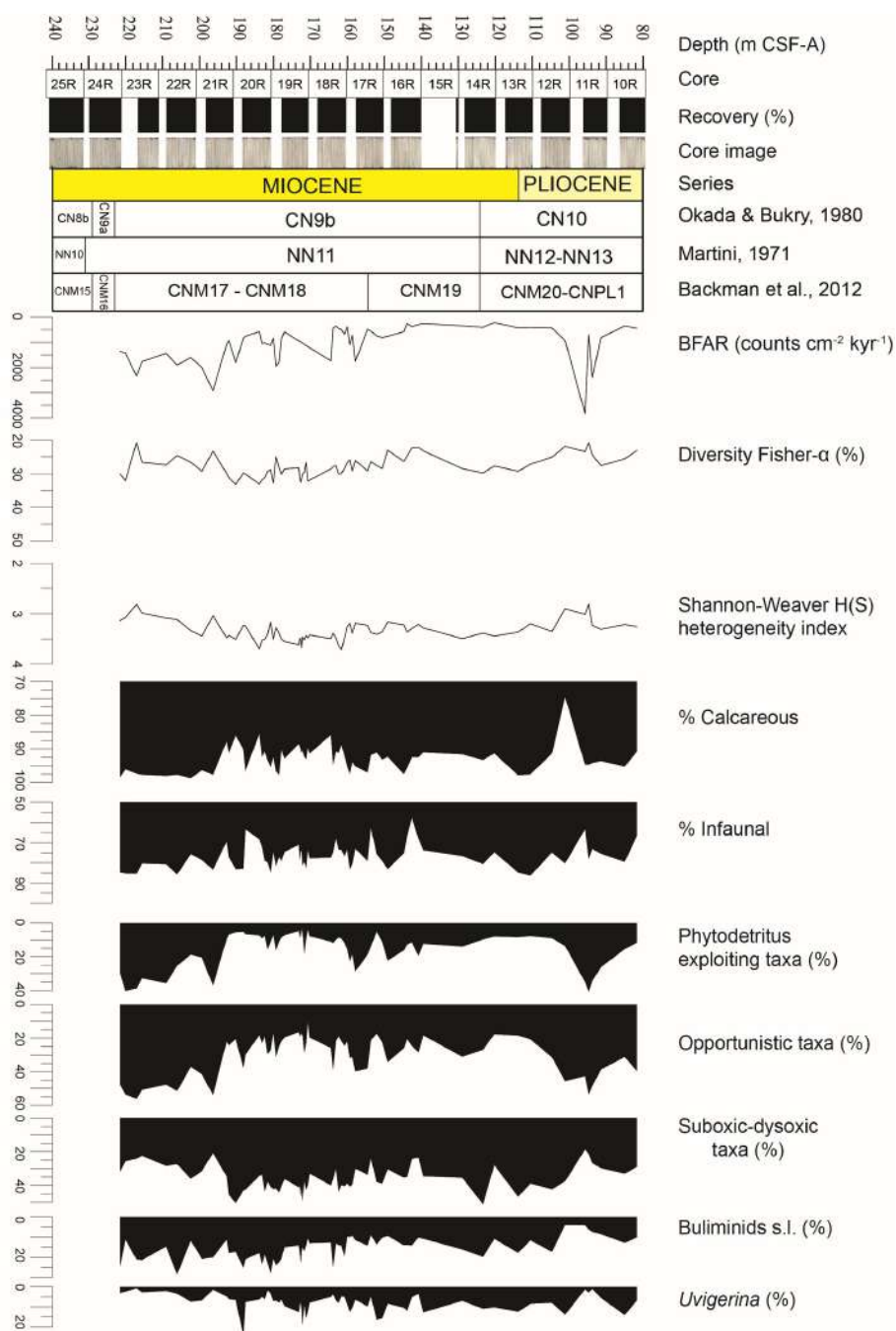
phytodetritus-exploiting taxa (PETs; Gooday, 1988, 1993; Suhr et al., 2003; Jorissen et al., 2007).

To assess changes in diversity and heterogeneity within the benthic foraminiferal assemblages, we calculated the Fisher  $\alpha$  index (Fisher et al., 1943) and the Shannon–Weaver heterogeneity index  $H(S)$  (Shannon, 1948). The benthic foraminiferal accumulation rates (BFARs) were calculated using the equation proposed by Herguera and Berger (1991):

$$\text{BFAR} = (\text{nr g}^{-1} > 63 \mu\text{m} \cdot \text{wt \%} > 63/100) \cdot \text{LSR} \cdot \text{DBD}. \quad (1)$$

The BFAR is expressed as counts  $\text{cm}^{-2} \text{kyr}^{-1}$  (Supplement Table S2), “ $\text{nr g}^{-1} > 63 \mu\text{m}$ ” is the number of benthic foraminifera per gram of sediment  $> 63 \mu\text{m}$ , “ $\text{wt \%} > 63$ ” is the weight percent of the sample  $> 63 \mu\text{m}$ , LSR is the linear sedimentation rate, and DBD is dry bulk density data (Sutherland et al., 2019b). BFAR is considered to be an indicator of export productivity from the surface, and it is used as a proxy for the delivery of food to the seafloor, which is a limiting factor for benthic foraminiferal productivity in the deep ocean (Gooday, 2003; Jorissen et al., 2007).

Species having a relative abundance exceeding  $> 2\%$  in at least one sample (Fig. 3) were described, and the most representative specimens of each species were imaged with a scanning electron microscope at the University of Zaragoza (Zeiss Merlin) and the University of Padova (TESCAN SO-



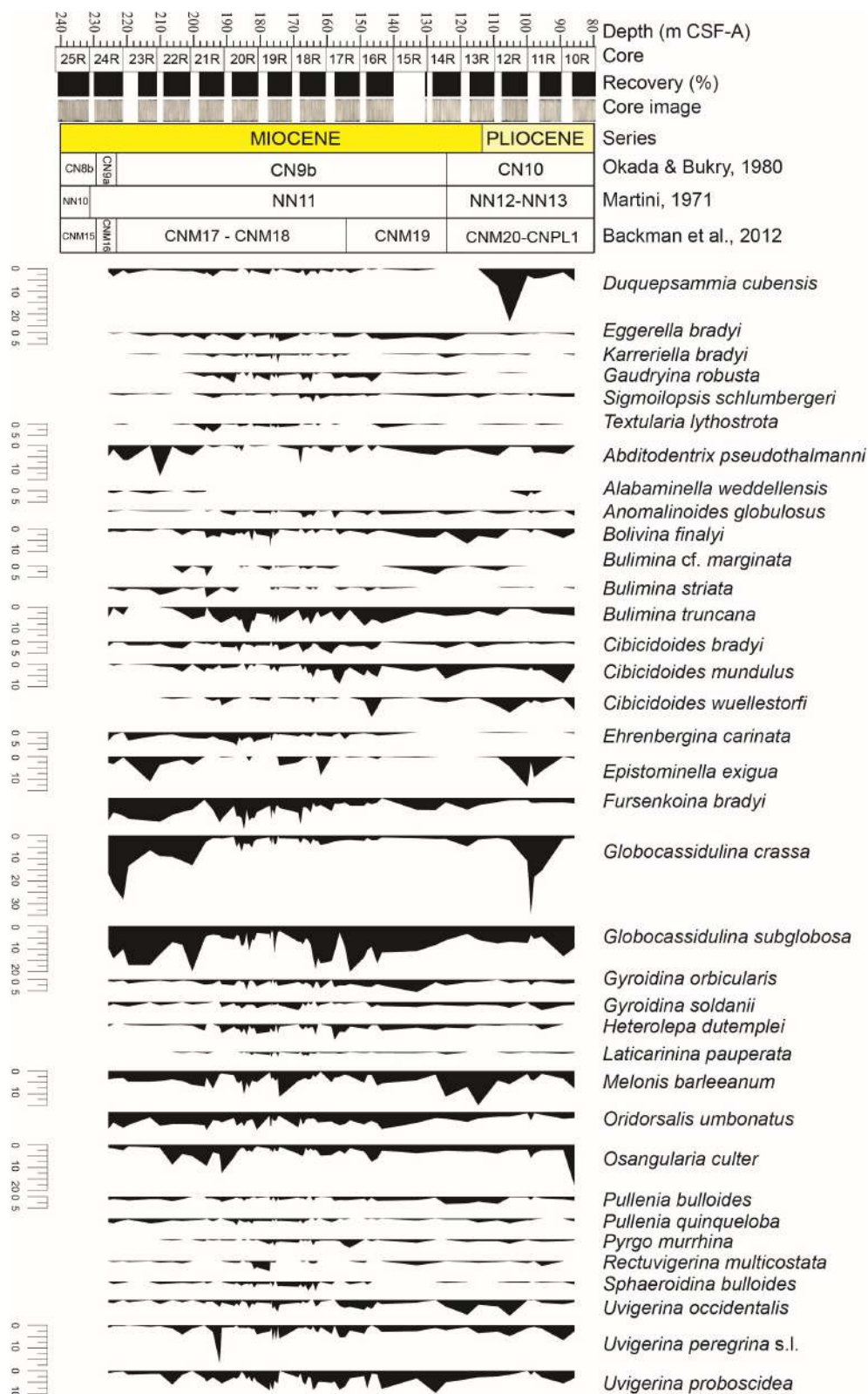
**Figure 2.** Results of quantitative analyses of benthic foraminiferal assemblages across the Late Miocene–Early Pliocene at IODP Site U1506 plotted against depth (m CSF-A). BFARs: benthic foraminiferal accumulation rates. At the top: depth (m CSF-A), core, core recovery (%), and core images. Calcareous nannofossil biozonations (Martini, 1971; Okada and Bukry, 1980; Backman et al., 2012) and chronostratigraphy are also reported.

LARIS) (Figs. 4 to 7). The specimens illustrated are deposited at the Natural Science Museum of the University of Zaragoza (Spain, repository numbers MPZ-2023/333 to MPZ-2023/371).

For taxonomic comparison with the type material, one of us (Laia Alegret) visited the National Paleontological Collec-

tion at GNS Science (Geological and Nuclear Sciences) in Lower Hutt, Wellington (New Zealand); the Cushman Collection at the Smithsonian Institution, National Museum of Natural History (USNM) in Washington DC (USA); and the foraminifera collection at the Natural History Museum (NHM) in London. We compared the specimens examined at





**Figure 3.** Relative abundance (%) of selected benthic foraminiferal taxa (> 2%) at IODP Site U1506 against depth. At the top: depth (m CSF-A), core, core recovery (%), and core images. Calcareous nannofossil biozonations (Martini, 1971; Okada and Bukry, 1980; Backman et al., 2012) and chronostratigraphy are also reported.

these institutions with those found in our samples, enhancing the reliability of our taxonomic investigation.

The bathymetric terminology follows Van Morkhoven et al. (1986) and Hayward et al. (2010): inner shelf (0–50 m), middle shelf (50–100 m), outer shelf (100–200 m), upper bathyal (200–600 m), middle bathyal (600–1000 m), lower bathyal (1000–2000 m), abyssal (2000–6000 m).

### 3 Results

#### 3.1 Benthic foraminifera assemblages

Benthic foraminifera are abundant, the tests are well preserved, and most specimens show fine surface details. All species constituting more than 2 % of the assemblages in at least one sample (36 species in total) are described and commented on in this study (Fig. 3). The diversity of the assemblages (Fisher  $\alpha$  index) ranges between 20 and 33. It generally reaches higher values in the lowermost part of the studied interval between 191.36 and 170.68 m, and it gradually decreases upwards, with a second minor increase between 134.46 and 107.91 m. The Shannon–Weaver heterogeneity index  $H(S)$  ranges between 2.8 and 3.7. It reaches higher values between 185.94 and 161.49 m and a minimum value in the upper part at around 95.05 m (Fig. 2).

At Site U1506, calcareous benthic foraminifera make up 75 %–98 % of the assemblages, and the abundance of agglutinated taxa (on average 5 %–10 % within the assemblage) reaches up to 25 % in only one sample (U1506A-12R-1, 110–112 cm, 101.41 m). Infaunal morphogroups dominate over the epifaunal ones, and their abundance typically ranges between 65 % and 85 % (Fig. 2). The infaunal group includes taxa such as *Bulimina truncana*, *Fursenkoina bradyi*, *Globocassidulina crassa*, *Globocassidulina subglobosa*, *Oridorsalis umbonatus*, and *Uvigerina proboscidea*, as well as the calcareous elongate uniserial foraminifera (e.g. *Nodosaria* and *Stilostomella* groups). All the agglutinated foraminifera recovered at Site U1506 belong to infaunal morphogroups (e.g. *Eggerella*, *Karreriella*, *Textularia*). Only one sample (U1506A-16R-3, 140–142 cm, 142.81 m) contains more than 40 % of epifaunal taxa, mainly *Cibicidoides wuellerstorfi*, *Cibicidoides mundulus*, and *Osangularia culter*.

Overall BFARs show high values (ca. 800–1000) in the lower and top parts of the study interval, with the highest values (ca. 2000–3000) recorded between 98.73 and 92.91 m. The lowest values (ca. 200–400) are recorded between 144.61 and 103.21 m.

#### 3.2 Taxonomy

This section presents systematic descriptions of the species whose relative abundance is > 2 % in at least one sample across the study interval at Site U1506. For each species, we included a synonymy list, taxonomic details, descriptions, re-

marks on taxonomy, and paleoecological and paleobathymetric notes.

Family Duquepsammiidae Seiglie and Baker, 1987

Genus *Duquepsammia* Seiglie and Baker, 1987

*Duquepsammia cubensis* (Cushman and Bermúdez, 1937)  
Fig. 4: 1a–c

1937 *Spiroplectoides cubensis* Cushman and Bermúdez, pl. 1, figs. 44–45

1985 *Bolivinopsis cubensis* (Cushman and Bermúdez); Thomas, pl. 1, fig. 1

1986 *Bolivinopsis cubensis* (Cushman and Bermúdez); Boersma et al., pl. 3, figs. 1–2

1989 *Bolivinopsis cubensis* (Cushman and Bermúdez); Hornibrook et al., pl. 15, fig. 5

2005 *Duquepsammia cubensis* (Cushman and Bermúdez); Kaminski and Gradstein, pl. 102, figs. 1–8

**Description.** Test free, elongate, initially planispiral, later biserial, rhomboidal in cross-section. The planispiral part of the test is wider than the biserial part. Sutures are slightly depressed, inclined at ca. 60° in the biserial part. The peripheral margin is acute. Wall finely agglutinated. The aperture is an interiomarginal slit.

**Remarks.** Despite the known stratigraphic range of *D. cubensis* spanning from the Late Eocene to the Late Miocene (Seiglie and Baker, 1987), the specimens found in the Early Pliocene at Site U1506 perfectly match the description by Kaminski and Gradstein (2005). Preservation ranges from moderately good (fully complete tests) to broken tests that typically miss the planispiral portion. Our specimens closely resemble *Spiroplectammia spectabilis* (Grzybowski, 1898) emend. Kaminski; however, *S. spectabilis* goes extinct at the end of the Paleocene (Kaiho et al., 1996). Moreover, the spiral part of *S. spectabilis* is less developed and with less chambers per whorl compared to the genus *Duquepsammia* (Seiglie and Baker, 1987).

**Paleoecology and paleobathymetric distribution.** This deep-water agglutinated taxon has been commonly documented from middle bathyal to abyssal water depths (Kaminski and Gradstein, 2005). *Duquepsammia cubensis* has been documented in sediments of lower–middle bathyal depths from the Chatham Rise, east of New Zealand (Kennett and Casey, 1969).

