Hall, I.R., Hemming, S.R., LeVay, L.J., and the Expedition 361 Scientists
Proceedings of the International Ocean Discovery Program Volume 361
publications.iodp.org

Data report: systematic taxonomy, morphology, and distribution of Late Neogene–Quaternary planktic foraminifera from the Agulhas Current region, International Ocean Discovery Program Expedition 361, Hole U1474A[1]

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[1] Singh, V.P., Dwivedi, R., and Pathak, S., 2026. Data report: systematic taxonomy, morphology, and distribution of Late Neogene–Quaternary planktic foraminifera from the Agulhas Current region, International Ocean Discovery Program Expedition 361, Hole U1474A. In Hall, I.R., Hemming, S.R., LeVay, L.J., and the Expedition 361 Scientists, South African Climates (Agulhas LGM Density Profile). Proceedings of the International Ocean Discovery Program, 361: College Station, TX (International Ocean Discovery Program). https://doi.org/10.14379/iodp.proc.361.204.2026

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Keywords
International Ocean Discovery Program, IODP, *JOIDES Resolution*, Expedition 361, South African Climates (Agulhas LGM Density Profile), Agulhas Current, Hole U1474A, planktic foraminifera, Late Neogene–Quaternary, scanning electron microscopy

References (RIS)

MS 361-204
Received 12 August 2025
Accepted 9 October 2025
Published 7 January 2026

Abstract

International Ocean Discovery Program Hole U1474A, drilled during Expedition 361 in the southwestern Indian Ocean, offers a high-quality archive for reconstructing Agulhas Current variability. The site yielded 104% core recovery over 256.11 m, spanning from the Late Miocene to recent. The sediments are exceptionally well preserved and contain a diverse planktic foraminiferal assemblage, including tropical, subtropical, temperate, and subpolar forms.

This study presents a detailed morphological and taxonomic analysis of Late Neogene–Quaternary planktic foraminifera from Hole U1474A, supported by scanning electron micrographs. Accurate species identification is essential for understanding mid-latitude paleoceanographic events and diachrony. The specimens exhibit minimal dissolution, with well-preserved wall textures and visible spines. A total of 63 species were identified, representing tropical to temperate faunas. Dominant genera include *Globigerinoides*, *Globoconella*, *Globigerinita*, and *Neogloboquadrina*. A semiquantitative distribution of these forms is also provided to support further biostratigraphic and paleoenvironmental reconstructions in the Agulhas Current region.

1. Introduction

The planktic foraminifera, which are excellent index fossils, form the backbone of the Cenozoic biostratigraphic and paleoceanographic studies. Because of their passive mode of life, they are susceptible to stresses caused by variations in water mass properties like temperature, salinity, and nutrient conditions. The response to changes in the ambient water mass conditions is recorded in the test of the planktic foraminifera, which is exploited for paleoceanographic and paleoclimatic studies. It therefore becomes prudent that these sensitive proxies be precisely identified to be used for paleoceanographic and paleoclimatic interpretations.

With the development of scanning electron microscopy (SEM), there has been a tremendous development in the taxonomic studies of planktic foraminifera over the last few decades. Several studies have been conducted on the taxonomic refinements of the Neogene–Quaternary planktic foraminifera (Lamb and Beard, 1972; Stainforth et al., 1975; Saito, 1977; Steineck and Fleisher, 1978; Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Jenkins, 1985; Cifelli and Scott, 1986; Hemleben et al., 1989; Hilbrecht, 1996; Fox and Wade, 2013; Schiebel and Hemleben, 2017; Lam and Leckie, 2020a, 2020b; Brummer and Kučera, 2022). The integration of taxonomic studies on fossilized tests and molecular genetic studies on extant species of planktic foraminifera (e.g., Darling et al., 2006; André et al., 2013; Spezzaferri et al., 2015; Schiebel and Hemleben, 2017; Poole and Wade, 2019, and others) has opened new avenues to ascertain the affinity of various morphotypes.

The growing number of works and literature on the taxonomic revision of planktic foraminifera has sparked a debate on the selection of the appropriate nomenclature and the generic and specific assignment of planktic foraminifera. It warrants the development of a precise concept of the taxonomic identification of planktic foraminifera for use in studies pertaining to marine geology.

Another important characteristic of planktic foraminifera is latitudinal provincialism (Bé and Tolderlund, 1971), which controls their distribution according to the latitudes. It is an essential aspect of planktic foraminiferal research that assists in paleoceanographic and paleoclimatic reconstructions.

This work aims to present a detailed SEM examination of well-preserved planktic foraminiferal specimens from Hole U1474A, which helps to determine the taxonomy and morphological variability of 63 Late Miocene–recent species.

