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Recent deep-sea benthic foraminifera from an active volcanic area: first insights around Nishinoshima, Northwest Pacific

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L.M.C.: Formal analysis, Investigation, Writing- Original draft preparation, Visualisation. S.K.: Investigation, Formal analysis, Writing- Reviewing and Editing. I.M.: Formal analysis, Writing- Reviewing and Editing. Y.T.: Investigation, Writing- Reviewing and Editing. Y.N.: Writing- Reviewing and Editing. T.T.: Conceptualisation, Writing- Reviewing and Editing. All authors read and approved the final manuscript.

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Recent deep-sea benthic foraminifera from an active volcanic area: first insights around Nishinoshima, Northwest Pacific

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Abstract

This study reports the preliminary results of the first analysis of benthic foraminifera of seafloor surface sediments from the Nishinoshima volcanic area. The samples were collected in 2015 during several DEEP TOW (deep ocean floor towed survey system) dredges on the summit and flank of Nishinoshima-Minami Knoll, a knoll ~8 km southeast of Nishinoshima Island that forms part of the same submarine volcanic edifice. The two stations DT-1170 (N9) and DT-1173 (N12) were sampled from water depths of 1062–1015 m and 516–203 m, respectively, and were located at distances of 10 and 8 km from the main Nishinoshima edifice, respectively. The two stations displayed a typical faunal structure for deep-sea environments, with low foraminiferal densities but highly diversified assemblages. A total of 131 species, excluding undetermined porcelaneous and hyaline species groups, were found, and are recent deep-sea benthic foraminifera previously identified in the bathyal depths around Izu-Bonin volcanic arc, or species found in the Neogene onland strata in the western Pacific region. We conclude that the bathyal benthic foraminiferal assemblages in the studied area are likely to be free from recent volcanic activity. We provide detailed taxonomic descriptions of the 21 commonly occurring species. This exploratory study therefore provides crucial basic information about benthic foraminiferal faunas in the Nishinoshima area, which could be used in future environmental analysis of this highly dynamic region.

Keywords: active volcanic island; benthic foraminifera; Bonin Islands; deep-sea environment; Nishinoshima

Introduction

Nishinoshima is a volcanic island belonging to the Bonin Islands and located in the North Pacific Ocean at 27°14’49” N 140°52’28” E, ~1000 km south of mainland Japan (Figure 1A). The island is a part of the Izu-Bonin volcanic arc, which is formed along the intra-oceanic convergent margin where the Pacific Plate is subducting beneath the Philippine Sea Plate. Nishinoshima Island is the subaerial summit of a submarine volcano that rises to a height of ~3000 m above the surrounding ocean floor. The main volcanic edifice includes satellite submarine knolls to the northeast, southeast, south and west with summits as shallow as 300 m below sea level (mbsl). The first eruptive activity of Nishinoshima volcano in recorded history was in May 1973 with an eruption from a shallow submarine vent that lasted 13 months, and for the next 40 years the only evidence of further activity was occasional reports of discoloured water in the area vent (Global Volcanism Program, 2017). A new period of subaerial eruptive activity began in November 2013, and went on to build a new island with a subaerial vent. Continuous mixed effusive-explosive activity continued until November 2015, consisting of Strombolian eruptions from a central pyroclastic cone, large gas-and-ash plumes, and extensive lava flows erupting from several vents. A similar phase of eruptive activity occurred between April and August 2017 (Japan Coast Guard, 2019), and further in December 2019 (Maeno *et al.*, 2021), and this activity is ongoing as of October 2022.

The combination of its history of eruptive activity and its isolated nature has made Nishinoshima an ideal case study for the recovery of life following eruptions. Thus, flora and fauna on its subaerial summit have been monitored in 1969, 1983, and 2004 (Abe, 2006 and references within). By contrast, however, studies about the marine ecosystems in the area, and especially the deep-sea benthic component, are still lacking.

Benthic foraminifera are among the most diverse and abundant meiobenthos living in and on the modern seafloor (Gooday *et al*., 1992; Sen Gupta, 2003). These micro-organisms can build a shell (called test) composed of either secreted calcium carbonate or agglutinated grains from the surrounding environment. Due to their small size, short lifespan, and abundance in the sediment of a wide range of environments, benthic foraminifera provide excellent records of environmental changes at various scales. Foraminiferal populations are known to rapidly adapt to natural and anthropogenic stress in their environment (e.g. Sen Gupta, 2003). In various volcanic areas worldwide, they have been shown to progressively recolonise their environments after eruption events such as ash fall to the deep-sea floor, for example around Deception Island, Antarctica (Finger and Lipps, 1981); in the Azores Islands, Portugal (Di Bella *et al*., 2015); after the 1991 eruption of Mt. Pinatubo, Philippines (Hess and Kuhnt, 1996; Hess *et al*., 2001); and in the sea around the island of Montserrat in the Lesser Antilles (Hart et al. 2022). In areas surrounding hydrothermal vents associated with submarine activity, low diversity and abundance of foraminiferal assemblages and/or their specific faunal composition have been reported from seamounts near the East Pacific Rise (Nienstedt and Arnold, 1988), in the Gulf of California (Molina-Cruz and Ayala-López, 1988), in the Tyrrhenian Sea (Panieri *et al*., 2005; Panieri, 2006), and also in areas around Japanese islands such as in the Okinawa Trough (Akimoto *et al*., 1992: Figure 1) and around the active Sakurajima volcano, in the semi-enclosed Kagoshima Bay in southwest Japan (Kitazato, 1979; Ôki, 1989; Figure 1). Around these hydrothermal vents, the assemblages dominated by agglutinated species were suggested to be associated with high acidity of the bottom waters (Kitazato, 1979; Nienstedt and Arnold, 1988; Ôki, 1989; Akimoto *et al*., 1992).

Recent benthic foraminiferal assemblages have been reported from bathyal to abyssal depths (195–4125 m depth) around remote volcanic islands in the Izu-Bonin volcanic arc region (Akimoto, 1990; Kaiho and Nishimura, 1992). However, to the best of our knowledge, no observations of the foraminiferal assemblages have so far been performed from the bathyal depths nearby the submarine volcanoes around the Bonin Islands (Ogasawara Archipelago), which are currently showing eruptive activity. Thus, we collected deep-sea sediment at two different bathyal depths from the active Nishinoshima volcanic island area in June 2015, and investigated the recent benthic foraminifera assemblages during the last stages of the 2013–2015 eruption phase and their association with submarine volcanic activity. In the future, similar snapshots of the benthic foraminifera assemblages in the area will help to determine the potential influence of the dynamic Nishinoshima volcanic system on the benthic faunal structure.

Material and Methods

Sediment sampling

Surface sediment was collected during cruise NT15-E02 of R/V *Natsushima* in June 2015, on submarine knolls surrounding Nishinoshima (Figure 1B). During the survey period, an exclusion zone was in place with a radius of 4.5 km from the main eruptive edifice. Moreover, previous analyses from nearby volcanic areas showed very low densities of meiofauna in the coarse sediment (unpublished data). The samples were therefore collected by DEEP TOW dredge, which collected the top 1 cm-thick sediment over several meters (Momma and Hotta 1989). Given the risk of eruption, the DEEP TOW dredge was chosen rather than a coring procedure, to avoid remaining in a static position for an extended period of time. In addition, the DEEP TOW dredge allowed us to collect large amounts of sediment containing a sufficient number of foraminifera for a comprehensive fauna analysis. Here we present data from two dredge stations located on Nishinoshima-Minami Knoll, which lies ~8 km to the south of Nishinoshima Island (Figure 1C). Station N9 (dredge DT-1170) was located on the eastern flank of the Nishinoshima-Minami Knoll (27°10'N, 140°55'E, ~10 km SSE of the active subaerial vent) and the dredge traversed a submarine ridge between water depths of 1062–1015 mbsl. Expendable bathythermograph (XBT) measurements taken during the cruise in the area recorded water temperatures of ~4°C at this water depth. Station N12 (dredge DT-1173) was located on the northern flank (27°11'N, 140°54'E, ~8 km south of the active subaerial vent) and the dredge traversed the upper slope to the summit of the knoll between water depths of 516–203 mbsl. XBT measurements in the area recorded water temperatures of ~15°C at these water depth ranges. Stations N9 and N12 are further referred to as the flank site and summit site, respectively. A vertical profile of the annual dissolved oxygen (DO) content near the sampling sites (27°5'N, 140°5'E) is recorded in the publicly available database Levitus94 (Levitus and Boyer, 1994). The oxygen minimum zone (OMZ) is identified between ~1000 and ~1400 mbsl (Figure 2), which is consistent with the general depth range of the OMZ in the NW Pacific, approximately between 500–1500 mbsl (Nagata *et al*., 1992). The mean annual DO is ~1.4 ml/L at the depth of station N9, and ~4.5 ml/L at the depth of station N12 (Figure 2). According to the oxygenation levels defined by Tyson and Pearson (1991), the deeper station N9 is located within the depth range of the OMZ and thus displays dysoxic conditions, while the shallower station N12 is located in oxic conditions.

Sediment analysis

The collected sediment from both stations was dried at room temperature and then weighed and sieved through 0.5, 1, 2 and 4 mm opening sieves for grain-size analysis following the Wentworth size classification (Wentworth, 1922). The percentage by mass of each sediment fraction was calculated. The sediment grains from both stations were inspected using a petrological microscope for mineral identification, based on previous work from Tamura *et al.* (2018). Optical microscope photographs of the fractions 0.5–1, 1–2, and 2–4 mm were taken.

Foraminifera analyses

The < 0.5 mm fraction of the sediment from both stations was sieved through 63, 125, 150, 300 and 500 µm-opening sieves, to facilitate the picking process. Benthic foraminifera from each fraction were hand-picked under a binocular microscope. When necessary, the fractions were split into appropriate aliquots. The total assemblages (live + dead, 63–500 µm) was investigated, without distinction between living and dead specimens. Given the low abundances, foraminiferal counts for each taxon were expressed in real numbers (Appendix A), and only the total foraminifera densities for both stations were normalised to 10 g of dry sediment, for the purpose of comparison. Relative abundances of hyalines, porcelaneous and agglutinated forms were calculated, as well as the percentage of smaller-sized specimens (63–125 µm) including juvenile forms. To quantify the species diversity, the Shannon index H was calculated using the PAST (PAleontological STatistics) software (Hammer *et al.*, 2001). Species showing a relative abundance greater than 2 % in any one of the two stations were considered as commonly occurring species. Specimens of these species were selected for Scanning Electron Microscope (SEM) imaging, and pictured in a Hitachi Miniscope TM3000 at JAMSTEC, as well as in a JEOL JSM-6510LV at Yokohama National University (YNU). Digital images were also taken for some specimens by Keyence digital microscope at YNU.

Results

Sediment characteristics

A total of 393 and 436 grams of sediment were collected at stations N9 and N12, respectively. The sediment from station N9 (flank site) had a large proportion of fine grains, with 47.6 % classed as silt and sand (Table 1). The sediment from station N12 (summit site) was coarser, with 60.3 % classed as pebbles and only 6.4 % as silt and sand. The grains of the very coarse sand (1–2 mm) from station N9 were grey in colour and consisted of fragments of porphyritic andesite, while those from station N12 were identified as light coloured dacite (Figure 3). The coarse sand fraction (0.5–1 mm) at station N9 contained clinopyroxene, plagioclase, and olivine crystals. The coarse sand fraction at station N12 also contained clinopyroxene and plagioclase crystals as well as orthopyroxene crystals but did not contain olivine crystals.