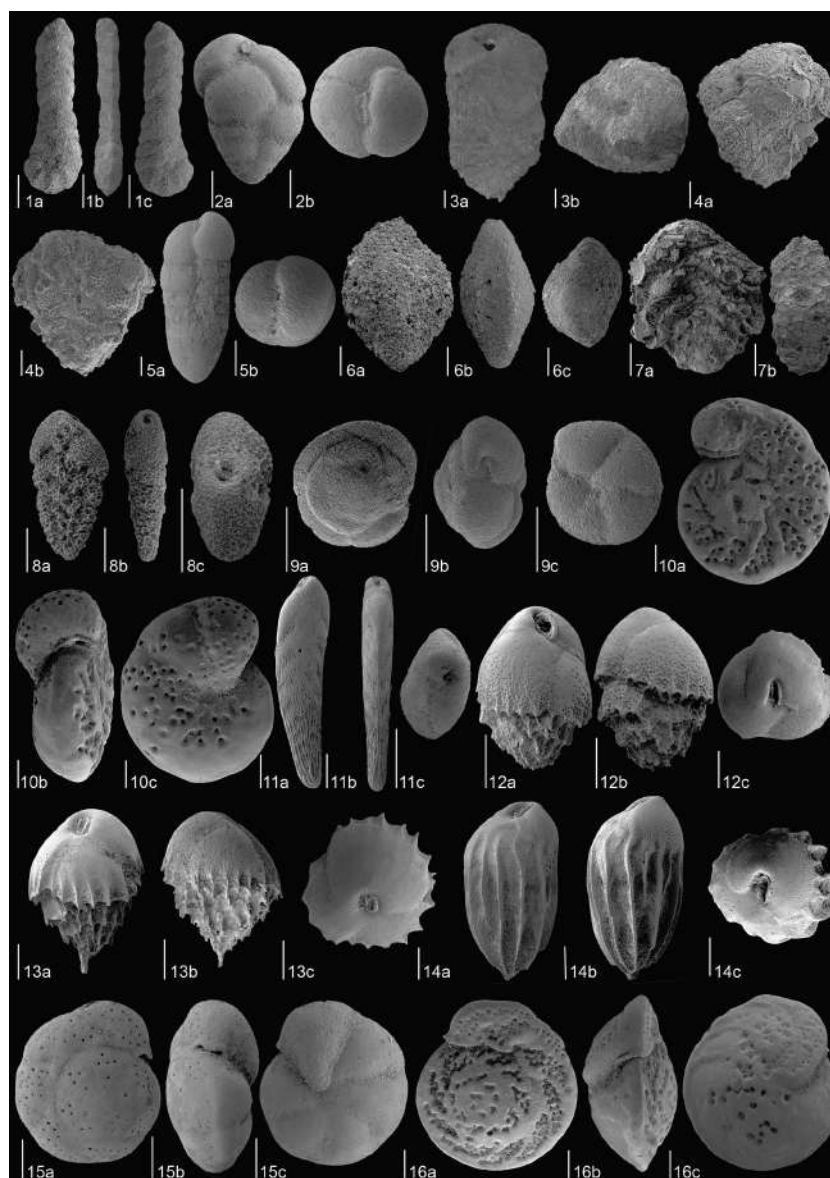
Family Eggerellidae Cushman 1937

Genus *Eggerella* Cushman 1933

*Eggerella bradyi* (Cushman 1911)  
Fig. 4: 2a–b

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

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



**Figure 4.** SEM images of the most common benthic foraminiferal species at Site U1506 identified in the Late Miocene–Early Pliocene. **(1)** *Duquepsammia cubensis* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/338: (a) frontal side, (b) side view, (c) dorsal side. **(2)** *Eggerella bradyi* (sample U1506A-21R-2W, 50–52 cm), MCNUZ-MPZ-2023/333: (a) frontal side, (b) outline view. **(3)** *Karrieriella bradyi* (sample U1506A-21R-2W, 50–52 cm), MCNUZ-MPZ-2023/334: (a) frontal side, (b) outline view. **(4)** *Gaudryina robusta* adult (sample U1506A-18R-4W, 125–127 cm), MCNUZ-MPZ-2023/335: (a) frontal side, (b) outline view. **(5)** *Gaudryina robusta* juvenile (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/336: (a) frontal side, (b) lateral side. **(6)** *Sigmilopsis schlumbergeri* (sample U1506A-13R-1W, 110–112 cm), MCNUZ-MPZ-2023/337: (a) dorsal side, (b), side view, (c) outline view. **(7)** *Textularia lythostrota* (sample U1506A-21R-2W, 50–52 cm), MCNUZ-MPZ-2023/339: (a) frontal view, (b), outline view. **(8)** *Abitrodentrix pseudothalmannii* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/340: (a) frontal view, (b), side view, (c) outline view. **(9)** *Alabaminella weddellensis* (sample U1506A-23R-3W, 78–80 cm), MCNUZ-MPZ-2023/341: (a) dorsal side, (b), side view, (c) ventral side. **(10)** *Anomalinoidea globulosus* (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/342: (a) dorsal side, (b), side view, (c) ventral side. **(11)** *Bolivina finlayi* (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/343: (a) frontal view, (b) side view, (c) outline view. **(12)** *Bulimina* cf. *marginata* (sample U1506A-21R-4W, 140–142 cm), MCNUZ-MPZ-2023/345: (a) frontal side, (b) dorsal side, (c) outline view. **(13)** *Bulimina striata* (sample U1506A-19R-4W, 97–99 cm), MCNUZ-MPZ-2023/346: (a) frontal side, (b) dorsal side, (c) outline view. **(14)** *Bulimina truncana* (sample U1506A-21R-4W, 140–142 cm), MCNUZ-MPZ-2023/347: (a) frontal side, (b) dorsal side, (c) outline view. **(15)** *Cibicides bradyi* (sample U1506A-11R-4W, 80–82 cm), MCNUZ-MPZ-2023/348: (a) dorsal side, (b), side view, (c) ventral side. **(16)** *Cibicides mundulus* (sample U1506A-10R-3W, 130–132 cm), MCNUZ-MPZ-2023/349: (a) dorsal side, (b), side view, (c) ventral side. All scale bars = 100  $\mu$ m, except for (9a–c), which have a scale bar = 50  $\mu$ m.



- 1951 *Eggerella bradyi* (Cushman); Phleger and Parker, p. 6, pl. 3, figs. 1–2  
 1986 *Eggerella* sp. (Cushman); Kurihara and Kennett; pl. 1, figs. 4–5  
 1987 *Eggerella bradyi* (Cushman); Loeblich and Tappan, p. 170, pl. 189, figs. 1–2  
 1998 *Eggerella bradyi* (Cushman); Robertson, p. 24, pl. 3, fig. 4  
 2010 *Eggerella bradyi* (Cushman); Hayward et al., p. 144, pl. 5, figs. 23–24  
 2013 *Eggerella bradyi* (Cushman); Holbourn et al., p. 232, figs. 1–4  
 2019 *Eggerella bradyi* (Cushman); Ridha et al., p. 222, fig. 8: 6a–b

**Description.** Test nearly conical, triserial, highly inflated chambers larger in the adult portion. Chambers are separated by narrow, depressed sutures. Wall smooth and finely agglutinated. The aperture is an elongated slit close to the base of the apertural face, surrounded by a small lip.

**Remarks.** The morphology of specimens retrieved at Site U1506 is consistent with the description provided for the holotype (USNM PP 26281) in the original description by Cushman (1911). Hermelin (1989) reported morphologic variants of *E. bradyi* in the western equatorial Pacific Ocean, with tests ranging from conical to cylindrical. Specimens at Site U1506 show conical forms and good preservation.

**Paleoecology and paleobathymetric distribution.** *Eggerella bradyi* is considered to be a cosmopolitan species, mostly found at bathyal and abyssal depths (Ingle and Keller, 1980). Hayward et al. (2010) reported it to be typical at lower bathyal depths (1000–2000 m) around New Zealand.

Family Verneulinidae Cushman, 1911

Genus *Gaudryina* d'Orbigny, 1839

*Gaudryina robusta* Cushman, 1913

Fig. 4: 3a–b; 4a–b

- 1913 *Gaudryina robusta* Cushman; p. 78, figs. 2a–c  
 1921 *Gaudryina robusta* Cushman; Cushman, p. 152, pl. 30, figs. 1a–c  
 1968 *Gaudryina robusta* Cushman; Chiji et al., pl. 7, fig. 4

**Description.** Large test, initially triserial and with triangular outline. In the last portion, it becomes biserial with slightly inflated chambers. Wall coarsely agglutinated. Sutures are slightly depressed. The aperture is a small opening located in the inner margin of the last chamber.

**Remarks.** Specimens found at Site U1506 are consistent with the original description of *G. robusta* by Cushman (1913). Juvenile specimens show more triangular tests with flat last chambers (Fig. 4: 4). Adult specimens present more inflated and biserial chambers in the last portion of the test (Fig. 4: 3). The preservation is fairly good, and the tests observed are typically complete.

Family Eggerellidae Cushman 1937

Genus *Karreriella* Cushman 1933

*Karreriella bradyi* (Cushman 1911)

Fig. 4: 5a–b

- 1911 *Gaudryina bradyi* Cushman; p. 67, text fig. 107  
 1921 *Gaudryina bradyi* Cushman; Cushman, p. 149, pl. 29, fig. 3  
 1960 *Karreriella bradyi* (Cushman); Barker, pl. 46, figs. 1–4  
 1994 *Karreriella bradyi* (Cushman); Loeblich and Tappan, p. 25, pl. 30, figs. 8–16  
 1994 *Karreriella bradyi* (Cushman); Jones, pl. 46, figs. 1–4  
 2002 *Karreriella bradyi* (Cushman); Hayward, p. 288, pl. 2, fig. 1  
 2002 *Karreriella bradyi* (Cushman); Kuhnt et al., p. 130, pl. 5, figs. 1–2, 14  
 2010 *Karreriella bradyi* (Cushman); Hayward et al., pl. 5, figs. 25–27  
 2013 *Karreriella bradyi* (Cushman); Holbourn et al., p. 318, figs. 1–4

**Description.** Test elongate, triserial in the early stage, biserial in the adult part. Chambers are inflated and divided by depressed sutures. Wall finely agglutinated. The aperture is an elongated slit at the base of the apertural face, and it is surrounded by a lip.

**Remarks.** The original description by Cushman (1911) and the examination of two specimens belonging to *K. bradyi* (Challenger Expedition, ZF1452 and ZF1453) at the NHM allow us to ascribe our specimens to this taxon. Specimens from Site U1506 are well preserved, tests are moderately large, and the last chamber tends to be more inflated as compared to the early chambers.

**Paleoecology and paleobathymetric distribution.** Around New Zealand, forms of *K. bradyi* have been found at middle bathyal to abyssal depths (500–4000 m; Hayward et al., 2010). It has been reported to typically occur in oligotrophic deep-water environments in the South China Sea (Kuhnt et al., 1999).

Family Hauerinidae Schwager 1876

Genus *Sigmoilopsis* Finlay, 1947

*Sigmoilopsis schlumbergeri* (Silvestri 1904)

Fig. 4: 6a–c

- 1884 *Planispira celata* (Costa); Brady, p. 197, pl. 8, figs. 1–4  
 1904 *Sigmoilina schlumbergeri* Silvestri, p. 267, 269, illustrated in Schlumberger, 1887, pl. 7, figs. 12–14, text figs. 6–7  
 1986 *Sigmoilopsis schlumbergeri* (Silvestri); Van Morkhoven et al., pl. 18, figs. 1a–e



- 1986 *Sigmoilopsis schlumbergeri* (Silvestri); Kurihara and Kennett; pl. 1, figs. 11–12  
 1987 *Sigmoilopsis schlumbergeri* (Silvestri); Loeblich and Tappan, pl. 356, figs. 8–13  
 1994 *Sigmoilopsis schlumbergeri* (Silvestri); Jones, pl. 8, figs. 1–4  
 2010 *Sigmoilopsis schlumbergeri* (Silvestri); Hayward et al., pl. 9, figs. 12–16  
 2013 *Sigmoilopsis schlumbergeri* (Silvestri); Holbourn et al., p. 506, figs. 1–2

**Description.** Moderately large, elongate and ovate test, relatively compressed in the side view. Initially, the chambers have a quinqueloculine arrangement, but then the angle between planes of coiling between successive chambers quickly increases, leading first to a sigmoid appearance in section. Subsequently, the arrangement shifts to a biserial pattern, where the chambers are positioned nearly opposite each other. The aperture is circular with a lip and a simple tooth, located at the end of a short neck. Wall agglutinated with calcareous cement, coated with small- to medium-sized grains.

**Remarks.** Our specimens are large, and the centre is typically coated by darker grains with occasionally some lighter stripes, while the periphery contains lighter grains. The wall includes sand grains and calcareous nannofossils. Most of the specimens of *S. schlumbergeri* observed at Site U1506 are typically broken along the periphery of the test and in the neck area. *Sigmoilopsis schlumbergeri* closely resembles *Sigmoilopsis celata* (Costa); the distinction is mainly based on the periphery and the sutures. Our specimens present defined sutures, and, in the intact specimens, an acute periphery was observed, characteristics reported for *S. schlumbergeri* (Van Morkhoven et al., 1986).

**Paleoecology and paleobathymetric distribution.** Documented commonly in middle bathyal to abyssal depths around New Zealand (Hayward et al., 2010). In the Gulf of Mexico, it has been reported to be most common in the upper part of the middle bathyal zone (Phleger and Parker, 1951).

Family Textulariidae Ehrenberg, 1838

Genus *Textularia* DeFrance, 1824

*Textularia lythostrota* (Schwager 1866)

Fig. 4: 7a–b

- 1866 *Placanium lythostrotum* Schwager: p. 194, pl. 4, fig. 4a–c  
 1986 *Textularia lythostrota* (Schwager); Kurihara and Kennett, pl. 1, figs. 1–2  
 1989 *Textularia lythostrota* (Schwager); Hermelin, pl. 1, figs. 2–5  
 1994 *Textularia lythostrota* (Schwager); Gupta, pl. 1, figs. 4, 15  
 2010 *Textularia lythostrota* (Schwager); Hayward et al., pl. 6, figs. 26–29

**Description.** Large, biserial test with maximum width and thickness close to the aperture, compressed in side view. Periphery rounded and lobulated. Chambers are at an angle of ca. 45°, divided by deeply depressed sutures. Coarsely agglutinated wall. The aperture is a small arch situated at the base of the last chamber.

**Remarks.** Specimens documented at Site U1506 are characterised by large tests, and the wall is coarsely agglutinated and includes biogenic grains such as calcareous nannofossils and broken pieces of planktonic foraminifera.

Family Bolivinitidae Cushman 1927

Genus *Abditodentrix* Patterson 1985

*Abditodentrix pseudothalmanni* (Boltovskoy and de Kahn 1981)

Fig. 4: 8a–c

- 1981 *Bolivinita pseudothalmanni* Boltovskoy and Guissani De Kahn: p. 44  
 1985 *Abditodentrix asketocomptella* Patterson, p. 140, pl. 1, figs. 1–9  
 1987 *Abditodentrix pseudothalmanni* (Boltovskoy and Guissani De Kahn); Loeblich and Tappan, pl. 554, figs. 1–2  
 1989 *Abditodentrix asketocomptella* (Patterson); Hermelin, pl. 10, fig. 16  
 1999 *Abditodentrix pseudothalmanni* (Boltovskoy and Guissani De Kahn); Kawagata, figs. 4–6  
 1989 *Abditodentrix asketocomptella* (Patterson); Hermelin, pl. 10, fig. 16  
 2010 *Abditodentrix pseudothalmanni* (Boltovskoy and Guissani De Kahn); Hayward et al., pl. 17, figs. 11–12  
 2019 *Abditodentrix pseudothalmanni* (Boltovskoy and Guissani De Kahn); Ridha et al., fig. 3: 9a–b

**Description.** Test elongate, biserial, flattened in side view with truncate edges, and rectangular in cross-section. Elongated chambers and depressed sutures. Terminal aperture with a toothplate on one side. Surface densely ornamented with reticulated costae.

**Remarks.** The identification of *A. pseudothalmanni* was based on the original description of *Abditodentrix asketocomptella* Patterson (1985), which is considered a junior synonym of *A. pseudothalmanni* by Loeblich and Tappan (1988). According to Hayward et al. (2010), *Abditodentrix* is distinguished from species belonging to *Bolivina* by having a rectangular cross-section. Our specimens show good preservation and rectangular cross-section; the tests are small, and the last two chambers tend to be slightly bigger and more inflated compared to the chambers in the early portion.

**Paleoecology and paleobathymetric distribution.** *Abditodentrix* is a close relative of *Bolivina* and most likely shares a similar infaunal lifestyle. This taxon has been reported to

occur in high-productivity environments with low-dissolved-oxygen concentrations (Hayward et al., 2002). At several sites located in the waters around New Zealand, it has been documented from middle shelf to abyssal, with peak abundance at bathyal depths (400–1500 m; Hayward et al., 2010).

Family Eponididae Hofker 1951

Genus *Alabaminella* Saidova 1975

*Alabaminella weddellensis* (Earland 1936)

Fig. 4: 9a–c

1936 *Eponides weddellensis* Earland: p. 57

1975 *Alabaminella weddellensis weddellensis* (Earland); Saidova, pl. 108, fig. 1

1986 *Epistominella rotunda* (Husezima and Maruhasi); Kurihara and Kennett; pl. 4, figs. 4–8

1987 *Alabaminella weddellensis* (Earland); Loeblich and Tappan, pl. 593, figs. 18–22

2001 *Alabaminella weddellensis* (Earland); Hayward et al., figs. 15U–W

2003 *Alabaminella weddellensis* (Earland); Hayward et al., figs. 4O–Q

2010 *Alabaminella weddellensis* (Earland); Hayward et al., pl. 25, figs. 20–22

2015 *Alabaminella weddellensis* (Earland); Boscolo Galazzo et al., pl. 1, figs. 6–10

**Description.** Test small, biconvex trochospiral, the spiral side more convex than the umbilical side. Chambers broad and low, five to six in the last whorl. Rounded periphery. The sutures are depressed and radial on the umbilical side and oblique on the spiral side. The test wall is calcareous, smooth, and finely perforated. The aperture is a small oblique interiomarginal and extraumbilical slit.

**Remarks.** Specimens found in the study material agree with the original description by Earland (1936). The preservation is moderately good, with the fine perforation of the wall and the depressed sutures reported in the literature visible in most of the specimens.

**Paleoecology and paleobathymetric distribution.** *Alabaminella weddellensis* has been suggested to have an opportunistic behaviour, and it is included in phytodetritus-exploiting taxa. It is used as a proxy for a high seasonal supply of organic carbon flux linked to seasonal phytoplankton blooms (Gooday, 1993; Smart et al., 1994). Hayward et al. (2010) reported *A. weddellensis* to be abundant at all depths from middle shelf to abyssal around New Zealand (85–5000 m).

Family Anomalinidae Cushman 1927

Genus *Anomalinoides* Brotzen 1942

*Anomalinoides globulosus* (Chapman and Parr 1937)

Fig. 4: 10a–c

1884 *Anomalina grosserugosa* (von Gümbel); Brady, p. 673, pl. 94, figs. 4–5

1937 *Anomalina globulosa* Chapman and Parr, p. 117, pl. 9, fig. 27

1953 *Anomalina* sp.; Phleger, Parker and Pierson, p. 48, pl. 10, figs. 26–28

1986 *Anomalinoides globulosus* (Chapman and Parr); Van Morkhoven et al., p. 36, pl. 9

1994 *Anomalinoides globulosus* (Chapman and Parr); Jones, p. 98, pl. 94, figs. 4–5

2013 *Anomalinoides globulosus* (Chapman and Parr); Holbourn et al., p. 52, figs. 1–3

**Description.** Test large, low trochospiral, inflated, with rounded periphery. The spiral side is moderately evolute and slightly convex, and the umbilical side is more convex and involute. The sutures are depressed and curved. The wall is calcareous and perforated, with larger pores on the spiral side. Aperture peripheral with a low equatorial arch bordered by a thick lip.

**Remarks.** At Site U1506, specimens are typically broken, missing the last chambers; the perforations are commonly well-preserved, with pores visible on both sides. In this study, we identified two morphotypes of *A. globulosus*: morphotype A perfectly fits the original description of *A. globulosus*; morphotype B is a flatter morphotype of *A. globulosus*. Most specimens of *A. globulosus* identified at Site U1506 belong to morphotype B, they are flatter than the type material, they have more chambers in the final whorl, and the last two chambers are moderately inflated. The pores are large on both sides; the sutures on the dorsal side are limbate, apart from the ones in the last chambers, which are flush to slightly depressed. Boersma (1984b) noted a flatter form of *Anomalinoides globulosus* in the south-western Pacific at intermediate depth (< 1000 m) that closely resembles the morphology depicted as *Anomalina grosserugosa* in Brady (1884) and agrees with our *A. globulosus* morphotype B.

**Paleoecology and paleobathymetric distribution.** This cosmopolitan species has been documented at middle bathyal to abyssal depths (Pflum and Frerichs, 1976; Van Morkhoven et al., 1986). Boersma (1984b) observed a flatter morphotype of *A. globulosus* at intermediate depths (ca. 1000 m) in the south-western Pacific.

Family Bolivinidae Glaessner 1937

Genus *Bolivina* d'Orbigny 1839

*Bolivina finlayi* Hornibrook 1961

Fig. 4: 11a–c

1961 *Bolivina finlayi* Hornibrook, pl. 9, figs. 169–171

1979 *Bolivina finlayi* Hornibrook; Hayward and Buzas, pl. 6, fig. 67

1989 *Bolivinita finlayi* Kennett; Hornibrook et al., p. 159, fig. 38

2004 *Bolivina finlayi* Hornibrook; Hayward, fig. 2P

**Description.** Test elongate, ovoid to triangular in outline, compressed. Chambers numerous (18–20), elongated, biserial, slightly inflated; suture slightly depressed. The early portion of the test presents numerous longitudinal striae up to and beyond the half length of the test, finely perforated; the final chamber is smooth and sparsely perforated. Slit-like aperture.

**Remarks.** The specimens found at Site U1506 are well preserved. The fine longitudinal striae, which extend across approximately half the length of the test, are difficult to observe under a microscope but are visible in the SEM images (Fig. 7: 1). This species is similar to *Bolivina punctatos-triata* (Kreuzberg, 1930), but our specimens lack the typical strongly curved sutures of *B. punctatos-triata*. Moreover, *B. punctatos-triata* is restricted to shelf depths around New Zealand (Hayward and Buzas, 1979). This species is also similar to *Bolivina striatula* (Cushman, 1922), but *B. striatula* present striae only in the lower half of the test and are highly perforated.

Family Buliminidae Jones 1875

Genus *Bulimina* d'Orbigny 1826

*Bulimina* cf. *marginata* d'Orbigny 1826

Fig. 4: 12a–c

1826 *Bulimina marginata* d'Orbigny: p. 269, n. 4, pl. 12, figs. 10–12

1999 *Bulimina marginata* f. *marginata* d'Orbigny; Hayward et al., pl. 9, fig. 5.

2008 *Bulimina marginata* d'Orbigny; Kender et al., p. 553, pl. 17, figs. 10–11

2010 *Bulimina marginata* f. *marginata* d'Orbigny; Hayward et al., pl. 17, figs. 23–24

**Description.** Test triserial and elongate, conical in outline and rounded in cross-section. Chambers rapidly increase in size and are larger and inflated close to the apertural end. The chamber margins are fringed with typical short spines. The sutures are distinct and depressed. The wall is calcareous and smooth. A short spine is often observed in the apical end. Loop-shaped aperture, with a lip.

**Remarks.** The holotype of *B. marginata* was not available at the USNM, but we examined the holotypes of *B. marginata grandissima* Martin (1952) (USNM 237467) and *Bulimina marginata tessellata* Cushman and Todd (1945) (USNM CC 44419), and both varieties show clear spines at the base of the chambers. *Bulimina marginata* is known for its high variability, with three forms documented in its type area, the Adriatic Sea, by Jorissen (1988) and two additional forms recognised in New Zealand by Hayward et al. (2010). Our specimens closely resemble the description of *B. marginata marginata* (Jorissen, 1988), characterised by an elongated test and undercut margins with short spines. The preservation of *B. marginata* is generally good at Site U1506.

**Paleoecology and paleobathymetric distribution.** *Bulimina marginata* is considered to be a cosmopolitan species (Murray, 1991). Around New Zealand this taxon occurs with the highest abundance at shelf and bathyal depths (0–2000 m; Hayward et al., 2010). Along with other *Bulimina* species, *B. marginata* is associated with low-oxygen conditions at the seafloor (Fontanier et al., 2002).

Family Buliminidae Jones 1875

Genus *Bulimina* d'Orbigny 1826

*Bulimina striata* d'Orbigny 1843

Fig. 4: 13a–c

1826 *Bulimina costata* d'Orbigny; pl. 18, fig. 1 (nomen nudum)

1843 *Bulimina striata* d'Orbigny in Guérinméneville, p. 9, pl. 2, fig. 16

1852 *Bulimina costata* d'Orbigny; d'Orbigny, p. 194

1986 *Bulimina mexicana* Cushman; Van Morkhoven et al., p. 61, pl. 19, figs. 1–4

1986 *Bulimina striata* d'Orbigny; Kurihara and Kennett, pl. 2, fig. 13

1994 *Bulimina striata* d'Orbigny; Loeblich and Tappan, pl. 242, figs. 8–14

2005 *Bulimina striata* d'Orbigny; Vénec-Peyre, p. 157, pl. 18, fig. 1

2010 *Bulimina striata* d'Orbigny; Hayward et al., pl. 17, figs. 25–27

2019 *Bulimina striata* d'Orbigny; Ridha et al., fig. 3: 13

**Description.** Test elongate, triserial, conical in side view. Rounded apertural end, acute apical end, subcircular in cross-section. Chambers are inflated and increase rapidly in size, separated by depressed sutures. Wall calcareous, ornamented with longitudinal costae that extend from the external margin and create short spines. The aperture is loop-shaped and extends up from the base of the final chamber; a lip merged with an internal toothplate is present and borders the aperture (Fig. 7: 2).

**Remarks.** In our material, the costae are not long and end as short spines at the margin of the chamber. The best-preserved specimens present a short spine in the apical end.

**Paleoecology and paleobathymetric distribution.** *Bulimina striata* is a shallow infaunal species interpreted as an indicator of suboxic conditions (Kaiho, 1994), and it has been linked to high-productivity conditions (Russo et al., 2007). In the Gulf of Mexico, it is dominant in the upper part of the middle bathyal zone (Bandy, 1961). Around New Zealand, *B. striata* occurs mostly outer shelf to the upper abyssal, with its greatest abundance between 200–2000 m (Hayward et al., 2010).

Family Buliminidae Jones 1875

Genus *Bulimina* d'Orbigny 1826



*Bulimina truncana* von Gümbel 1868

Fig. 4: 14a–c

- 1868 *Bulimina truncana* von Gümbel; p. 644, pl. 2, figs. 77a–b  
 1884 *Bulimina rostrata* Brady; p. 408, pl. 51, figs. 14–15  
 1979 *Bulimina truncana* von Gümbel; Hayward and Buzas p. 45, pl. 7, figs. 87–88  
 1986 *Bulimina rostrata* Brady; Kurihara and Kennett, pl. 2, figs. 12–13  
 1991 *Bulimina alazanensis* Cushman; Schroder-Adams, p. 624, pl. 1, fig. 5  
 1999 *Bulimina truncana* von Gümbel; Kawagata, fig. 5–7  
 2001 *Bulimina truncana* von Gümbel; Hayward et al., figs. 14DD–EE  
 2010 *Bulimina truncana* von Gümbel; Hayward et al., pl. 17, figs. 28–29  
 2019 *Bulimina truncana* von Gümbel; Ridha et al., fig. 3: 10a–b

**Description.** Test triserial, elongate, sub-triangular in cross-section. The apertural end is rounded and pointed in the apical end. The test has the greatest width near the apertural end. The chambers are concealed by surface ornamentations. Wall calcareous, finely perforated, with marked longitudinal costae occurring almost throughout the test. The final chambers are smooth. The costae form a spinose protuberance in the initial portion. Loop-shaped aperture with an internal tooth plate.

**Remarks.** Our specimens agree with the original description of von Gümbel (1868) and with the description of Hayward et al. (2010). At Site U1506, *B. truncana* presents typically elongate tests with distinct continuous costae; the aperture is loop-shaped; and, in the specimens with good preservation, the internal tooth plate can be observed (Fig. 7: 3a–b).

**Paleoecology and paleobathymetric distribution.** This cosmopolitan species (von Gümbel, 1868) has been documented around New Zealand from upper bathyal to abyssal depths, with the highest abundance at middle to lower bathyal depths (700–2000 m; Hayward et al., 2010).

Family Cibicididae Cushman 1927

Genus Cibicoides Thalmann 1939

*Cibicoides bradyi* (Trauth 1918)

Fig. 4: 15a–c

- 1918 *Truncatulina bradyi* Trauth, p. 235  
 1976 *Cibicoides bradyi* (Trauth); Pflum and Frerichs, pl. 3, figs. 6–7  
 1989 *Cibicoides bradyi* (Trauth); Hermelin, pl. 17 figs. 2–4  
 1994 *Gyroidina bradyi* (Trauth); Jones, p. 99, pl. 95, fig. 5  
 1999 *Cibicoides bradyi* (Trauth); Kawagata, fig. 7.1  
 2010 *Cibicides bradyi* (Trauth); Hayward et al., pl. 22, figs. 1–3

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

2019 *Cibicoides bradyi* (Trauth); Ridha et al., fig. 8: 1a–b

**Description.** Test trochospiral, unequally biconvex, periphery rounded without a keel. Umbilical side involute, spiral side evolute. Chambers inflated, six to eight per whorl. Wall calcareous, coarsely perforated on the spiral side, finely perforated on the umbilical side. Sutures are radial on the umbilical side and oblique to slightly curved on the spiral side. The aperture is a small slit that extends from the periphery to the spiral side.

**Remarks.** At Site U1506, specimens of *C. bradyi* show good preservation, and it is possible to observe both the oblique sutures and the pores on the spiral side. Compared to other *Cibicoides* species (e.g. *Cibicoides mundulus* or *Cibicoides mexicanus*), it is characterised by a smaller test and fewer chambers per whorl. Commonly, the umbilicus is slightly open, and on rare occasions a small umbilical plug is present.

**Paleoecology and paleobathymetric distribution.** *Cibicoides bradyi* has been related to well-oxygenated bottom waters (Denne and Sen Gupta, 1991; Barmawidjaja et al., 1992). Around New Zealand, *C. bradyi* occurs mostly from middle bathyal to abyssal depths (800–4000 m; Hayward et al., 2010). Egger (1893) documented *C. bradyi* from outer shelf to abyssal water depths (100–4000 m).

Family Cibicididae Cushman 1927

Genus Cibicoides Thalmann 1939

*Cibicoides mundulus* (Brady et al., 1888)

Fig. 4: 16a–c

- 1888 *Truncatulina mundula* Brady, Parker and Jones; p. 228, pl. 45, figs. 25a–c  
 1953 *Cibicides kullenbergi* Parker; Phleger, Parker and Pierson, p. 49, pl. 11, figs. 7–8  
 1955 *Cibicoides mundulus* (Brady, Parker and Jones); Loeblich and Tappan, p. 25, figs. 4a–c  
 1986 *Cibicoides mundulus* (Brady, Parker and Jones); Van Morkhoven et al., pl. 21  
 1989 *Cibicoides mundulus* (Brady, Parker and Jones); Hermelin, pl. 17, figs. 9–11  
 2013 *Cibicoides mundulus* (Brady, Parker and Jones); Holbourn et al., p. 196, figs. 1–8  
 2019 *Cibicoides mundulus* (Brady, Parker and Jones); Ridha et al., fig. 8: 2a–c

**Description.** Test trochospiral, keeled, biumbonate, unequally biconvex with the umbilical side more convex; 10 to 12 chambers in the last whorl, low and inflated, separated by flush curved sutures. Wall calcareous with fine pores on the umbilical side and coarser pores on the spiral side. The aperture is an equatorial slit that extends on the spiral side, rounded by a lip.