Benthic foraminiferal assemblages

The foraminiferal assemblages show relatively low densities in both stations N9 and N12 (12 and 45 individuals/10 g of sediment, respectively; Table 2) but were highly diversified (H values of 3.27 and 3.13, respectively; Table 2). A total of 131 species, excluding undetermined porcelaneous and hyaline species groups, were identified in the area (Appendix A), and the number of species at stations N9 and N12 were 78 and 72 species, respectively (Table 2). At station N12 (summit site), the percentage of smaller-sized forms (63–125 μm) including juvenile forms represented almost half of the assemblages (49.3 %), with 30 species exclusively present in this fraction (Appendix A), while they were only 17.0 % at station N9 (flank site). The hyaline forms were dominant at both stations N9 and N12 (81.9 and 92.9 %, respectively; Table 2). The second most dominant forms at station N9 were the agglutinated forms (17.4 %), whereas at station N12 they were the porcelaneous forms (6.6 %). Twenty-one commonly occurring species were listed and imaged (Table 3; Figures 4, 5 and 6).

At station N9 (flank site), the species *Globocassidulina oriangulata* dominated the assemblage, with a relative abundance representing a quarter of the total assemblage (26.4 %; Table 3). The other abundant species were *Burseolina pacifica* (9.6 %), *Globocassidulina subglobosa* (4.3 %), *Bigenerina nodosaria* (4.0 %), *Osangularia bengalensis* (3.8 %), *Cyclammina cancellata* (3.6 %), *Bueningia creeki* (3.4 %), *Hoeglundina elegans* (3.4 %), *Cibicides lobatulus* (2.6 %), *Lenticulina* sp. 4 (2.6 %), *Paracassidulina nabetaensis* (2.6 %), *Oridorsalis umbonatus* (2.3 %), and *Valvulina arenacea* (2.1 %).

At station N12 (summit site), three cassidulinid species were observed in abundance: *G. subglobosa* (16.6 %; Table 3), *G. oriangulata* (16.2 %), and *P. nabetaensis* (10.5 %), and were followed by *Triloculinella pseudooblonga* (5.2 %), *Cibicides conoideus* (4.7 %), *Discorbis vilardeboanus* (3.9 %), *Bolivina vadescens* (3.1 %), *Lenticulina suborbicularis* (2.8 %), *Abditodemtrix pseudothalmanni* (2.1 %), *Lenticulina platyrhinos* (2.1 %), and *Globocassidulina venustas* (2.1 %).

The foraminifera species found in our two stations are common for bathyal environments near remote islands in the western Pacific Ocean. *Hoeglundina elegans*, *C. conoideus*, and species from the genus *Discorbis*, which are species characterising the shallower station N12 (summit site, 516–203 mbsl), have for example been reported from upper bathyal depths in the northern Izu Islands at 195–532 mbsl (Akimoto, 1990). Furthermore, *B. nodosaria*, *C. cancellata*, *B. creeki*, and *B. pacifica*, which are characteristic species for the deeper station N9 (flank site, 1062–1015 mbsl), have been hitherto known mostly from mid-bathyal to abyssal depths, for example ca. >600 mbsl in the Izu Islands region (Akimoto, 1990; Kaiho and Nishimura, 1992), and at 747 mbsl around the Marshall Islands, tropical NW Pacific Ocean (Cushman *et al*., 1954). *Bueningia creeki* was also found at water depth of 468 mbsl, off Likiep Island, Marshall Islands, where bottom temperature was ~6 °C (Todd, 1965), similar to our station N9 (~4°C). *Globocassidulina oriangulata* from the deeper station N9 and shallower station N12, respectively, is the most dominant species in our assemblage, and it has also been reported from upper and lower bathyal depths in the northern Izu Islands at 195–532 mbsl and 1453–1874 mbsl (Akimoto, 1990). However, its microhabitat is not well understood. *Globocassidulina subglobosa* and *P. nabetaensis*, which are abundant species at station N12 (summit site), have been recorded at deeper than lower bathyal depths in the Izu-Bonin Arc region (Akimoto, 1990; Kaiho and Nishimura, 1992). Agglutinated species occur distinctly in the deeper station N9.

Discussion

The benthic foraminiferal assemblage at deep bathyal station N9 (flank site, 1062–1015 mbsl) is dominated by *Globocassidulina oriangulata*, accompanied by *Burseolina pacifica* and *Globocassidulina subglobosa*, while the assemblage at upper bathyal station N12 (summit site, 516–203 mbsl) is rich in *G. subglobosa* followed by *G. oriangulata* and *Paracassidulina nabetaensis*. These cassidulinids, found at the two stations, have been reported to inhabit the bathyal depths around Japan (Inoue, 1989; Nomura, 1984), and around the remote islands and submarine volcanos in the Northwest Pacific (e.g. Akimoto, 1990). Nienstedt and Arnold (1988) reported a calcareous species-rich assemblage dominated by *Cassidulina carinata* and other cassidulinids from pyroclastic deposits of a seamount (1247 mbsl) located east of the East Pacific Rise, where hydrothermal activity was present. Panieri *et al*. (2005) found that *Globocassidulina subglobosa* was abundant in area of the shallow-water hydrothermal environment of the Secca del Capo region (266–302 mbsl), the Aeolian arc of the Tyrrhenian Sea, where volcanic gas emission and hydrothermal activity were no longer observed.

The foraminiferal assemblages seen at stations N9 and N12 are highly diverse (Table 2). In general, the number of benthic foraminifera species are limited (low diversity) in areas with significant volcanic ash fallout on the seafloor (Hess and Kuhnt, 1996; Hess *et al.*, 2001; Hart *et al.*, 2022). Low diversity assemblages of benthic foraminifera have also been observed in the vicinity of high hydrothermal activity areas, where it is also believed that the acidified seawater dissolves calcium carbonate and causes agglutinated foraminifera to dominate the assemblages (Di Bella *et al.*, 2015; Molina-Cruz and Ayala-López, 1988, Panieri *et al.*, 2005; Panieri, 2006). At our station N9 (1062–1015 mbsl), the assemblages were composed of about 10% of the agglutinated species *Bigenerina nodosaria*, *Cyclammina cancellata*, and *Vulvulina arenacea* (Table 3). Hydrothermal sediments at depths of 1300–1400 mbsl within the Okinawa Trough, a back-arc basin, yield 25–76% of agglutinated species dominated by *Saccorhiza ramosa* or *Rhabdammina* sp (Akimoto *et al.*, 1992). Nienstedt and Arnold (1988) also reported benthic foraminiferal assemblages dominated by agglutinated species from the genera *Cyclammina*, *Bathysiphon*, and *Rhabdammina*, from ferromanganese-rich sediments affected by hydrothermal activity on a seamount east of the East Pacific Rise (1225 mbsl). These past studies suggest that foraminiferal assemblages affected by hydrothermal activity are dominated by agglutinated tubular-test species. These relative abundance and species composition of agglutinated species are however different from the assemblages observed around Nishinoshima Island.

At stations N9 and N12, the seafloor sediments are volcanoclastics delivered from volcanic activities (Figure 3), but the foraminiferal assemblages were diverse, rich in calcareous species such as cassidulinids with low abundance of agglutinated species. Therefore, the recent

Nishinoshima eruptions may have a limited impact on the seafloor environment, and potential impacts of volcanic eruption or hydrothermal activity are not identified. With scarce environmental data, such as water properties at the sediment-water interface, it is still an open question whether our foraminiferal assemblages are permanent stable ones that reflects the normal deep-sea environment unaffected by hydrothermal vents, or whether these assemblages are in the process of transition after the recent eruptive activities at Nishinoshima. Hence, we recommend continued monitoring of benthic foraminifera around this area in the future, to see how assemblages may change over time. Since Nishinoshima is still active today, more quantitative samples can be collected from this area and trends may emerge that enhance our understanding of a shifting seafloor in dynamic volcanic areas.

Conclusions

This study presents the first insights about bathyal benthic foraminiferal assemblages and their surrounding deep-sea sediments around the remote active volcanic island of Nishinoshima. Though the collected data are limited, our observations show low density of foraminifera in both stations N9 and N12 (12 and 45 individuals/10 g of sediment, respectively) with high diversity of the bathyal assemblages (H values of 3.27 and 3.13, respectively). In this paper, we describe and quantify the 21 commonly occurring species of benthic foraminifera in our assemblages. The differences in species composition and sediment characteristic probably reflect the distinct environmental settings between our two stations. Our observations suggest that recent volcanic eruptions have had imperceptible impact on the surrounding seafloor environment, and we conclude that the disturbance expected by volcanic eruptions and increased hydrothermal activity is not present in the area investigated around Nishinoshima. These results encourage further more detailed and repeated studies about the foraminiferal response to submarine hydrothermal and eruptive activity.

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Systematic Paleontology

In the following section, 21 species, occurring >2 % in any one of stations, are described and illustrated. Classification of foraminifera has been revised much by molecular phylogenetic research since morphology-based classification of Loeblich and Tappan (1987). In this study we follow the classification scheme mostly of Loeblich and Tappan (1987) for calcareous taxa and Kaminski (2004) for agglutinated taxa, in combination with the suprasuperfamily classification scheme of Pawlowski *et al.* (2013) and Rigaud *et al.* (2015).

Phylum Foraminifera d'Orbigny, 1826

Class Tubotharamea Pawlowski, Holzmann and Tyszka, 2013

Order Miliolida Delage and Hérouard, 1896, *emend*. Pawlowski *et al*., 2013

Suborder Miliolina Delage and Hérouard, 1896

Superfamily Milioloidea Ehrenberg, 1839

Family Hauerinidae Schwager, 1876

Subfamily Miliolinellinae Vella, 1957

Genus ***Triloculinella*** Riccio, 1950

Triloculinella pseudooblonga (Zheng, 1980)

Figure 4.1

Miliolinella pseudooblonga Zheng, 1980, p. 158, 177, pl. 2, figs. 5a–c.

Triloculinella pseudooblonga (Zheng). Loeblich and Tappan, 1994, p. 57, pl. 88, figs. 7–18, pl. 97, figs. 10–12, pl. 98, figs. 1–3, 7–9.

Type locality.— Off Zhongsha Islands, South China Sea; Recent.

Occurrence.— This species occurs at a relative abundance of 3.9% only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— Samples at ~20–293 m in the Timor Sea, off northern Australia (Loeblich and Tappan, 1994).

Remarks.— The specimen illustrated here possesses a distinct apertural flap instead of an apertural tooth. This species differs from *Triloculinella chiastocrysis* Loeblich and Tappan, 1994 in having less obliquely arranged chambers and narrower apertural opening without a wide apertural flap.