**Remarks.** The specimens of *C. mundulus* found at Site U1506 match the original description by Brady, Parker, and Jones in 1888, as well as the descriptions successively given by Van Morkhoven et al. (1986) and Holbourn et al. (2013). Our specimens display a medium to large test size and are moderately well preserved.

**Paleoecology and paleobathymetric distribution.** The bathymetric distribution of *C. mundulus* ranges from bathyal to abyssal depths (Van Morkhoven et al., 1986). This species has been associated with oligotrophic and oxic environments at the seafloor (Loubere 1994; Fariduddin and Loubere 1997; Schmiedl et al., 1997; De Rijk et al., 2000).

#### Family Cibicididae Cushman 1927

##### Genus Cibicidoides Thalmann 1939

##### *Cibicidoides wuellerstorfi* (Schwager 1866)

Fig. 5: 1a–c

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

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

1979 *Cibicides wuellerstorfi* (Schwager); Hayward and Buzas, pl. 11, figs. 140–142

1986 *Planulina wuellerstorfi* (Schwager); Van Morkhoven et al., pl. 14

1989 *Planulina wuellerstorfi* (Schwager); Hornibrook et al., fig. 22, n. 7

2010 *Cibicides wuellerstorfi* (Schwager); Hayward et al., pl. 23 figs. 17–22

2013 *Planulina wuellerstorfi* (Schwager); Holbourn et al., p. 416, figs. 1–3

2019 *Cibicidoides wuellerstorfi* (Schwager); Ridha et al., fig. 8: 3a–c

**Description.** Test compressed, discoidal, and low trochospiral. In cross-section, the test is compressed planoconvex, with a flat spiral side and an evolute, more convex umbilical side. Carinate periphery is acute; 8 to 10 chambers in the final whorl, narrow and curved, separated by thick and curved sutures. Sutures limbate, curved on the spiral side and more sinusoid on the umbilical side; slightly depressed between the last chambers. Medium-sized umbo on the umbilical side. Wall calcareous with coarse pores on the spiral side and finer pores on the umbilical side. The aperture is an equational interiomarginal slit with a lip extending on both sides.

**Remarks.** Specimens at Site U1506 show fairly good preservation and have overall large tests, with thick and elevated sutures and coarse pores with a rounded keel on the spiral side. The tests show variability in the level of compression; some specimens present a distinctly convex umbilical side.

**Paleoecology and paleobathymetric distribution.** This epifaunal species has been associated with high-energy environments, well-oxygenated bottom waters, and intermediate to

high temperatures (Lutze and Thiel, 1989; Linke and Lutze, 1993; Mackensen et al., 1995). Hayward et al. (2010) reported *C. wuellerstorfi* to be abundant from upper bathyal to abyssal depths (400–3000 m) around New Zealand.

#### Family Ehrenberginidae Cushman 1927

##### Genus Ehrenbergina Reuss 1850

##### *Ehrenbergina carinata* Eade 1967

Fig. 5: 2a–c

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

1983 *Ehrenbergina carinata* Eade; Nomura, pl. 5, figs. 5–6

2010 *Ehrenbergina carinata* Eade; Hayward et al., pl. 18, figs. 9–11

2019 *Ehrenbergina carinata* Eade; Ridha et al., fig. 4: 4a–b

**Description.** Test triangular in both cross-section and dorsal view. The ventral side is raised toward the central keel; the dorsal side is flat and slightly concave. Chambers biserially arranged, slightly inflated in the adult portion. The sutures are depressed on the ventral side and slightly raised on the dorsal side. Wall calcareous and finely perforated on both sides. Well-developed peripheral keel, with large spines extending from each chamber. The apertural face is flat without pores. The aperture is an elongated slit that extends from the margin with the previous chamber into the apertural face, bordered by a narrow lip that partially covers the aperture.

**Remarks.** Two paratypes of *Ehrenbergina carinata* were examined at the GNS collection in Wellington (TF 1561), and they are consistent with our material. The larger specimens of *E. carinata* at Site U1506 are generally well preserved, with a developed keel and evident spines protruding from it. We identified this species as *E. carinata* based on the keel, the spines, and the smooth dorsal side, which differentiate it from *Ehrenbergina aspinosa*, characterised by smaller spines and more raised sutures on the dorsal side.

**Paleoecology and paleobathymetric distribution.** This shallow infaunal species has been associated with low-oxygen conditions and high nutrient levels (Nomura et al., 1991; Gupta et al., 2006, 2008). Around New Zealand, *E. carinata* has been documented at bathyal depths (400–2000 m; Hayward et al., 2010).

#### Family Pseudoparrellidae Voloshinova 1952

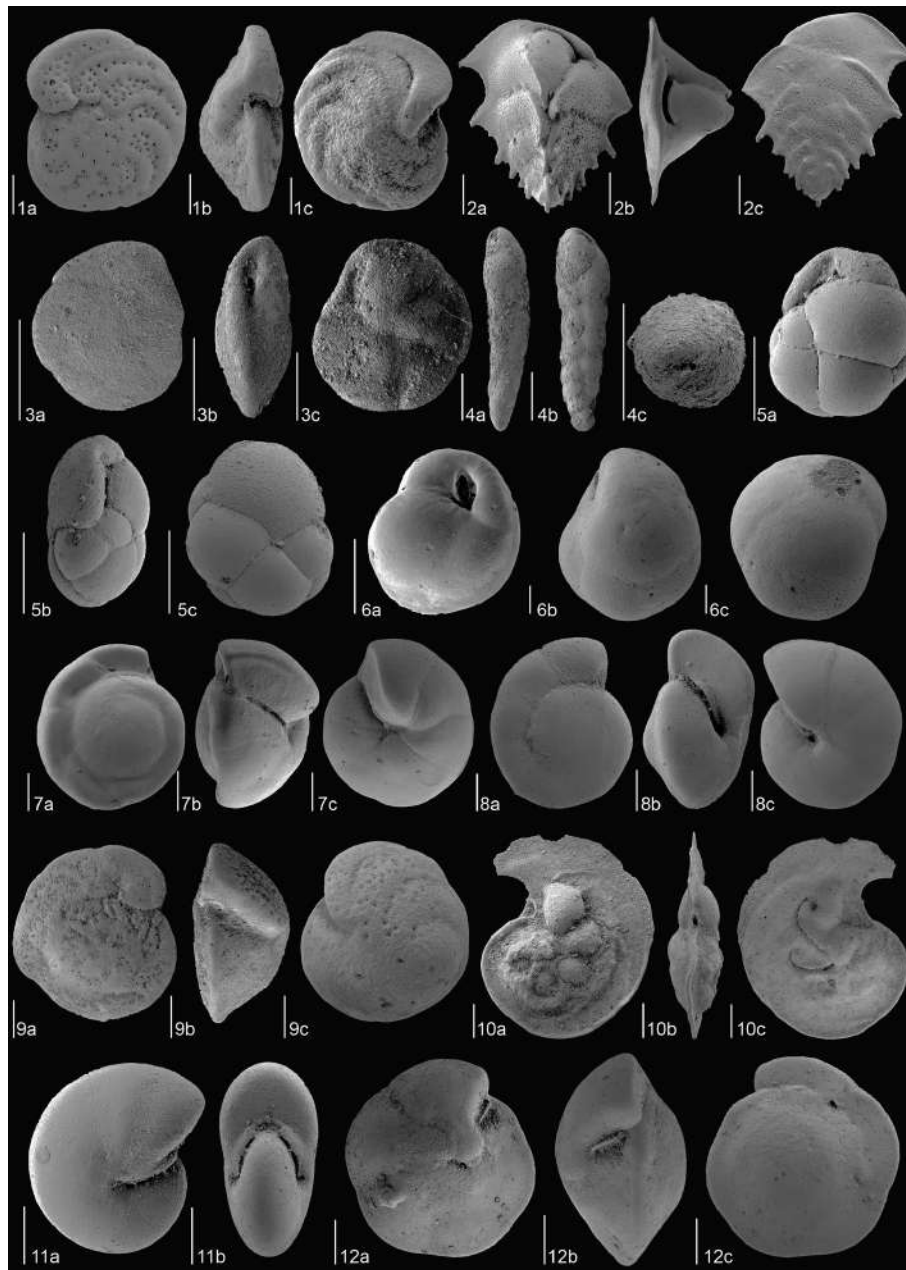
##### Genus Epistominella Husezima and Maruhasi 1944

##### *Epistominella exigua* (Brady 1884)

Fig. 5: 3a–c

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

1986 *Epistominella exigua* (Brady); Kurihara and Kennett, pl. 3, figs. 10–12



**Figure 5.** SEM images of the most common benthic foraminiferal species at Site U1506 identified in the Late Miocene–Early Pliocene. **(1)** *Cibicidoides wuellerstorfi* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/350: (a) dorsal side, (b), side view, (c) ventral side. **(2)** *Ehrenbergina carinata* (sample U1506A-19R-4W, 97–99 cm), MCNUZ-MPZ-2023/351: (a) frontal side, (b) apertural view, (c) dorsal side. **(3)** *Epistominella exigua* (sample U1506A-11R-4W, 80–82 cm), MCNUZ-MPZ-2023/352: (a) dorsal side, (b) apertural view, (c) ventral side. **(4)** *Fursenkoina bradyi* (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/344: (a) frontal view, (b) side view, (c) outline view. **(5)** *Globocassidulina crassa* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/353: (a) apertural view, (b) side view, (c) dorsal side. **(6)** *Globocassidulina subglobosa* (sample U1506A-12R-1W, 110–112 cm), MCNUZ-MPZ-2023/354: (a) apertural view. **(6)** *Globocassidulina subglobosa* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/355: (b) side view, (c) dorsal side. **(7)** *Gyroidina orbicularis* (sample U1506A-20R-1W, 50–52 cm), MCNUZ-MPZ-2023/356: (a) dorsal side, (b) side view, (c) ventral side. **(8)** *Gyroidina soldanii* (sample U1506A-21R-2W, 50–52 cm), MCNUZ-MPZ-2023/357: (a) dorsal side, (b) side view, (c) ventral side. **(9)** *Heterolepa dutemplei* (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/358: (a) dorsal side, (b) side view, (c) ventral side. **(10)** *Laticarinina pauperata* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/359: (a) dorsal side, (b), side view, (c) ventral side. **(11)** *Melonis barleeanum* (sample U1506A-20R-1W, 50–52 cm), MCNUZ-MPZ-2023/360: (a) side view, (b) apertural view. **(12)** *Oridorsalis umbonatus* (sample U1506A-18R-4W, 50–52 cm), MCNUZ-MPZ-2023/361: (a) dorsal side, (b), side view, (c) ventral side. All scale bars = 100  $\mu$ m.



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

2010 *Epistominella exigua* (Brady); Hayward et al., pl. 31, figs. 6–10

2013 *Epistominella exigua* (Brady); Holbourn et al., p. 340, figs. 1–6

2015 *Epistominella exigua* (Brady); Boscolo Galazzo, pl. 1, figs. 11–13

**Description.** Test small to medium in size, low trochospiral and biconvex, compressed, with an acute periphery. Around five slightly inflated chambers for each of the three whorls. The sutures are oblique and straight on the dorsal side and radial, depressed, and slightly curved on the umbilical side. Wall calcareous, typically glassy and translucent. The aperture is an elongated interiomarginal slit, parallel to the peripheral margin, extending from the face of the last chamber onto the umbilical side.

**Remarks.** Our specimens agree with the original description by Brady (1884). Due to recrystallisation, our specimens do not present the typical glassy and translucent wall. Only well-preserved specimens show the fine perforations described by Brady (1884) in the original description and illustrated by Holbourn et al. (2013). The radial and curved sutures on the umbilical side and the aperture have been used as the main morphological features to recognise this species, being observable in most of the specimens.

**Paleoecology and paleobathymetric distribution.** In the Gulf of California, *E. exigua* has been found in the upper–middle bathyal zone (Bandy, 1961), while around New Zealand, the highest abundance has been documented at lower bathyal to abyssal depths (1000–5000 m; Hayward et al., 2010). *Epistominella exigua* is considered a phytodetritus-exploiting taxon, having opportunistic behaviour and showing high abundance related to phytoplankton blooms. This species, along with other phytodetritus-exploiting taxa, is used as a proxy for highly seasonal nutrient supply (Goody, 1988, 1993; Jorissen et al., 2007; Corliss et al., 2009).

Family Bolivinitidae Cushman, 1927

Genus *Fursenkoina* Loeblich and Tappan, 1961

*Fursenkoina bradyi* (Cushman, 1922)

Fig. 5: 4a–c

1922 *Virgulina bradyi* Cushman, p. 155, pl. 24, figs. 1

1960 *Virgulina bradyi* Cushman; Barker, pl. 52, fig. 9

1985 *Fursenkoina bradyi* (Cushman); Thomas, pl. 3, fig. 7

1994 *Fursenkoina bradyi* (Cushman); Jones, pl. 52, fig. 9

**Description.** Test elongate, twisted, fusiform, with the maximum width in the final whorl, circular in cross-section. Chambers biserially arranged; moderately rounded; not inflated; and separated by distinct, curved sutures. The wall is calcareous and smooth. Elongate and oval aperture, extending from the base of the last chamber.

**Remarks.** The specimens ascribed to *F. bradyi* at Site U1506 mostly agree with the original description by Cushman (1922) and with the holotype (USNM PP 16287 A). However, the chambers of the specimens observed at Site U1506 are not inflated. Due to partial recrystallisation and the presence of particularly delicate elements, certain distinctive morphological characteristics, such as the fine perforation of the wall and the toothplate in the aperture, are not always visible or present in our specimens.

**Paleoecology and paleobathymetric distribution.** This cosmopolitan species typically occurs at upper bathyal depths (Jones, 1994). Kaiho (1994) assigned the genus *Fursenkoina* to the dysoxic indicators.

Family Cassidulinidae d'Orbigny 1839

Genus *Globocassidulina* Voloshinova 1960

*Globocassidulina crassa* (d'Orbigny 1839)

Fig. 5: 5a–c

1839 *Cassidulina crassa* d'Orbigny, p. 56, pl. 7, figs. 18–20

1967 *Globocassidulina crassa* (d'Orbigny); Eade, fig. 4

1983 *Globocassidulina crassa* (d'Orbigny); Nomura, p. 37–40, text figs 31–32, pl. 3, figs. 9a–c, 10a–b

2001 *Globocassidulina crassa* (d'Orbigny); Hayward et al., figs. 14MM–NN

2010 *Globocassidulina crassa* (d'Orbigny); Hayward et al., pl. 19, figs. 19–21

**Description.** Test subcircular, oval to circular in outline, compressed in profile, and with a rounded periphery. Chambers are biserially arranged with a planispiral coil. The sutures are distinct and slightly depressed. Wall calcareous, smooth, and finely perforated. The primary aperture is a narrow slit extending up the apertural face at an angle, without apertural toothplates.

**Remarks.** Our specimens are characterised by generally small tests; no large tests have been found at Site U1506. Previously denominated as *Cassidulina crassa* (i.e. Sejrup and Guilbault, 1980; Murray, 1991; Suhr and Pond, 2006), we attributed this species to the genus *Globocassidulina* following the description of Loeblich and Tappan (1988). According to these authors, the main difference between the two genera is the aperture, slit-like and extending up the apertural face in *Globocassidulina*, and a narrow slit at the base of the apertural face and parallel to the peripheral margin in *Cassidulina*. Our specimens present an aperture typical of the genus *Globocassidulina* (Fig. 7: 4).

**Paleoecology and paleobathymetric distribution.** *Globocassidulina crassa* is a cold-water species, related to strong bottom currents (Schmiedl et al., 1997). This species has been associated with phytoplankton blooms and is considered to be a phytodetritus-exploiting taxon (Suhr and Pond, 2006). Hayward et al. (2010) documented this species around New Zealand from middle shelf to abyssal depths.