Class Nodosariata Mikhalevich, 1992, *emend*. Rigaud *et al.*, 2015

Subclass Nodosariana Mikhalevich, 1992

Order Vaginulinida Mikhalevich, 1993

Family Vaginulinidae Reuss, 1860

Subfamily Lenticulininae Chapman, Parr and Collins, 1934

Genus ***Lenticulina*** Lamarck, 1804

Lenticulina platyrhinos Zheng, 1980

Figure 4.2

Lenticulina platyrhinos Zheng, 1980, p. 159, pl. 3, figs. 2a, b, text-fig. 1; Debenay, 2013, p. 224, pl. 20 (unnumbered).

Type locality.— Off Zhongsha Islands, South China Sea; Recent

Occurrence.— This species occurs at a relative abundance of 2.1% only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— From samples off Zhongsha Islands, South China Sea (Zheng, 1980), and at 600 m of the Northern Shelf off Fiji, southwest Pacific (Debenay, 2013).

Remarks.— This species is characterised by the compressed, involutely coiled test with a compressed snout-like extension of aperture.

Lenticulina suborbicularis Parr, 1950

Figure 4.3

Lenticulina (*Robulus*) *suborbicularis* Parr, 1950, p. 321, pl. 11, figs. 5, 6.

Robulus suborbicularis Parr. Saidova, 1975, p. 190, pl. 52, figs. 5, 6.

Lenticulina suborbicularis Parr. Zheng, 1980, p. 160, pl. 2, figs. 10a–11b; Loeblich and Tappan, 1994, p. 63, pl. 123, figs. 1–9; Hayward *et al*., 2010, p. 179, pl. 14, figs. 29–30.

Type locality.— From samples at 155–122 m off Maria Island, Tasmania, southwestern Pacific Ocean; Recent.

Occurrence.— This species occurs more at the upper bathyal depths of Station N12 (516–203 mbsl) than the uppermost part of lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 2.8% and 0.9 %, respectively.

Distribution.— From the outer shelf to upper bathyal depths in the western Pacific Ocean (e.g., Saidova, 1975; Loeblich and Tappan, 1994), at 600 m depth on the Northern shelf off Fiji, southwestern Pacific (Debenay, 2013), and off Zhongsha Islands, South China Sea (Zheng, 1980).

Remarks.— This species resembles *Lenticulina orbicularis* (= *Robulus orbicularis* d'Orbigny, 1826) but differs in having chambers gradually increased in width for the greater part of each chamber, instead of chambers almost equal width throughout.

Lenticulina **sp. 4**

Figure 4.4

Lenticulina species 5. Debenay, 2013, p. 226, pl. 20 (unnumbered).

Occurrence.— This species occurs more at the uppermost part of lower bathyal depths of Station N9 (1062–1015 mbsl) than the upper bathyal depths of Station N12 (516–203 mbsl), with relative abundances of 2.6% and 0.8 %, respectively.

Distribution.— From sample at 600 m depth of Northern shelf off Fiji (Debenay, 2013).

Remarks.— Our specimen is characterized by having moderately large, inornate lenticular test that is composed by seven chambers in the last coil. The earlier chambers in the penultimate coil are observed through the transparent umbonal portion due to its slightly evolute coiled chamber arrangement. It resembles to *Lenticulina limbosa* (= *Cristellaria* (*Robulina*) *limbosa* Reuss, 1863) but differs in lack of distinct peripheral keel.

Class Globothalamea Pawlowski, Holzmann and Tyszka, 2013

Subclass Textulariana Mikhalevich, 1980

Order Loftusiida Kaminski and Mikhalevich, in Kaminski, 2004

Suborder Loftusiina Kaminski and Mikhalevich, in Kaminski, 2004

Superfamily Loftusioidea Brady, 1884

Family Cyclamminidae Marie, 1941

Subfamily Cyclammininae Marie, 1941

Genus ***Cyclammina*** Brady, 1879

Cyclammina cancellata Brady, 1879

Figure 4.5

Cyclammina cancellata Brady, 1879, p. 62; Brady, 1884, p. 351, pl. 37, figs. 8–16; Cushman, 1910, p. 110, figs. 168–170 (not fig. 171); Barker, 1960, p. 76, pl. 37, figs. 8–16; Zheng, 1988, p. 73, pl. 221, figs.5, 6, pl. 22, figs. 1–3; Jones, 1994, p. 43, pl. 37, figs. 8–16.

Type locality.— Lectotype from the Challenger Station 168 at ~2012 m, off New Zealand, Southwest Ocean; Recent.

Occurrence.— This species occurs at a relative abundance of 3.6% only from the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl).

Distribution.— From samples at ~3430–3660 m in the Northwest Pacific Ocean east of Japan (Brady, 1884), at ~255–1550 m around the North Pacific Ocean (Cushman, 1910).

Remarks.— Brady's (1884) figure (pl. 37, fig. 9) was lectotypified by Banner (1966). This species is characterised by the test with 11–15 chambers in the last coil and the broadly rounded peripheral margin. It is distinguished from *Cyclammina trullissata* (= *Trochammina trullissata* Brady, 1879) that shows the test composed by a greater number of chambers in the last coil and subacute peripheral margin of the test. The test surface of our specimens is smooth and coloured in dark brown marked with yellowish-brown spots probably caused by volcanic substrates on the seafloor.

Order Textulariida Delage and Hérouard, 1896, *sensu* Pawlowski *et al*., 2013

Suborder Textulariina Delage and Hérouard, 1896

Superfamily Textularioidea Ehrenberg, 1838

Family Textulariidae Ehrenberg, 1838

Subfamily Textulariinae Ehrenberg, 1838

Genus ***Bigenerina*** d'Orbigny, 1826

Bigenerina nodosaria d'Orbigny, 1826

Figure 4.6

Bigenerina nodosaria d'Orbigny, 1826, p. 261; Brady, 1884, p. 369, pl. 44, figs. 14–18; Barker, 1960, p. 90, pl. 44, figs. 14–18; Zheng, 1988, p. 120, pl. 32, figs. 2, 3, pl. 33, fig. 1; Jones, 1994, p. 49, pl. 44, figs. 14–18; Loeblich and Tappan, 1994, p. 27, pl. 31, figs. 8–12, pl. 32, figs. 11, 12; Holbourn *et al*., 2013, p. 64, fig. 1; Debenay, 2013, p. 77, pl. 1 (unnumbered).

Type locality.— Adriatic Sea; Recent.

Occurrence.— This species occurs at a relative abundance of 4.0% only from the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl).

Distribution.— From samples at ~50–3000 m in the world oceans (Brady, 1884), at 200 m of the Northern shelf off New Caledonia (Debenay, 2013).

Remarks.— The appearance of the test surface of this species is variable because the species forms their agglutinated test after reflecting the composition of seafloor sediments. The test of our specimens is composed by coarse lithic grains derived from the volcanic activities.

Family Valvulinidae Berthelin, 1880

Subfamily Valvulininae Berthelin, 1880

Genus ***Vulvulina*** d'Orbigny, 1826

Vulvulina arenacea (Bagg, 1908)

Figure 4.7

Bigenerina arenacea Bagg. 1908, p. 132, pl. 5, figs. 4, 5; Cushman, 1911, p. 29, fig. 50a, b.

Vulvulina arenacea (Bagg). Cushman, 1932, p. 79, pl. 10, fig. 13; Zheng, 1988, p. 80, pl. 30, figs. 4–8.

Type locality.— From sample Albatross Station 4508 at ~905 m around Hawaiian Islands, northern central Pacific Ocean; Recent.

Occurrence.— This species occurs at a relative abundance of 2.1% only from the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl).

Distribution.— From samples at ~905 m and ~1345–1582 m around Hawaiian Islands (Bagg, 1908), at ~495 and 1004 m off Hawaiian Islands and at ~1570 and 1810 m of Guam (Cushman, 1911), at ~904 m off Philippine (Cushman, 1932) and at 600 m in the East China Sea (Zheng, 1988).

Remarks.— This large arenaceous species is distinguished from *Vulvulina pennatula* (= *Nautilus* (*Orthoceras*) *pennatula* Batsch, 1791) and its allied species by having the compressed test with less acute and nearly parallel-sided chamber margin at chevron-shaped uniserial portion.

Order Robertinida Loeblich and Tappan, 1984

Suborder Robertinina Loeblich and Tappan, 1984

Superfamily Ceratobuliminoidea Cushman, 1927b

Family Epistominidae Wedekind, 1937

Genus ***Hoeglundina*** Brotzen, 1948

Hoeglundina elegans (d'Orbigny, 1826)

Figure 4.8

Rotalia (*Turbinulina*) *elegans* d'Orbigny, 1826, p. 276.

Epistomina elegans (d'Orbigny). Cushman, 1927a, p. 182, pl. 31, figs. 1-6.

Höeglundina elegans (d'Orbigny). Phleger and Parker, 1951, p. 22, pl. 12, figs. 1a, b.

Hoeglundina elegans (d'Orbigny). LeRoy, 1964, p. F38, p. 6, figs. 27, 28; Akimoto, 1990, pl. 21, figs. 7a, b, pl. 24, figs. 6a–c; Kaiho and Nishimura, 1992, pl. 3, fig. 14; Holbourn *et al.*, 2013, p. 298, figs. 1–3.

Hoeglundina elegans (d'Orbigny) form 1. Debenay, 2013, p. 199, pl. 17 (unnumbered).

Hoeglundina elegans (d'Orbigny) form 2. Debenay, 2013, p. 199, pl. 17 (unnumbered).

Type locality.— Type locality not designated; age not given.

Occurrence.— This species occurs at both the upper bathyal depths of Station N12 (516–203 mbsl) and the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 1.8% and 3.4 %, respectively.

Distribution.— From neritic to bathyal depths around the world ocean, but not in the highest latitude (Holbourn *et al.*, 2013); at 1945 m depth north of Hachijojima Island in the Izu islands (Kaiho and Nishimura, 1992).

Subclass Rotaliana Mikhalevich, 1980

Order Rotaliida Delage and Hérouard, 1896

Superfamily Cassidulinoidea d'Orbigny, 1839a

Family Bolivinitidae Cushman, 1927b

Subfamily Bolivinitinae Cushman, 1927b

Genus ***Bolivina*** d'Orbigny, 1839b

Bolivina vadescens Cushman, 1933

Figure 4.9

Bolivina vadescens Cushman, 1933, p. 81, p. 8, fig. 11; Loeblich and Tappan, 1994, p. 111, pl. 214, figs. 1–4, 7–12; Debenay, 2013, p. 172, pl. 12 (unnumbered).

Type locality.— Off Nairai, Fiji, tropical southwestern Pacific Ocean, ~22 m (12 fathoms); Recent.

Occurrence.— This species occurs at a relative abundance of 3.1% only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— From samples at 5–40 m off New Caledonia (Debenay, 2013); at 53–102 m in the Timor Sea, northern Australia (Loeblich and Tappan, 1994).

Remarks.— The specimens treated here are much smaller size and are probably all juveniles.

Genus ***Abditodentrix*** Patterson, 1985

Abditodentrix pseudothalmanni (Boltovskoy and Guissani de Khan, 1981)

Figure 4.10

Bolivina pseudothalmanni Boltovskoy and Guissani de Khan, 1981, p. 44, pl. 1, figs. 1–5.