Family Cassidulinidae d'Orbigny 1839

Genus *Globocassidulina* Voloshinova 1960

*Globocassidulina subglobosa* (Brady 1881)

Fig. 5: 6a–c

1881 *Cassidulina subglobosa* Brady, p. 60

1884 *Cassidulina subglobosa* Brady, pl. 54, figs. 17a–c

1951 *Cassidulina subglobosa* Brady; Phleger and Parker, p. 27, pl. 14, figs. 11–12

1983 *Globocassidulina subglobosa* (Brady); Nomura, fig. 16, pl. 2, figs. 8a–c, pl. 13, figs. 5–6

1986 *Globocassidulina subglobosa* (Brady); Kurihara and Kennett; pl. 5, figs. 4–8

2001 *Globocassidulina subglobosa* (Brady); Hayward et al., fig. 14QQ

2003 *Globocassidulina subglobosa* (Brady); Hayward et al., fig. 4J

2010 *Globocassidulina subglobosa* (Brady); Hayward et al., pl. 20, figs. 4–6

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

2019 *Globocassidulina subglobosa* (Brady); Ridha et al., fig. 4: 2

**Description.** Test subglobular, chambers biserially arranged with a rounded periphery, and subcircular in cross-section. The size is highly variable. Chambers inflated, separated by slightly depressed sutures. The wall is calcareous, and the surface is smooth and finely perforated. The primary aperture is a straight loop-like slit extending up the apertural face, with an apertural toothplate on the posterior side.

**Remarks.** Specimens of *G. subglobosa* at Site U1506 agree with the original description by Brady (1881). Most of our specimens have a small test, and larger specimens have been found occasionally, particularly between 194.75 and 103.21 m CSF-A. The good preservation allows for the recognition of the diagnostic morphological features, and SEM images show the apertural toothplate in the primary aperture (Fig. 7: 5).

**Paleoecology and paleobathymetric distribution.** This species is interpreted as an indicator of oxic conditions, strong bottom currents, and oligotrophic environments with low pulsed food supply (Schmiedl et al., 1997; Kaiho, 1999). This opportunistic species has been associated with high phytodetritus pulses to the seafloor and therefore is considered a phytodetritus-exploiting taxon (Gooday, 1993; Suhr et al., 2003; Jorissen et al., 2007). *Globocassidulina subglobosa* shows high abundance at lower bathyal to abyssal depths around New Zealand (Hayward et al., 2010). In the Gulf of California and the Gulf of Mexico, it has been documented mainly at upper to middle bathyal depths (Bandy, 1961; Pflum and Frerichs, 1976).

Family Cancrisidae Chapman, Parr and Collins 1934

Genus *Gyroidinoides* Brotzen 1942

*Gyroidina orbicularis* d'Orbigny 1826

Fig. 5: 7a–c

1826 *Gyroidina orbicularis* d'Orbigny, p. 278

1979 *Gyroidina* sp.; Hayward and Buzas, pl. 18, figs. 226–228

1989 *Gyroidina orbicularis* d'Orbigny; Hermelin, pl. 16, figs. 7–9

1987 *Gyroidina orbicularis* d'Orbigny; Loeblich and Tappan, pl. 716, figs. 8–13

1989 *Gyroidina zelandica* Finlay; Hornibrook et al., fig. 20, n. 11a–b

1994 *Gyroidina orbicularis* d'Orbigny; Jones, pl. 115, fig. 6;

2010 *Gyroidina orbicularis* d'Orbigny; Hayward et al., pl. 27, figs. 1–6

**Description.** Test moderately large to large in size, planoconvex, flat on the spiral side, and highly convex on the umbilical side. The periphery is angular with a rounded keel. Around seven to nine chambers in the last whorl. The sutures are oblique on the spiral side and depressed, radial to slightly curved on the umbilical side. Wall calcareous and smooth. The aperture is an interiomarginal slit not connected to the umbilicus.

**Remarks.** At Site U1506, specimens of *G. orbicularis* have large tests and are fairly well preserved. The species *Gyroidina zelandica* Finlay (1939) illustrated by Hornibrook et al. (1989) is characterised by a flat spiral side and conical dorsal side, eight chambers per coil (maximum nine chambers), a small umbilicus, and an angular periphery. Based on the comparison of the original description of both species, we consider *G. zelandica* to be a synonym of *G. orbicularis*.

**Paleoecology and paleobathymetric distribution.** Around New Zealand, this species has been documented from bathyal to abyssal depths (200–5000 m; Hayward et al., 2010).

Family Cancrisidae Chapman, Parr and Collins 1934

Genus *Gyroidinoides* Brotzen 1942

*Gyroidina soldanii* d'Orbigny 1826

Fig. 5: 8a–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

1994 *Gyroidina neosoldanii* Brotzen; Loeblich and Tappan, pl. 361, figs. 13–15; pl. 362, figs. 1–7

2001 *Gyroidinoides soldanii* (d'Orbigny); Hayward et al., figs. 15HH–II

2010 *Gyroidina soldanii* d'Orbigny; Hayward et al., pl. 27, figs. 7–12

2013 *Gyroidinoides soldanii* (d'Orbigny); Holbourn et al., p. 278, figs. 1–3

2019 *Gyroidinoides soldanii* (d'Orbigny); Ridha et al., fig. 6: 3a–c

**Description.** Test planoconvex, trochospiral, with a rounded to angular periphery. The spiral side is evolute and flat, and the umbilical side is involute and more rounded; 8 to 10 chambers in the last whorl, wall calcareous and smooth, with fine perforations. The sutures are radial and depressed, straight on the umbilical side, and more curved on the spiral side. The aperture is an extraumbilical interiomarginal slit.

**Remarks.** This species has been identified following the original description by d'Orbigny (1826) and the more recent one by Hayward et al. (2010). Specimens at Site U1506 show good preservation, the test size ranges from medium to large, and some juvenile specimens have been observed occasionally. In the larger and better-preserved specimens, it is possible to observe the fine perforations of the test.

**Paleoecology and paleobathymetric distribution.** This cosmopolitan species is commonly found at bathyal depths (Holbourn et al., 2013). In New Zealand, it occurs from outer shelf to lower abyssal depths (100–5000 m; Hayward et al., 2010).

Family Cibicididae Cushman 1927

Genus *Heterolepa* Franzenau, 1884

*Heterolepa dutemplei* (d'Orbigny 1846)

Fig. 5: 9a–c

1846 *Rotalina dutemplei* d'Orbigny, p. 157, pl. 8, figs. 19–21

1986 *Cibicidoides dutemplei* (d'Orbigny); Van Morkhoven et al., p. 112, pl. 35.

1987 *Heterolepa dutemplei* (d'Orbigny); Loeblich and Tappan, p. 632, pl. 709, figs. 1–8

1996 *Heterolepa dutemplei* (d'Orbigny); Revets, p. 67, pl. 2, figs. 9–12.

2013 *Heterolepa dutemplei* (d'Orbigny); Holbourn et al., p. 294, figs. 1–3

**Description.** Test trochospiral, planoconvex in cross-section with a flat spiral side and a convex umbilical side; 9 to 10 chambers in the last whorl, inflated and separated by curved and slightly depressed sutures. The sutures on the umbilical side form a pinwheel pattern. Wall calcareous with pores on both sides of the test. The aperture is an equatorial slit, extending onto the spiral side, surrounded by a thin lip.

**Remarks.** Specimens found at Site U1506 were ascribed to *H. dutemplei* following the description of Van Morkhoven et al. (1986) and Holbourn et al. (2013). Our specimens are large and well preserved. In some specimens, the early whorl on the spiral side is covered by a thick and crystalline area, which is a typical feature of *Cibicidoides mexicanus* (Nuttall, 1932). *Heterolepa dutemplei* bears a striking resemblance to *Cibicidoides mexicanus* (Nuttall), suggesting a possible evolutionary connection between these two species

(Van Morkhoven et al., 1986). Our specimens show the pinwheel pattern on the umbilical side, which is a distinctive feature of *H. dutemplei*. Furthermore, *C. mexicanus* is known to have a stratigraphic range that extends from the late Eocene to the Early Miocene, whereas *H. dutemplei* has been identified from the Early Miocene through the Pliocene.

**Paleoecology and paleobathymetric distribution.** *Heterolepa dutemplei* spans from shelf to upper bathyal water depths (Van Morkhoven et al., 1986). The presence of this epifaunal species has been linked to environments characterised by high oxygen levels and low salinity (Hageman, 1979; Van der Zwaan, 1982; Jonkers, 1984).

Family Discorbinellidae Sigal 1952

Genus *Laticarinina* Galloway and Wissler 1927

*Laticarinina pauperata* (Parker and Jones 1865)

Fig. 5: 10a–c

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

1986 *Laticarinina pauperata* (Parker and Jones); Van Morkhoven et al., p. 89, pl. 26

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

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

1987 *Laticarinina pauperata* (Parker and Jones); Loeblich and Tappan, pl. 631, figs. 1–4

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

2010 *Laticarinina pauperata* (Parker and Jones); Hayward et al., pl. 24, figs. 19–21

2013 *Laticarinina pauperata* (Parker and Jones); Holbourn et al., p. 328, figs. 1–2

2019 *Laticarinina pauperata* (Parker and Jones); Ridha et al., fig. 7: 3a–b

**Description.** Test large, elliptical in outline, strongly compressed in profile, with a wide and transparent keel. Planoconvex to unequally biconvex. Both sides are evolute, the spiral side is flat to slightly convex, and the umbilical side is raised. Six to eight inflated chambers in the last whorl. Sutures are radial and depressed on the umbilical side and flush, barely distinguishable on the spiral side. Wall calcareous and smooth. The aperture consists of a subequatorial slit.

**Remarks.** Our specimens show large and compressed tests with a wide and transparent keel. We distinguished this species from *Laticarinina altocamerata*, based on the more compressed test and the less raised umbilical side. Most of the specimens observed at Site U1506 have a broken keel.

**Paleoecology and paleobathymetric distribution.** Kaiho (1994) related this species to oxic conditions on



the seafloor. Hayward et al. (2010) documented *L. pauperata* from lower bathyal to abyssal depths (1500–3000 m) around New Zealand.

Family Nonionidae Schultze 1854

Genus *Melonis* Montfort 1808

*Melonis barleeana* (Williamson 1858)

Fig. 5: 11a–b

1858 *Noniona barleeana* Williamson, p. 32, pl. 3, figs. 68–69

1985 *Melonis barleeana* (Williamson); Thomas, p. 677, pl. 12, fig. 3

1986 *Melonis barleeana* (Williamson); Kurihara and Kennett, pl. 9, figs. 10–11

1987 *Melonis barleeana* (Williamson); Loeblich and Tappan, pl. 696, figs. 5–6

1989 *Melonis barleeana* (Williamson); Hermelin, p. 88, pl. 17, fig. 12

1994 *Melonis barleeana* (Williamson); Loeblich and Tappan, p. 159, pl. 347, figs. 1–5

2013 *Melonis barleeana* (Williamson); Holbourn et al., p. 354, figs. 1–2

2019 *Melonis barleeana* (Williamson); Ridha et al., fig. 7: 6a–b

**Description.** Test planispiral, involute, laterally compressed, and symmetrical. Open umbilicus on both sides, 10 to 12 chambers, gradually increasing in size in the final whorl. The chambers are separated by slightly depressed sutures, slightly curved. Wall calcareous, coarsely perforated. The aperture is a low interiomarginal, equatorial slit that extends to both umbilici.

**Remarks.** We were able to distinguish *M. barleeana* from *Melonis pompilioides* based on the flatter test shape of *M. barleeana*, which generally has more chambers in the last whorl. Our specimens bear a close morphological resemblance to *Melonis affinis* (Reuss), apart from the prominent apertural lip, which allows us to identify them as *M. barleeana* (Milker and Schmiedl, 2012). Moreover, the type levels of the two species are very different: Oligocene for *M. affinis* and recent for *M. barleeana* (Holbourn et al., 2013). Our specimens are all well preserved and characterised by small tests with visible pores.

**Paleoecology and paleobathymetric distribution.** Around New Zealand, this species has been documented from the outer shelf to abyssal depths (Hayward et al., 2010), with no depth preference. *Melonis* has been related to suboxic and eutrophic conditions on the seafloor (Kaiho, 1994; Hayward et al., 2010).

Family Orispiralidae Loeblich and Tappan 1984

Genus *Oridorsalis* Andersen 1961

*Oridorsalis umbonatus* (Reuss 1851)

Fig. 5: 12a–c

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

1983 *Oridorsalis umbonatus* (Reuss); Dailey, p. 767, pl. 6, figs. 1–3

1983 *Oridorsalis umbonatus* (Reuss); Tjalsma and Lohmann, p. 18, pl. 6, figs. 8a–b

1986 *Oridorsalis umbonatus* (Reuss); Kurihara and Kennett, pl. 6, figs. 11–13

1989 *Oridorsalis umbonatus* (Reuss); Hermelin, pl. 16, figs. 1–5

1994 *Oridorsalis umbonatus* (Reuss); Bolli et al., p. 372, pl. 58, figs. 10–13

1999 *Oridorsalis umbonatus* (Reuss); Kawagata, fig. 10.4

2001 *Oridorsalis umbonatus* (Reuss); Alegret and Thomas, pl. 9, fig. 8–9

2001 *Oridorsalis umbonatus* (Reuss); Hayward et al., figs. 16R–S

2010 *Oridorsalis umbonatus* (Reuss); Hayward et al., pl. 30, figs. 3–6

2013 *Oridorsalis umbonatus* (Reuss); Alegret and Thomas, pl. I, fig. 16

2019 *Oridorsalis umbonatus* (Reuss); Ridha et al., fig. 6: 6a–d

**Description.** Test trochospiral, unequally biconvex, and lenticular. The outline is lobulated with an acute periphery. The spiral side is more evolute and convex, and the umbilical side is involute and less convex. Five to six chambers in the last whorl. On the spiral side, the chamber sutures are at a right angle to the spiral suture, and on the umbilical side the sutures are radial and slightly curved towards the umbo. Wall calcareous and smooth. The aperture is an interiomarginal slit extending from the periphery to the umbilicus.

**Remarks.** The lobulated outline and curved sutures towards the umbo and the chamber sutures at right angles to the spiral suture serve as the primary diagnostic features of *O. umbonatus*. At Site U1506, the size of *O. umbonatus* varies from small to moderately large. In some specimens the last chamber is broken or completely missing.

**Paleoecology and paleobathymetric distribution.** *Oridorsalis umbonatus* has a carbon isotope signature typical for shallow infaunal taxa (e.g. Thomas and Shackleton, 1996; Katz et al., 2003). It has been reported from lower bathyal to abyssal depths in the Indian, Atlantic, and Pacific oceans and the Southern Ocean (Corliss, 1979; Streeter and Shackleton, 1979; Gupta, 1994; Hayward et al., 2010; Alegret and Thomas, 2013). Previous studies have associated this species with high-oxygen environments (Hayward et al., 2010).

Family Osangulariidae Loeblich and Tappan 1964

Genus *Osangularia* Brotzen 1940

*Osangularia culter* (Parker and Jones 1865)

Fig. 6: 1a–c

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

- 1866 *Anomalina bengalensis* Schwager; 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, Parker and Pierson, p. 42, pl. 9, figs. 11–16  
 1979 *Osangularia culter* (Parker and Jones); Hayward and Buzas, pl. 15, figs. 193–194; pl. 22, figs. 279–281  
 1989 *Osangularia culter* (Parker and Jones); Hermelin, p. 84, pl. 16, figs. 11–13  
 1994 *Osangularia bengalensis* (Schwager); Jones, p. 100, pl. 96, fig. 3  
 1995 *Osangularia culter* (Parker and Jones); Nomura, p. 278, pl. 4, fig. 8  
 2013 *Osangularia culter* (Parker and Jones); Holbourn et al., p. 386, figs. 1–2  
 2019 *Osangularia culter* (Parker and Jones); Ridha et al., fig. 6: 7a–c

**Description.** Test trochospiral and lenticular. The umbilical side is more convex and involute, and the spiral side is less convex and evolute. The periphery is acute with a thin, serrate keel; 8 to 10 chambers in the last whorl; sutures are raised and curved on the spiral side and depressed and radial on the umbilical side. Wall calcareous, smooth, finely perforated. The aperture is an interiomarginal slit extending from the umbilicus to the periphery.