Abditodentrix pseudothalmanni (Boltovskoy and Guissani de Khan). Loeblich and Tappan, 1987, p. 503, pl. 554, figs. 1–5; Ujiié, 1990, p. 29, pl. 12, fig. 2; Xu and Ujiié, 1994, figs. 6.6–6.8; Loeblich and Tappan, 1994, p. 113, pl. 218, figs, 1, 2; Ujiié, 1995, p. 60, pl. 4, figs. 7, 8.

Type locality.— DSDP Site 173 South Atlantic Ocean (39°57.71' N, 125°27.12' W), 2927 m; Miocene.

Occurrence.— This species occurs at a relative abundance of 2.1% only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— Samples at 808 m in the Timor Trough, north of Australia (Loeblich and Tappan, 1994); at 694–3360 m of water depth around the Ryukyu Island Arc, Northwest Pacific (Kawagata and Ujiié, 1996).

Remarks.— The specimens treated here have a compressed test with the reticulate ornament and the irregular periphery but without keel-like fringing.

Superfamily Cassidulinoidea d'Orbigny, 1839a

Family Cassidulinidae d'Orbigny, 1839a

Subfamily Cassidulininae d'Orbigny, 1839a

Genus ***Globocassidulina*** Voloshinova, 1960

Globocassidulina oriangulata Belford, 1966

Figure 4.11

Globocassidulina oriangulata Belford, 1966, p. 148, pl. 25, figs. 1–5, text-figs.16.13, 14; Nomura, 1983b, p. 43, pl. 3, figs. 16, 17, pl. 6, fig. 16, pl. 16, figs. 11, 12, pl. 17, figs. 1, 2; Akimoto, 1990, pl. 18, fig. 2.

Type locality.— From Nuru Valley, New Guinea; Miocene.

Occurrence.— This species occurs more at the upper bathyal depths of Station N12 (516–203 mbsl) than the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 16.2% and 26.4 %, respectively.

Distribution.— From the lower shelf and lower bathyal depths (532 m and 1453 m) on the northeastern flank of the Shinkurose Bank, northeast of Hachijojima Island, in the Izu-Bonin Islands (in list of Akimoto, 1990).

Remarks.— This species is characterised in having a tripartite aperture with a distinct triangular toothplate attached to outer margin and narrow lip along basal margin.

Globocassidulina subglobosa (Brady, 1881)

Figure 4.12

Cassidulina subglobosa Brady, 1881, p. 60; Brady, 1884, p. 430, pl. 54, figs. 17 a–c; Barker, 1960, p. 112, pl. 54, figs. 17a–c.

Globocassidulina subglobosa (Brady). Belford, 1966, p. 149, pl. 25, figs. 11–16; text-fig. 17, 1–6; text-fig. 18, 1–4; Nomura, 1983a, pl. 13, figs. 5, 6; Nomura, 1983b, p. 20, pl. 2, figs. 8a–c, 9; Ujiié, 1995, p. 62, pl. 5, fig. 7; Holbourn *et al*., 2013, p. 265, figs. 1, 2.

Type locality.— From Challenger Station 120 at 1234 m, off Brazil, South Atlantic Ocean (8°37' S, 34°28' W), western Atlantic Ocean; Recent.

Occurrence.— This species occurs more at the upper bathyal depths of Station N12 (516–203 mbsl) than the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 16.6% and 4.3 %, respectively.

Distribution.— This cosmopolitan deep-sea species is widespread around northwest Pacific Ocean and occurs at outer shelf to lower abyssal depths (90–5000 m) (Jones, 1994).

Remarks.— Kaiho and Nishimura (1992) reported *Globocassidulina subglobosa* that showed a simple slit-like aperture perpendicular to the inner margin of the last chamber (Pl. 3, Fig. 23), rather than an oblique loop-shaped, toothed aperture of typical *G. subglobosa*, from the bathyal to upper abyssal depths (1109–3567 m) in the Izu Islands. Their figured *G. subglobosa* is possibly identified to *Globocassidulina hooperi* Clark, 1994 that was found at the upper to lower abyssal depths (2982–4780 m) in the southwest Pacific Ocean. Therefore, distribution of *G. subglobosa* needs to be reassessed.

Globocassidulina venustas Nomura, 1983a

Figure 5.1

Globocassidulina venustas Nomura, 1983a, p. 60, pl. 1, figs. 7, 8, pl. 14, figs. 4–7.

Priontolegna sp.1, Kawagata and Kamihashi, 2016, p. 51, fig. 19.4.

Type locality.— From Nojima Formation, Miura Peninsula, Japan; Pleistocene.

Occurrence.— This species occurs at a relative frequency of 2.1% only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— This species has been reported as a fossil record from the Pleistocene in Japan (Nomura, 1983a) and New Zealand (Kawagata and Kamihashi, 2016), and has been reported from upper bathyal to lower bathyal depths (676–1875 m) off Tanegashima Island in the western margin of the North Pacific Ocean (Akimoto, 1990).

Remarks.— Our specimen is characterised by having the minute, inornate lenticular test showing circular or slightly serrate outline from side view and is identical to *G. venustas* Nomura, 1983a, except that 4 pair of chambers in the last coil differs in 5–6 pair of chambers of the typical form.

Genus ***Paracassidulina*** Nomura, 1983a

Paracassidulina nabetaensis Nomura, 1983a

Figures 5.2–5.4

Paracassidulina nabetaensis Nomura, 1983a, p. 98, pl. 2, figs. 16, 17, pl. 5, fig. 5, pl. 25, fig. 7, text-figs. 58–60.

Paracassidulina nipponensis (Eade). Akimoto, 1990, pl. 19, fig. 2.

Type locality.— From beach sand of Nabeta Cove, Izu Peninsula, Japan; Recent.

Occurrence.— This species occurs more at the upper bathyal depths of Station N12 (516–203 mbsl) than the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 10.5% and 2.6%, respectively.

Distribution.— From beach sand of Nabeta Cove, Izu Peninsula, Japan (Nomura, 1983a); at lower bathyal depth (1459 m) on the eastern flank of the Shinkurose Bank, northeast Hachijojima Island (Akimoto, 1990).

Remarks.— The specimens examined in this study are characterised by the inornate compressed, coiled biserial test with ~5 pair of subinflated chambers in adult, lobulate periphery and incised sutures and possess an interiomarginal slit aperture. Our specimens are identical to P. nabetaensis except for the absence of apertural grooves represented by Nomura (1983a). *Paracassidulina nabetaensis* differs from other similar *Paracassidulina* species; *P. nipponensis* (= *Globocassidulina nipponensis* Eade, 1969), *P. izuensis* (= *Cassidulina izuensis* Aoki, 1967) and *P. sagamiensis* (= *Cassidulina sagamiensis* Asano and Nakamura, 1937) by the lobulate periphery; *P. oshimai* (= *Cassidulina oshimai* Aoki, 1967) and *P. miuraensis* (= *Cassidulinoides miuraensis* Higuchi, 1956) by the larger test of coiled biserial chamber arrangement throughout with more inflated chambers and lobulate periphery, instead of coiled–rectilinear biserial test with less lobulate periphery.

Subfamily Ehrenbergininae Cushman, 1927b

Genus ***Burseolina*** Seguenza, 1880

Burseolina pacifica (Cushman, 1925)

Figure 5.5

Cassidulina calabra (Seguenza). Brady, 1884, p. 431, pl. 113, fig. 8; Sidebottom, 1918, p. 128, pl. 3, fig. 22.

Cassidulina pacifica Cushman, 1925, p. 53, pl. 9, figs. 14–16; Parr, 1950, p. 343, pl. 12, figs. 23, 24; Barker, 1960, p. 232, pl. 113, fig. 8.

Cushmanulla pacifica (Cushman). Saidova, 1975, p. 336, pl. 88, figs. 11, 12, pl. 115, fig. 4.

Globocassidulina pacifica (Cushman). Jones, 1994, p. 111, pl. 113, fig. 8.

Burseolina pacifica (Cushman). Nomura, 1983b, p. 57, text-fig. 48, pl. 5, figs.1–4, pl. 6, fig. 2, pl. 21, figs. 6–10; Akimoto, 1990 (in list); Debenay, 2013, p. 235, pl. 21 (unnumbered).

Type locality.— From Challenger Station 185 at ~285 m, Tress Strait off Raine Island, South Pacific Ocean; Recent.

Occurrence.— This species occurs more at the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl) than the upper bathyal depths of Station N12 (516–203 mbsl), with relative abundances of 9.6% and 1.5 %, respectively.

Distribution.— From the mid bathyal depths (532–523 m) at the eastern flank of the Shinkurose Bank, northeast Hachijojima Island (Akimoto, 1990); from the mid bathyal depth of 600 m at northern shelf off New Caledonia (Debenay, 2013).

Remarks.— Our specimen shows a moderately large globular test as seen in the type figure of Brady (1884). Parr (1950) mentioned that the greater sized specimens (> 1 mm in diameter) showed rather laterally compressed test than typical globular one.

Superfamily Discorboidea Ehrenberg, 1838

Family Bueningiidae Saidova, 1981

Genus ***Bueningia*** Finlay, 1939

Bueningia creeki Finlay, 1939

Figure 5.6

Bueningia creeki Finlay, 1939, p. 123, pl. 14, figs. 82–84; Todd, 1965, p. 28, pl. 8, fig. 4; Akimoto, 1990 (in list); Loeblich and Tappan, 1994, p. 137, pl. 274, figs. 1–9; Debenay, 2013, p. 188, pl. 17 (unnumbered).

Type locality.— From Marsden, Greymouth, New Zealand; early Miocene.

Occurrence.— This species occurs at a relative abundance of 3.4% only from the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl).

Distribution.— From samples at 260–275 m in Timor Sea (Loeblich and Tappan, 1994); at 477m off east Tanegashima Island, southwest Japan (Akimoto, 1990); at 600 m at northern shelf off New Caledonia (Debenay, 2013).

Family Discorbidae Ehrenberg, 1838

Genus ***Discorbis*** Lamarck, 1804

Discorbis vilardeboanus (d'Orbigny, 1839b)

Figure 5.7

Rosalina vilardeboana d'Orbigny, 1839b, p. 44, pl. 86, figs. 13–15; Barker, 1960, p. 178, pl. 86, fig. 9; Akimoto, 1990, p. 211, pl. 22, figs. 16a–c; Jones, 1994, p. 93, pl. 86, fig. 9; Debenay, 2013, p. 211, Plate 15 (unnumbered).

Discorbina vilardeboana (d'Orbigny). Brady, 1884, p. 645, pl. 86, fig. 9. (not pl. 88, fig. 2)

Discorbis mira Cushman, 1922, p. 39, pl. 6, figs. 10, 11.

Type locality.— Off Falkland Islands, South Atlantic Ocean; Recent.

Occurrence.— This species occurs at a relative abundance of 3.9 % only from the upper bathyal depths of Station N12 (516–203 mbsl).

Distribution.— From "Albatross" samples from the inner shelf depths (~5.5–45 m) of Fiji and adjacent islands in the tropical southwest Pacific Ocean (Todd, 1965).

Superfamily Planorbulinoidea Schwager, 1877

Family Cibicididae Cushman, 1927b

Subfamily Cibicidinae Cushman, 1927b

Genus ***Cibicides*** de Montfort, 1808

Cibicides conoideus Galloway and Wissler, 1927

Figure 6.1

Cibicides conoideus Galloway and Wissler, 1927, p. 63, pl. 10, fig. 7.

Cibicidoides mediocris (Finlay). Akimoto, 1990, pl. 20, fig. 3 (pl. 23, fig. 2?).

Cibicides sp. A. Ujiié, 1995, p. pl. 11, figs. 2a–c.

Type locality.— From Lomita Quarry in the Palos Hills, California, USA; Pleistocene.

Occurrence.— This species occurs more at the upper bathyal depths of Station N12 (516–203 mbsl) than the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl), with relative abundances of 4.7% and 1.3%, respectively.

Distribution.— From mid bathyal to mid abyssal depths (~700–3200 m) around the Ryukyu Island Arc, northwestern Pacific Ocean (Kawagata and Ujiié, 1996); outer shelf to lower bathyal depths (195–1874 m) around Hachijojima Island, northern Izu Islands (Akimoto, 1990).

Remarks.— This species resembles *Cibicides refulgens* de Montfort, 1808 in having strong planoconical test but differs by the distinct umbilical boss in its involute side.

Cibicides lobatulus (Walker and Jacob, in Kanmacher, 1798)

Figure 6.2

Nautilus lobatulus Walker and Jacob, in Kanmacher, 1798, p. 642, pl. 14, fig. 36.

Truncatulina lobatulus (Walker and Jacob). d'Orbigny, 1939b, p. 134, pl. 2, figs. 22–24.

Cibicides lobatulus (Walker and Jacob). Barker, 1960, p. 190, pl. 92, fig. 10; Jones, 1994, p. 97, pl. 92, fig. 10; Holbourn *et al*., 2013, p. 152, figs. 1–3.

Lobatula lobatula (Walker and Jacob). Loeblich and Tappan, 1987, p. 583, pl. 637, figs. 10–13.

Type locality.— From shore sand of Whistable, Kent, England; Recent.

Occurrence.— This species occurs more at the upper bathyal depths of Station N9 (1062–1015 mbsl) than the uppermost of the lower bathyal depths of Station N12 (516–203 mbsl), with relative abundances of 2.6% and 0.1%, respectively.

Distribution.— Cosmopolitan; This species has been reported from the shelf to abyssal depths (Jones, 1994), and often occurs at depths shallower than 1000 m (Holbourn *et al*., 2013).

Remarks.— This species has often been described under the genus *Lobatula* Fleming, 1828, that is different from *Cibicides* de Montfort, 1808 in showing less convexity on the umbilical side and a shorter extension of the apertural slit along the spiral suture (e.g. Loeblich and Tappan, 1987). However, these morphological features are variable even in the same genera. We regard the genus *Lobatula* as a subjective junior synonym of *Cibicides*.

Superfamily Chilostomelloides Brady, 1881

Family Alabaminidae Hofker, 1951

Genus ***Osangularia*** Brotzen, 1940

Osangularia bengalensis (Schwager, 1866)

Figure 6.3

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

Osangularia bengalensis (Schwager). Srinivasan and Sharma, 1980, p. 60, pl. 8, figs. 3–5; Ujiié, 1990, p. 49, pl. 28, fig. 7a–c; Kaiho and Nishimura, 1992, pl. 4, figs. 17a–c.

Type locality.— From Car Nicobar, Indian Ocean; Pliocene.

Occurrence.— This species occurs both stations but is more abundant in the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl) than the upper bathyal depths of Station N12 (516–203 mbsl), with relative abundances of 3.8% and 0.8%, respectively.

Distribution.— From lower bathyal to lower abyssal depths (1453–4050 m) around Hachijojima Island, the northern Izu Islands (Akimoto, 1990).

Remarks.— Some previous researches considered *Osangularia bengalensis* as primary junior synonym of *Osangularia culter* (= *Planorbulina farca* var. *ungeriana* subvar. *culter* Parker and Jones, 1865) (e.g., Hermelin, 1989; Holbourn *et al.*, 2013) and regarded *O.*

bengalensis as possible shallow-water form of *O. culter* (e.g. Hermelin, 1989). Srinivasan and Sharma (1980) designated neotype of *O. bengalensis* and mentioned that *O. bengalensis* is distinguished from *O. culter* by having more biconvex test, instead of flatter spiral side of the latter species. The specimen treated here is characterised in showing a distinct biconvex in profile of the test and is comparable well with the topotypes of *O. bengalensis* (H. S. Srinivasan's Collection P48592 housed in Natural History Museum, London).

Genus ***Oridorsalis*** Andersen, 1961

Oridorsalis umbonatus (Reuss, 1851)

Figure 6.4

Rotalia umbonatus Reuss, 1851, p. 75, pl. 5, figs. 35a–c.

Eponides umbonata (Reuss). Cushman, 1929, p. 98, pl. 14, figs. 8a–c.

Eponides umbonatus (Reuss). Cushman and Stainforth, 1945, p. 62, pl. 11, figs. 4a, b.

Oridorsalis umbonatus (Reuss). Parker, 1964, p. 627, pl. 99, figs. 4–6; Ujiié, 1990, p. 48, pl. 28, figs. 1–6, text-fig. 4; Xu and Ujiié, 1994, p. 518, figs. 10.1, 10.2.

Type locality.— Locality not designated but near Berlin, Germany; Eocene.

Occurrence.— This species occurs at a relative abundance of 2.3% only from the uppermost of the lower bathyal depths of Station N9 (1062–1015 mbsl).

Distribution.— Cosmopolitan. From lower shelf to abyssal depths (Jones, 1994).

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Figures, Tables and Appendix captions

Figure 1. Maps of the studied area. **A**. General map of the region. The star shows the location of Nishinoshima island. **B**. Stations and dive tracks around the main Nishinoshima edifice during cruise NT15-E02, June 2015. **C**. Zoom on the Nishinoshima-Minami Knoll with the two studied stations DT-1173 (N12) and DT-1170 (N9). From Natsushima NT15-E02 Cruise Report (Tamura, 2015).

Figure 2. Vertical profile of annual dissolved oxygen content around Nishinoshima (27°5'N, 140°5'E) (data supplied by the Levitus94). Depth range for each station are shown.

Figure 3. Pictures of the sediment from size fractions 0.5–1, 1–2 and 2–4 mm for stations N9 (left) and N12 (right). Mineral abbreviations: pl: plagioclase; ol: olivine; cpx: clinopyroxene; opx: orthopyroxene. Scale bars = 1 mm.

Figure 4. Photographs of commonly occurring benthic foraminifera from the deep sea adjacent to Nishinoshima (1). Scale bars: 100 µm unless otherwise stated. **1,** *Triloculinella pseudooblonga* (Zheng), Sample NT15-E02 1173 (N12), **a,** SEM micrograph, apertural side view, **b,** SEM micrograph, side view; **2,** *Lenticulina platyrhinos* Zheng, Sample NT15-E02 1173 (N12), light micrograph, side view; **3,** *Lenticulina suborbicularis* Parr, Sample NT15-E02 1173 (N12), light micrograph, side view; **4,** *Lenticulina* sp. 4, Sample NT15-E02 1173 (N12), light micrograph, side view; **5,** *Cyclammina cancellata* Brady, Sample NT15-E02 1170 (N9), light micrograph, side view; **6,** *Bigenerina nodosaria* d'Orbigny, Sample NT15-E02 1170 (N9), light micrograph, side view; **7,** *Vulvulina arenacea* (Bagg), Sample NT15-E02 1170 (N9), light micrograph, side view; **8,** *Hoeglundina elegans* (d'Orbigny), Sample NT15-E02 1170 (N9), **a,**

SEM micrograph, umbilical view, **b**, SEM micrograph, edge view, **c**, SEM micrograph, spiral view; **9,** *Bolivina vadescens* Cushman, Sample NT15-E02 1173 (N12), SEM micrograph, side view; **10,** *Abditodentrix pseudothalmanni* (Boltovskoy and Guisani de Khan), Sample NT15-E02 1173 (N12), **a**, SEM micrograph, side view, **b**, SEM micrograph, apertural side view; **11,** *Globocassidulina oriangulata* Belford, Sample NT15-E02 1170 (N9), **a**, SEM micrograph, apertural side view, **b**, SEM micrograph, apertural edge view, **c**, light micrograph, apertural side view; **12,** *Globocassidulina subglobosa* (Brady), Sample NT15-E02 1173 (N12), SEM micrograph, apertural side view.

Figure 5. Photographs of commonly occurring benthic foraminifera from the deep sea adjacent to Nishinoshima (2). Scale bars: 100 µm unless otherwise stated. **1,** *Globocassidulina venustas* Nomura, Sample NT15-E02 1173 (N12), **a**, SEM micrograph, side view, **b**, SEM micrograph, apertural edge view, **c**, SEM micrograph, apertural side view, **d**, light micrograph, apertural side view; **2, 3, 4,** *Paracassidulina nabetaensis* Nomura, 2, Sample NT15-E02 1170 (N9), **a**, SEM micrograph, apertural side view, **b**, SEM micrograph, apertural edge view, 3, Sample NT15-E02 1170 (N9), light micrograph, apertural side view; 4, juvenile, Sample NT15-E02 1173 (N12), **a**, SEM micrograph, apertural edge view, **b**, SEM micrograph, apertural side view, **c**, light micrograph, apertural side view; **5,** *Burseolina pacifica* (Cushman), Sample NT15-E02 1170 (N9), **a**, SEM micrograph, apertural side view, **b**, SEM micrograph, apertural edge view; **6,** *Bueningia creeki* Finlay, Sample NT15-E02 1170 (N9), **a**, SEM micrograph, umbilical view, **b**, SEM micrograph, aperture edge view, **c**, SEM micrograph, spiral view; **7,** *Discorbis vilardeboanus* (d'Orbigny), Sample NT15-E02 1173 (N12), **a**, SEM micrograph, spiral view, **b**, SEM micrograph, umbilical view.

Figure 6. Photographs of commonly occurring benthic foraminifera from the deep sea adjacent to Nishinoshima (3). Scale bars: 100 µm unless otherwise stated. **1,** *Cibicides conoideus* Galloway and Wissler, Sample NT15-E02 1170 (N9), **a**, light micrograph, spiral view, **b**, SEM micrograph, spiral view, **c**, SEM micrograph, apertural edge view, **d**, SEM micrograph, umbilical view, **e**, light micrograph, umbilical view; **2,** *Cibicides lobatulus* (Walker and Jacob), Sample NT15-E02 1170 (N9), **a**, light micrograph, spiral view, **b**, light micrograph, apertural edge view, **c**, light micrograph, umbilical view; **3,** *Osangularia bengalensis* (Schwager), Sample NT15-E02 1170 (N9), **a**, SEM micrograph, umbilical view, **b**, SEM micrograph, apertural edge view, **c**, SEM micrograph, spiral view; **4,** *Oridorsalis umbonatus* (Reuss), Sample NT15-E02 1170 (N9), **a**, SEM micrograph, spiral view, **b**, SEM micrograph, apertural edge view, **c**, SEM micrograph, umbilical view.