**Remarks.** Specimens at Site U1506 were ascribed to *O. culter* based on the original description by Parker and Jones (1865). Our specimens exhibit a relatively good state of preservation, with the peripheral keel remaining intact.

**Paleoecology and paleobathymetric distribution.** This species, known for its wide distribution, has been documented globally. Previous studies (Brady, 1884; Frerichs, 1970; Pflum and Frerichs, 1976; Holbourn et al., 2013) suggest that this cosmopolitan species is typically found at depths not exceeding 700 m.

Family Nonionidae Schultze 1854

Genus *Pullenia* Parker and Jones 1862

*Pullenia bulloides* (d'Orbigny 1846)

Fig. 6: 2a–b

- 1846 *Nonionina bulloides* d'Orbigny; d'Orbigny, p. 107, pl. 5, figs. 9–10  
 1884 *Pullenia sphaeroides* (d'Orbigny); Brady, p. 615, pl. 84, figs. 12–13  
 1960 *Pullenia bulloides* (d'Orbigny); Barker pl. 84, figs. 12–13  
 1975 *Pullenia sphaeroides* (d'Orbigny); Saidova, pl. 70, fig. 7  
 1986 *Pullenia bulloides* (d'Orbigny); Kurihara and Kennett, pl. 6, figs. 5–6  
 1989 *Pullenia bulloides* (d'Orbigny); Hermelin, pl. 15, figs. 4–5

- 1990 *Pullenia bulloides* (d'Orbigny); Thomas et al., pl. 10, fig. 15  
 1994 *Pullenia bikiniensis* McCulloch; Loeblich and Tappan, p. 159, pl. 348, figs. 9–14  
 1999 *Pullenia bulloides* (d'Orbigny); Kawagata, fig. 9.5  
 2001 *Pullenia bulloides* (d'Orbigny); Hayward et al., figs. 16T–U  
 2010 *Pullenia bulloides* (d'Orbigny); Hayward et al., pl. 29, figs. 15–17  
 2013 *Pullenia bulloides* (d'Orbigny); Holbourn et al., p. 442, figs. 1–3  
 2019 *Pullenia bulloides* (d'Orbigny); Ridha et al., fig. 7: 7a–b

**Description.** Test globular, planispiral, and involute. The outline is circular, and the periphery is broadly rounded. Four to five inflated chambers in the last whorl, separated by radial and slightly depressed sutures. Wall calcareous and smooth. The aperture is a narrow interiomarginal slit, stretching from the periphery to the umbilici.

**Remarks.** At Site U1506, the specimens belonging to *P. bulloides* exhibit excellent preservation and are characterised by moderately large tests consisting of three to six chambers with close umbilici. This species closely resembles *P. quinqueloba*, but it can be distinguished by its more subglobular shape and circular outline.

**Paleoecology and paleobathymetric distribution.** *Pullenia bulloides* is a cosmopolitan species found at middle to lower bathyal depths in the Pacific, as documented by Smith (1964). In the vicinity of New Zealand, Hayward et al. (2010) reported its highest abundance at middle bathyal to abyssal depths.

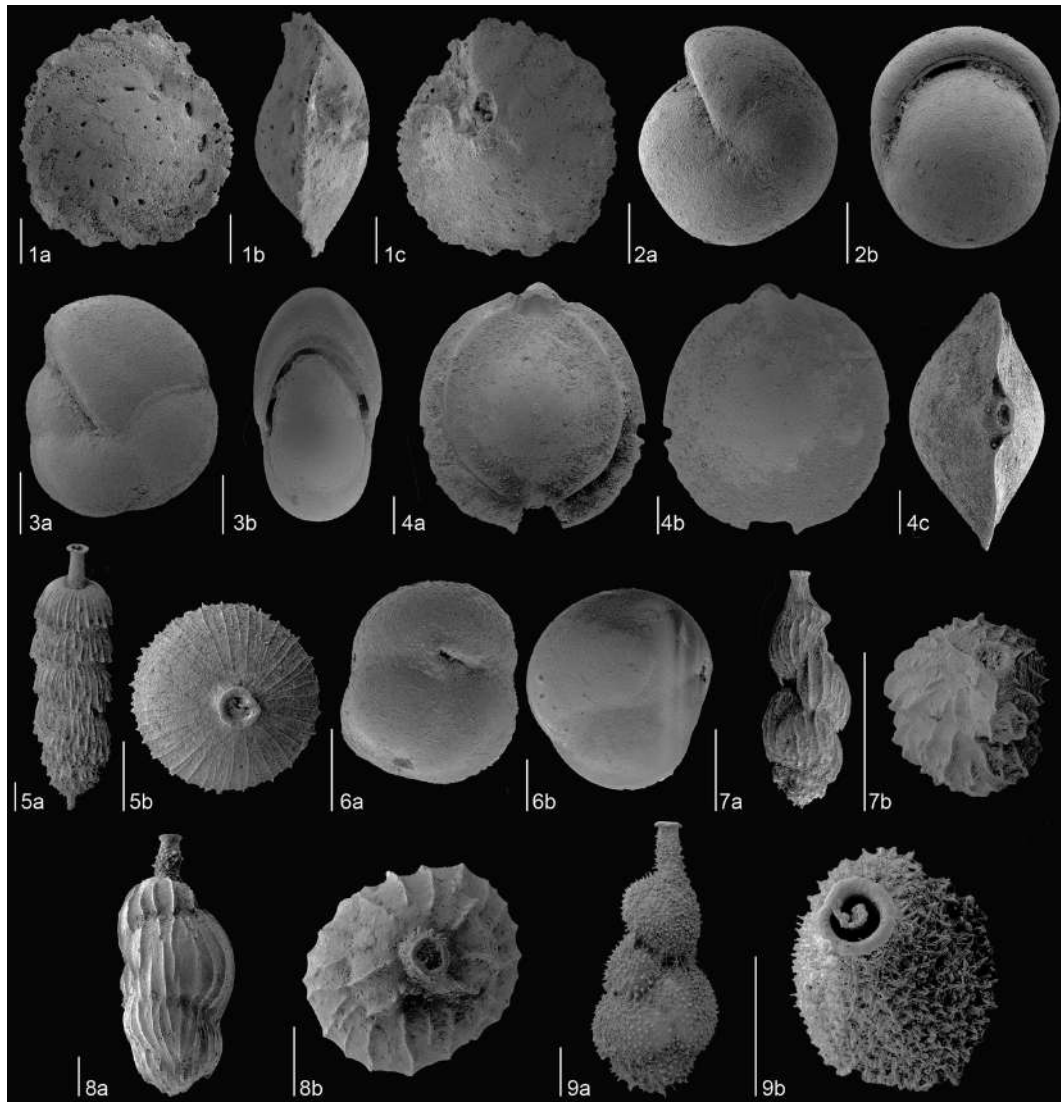
Family Nonionidae Schultze, 1854

Genus *Pullenia* Parker and Jones, 1862

*Pullenia quinqueloba* (Reuss, 1851)

Fig. 6: 3a–b

- 1851 *Nonionina quinqueloba* Reuss; Reuss, p. 71, pl. 5, figs. 31a–b  
 1884 *Pullenia quinqueloba* (Reuss); Brady, p. 617, pl. 84, figs. 14–15  
 1975 *Pullenia borealis* Saidova; Saidova, pl. 69, fig. 9  
 1983 *Pullenia quinqueloba* (Reuss); Tjalsma and Lohmann, p. 36, pl. 16, fig. 2  
 1986 *Pullenia osloensis* Feyling-Hanssen; Kurihara and Kennett; pl. 6, figs. 7–8  
 1990 *Pullenia quinqueloba* (Reuss); Thomas et al., pl. 10, fig. 19  
 1994 *Pullenia borealis* Saidova; Loeblich and Tappan, pl. 348, figs. 1–6  
 1994 *Pullenia quinqueloba* (Reuss); Jones, pl. 84, figs. 14–15  
 2010 *Pullenia quinqueloba* (Reuss); Hayward et al., pl. 29, figs. 18–20



**Figure 6.** SEM images of the most common benthic foraminiferal species at Site U1506 identified in the Late Miocene–Early Pliocene. (1) *Osangularia culter* (sample U1506A-18R-4W, 50–52 cm), MCNUZ-MPZ-2023/362: (a) dorsal side, (b), side view, (c) ventral side. (2) *Pullenia bulloides* (sample U1506A-21R-4W, 140–142 cm), MCNUZ-MPZ-2023/363: (a) side view, (b), apertural view. (3) *Pullenia quinqueloba* (sample U1506A-19R-4W, 97–99 cm), MCNUZ-MPZ-2023/364: (a) side view, (b), apertural view. (4) *Pyrgo murrhina* (sample U1506A-16R-1W, 136–138 cm), MCNUZ-MPZ-2023/365: (a) frontal side, (b) dorsal side, (c) apertural view. (5) *Rectuvigerina multicosata* (sample U1506A-20R-6W, 50–52 cm), MCNUZ-MPZ-2023/366: (a) frontal side, (b) outline view. (6) *Sphaeroidina bulloides* (sample U1506A-18R-5W, 116–118 cm), MCNUZ-MPZ-2023/367: (a) frontal side. (6) *Sphaeroidina bulloides* (sample U1506A-18R-5W, 116–118 cm), MCNUZ-MPZ-2023/368: (b) side view. (7) *Uvigerina occidentalis* (sample U1506A-12R-1W, 110–112 cm), MCNUZ-MPZ-2023/369: (a) frontal side, (b) outline view. (8) *Uvigerina peregrina* (sample U1506A-17R-2W, 133–135 cm), MCNUZ-MPZ-2023/370: (a) frontal side, (b) outline view. (9) *Uvigerina proboscidea* (sample U1506A-11R-3W, 30–32 cm), MCNUZ-MPZ-2023/371: (a) frontal side, (b) outline view. All scale bars = 100 µm.

2013 *Pullenia quinqueloba* (Reuss); Holbourn et al., p. 448, figs. 1–2

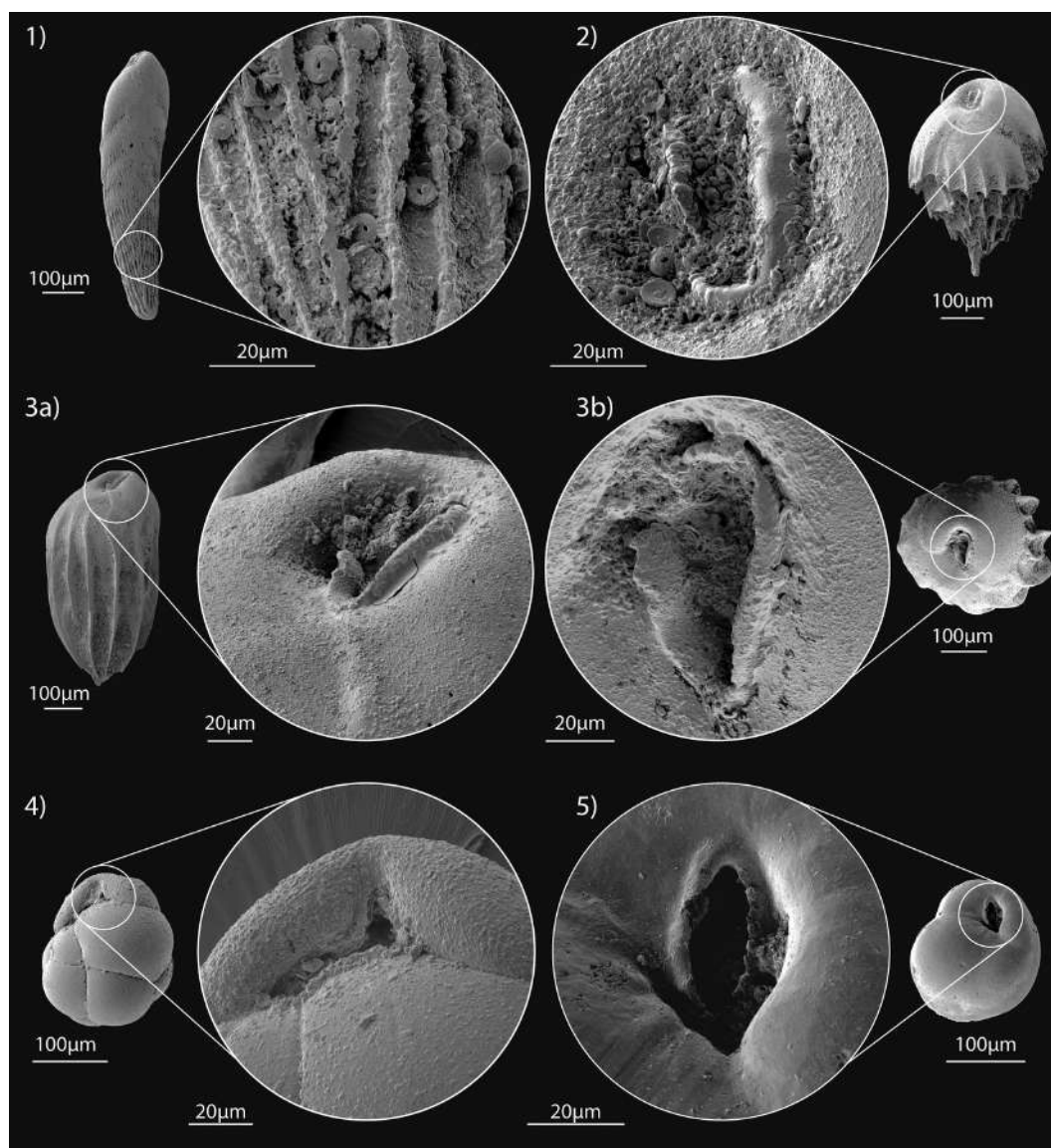
2019 *Pullenia quinqueloba* (Reuss); Ridha et al., fig. 7: 8a–b

**Description.** Test globular, planispiral, and involute. Compressed in apertural view and with a rounded periphery in umbilical view. Five chambers with a triangular shape, in-

flated and gradually increasing in size in the last whorl. The sutures are depressed, radial, and slightly curved. Wall calcareous, smooth, and finely perforated. The aperture is a narrow interiomarginal slit, stretching from the periphery to the umbilici.

**Remarks.** Specimens ascribed to *P. quinqueloba* generally display a small size and are well preserved. *Pullenia quin-*





**Figure 7.** Close-up SEM images of selected Late Miocene–Early Pliocene benthic foraminiferal species at Site U1506. **(1)** *Bolivina finlayi* (sample U1506A-21R-1W, 140–142 cm), MCNUZ-MPZ-2023/343, close-up view of the striae; **(2)** *Bulimina striata* (sample U1506A-19R-4W, 97–99 cm), MCNUZ-MPZ-2023/346, detail of the aperture; **(3a–b)** *Bulimina truncana* (sample U1506A-21R-4W, 140–142 cm), MCNUZ-MPZ-2023/347, aperture; **(4)** *Globocassidulina crassa* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/353, aperture; **(5)** *Globocassidulina subglobosa* (sample U1506A-11R-1W, 105–107 cm), MCNUZ-MPZ-2023/354, aperture.

*queloba* is distinguished from *P. bulloides* by its smaller and more compressed test, characterised by five triangular chambers and a more lobulated outline.

**Paleoecology and paleobathymetric distribution.** *Pullenia quinqueloba* has a wide paleobathymetric range, from middle shelf to abyssal (50–5000 m), with slightly higher relative abundances at abyssal depths in New Zealand (Hayward et al., 2010).

Family Hauerinidae Schwager 1876

Genus *Pyrgo* Defrance 1824

*Pyrgo murrhina* (Schwager 1866)

Fig. 6: 4a–c

1866 *Biloculina murrhina* Schwager; Schwager, p. 203, pl. 4, figs. 15a–c

1945 *Pyrgo murrhina* (Schwager); Cushman and Todd, p. 12, pl. 2, fig. 5

1986 *Pyrgo murrhina* (Schwager); Van Morkhoven et al., p. 50, pl. 15

1986 *Pyrgo murrhina* (Schwager); Kurihara and Kennett; pl. 1, fig. 13

- 1989 *Pyrgo murrhina* (Schwager); Hermelin, pl. 2, figs. 12, 15–16
- 1994 *Pyrgo murrhina* (Schwager); Loeblich and Tappan, pl. 91, figs. 11–15
- 1994 *Pyrgo murrhina* (Schwager); Jones, pl. 2, figs. 10–11, 15
- 1998 *Pyrgo murrhina* (Schwager); Robertson, p. 34, pl. 10, fig. 2
- 2010 *Pyrgo murrhina* (Schwager); Hayward et al., pl. 7, figs. 20–23
- 2013 *Pyrgo murrhina* (Schwager); Holbourn et al., p. 458, figs. 1–2

**Description.** Test large, slightly compressed, circular to oval in outline, and elliptical in cross-section. The periphery presents a wide peripheral flange with a keel and two small spines on the opposite side of the aperture. Wall porcellaneous and smooth. The aperture is circular to oval, and it ends with a short bifid tooth at the end of a short neck.

**Remarks.** Complete specimens of *P. murrhina* are uncommon at Site U1506, with the fragile neck and small spines often missing. Instead, we predominantly found fragmented pieces, typically comprising only one side of the test. We identified this species by the presence of a compressed test, an oval outline, and a keel that despite being occasionally damaged remains visible in many cases.

**Paleoecology and paleobathymetric distribution.** *Pyrgo murrhina* has a cosmopolitan distribution (Van Morkhoven et al., 1986). *P. murrhina* is a bathyal to abyssal species, and most records east of New Zealand range from 1000 m to 4000 m; its upper depth limit off the east coast of New Zealand shallows southwards, from middle–upper bathyal up to the upper shelf around the subantarctic islands (Bandy and Arnal, 1957; Hayward et al., 2010).

Family Siphogenerinoididae Saidova 1981

Genus *Rectuvigerina* Mathews 1945

*Rectuvigerina multicostata* (Cushman and Jarvis 1929)

Fig. 6: 5a–b

- 1929 *Siphogenerina multicostata* Cushman and Jarvis: p. 14, pl. 3, fig. 6
- 1949 *Siphogenerina spinea* Bermúdez; Bermúdez, p. 223, pl. 13, figs. 78–79
- 1986 *Rectuvigerina multicostata* (Cushman and Jarvis); Van Morkhoven et al., p. 115, pl. 36
- 1986 *Rectuvigerina* sp.; Kurihara and Kennett, pl. 3, fig. 9
- 1987 *Rectuvigerina multicostata* (Cushman and Jarvis); Loeblich and Tappan, p. 519, pl. 569, figs. 28–29
- 1993 *Rectuvigerina multicostata* (Cushman and Jarvis); Katz and Miller, pl. 1, fig. 2
- 1998 *Rectuvigerina multicostata* (Cushman and Jarvis); Robertson, p. 144, pl. 55, figs. 6–7
- 2013 *Rectuvigerina multicostata* (Cushman and Jarvis); Holbourn et al., p. 47, fig. 1

**Description.** Test elongated, initially triserial and later uniserial. The chambers are inflated and gradually increase in size. The chambers are separated by depressed sutures. Wall calcareous with fine pores and longitudinal costae, which can form short spines, mostly in the early chambers. Some specimens present a basal spine. The aperture is terminal and rounded with a lip at the end of a long neck.

**Remarks.** The holotype of *R. multicostata* (USNM CC 10056) was checked at the Smithsonian Institution. Our specimens fully agree with the holotype and the original description by Cushman and Jarvis (1929). At Site U1506, *R. multicostata* has commonly large tests. The best-preserved specimens show the basal spine and a wide, thin lip around the aperture.

**Paleoecology and paleobathymetric distribution.** This species has been documented at bathyal depths (Van Morkhoven et al., 1986), and it thrives in regions characterised by a significant influx of organic matter resulting from elevated surface productivity (Holbourn et al., 2013).

Family Sphaeroidinidae Cushman 1927

Genus *Sphaeroidina* d'Orbigny 1826

*Sphaeroidina bulloides* d'Orbigny 1826

Fig. 6: 6a–b

- 1826 *Sphaeroidina bulloides* d'Orbigny: p. 267, Model No. 65, illustrated in Parker et al., 1865, pl. 2, fig. 58
- 1846 *Sphaeroidina austriaca* d'Orbigny: p. 284, pl. 20, figs. 19–21
- 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
- 1986 *Sphaeroidina bulloides* d'Orbigny; Van Morkhoven et al., p. 80, pl. 24
- 1989 *Sphaeroidina bulloides* d'Orbigny; Kurihara and Kennett, pl. 2, fig. 1
- 1994 *Sphaeroidina bulloides* d'Orbigny; Jones, p. 91, pl. 84, figs. 1–2
- 1999 *Sphaeroidina bulloides* d'Orbigny; Hayward et al., pl. 11, figs. 15–16
- 2010 *Sphaeroidina bulloides* d'Orbigny; Hayward et al., pl. 32, figs. 12–13
- 2013 *Sphaeroidina bulloides* d'Orbigny; Holbourn et al., p. 520, figs. 1–3
- 2019 *Sphaeroidina bulloides* d'Orbigny; Ridhaa et al., fig. 7: 2a–c

**Description.** Test subglobular, typically with three chambers visible and the last chamber covering half of the test. The sutures are slightly depressed. Wall calcareous and smooth. The aperture is round with a lip and a simple tooth.

**Remarks.** Our specimens are well preserved. Notably, the larger specimens display a thicker, opaque wall, whereas the smaller specimens are characterised by more translucent and thinner walls.

**Paleoecology and paleobathymetric distribution.** *Sphaeroidina bulloides* is a cosmopolitan species; its bathymetric distribution spans from shelf to abyssal depths (Van Morkhoven et al., 1989; Holbourn et al., 2013). Around New Zealand, it is most common between outer shelf and lower bathyal depths (100–1000 m; Hayward et al., 2010). Its upper depth limit is in the middle shelf (Van Morkhoven et al., 1986). Kaiho (1994) included *S. bulloides* in the suboxic group.

Family Uvigerinidae Haeckel 1894

Genus *Uvigerina* d'Orbigny 1826

*Uvigerina occidentalis* Cushman 1923

Fig. 6: 7a–b

1923 *Uvigerina occidentalis* Cushman, p. 34, pl. 5, figs. 3–4

1995 *Uvigerina* sp.; Yassini and Jones, fig. 613

2001 *Trifarina occidentalis* (Cushman); Hayward et al., figs. 14UU–VV

2010 *Trifarina occidentalis* (Cushman); Hayward et al., pl. 21, figs. 18–20

**Description.** Test small, minute, and elongated and widest in the middle. Triangular to subcircular in cross-section. Chambers distinct and progressively increasing in size, sutures incised. Wall calcareous and ornamented with longitudinal fine costae, continuous over chambers but not across sutures. The aperture is terminal with a lip, at the end of the neck.

**Remarks.** Our specimens fully agree with the holotype (USNM CC 2357) and with the original description by Cushman (1923). Hayward et al. (2010) assigned this species to the genus *Trifarina*; which is characterised by having sharp edges, “angles sharp to longitudinally carinate” according to Loeblich and Tappan (1988). However, our specimens display more rounded edges, and therefore we assigned them to the genus *Uvigerina*. *Uvigerina occidentalis* was differentiated from other *Uvigerina* species based on its small, elongated, and fusiform test ornamented with costae. In contrast, the other *Uvigerina* species with costae (e.g. *Uvigerina peregrina*) exhibit larger tests and inflated chambers.

**Paleoecology and paleobathymetric distribution.** In the vicinity of New Zealand, *U. occidentalis* ranges from outer shelf to abyssal, and it is most abundant at bathyal depths (Hayward et al., 2010).

Family Uvigerinidae Haeckel 1894

Genus *Uvigerina* d'Orbigny 1826

*Uvigerina peregrina* s.l. Cushman 1923

Fig. 6: 8a–b

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

1986 *Uvigerina peregrina* Cushman; Kurihara and Kennett, pl. 3, figs. 1–3

1987 *Uvigerina peregrina* Cushman; Loeblich and Tappan, pl. 573, figs. 24–28

1989 *Uvigerina peregrina* Cushman; Hermelin, pl. 12, figs. 6–8

1999 *Uvigerina peregrina* Cushman; Kawagata, figs. 5–8

2001 *Uvigerina peregrina* Cushman; Hayward et al., figs. 14WW–XX

2003 *Uvigerina peregrina* Cushman; Hayward et al., fig. 4M

2005 *Uvigerina peregrina* Cushman; Schönfeld and Altenbach, fig. 2c

2008 *Uvigerina peregrina* Cushman; Lobegeier and Sen Gupta, pl. 3, fig. 11

2010 *Uvigerina peregrina* Cushman; Hayward et al., pl. 21, figs. 27–31

2019 *Uvigerina peregrina* Cushman; Ridha et al., fig. 5: 6a

**Description.** Test small to medium in size, triserial, and fusiform. Generally, 2.5 times as long as wide. Chambers inflated and gradually increasing in size. Wall calcareous and ornamented with raised longitudinal costae, not continuous but separated by depressed sutures. The basal end is often ornamented by short spines. The aperture is rounded and terminal, at the end of a short cylindrical neck, typically covered in small spines.

**Remarks.** The holotype of *U. peregrina* checked at the Smithsonian (USNM PP 17574) shows deep costae that reach the last chambers. Following Hayward et al. (2010), we used a broad concept of this species (*Uvigerina peregrina* s.l.). The specimens observed at Site U1506 exhibit distinctive features such as large tests, inflated chambers, and longitudinal costae; however, the high variability in these characteristics made differentiating distinct taxa impossible. The overall preservation is reasonably good; however, the neck region is frequently found to be broken. In the best-preserved specimens, small spines were observed around the neck area.

**Paleoecology and paleobathymetric distribution.** This cosmopolitan species has been documented from shelf to abyssal depths. Around New Zealand, it occurs with the highest abundance from middle bathyal to abyssal depths; in the South Atlantic, it is common at lower bathyal depths (Mead, 1985; Schönfeld and Altenbach, 2005; Schweizer, 2006; Hayward et al., 2010). *Uvigerina peregrina* has been linked to oxygen-depleted water masses and eutrophic conditions at the seafloor (Lohmann, 1978; Streeter and Shackleton, 1979; Schnitker, 1979; Miller and Lohmann, 1982).



Family Uvigerinidae Haeckel 1894

Genus *Uvigerina* d'Orbigny 1826

*Uvigerina proboscidea* Schwager 1866

Fig. 6: 9a–b

1866 *Uvigerina proboscidea* Schwager: p. 250, pl. 7, fig. 96

1945 *Uvigerina proboscidea* Schwager; Cushman and Todd, p. 50, pl. 7, figs. 28–29

1986 *Uvigerina proboscidea* Schwager; Kurihara and Kennett, pl. 3, fig. 6

1986 *Uvigerina proboscidea* Schwager; Van Morkhoven et al., p. 28, pl. 6.

1993 *Uvigerina proboscidea* Schwager; Katz and Miller, pl. 4, fig. 8

1995 *Uvigerina proboscidea* Schwager; Nomura, p. 274, pl. 2, fig. 5

2001 *Neouvigerina proboscidea* Schwager; Hayward et al., fig. 14RR

2010 *Neouvigerina proboscidea* Schwager; Hayward et al., pl. 21, figs. 9–11

2013 *Uvigerina proboscidea* Schwager; Holbourn et al., p. 602, figs. 1–3

2019 *Uvigerina proboscidea* Schwager; Ridha et al., fig. 5: 5c

**Description.** The test is triserial and elongate, about 2.5 times as long as broad. Circular in cross-section with a basal spine. The inflated chambers have a subspherical shape and are separated by depressed sutures. Wall calcareous, finely perforated, and hispid. The aperture is terminal with a lip, located at the end of a short neck.

**Remarks.** Specimens observed at Site U1506 exhibit good preservation. The neck area is frequently preserved without damage. Among the *Uvigerina* species observed at Site U1506, *U. proboscidea* is the only species without costae and being solely ornamented by short spines.

**Paleoecology and paleobathymetric distribution.** The greatest abundance around New Zealand ranges from the outer shelf to upper bathyal depths (100–600 m; Hayward et al., 2010). This species has been associated with high-productivity conditions and low seasonality of the food supply (Loubere, 1998; Gupta and Thomas, 1999; Loubere and Fariduddin, 1999).

## 4 Discussion

### 4.1 Paleobathymetry

Shipboard and post-cruise studies of benthic foraminifera and ostracods indicate lower bathyal depths from the Miocene to the Pliocene at Site U1506 (Sutherland et al., 2019b, 2020). Here we present a more detailed analysis of the paleodepth distribution of benthic foraminifera across the

Late Miocene–Early Pliocene at this site. Our paleobathymetric estimates are based on the presence and abundance of depth-dependent species, with paleodepths and upper depth limits derived from Van Morkhoven et al. (1986) and Hayward et al. (1999, 2001, 2004, 2010). The pattern of occurrence of benthic foraminifera at various depths is shown in Fig. 8.

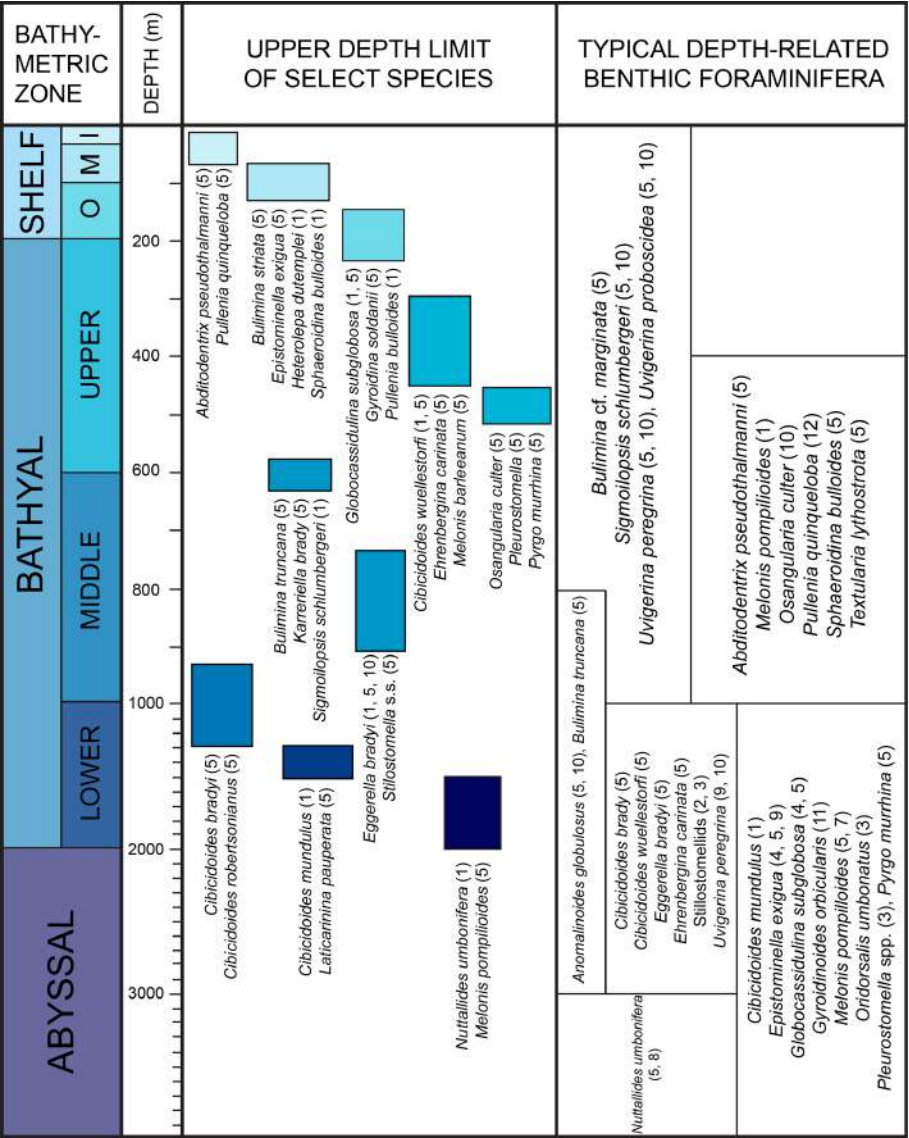
The occurrence of species such as *Heterolepa dutemplei* (up to 7 %), *Eggerella bradyi* (up to 4 %), *Karreriella bradyi* (up to 4 %), *Osangularia culter* (1 %–18 %), and *Textularia lythostrota* (up to 4 %), which have their upper depth limit in the outer shelf zone and are not typically found at depths shallower than ca. 600 m, suggests deposition at paleodepths deeper than upper-shelf bathyal settings. The study interval contains a high percentage of species that are common at lower bathyal to abyssal depths, such as *Bulimina truncana* (up to 11 %), *Cibicidoides mundulus* (up to 9 %), *Epistominella exigua* (up to 13 %), *Globocassidulina subglobosa* (up to 20 %), *Oridorsalis umbonatus* (up to 11 %), and *Uvigerina peregrina* (up to 16 %). Stilostomellids (maximum abundance 13 %) and Nodosariids (maximum abundance 9 %) have been observed in all the samples and are typically abundant at bathyal and abyssal depths (Hayward et al., 1999, 2002; Kennett and Casey, 1969). Abyssal taxa (> 2000 m) such as *Nuttallides umbonifera* make up < 3 % of the assemblages.