Table 1. Grain-size analysis for the two studied stations, numbers give percentage by mass.

Table 2. Site and foraminifera assemblage characteristics for the two studied stations. P: Porcelaneous, H: Hyaline, A: Agglutinated.

Table 3. Percentage of 21 commonly occurring foraminifera species for the two studied stations. P: Porcelaneous, H: Hyaline, A: Agglutinated.

Appendix A. Census data of benthic foraminifera for each size fraction at the two studied stations.

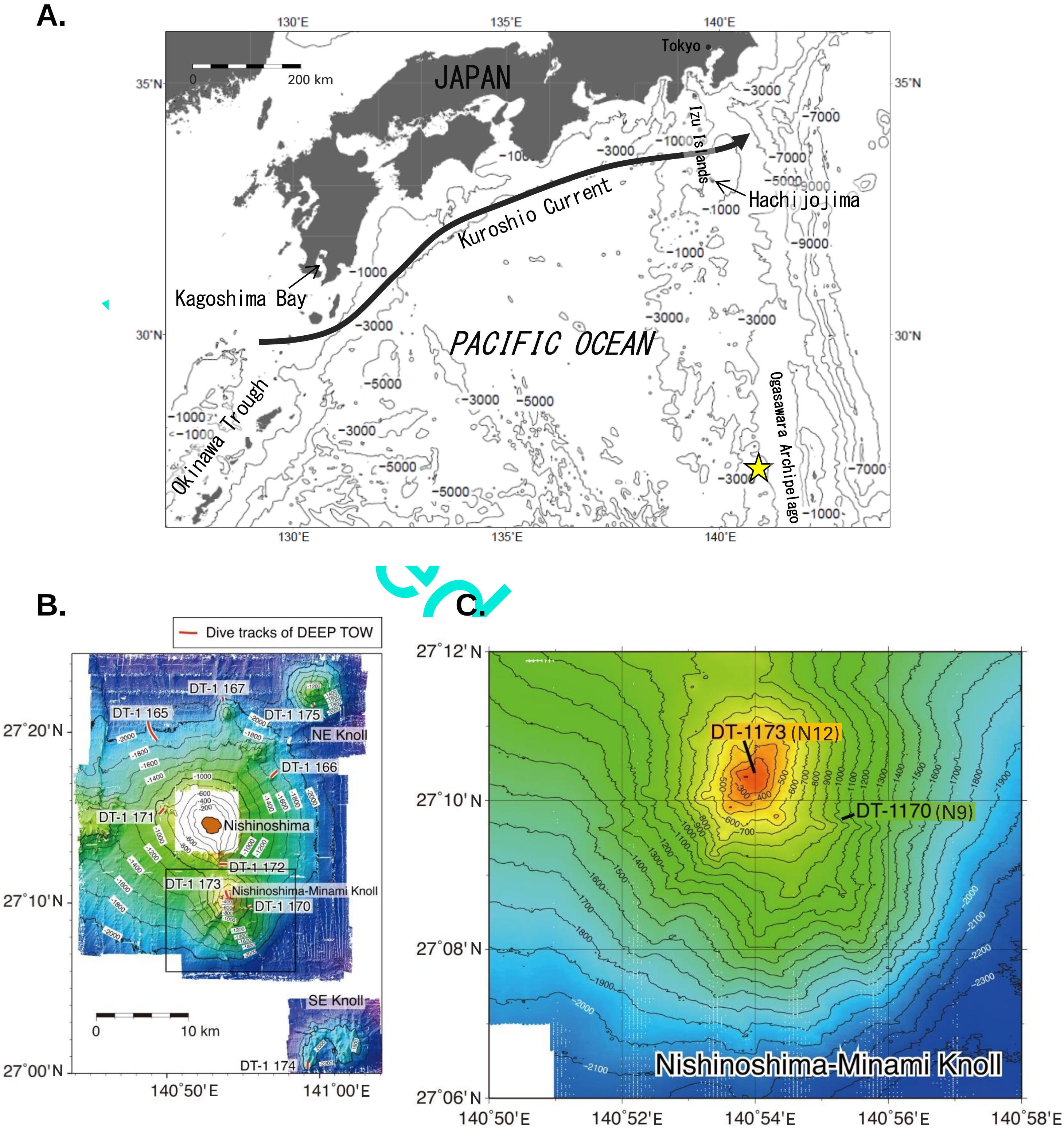


Figure 1. Maps of the studied area. **A.** General map of the region. The star shows the location of Nishinoshima island. **B.** Stations and dive tracks around the main Nishinoshima edifice during cruise NT15-E02, June 2015. **C.** Zoom on the Nishinoshima-Minami Knoll with the two studied stations DT-1173 (N12) and DT-1170 (N9). From Natsushima NT15-E02 Cruise Report.

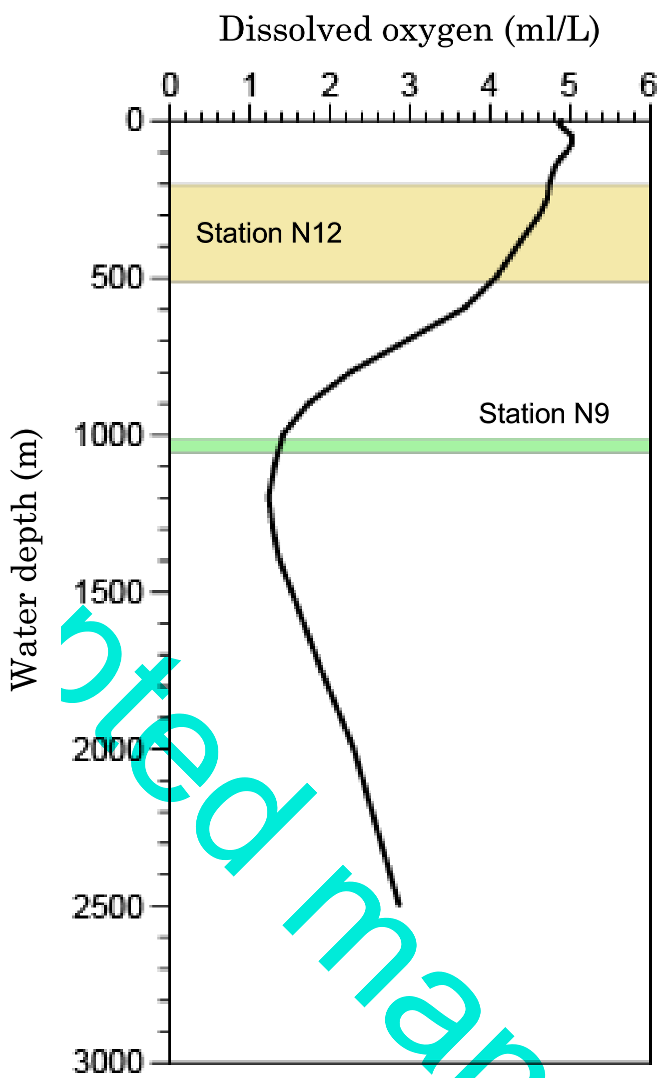


Figure 2. Vertical profile of annual dissolved oxygen content around Nishinoshima (27°5'N, 140°5'E) (data supplied by the Levitus94). Depth range for each station are shown.

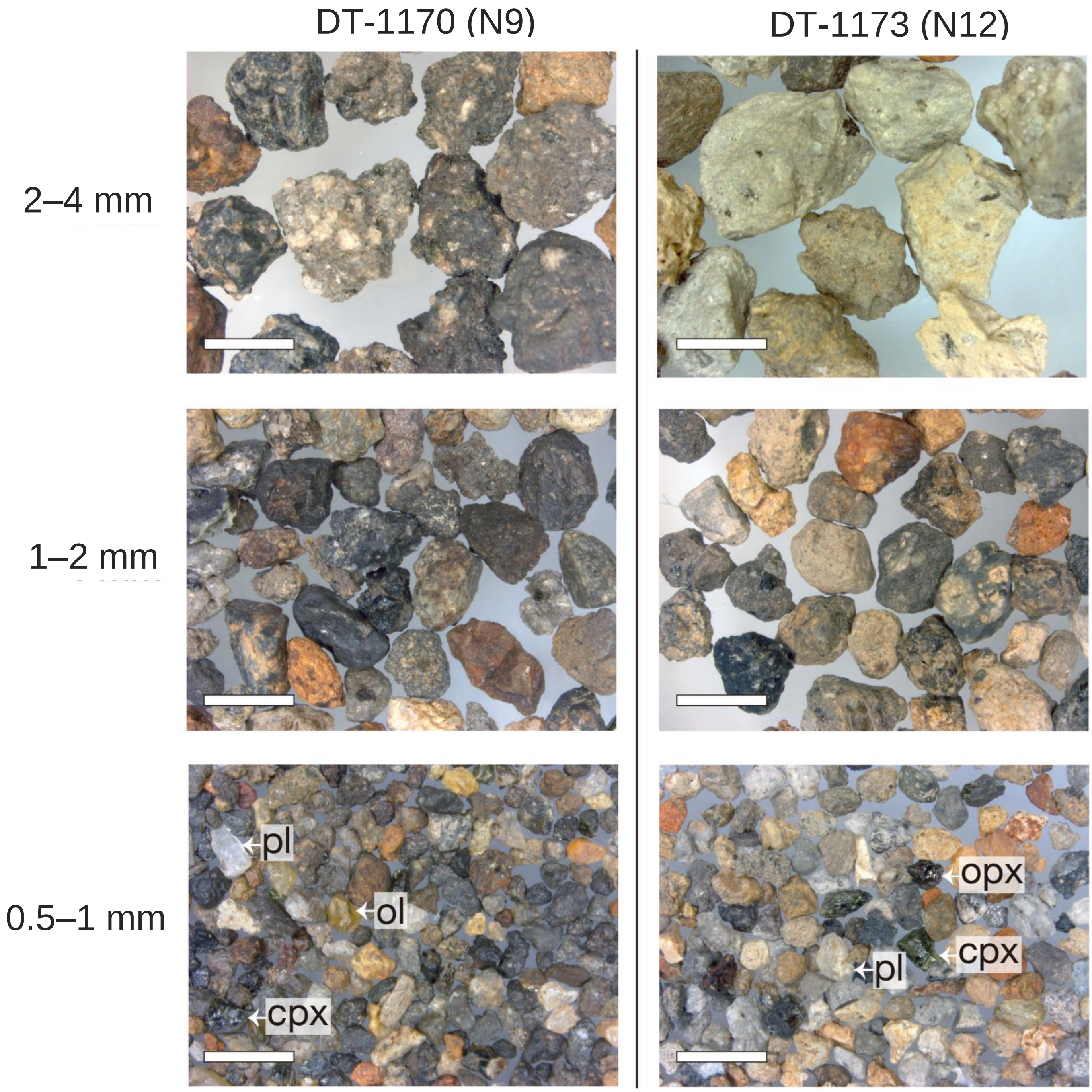
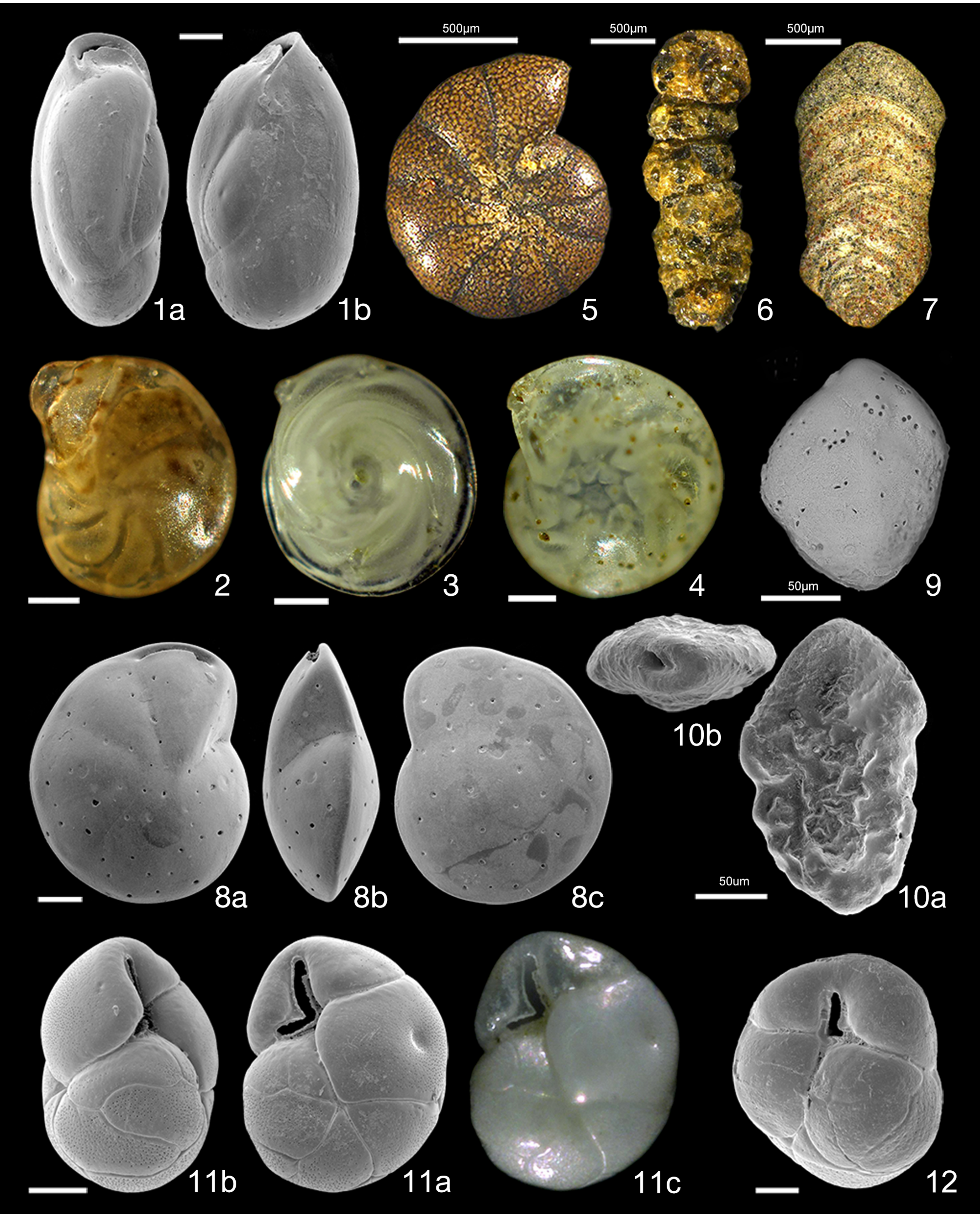
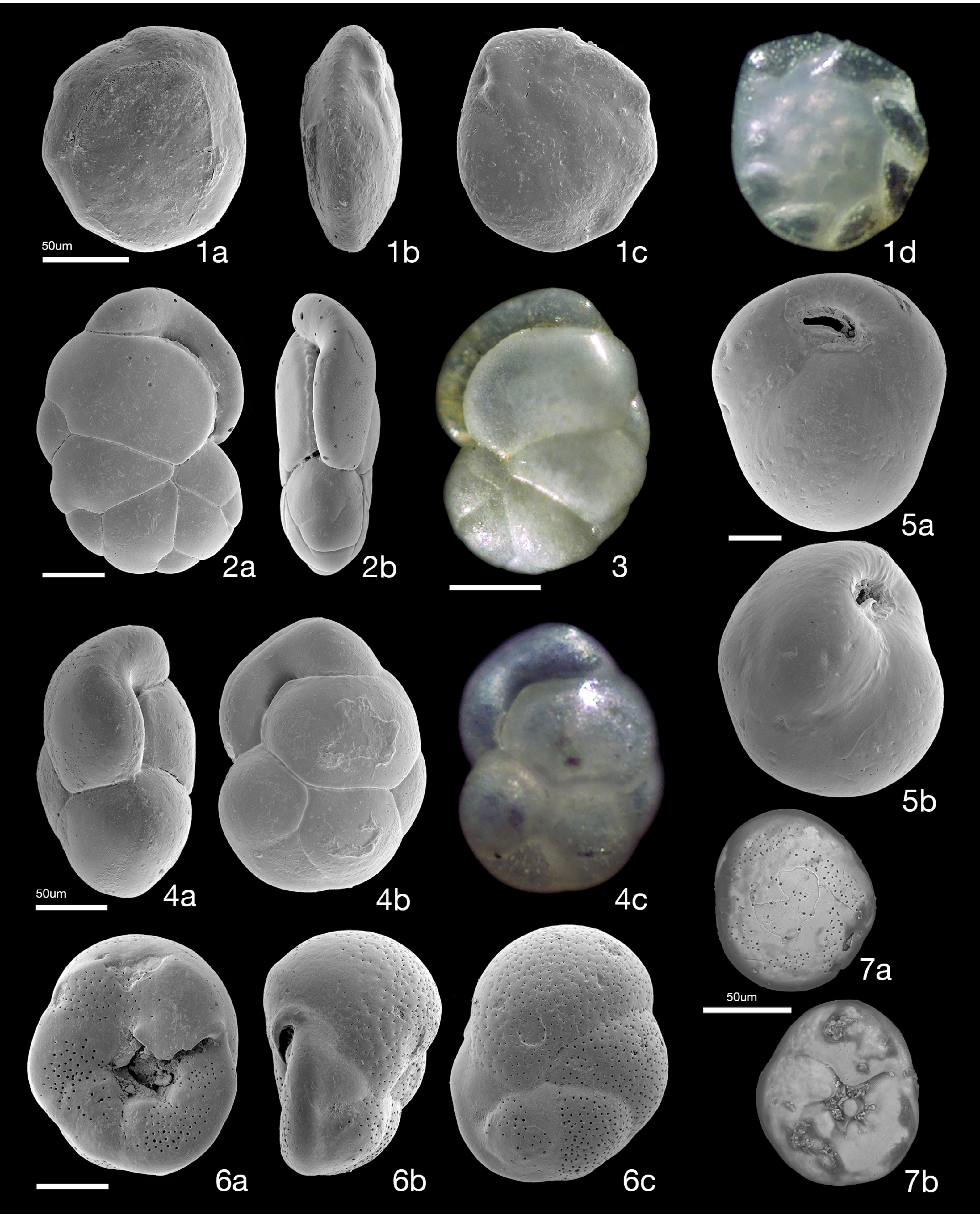


Figure 3. Pictures of the sediment from size fractions 0.5–1, 1–2 and 2–4 mm for stations N9 (left) and N12 (right). Mineral abbreviations: pl: plagioclase; ol: olivine; cpx: clinopyroxene; opx: orthopyroxene. Bars = 1 mm.



500µm
500µm
500µm
1a
1b
5
6
7
2
3
4
50µm
9
10b
50um
8a
8b
8c
10a
11b
11a
11c
12


50um
1a
1b
1c
1d
2a
2b
3
5a
50um
4a
4b
4c
5b
7a
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6a
6b
6c
7b

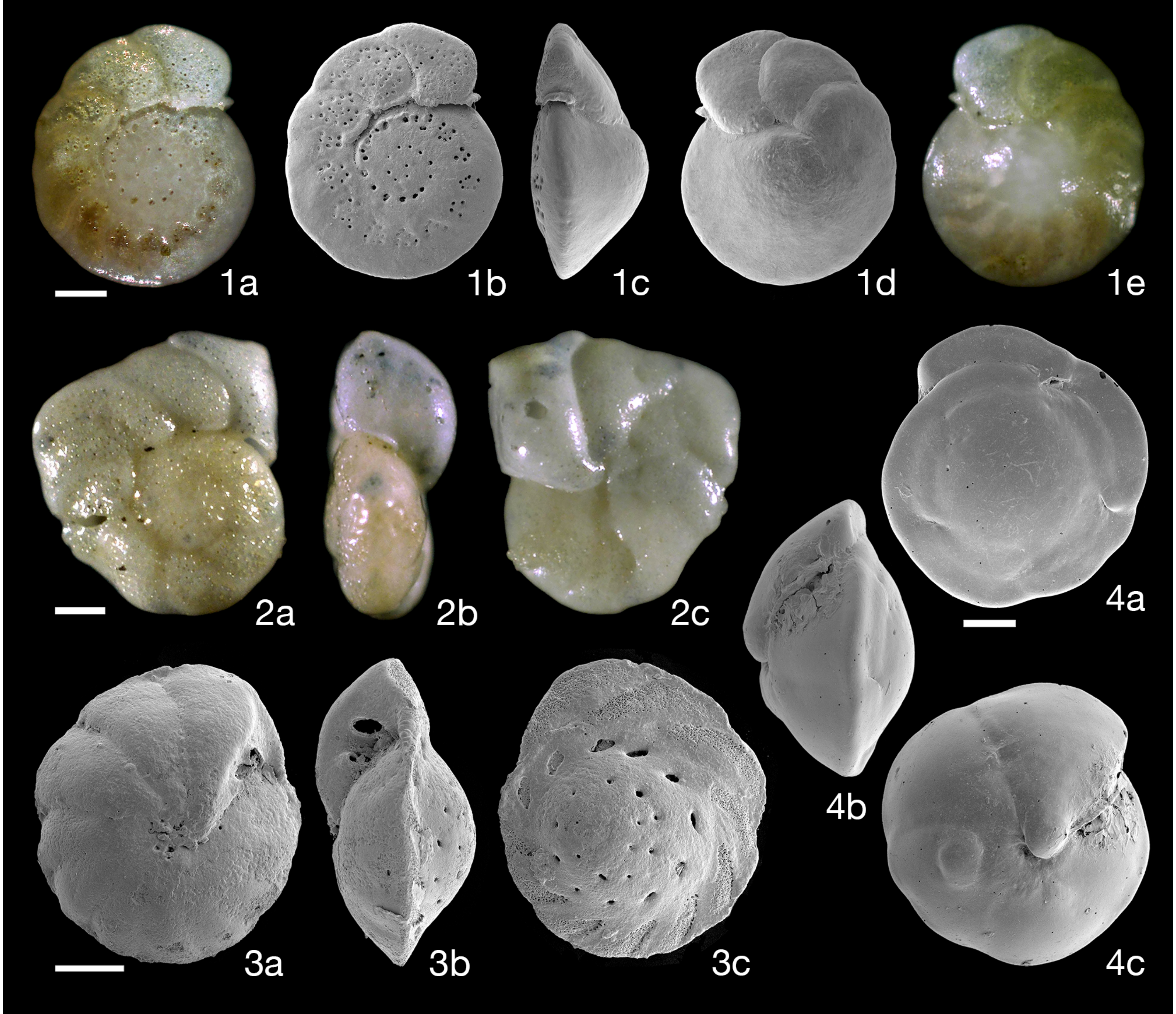
1a
1b
1c
1d
1e
2a
2b
2c
4a
4b
3a
3b
3c
4c

Table 1. Grain-size analysis for the two studied stations, numbers give percentage by mass.