Based on these new data and in agreement with Sutherland et al. (2019b, 2020), we interpret the study interval at Site U1506 deposited in the lower bathyal zone, between ca. 1000 and 2000 m paleodepth.

### 4.2 Paleoenvironmental interpretations

The comparison of recent and fossil benthic foraminifera is a valuable tool to reconstruct paleoenvironmental parameters such as nutrient supply to the seafloor, bottom water oxygenation, or seasonality (e.g. Bernhard, 1986; Jorissen et al., 1995; Fontanier et al., 2002). This approach is commonly employed in paleoceanographic studies, but we acknowledge that the ecology of present-day foraminifera is not fully resolved (Murray, 2006).

At Site U1506, the paleoenvironmental and paleoceanographic changes across the Late Miocene–Early Pliocene were documented by Gastaldello et al. (2023a), who carried out a multi-proxy analysis and identified two intervals with paleoenvironmental significance. The older interval (Interval 1, from 221.75 to 194.75 m, 7.4 to 6.7 Ma) is characterised by a high relative abundance of PETs (e.g. *E. exigua*, *G. crassa*, *G. subglobosa*), indicative of high seasonal surface primary productivity due to phytoplankton blooms. The low abundance of species that can thrive in oxygen-deficient conditions (e.g. *Bulimina*, *Uvigerina*; Kaiho, 1994) and the high coarse fraction accumulation rates point to intense bottom currents and well-oxygenated waters during this interval (Gastaldello et al., 2023a). The younger interval (Interval



**Figure 8.** Paleobathymetric distribution and upper depth limits of Neogene benthic foraminifera. (1) Van Morkhoven et al. (1986), (2) Hayward et al. (1999), (3) Hayward et al. (2001), (4) Hayward et al. (2004), (5) Hayward et al. (2010), (6) Smith (1964), (7) Igle and Keller (1980), (8) Douglas and Woodruff (1981), (9) Mead (1985), (10) Pflum and Frerichs (1976), (11) Corliss (1979), (12) Ingle (1980). Modified after Van Morkhoven et al. (1986).

2, from 194.75 to 82.01 m, 6.7 to 4.5 Ma) is characterised by abundant infaunal morphogroups and species adapted to low-oxygen conditions and high productivity (such as *Bolivina*, *Bulimina*, *Fursenkoina*, *Melonis*, and *Uvigerina* species; Kaiho, 1994; Smart et al., 2007), pointing to a continuous and high food supply and oxygen deficiency at the seafloor (Gastaldello et al., 2023a). The change in productivity regime and current strength at 6.7 Ma correlates with a stratigraphic change in the seismic profiles, which show a switch from complex bedforms prior to 6.7 Ma to a layer-cake pattern afterwards (Gastaldello et al., 2023a). The diverse expression of the Biogenic Bloom

has been related to a change in ocean and atmospheric circulation during the Late Miocene. During Interval 1, the northward migration of the Westerlies and the strengthening of the East Australian Current (EAC) led to an increased influence of this current at Site U1506, accounting for the strong bottom currents and the productivity conditions inferred from benthic foraminifera (Gastaldello et al., 2023a). After 6.7 Ma, the southward movement and the weakening of the Westerlies and the EAC led to weaker bottom currents. The intensification of the Asian monsoon, the drying of the Asian landmass, and the resulting weathering increase could have led to a higher food supply to the seafloor during Inter-

val 2, as inferred from benthic foraminifera (Gastaldello et al., 2023a).

Based on new data from this study, we redefined the thickness and the position of Interval 2 (old Interval 2 from Gastaldello et al., 2023a), which now spans from 194.75 to 103.21 m (6.7 to 4.9 Ma), and defined a third interval between 103.21 and 82.01 m (4.9 to 4.5 Ma) (Fig. 9). The previous paleoenvironmental interpretations of Interval 2 from Gastaldello et al. (2023a) remain unchanged. Interval 3 spans from 4.9 to 4.5 Ma (103.21 and 82.01 m), the upper part of the study section, and is characterised by high BFARs (maximum value of ca. 3800 at 96.05 m), low diversity and heterogeneity, low relative abundance of buliminids s.l. and *Uvigerina*, and high relative abundance of PETs (e.g. *A. weddellensis*, *E. exigua*, and *G. crassa*) (Fig. 9). The high BFARs are probably linked to the rapid proliferation of PETs, as these small-sized benthic foraminifera tend to form large populations, which in turn increase the test counts per gram of sediment. These assemblage changes suggest a transition in the productivity regime from a phase of continuous food supply and low-oxygen conditions observed during Interval 2 to a phase of increased seasonality in food supply, along with well-oxygenated bottom waters, during Interval 3. These observations collectively suggest a scenario of elevated productivity, as indicated by high BFARs, small-sized specimens, and abundance peaks in PETs and opportunistic taxa. These findings could potentially be interpreted in terms of high seasonal surface primary productivity driven by phytoplankton blooms.

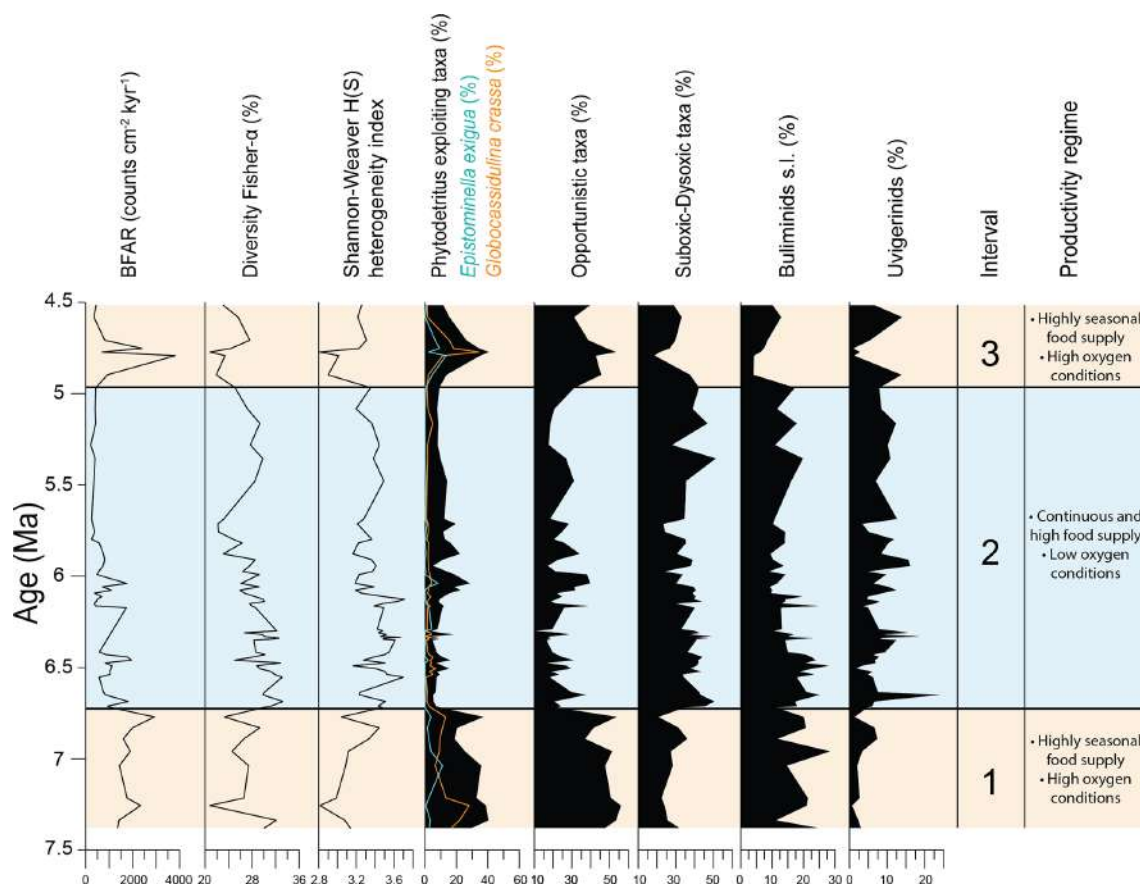
The paleoenvironmental conditions inferred for Interval 3 are comparable to those in Interval 1, although both the benthic foraminifera assemblages and the paleoceanographic settings are not comparable. Considering the benthic foraminifera assemblages, the main difference between Intervals 1 and 3 could be observed in the composition of the PET group. Both intervals 1 and 3 are dominated by PETs, with a similar relative abundance of *A. weddellensis*, *E. exigua*, and *G. crassa*. The main difference between Interval 3 and Interval 1 can be observed in the relative abundance of *G. subglobosa*, higher in Interval 1 and lower in Interval 3. While *G. subglobosa* is known to have a preference for high-oxygen conditions (Kaiho, 1999), the decrease in relative abundance of this species in Interval 3 could not be attributed to a change in oxygenation levels since the suboxic–dysoxic taxa show low values in both Interval 1 and 3. The decrease in *G. subglobosa* could rather be attributed to changes in ocean currents during these two intervals. The productivity regime inferred during Interval 1 in Gastaldello et al. (2023a) has been linked to a northward migration of the Westerlies and a strengthening of the EAC. In turn, the EAC strengthening has been associated with high current activity and high abundance of *G. subglobosa* and *G. crassa*. However, in the warmer Early Pliocene (Interval 3), the Westerlies exhibited reduced strength and shifted poleward (to the south) (Brierley et al., 2009; Abell et al., 2021). Moreover,

previous studies on the Lord Howe Rise (ODP Site 590) reported a weakening of the EAC during the Early Pliocene related to the closure of the Central American Seaway around 4.8–4.0 Ma (Haug and Tiedemann, 1998; Haug et al., 2001; Steph et al., 2006; Karas et al., 2011). Sea surface temperatures (SSTs) at Site 590 show stable values comparable to modern annual values, indicating that there has been no migration of the EAC over the site during the Early Pliocene (Karas et al., 2011). The low relative abundance of *G. subglobosa* during Interval 3 could be related to a weaker EAC and to less intense bottom water currents at Site U1506. Instead, compared to the previous interpretation by Gastaldello et al. (2023a), the high abundance of *G. crassa* documented in both Interval 1 and 3 indicates that this species is not influenced by the bottom water strength as previously thought. The Early Pliocene was characterised by substantially higher global temperatures compared to the present-day climate. The equatorial Pacific was characterised by warmer equatorial SSTs, persistent El Niño conditions, and a minimal east–west gradient (Fedorov et al., 2006; Groeneveld et al., 2006; Steph et al., 2006; Drury et al., 2018). At the same time, the ocean tropical warm pool expanded towards the poles, and the temperature gradient between the Equator and the mid-latitudes experienced a notable decrease, leading to a weakening of the Hadley and Walker cells (Fedorov et al., 2006; Brierley et al., 2009). A modelling study of the Early Pliocene showed that these conditions may have contributed to increased tropical cyclone activity in the Pacific, including the south-western Pacific region, resulting in intensified vertical mixing of the ocean waters (Fedorov et al., 2006). The development of a deeper mixed layer during the winter season is often linked to intensified phytoplankton blooms and the consequent high abundance of PETs. This deeper mixed layer plays a crucial role in transporting nutrients, thereby promoting the enhanced growth rates of phytoplankton during the following spring period (Campbell and Aarup, 1992; Thomas and Gooday, 1996). Therefore, this mechanism could account for the high-productivity conditions inferred from the benthic foraminiferal assemblages during Interval 3. Although the paleoenvironmental conditions in Intervals 1 and 3 are similar, they occurred in different climatic settings and were influenced by distinct climatic processes.

## 5 Conclusions

We conducted a comprehensive investigation of Late Miocene–Early Pliocene benthic foraminifera from Site U1506 in the Tasman Sea, with a specific focus on the paleoceanographic phenomenon known as the Biogenic Bloom. Benthic foraminifera exhibit overall well-preserved tests with fine surface details, allowing for accurate taxonomic identification. The taxonomic dataset in this study comprises a systematic description and illustration of the 36 most common species (those making up > 2 % of the assemblages in at





**Figure 9.** Changes in benthic foraminiferal proxies and relative abundance of selected taxa across the Late Miocene–Early Pliocene at IODP Site U1506 plotted against age (Ma). Highlighted Interval 1 (orange), Interval 2 (blue), and Interval 3 (orange) indicate the productivity regimes.

least one sample), including taxonomic details and remarks and paleoecological and paleobathymetric annotation. The benthic foraminiferal assemblages in the Tasman Sea consist of cosmopolitan species that have been described from Upper Miocene and Lower Pliocene deposits from other regions and from the Holocene in the south-western Pacific Ocean.

A detailed paleodepth interpretation of Site U1506 across the Late Miocene–Early Pliocene was performed based on the abundance and distribution of depth-dependent benthic foraminifera. The simultaneous occurrence of species not commonly encountered at depths shallower than ca. 600 m (e.g. *H. dutemplei*, *E. bradyi*, *O. culter*) coupled with the present species that are most abundant at lower bathyal to abyssal depths (e.g. *E. exigua*, *G. subglobosa*, *U. peregrina*), alongside the low abundance of abyssal taxa (e.g. *N. umbonifera* and *P. bulloides*), indicates a lower bathyal environment at Site U1506.

Three intervals with paleoenvironmental significance were differentiated across the study record. We redefined the position of Interval 2 (6.7 to 4.9 Ma) defined in Gastaldello et al. (2023a) and defined Interval 3 (4.9 to 4.5 Ma). The elevated BFAR and relative abundance of PETs observed during

Interval 3 indicate a scenario of high seasonal surface primary productivity driven by phytoplankton blooms. A similar situation was previously noted for Interval 1. However, in this study, we observed a notable difference in the relative abundance among PETs between the two intervals (1 and 3). When PETs are abundant, the phytodetritus species *G. subglobosa* shows high abundance in Interval 1 but low abundance in Interval 3. This pattern is attributed to varying strengths of bottom currents. *Globocassidulina subglobosa* exhibits high abundances during periods of intense current activity (Interval 1), while its relative abundance declines when the bottom water currents weaken (Interval 3). Our findings thus contribute to a better understanding of the regional imprint of the Biogenic Bloom in the Tasman Sea and provide insights into the paleoenvironmental and paleoceanographic changes that occurred during this time interval.

**Data availability.** Data generated in this study are included in the Supplement and will be available at Pangaea <https://doi.org/10.1594/PANGAEA.963742> (Gastaldello et al., 2023b).

**Supplement.** The supplement related to this article is available online at: <https://doi.org/10.5194/jm-43-1-2024-supplement>.

**Author contributions.** Conceptualisation: MEG, CA, LA; data curation: MEG, LA; investigation: MEG; supervision: CA, LA; writing – original draft: MEG.

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