Station	Silt and sand (< 0.5 mm)	Coarse sand (0.5–1 mm)	Very coarse sand (1–2 mm)	Granule (2–4 mm)	Pebble (> 4 mm)
DT-01170 (N9 - flank site)	47.6	14.1	16.5	9.3	12.5
DT-01173 (N12 - summit site)	6.4	9.7	11.2	12.5	60.3

Table 2. Site and foraminifera assemblage characteristics for the two studied stations. P: Porcelaneous, H: Hyaline, A: Agglutinated.

Station	Distance from main edifice (km)	Water depth (m)	Foraminiferal density (specimens per 10 g sed.)	No of species	Shannon (H)	Specimens 63–125 µm (%)	Type of foraminiferal test		
							P (%)	H (%)	A (%)
DT-01170 (N9 - flank site)	10	1062–1015	12	78	3.27	17.0	0.6	81.9	17.4
DT-01173 (N12 - summit site)	8	516–203	45	72	3.13	49.3	6.6	92.9	0.4

Table 3. Percentage of 21 commonly occurring foraminifera species for the two studied stations. P: Porcelaneous, H: Hyaline, A: Agglutinated.

Species	Test type	Station N9 (%)	Station N12 (%)
Triloculinella pseudooblonga	P	0	5.2
Abditodentrix pseudothalmanni	H	0	2.1
Bolivina vadescens	H	0	3.1
Bueningia creeki	H	3.4	0
Burseolina pacifica	H	9.6	1.5
Cibicides conoideus	H	1.3	4.7
Cibicides lobatulus	H	2.6	0.1
Globocassidulina oriangulata	H	26.4	16.2
Globocassidulina subglobosa	H	4.3	16.6
Globocassidulina venusta	H	0	2.1
Hoeglundina elegans	H	3.4	1.8
Lenticulina platyrhinos	H	0	2.1
Lenticulina suborbicularis	H	0.9	2.8
Lenticulina sp. 4	H	2.6	0.8
Oridorsalis umbonatus	H	2.3	0
Osangularia bengalensis	H	3.8	0.8
Paracassidulina nabetaensis	H	2.6	10.5
Rosalina vilardeboana	H	0	3.9
Bigenerina nodosaria	A	4.0	0
Cyclammina cancellata	A	3.6	0
Vulvulina arenacea	A	2.1	0

Appendix A. Census data of benthic foraminifera for each size fraction at the two studied stations.

Station name (water depth)	DT-1170, N9 (1062–1015 m)							DT-1173, N12 (516–203 m)						
Fraction	(63–125μm)*8	(125–150μm)	(150–300μm)	(300–500μm)	(>500μm)	total	total %	(63–125μm)*8	(125–150μm)*4	(150–300μm)*16	(300–500μm)*4	(>500μm)	total	total %
Adelosina sp. 1												1	1	0.05
Nummulopyrgo toddae				1		1	0.21							
Pyrgo depressa												1	1	0.05
Pyrgo sarsi											4	11	15	0.77
Pyrgo sp. 1												1	1	0.05
Pyrgo sp. 2												1	1	0.05
Quinqueloculina cf. *auberiana*				1		1	0.21							
Quinqueloculina aff. *Sagamiensis*			1			1	0.21							
Sigmoilina obesa												1	1	0.05
Triloculinella pseudooblonga								40	28	16	16	2	102	5.24
Porcelaneous other								8					8	0.41
Abditodentrix pseudothalmanni								40					40	2.05
Amphistegina lessonii												2	2	0.10
Amphistegina radiata			1			1	0.21				4		4	0.21
Anomarinoides globulosus												1	1	0.05
Astacolus crepidulus												1	1	0.05
Astrononion hanyuadaense		1				1	0.21							
Baggina sp.1				1		1	0.21							
Bolivina earlandi								8					8	0.41
Bolivina retia		1	2			3	0.64							
Bolivina subreticulata			1			1	0.21							
Bolivina vadescens								48	12				60	3.08
Bolivinella cf. *seminuda*		1				1	0.21							
Bolivina sp. 1								16					16	0.82
Bueningia creeki		3	10	2	1	16	3.40							
Buliminella elegans								8					8	0.41
Buliminella sp. 1			1			1	0.21							
Buliminella sp. 2								8					8	0.41
Burseolina pacifica				14	31	45	9.57			16	12	1	29	1.49
Carpenteria balaniformis											4	1	5	0.26
Cassidelina subcapitata								16	4				20	1.03
Cassidulina sp. 1								8					8	0.41
Cibicides conoideus		2	4			6	1.28	48		32	8	4	92	4.72
Cibicides lobatulus			3	7	2	12	2.55					1	1	0.05
Cibicides cf. *refulgens*			2			2	0.43							
Cibicides aff. *temperata*												1	1	0.05
Cibicides tenuimargo				1		1	0.21							

Appendix A. Census data of benthic foraminifera for each size fraction at the two studied stations.

Cibicides sp. 1									4				4	0.21
Cibicidoides bradyi			1			1	0.21							
Cibicidoides cf. pachyderma				2		2	0.43							
Cibicidoides wuellerstorfi			1			1	0.21							
Cibicidoides spp.		1				1	0.21		4				4	0.21
Conorbella sp. 1								32					32	1.64
Dentalina sp. 1											4		4	0.21
Discorbinella bertheloti												1	1	0.05
Discorbinella sp. 1								32					32	1.64
Discorbis vilardeboanus								72	4				76	3.90
Ehrenbergina pacifica			1			1	0.21			32			32	1.64
Elphidium sp. 1				1	1	2	0.43							
Entomorphinoides intricata									4				4	0.21
Epistominella exigua			2			2	0.43							
Eponides cribrorepandus												7	7	0.36
Eusphaeroidina inflata				1		1	0.21							
Evolvocassidulina orientalis								16					16	0.82
Fijiella simplex			1			1	0.21							
Fissurina marginata								8					8	0.41
Fissurina sp. 1								16					16	0.82
Globocassidulina depressa											12		12	0.62
Globocassidulina elegans			3	6		9	1.91							
Globocassidulina oriangulata	64	30	29	1		124	26.38	160	40	96	20		316	16.22
Globocassidulina subglobosa			5	15		20	4.26	192	40	80	12		324	16.63
Globocassidulina venusta								40					40	2.05
Gyroidina lamarckiana		2				2	0.43	16					16	0.82
Gyroidina orbicularis				1		1	0.21							
Gyroidina soldanii				1		1	0.21	8	4		4	1	17	0.87
Gyroidina sp. 1			1			1	0.21							
Gyroidinoides nipponica			1			1	0.21							
Gyroidinoides zelandica			3			3	0.64							
Heterolepa praecincta				2	4	6	1.28							
Hoeglundina elegans			2	7	7	16	3.40			16	16	4	36	1.85
Homalohedra aff. *acuticosta*			2			2	0.43							
Lagena sp. 1		1				1	0.21							
Lenticulina angulata		1				1	0.21							
Lenticulina asterizans										16			16	0.82
Lenticulina convergens					3	3	0.64							
Lenticulina gibba			1			1	0.21							

Appendix A. Census data of benthic foraminifera for each size fraction at the two studied stations.

Lenticulina lucida												2	2	0.10
Lenticulina orbicularis												5	5	0.26
Lenticulina platyrhinos											20	20	40	2.05
Lenticulina subgibba				2		2	0.43					7	7	0.36
Lenticulina cf. *subgibba*											4		4	0.21
Lenticulina suborbicularis				1	3	4	0.85				32	22	54	2.77
Lenticulina tasmanica					2	2	0.43					1	1	0.05
Lenticulina sp. 1					1	1	0.21							
Lenticulina sp. 2												1	1	0.05
Lenticulina sp. 3												1	1	0.05
Lenticulina sp. 4				4	8	12	2.55				8	8	16	0.82
Lernella inflata			2			2	0.43							
Lingulina grandis												1	1	0.05
Lingulina sp. 1								8					8	0.41
Neoeponides procerus					1	1	0.21					1	1	0.05
Nonion sp. 1								8					8	0.41
Oolina globosa		2				2	0.43							
Oridorsalis umbonatus		2	2	5	2	11	2.34							
Osangularia bengalensis		4	12	2		18	3.83	16					16	0.82
Paracassidulina nabetaensis			12			12	2.55		16	160	28		204	10.47
Paracassidulina neocarinata								16					16	0.82
Paracassidulina tomiyensis			3			3	0.64				12		12	0.62
Patellina corrugata								8					8	0.41
Planopulvinulina dispansa												3	3	0.15
Planulina arimiensis		2	1			3	0.64							
Planulina sp.1		1				1	0.21							
Poroeponides sp. 1			1			1	0.21							
Pseudodimorphina galapagosensis												2	2	0.10
Pullenia sp. 1				1		1	0.21							
Pulvinulina spp.									16		8		24	1.23
Rosalina cf. *irregularis*										1			1	0.05
Saracenaria cf. *latifrons*										1			1	0.05
Siphogenerina cf. *indica*			1			1	0.21							
Spirillina vivipara								8					8	0.41
Stomatorbina concentrica												1	1	0.05
Streptochilus globulosum	8					8	1.70							
Trifarina hughesi			1			1	0.21							
Uvigerina proboscidea			3			3	0.64							
Vaginulina subelegans			1			1	0.21							

Appendix A. Census data of benthic foraminifera for each size fraction at the two studied stations.

Hyaline other								48					48	2.46
Ammobaculites agglutinans					4	4	0.85							
Ammodiscus tenuis				1	1	2	0.43							
Ammodiscus cf. tenuis			1	1	1	3	0.64							
Ammolagena clavata				1	1	2	0.43							
Bigenerina nodosaria				1	18	19	4.04							
Buzasina aff. *ringens*			1	1		2	0.43							
Cyclammina cancellata				2	15	17	3.62							
Cyclammina cf. *cancellata*				1	4	5	1.06							
Cyclammina pusilla					1	1	0.21							
Haplophragmoides cf. *canariensis*			1			1	0.21							
Haplophragmoides sp. 1					2	2	0.43							
Haplophragmoides sp. 2								8					8	0.41
Jaculella acuta					1	1	0.21							
Karreriella bradyi			1			1	0.21							
Martinottiella communis					3	3	0.64							
Trochammina spp.	8		1			9	1.91							
Vulvulina arenacea					10	10	2.13							
TOTAL	80	54	122	87	127	470	100	960	176	466	228	118	1948	100