2. Materials and methods

2.1. Location and modern oceanography of the study area

International Ocean Discovery Program (IODP) Hole U1474A was drilled during Expedition 361 in the northernmost part of the Natal Valley (31°13.00′S, 31°32.71′E) at a water depth of 3045 meters below sea level (mbsl), which is well above the carbonate compensation depth, resulting in good preservation of biogenic material (Figure **F1**; **Hall et al.**, 2017). This site is located in the path of the Agulhas Current. It has the potential to record the variation in faunal assemblages due to the changes in the intensity of the current. The Agulhas Current is the largest western boundary current (Simon et al., 2013) that affects the surface dynamics in the Indian Ocean. The warm water of the Agulhas Current transported to the Atlantic Ocean via the Indo-Atlantic gateway by the Agulhas leakage in the form of eddies and rings (Lutjeharms, 2006) has a significant impact on the returning arm of the Atlantic Meridional Overturning Circulation. After 40°S, the Agulhas Current retroflects and returns to the Indian Ocean as the Agulhas Return Current, which flows along

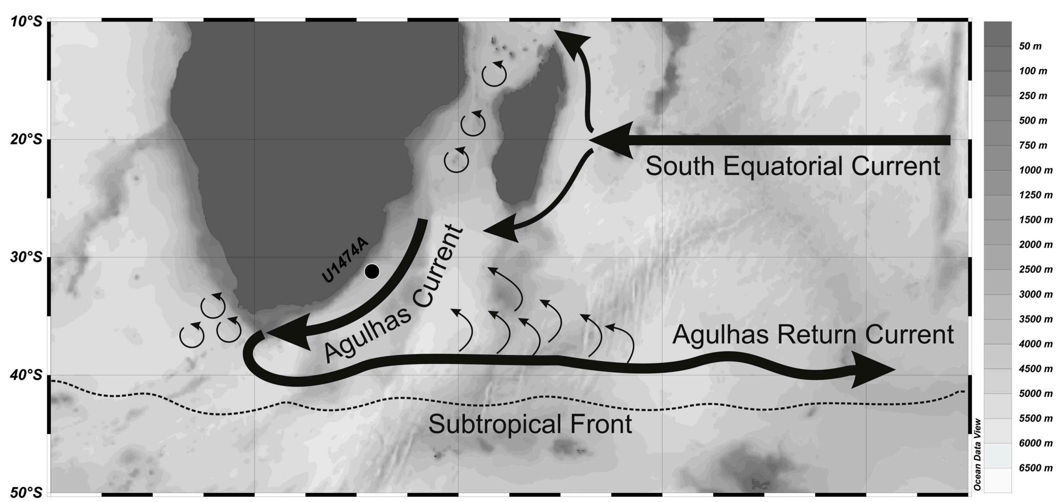

Figure F1. Bathymetric map of the southwest Indian Ocean with the location of the study area and current systems. Hole U1474A (31°13.00′S, 31°32.71′E) is located in the path of the upstream Agulhas Current. The position of the Subtropical Front is marked after Orsi et al. (1995). Map created using Ocean Data View software version 5.6.3 (Schlitzer 2022).

the Subtropical Front (Lutjeharms, 2009). The Subtropical Front is a hydrodynamic front that is the "gatekeeper" south of Africa (Graham and De Boer, 2013). It changes its position with variation in the climate, with a more northward position indicative of glacial climate and a southward position marking a return to warmer conditions (Peeters et al., 2004; Caley et al., 2014; Singh et al., 2023). The northward position of the Subtropical Front allows the ingression of cold temperate waters into the relatively warmer subtropical latitude, thereby causing a shift in the ecotones and changing the faunal assemblages to be dominated by characteristic cold-water forms. In the present work, we observed several episodes of significant rise in the relative abundance of cold-water forms, dominated by the genus *Globoconella*. Thus, the variation in the planktic foraminiferal assemblage is an important proxy for paleoceanographic reconstruction.

The terrigenous part of the sediment core recovered from Hole U1474A is clay dominated, and the biogenic fraction of the sediment is composed primarily of calcareous nannofossils, foraminifera, and siliceous sponge spicules, which makes it foram-nanno ooze (**Hall et al.**, 2017).

The total length of the cored section is 254.1 m, with core recovery of 104% in 29 advanced piston cores (**Hall et al.**, 2017). The dominant lithology consists of yellow to greenish gray clay that contains foraminifera and nannofossils, with occasional occurrences of sand and turbidite lenses. Total biogenic carbonate concentration is estimated to be around 39% (**Hall et al.**, 2017). Of the total cored length, we used 233.4 m, comprising 25 cores for the present work (361-U1474A-1H through 25H), from which the sediments were sampled at an interval of 30 cm. The volume of each sample was 10 cm^3, and the approximate temporal gap between the two samples was calculated to be 6–8 ky (Singh et al., 2023). A total of 710 samples, spanning Late Miocene to recent, were analyzed for planktic foraminiferal assemblages to establish Late Neogene–Quaternary biostratigraphy and paleoceanography in the Agulhas Current region.

2.2. Sample processing using the wet-sieving technique

In this study, planktic foraminiferal assemblages from Hole U1474A core samples obtained from Kochi Core Center (Japan) were studied. A detailed biostratigraphy was established (Singh et al., 2025) for the 710 samples at 30 cm sampling intervals, spanning the last ~7 My. Additionally, planktic foraminiferal census count and stable isotope data for these samples were generated for the Late Neogene–Quaternary paleoceanographic and paleoclimatic reconstruction.

The samples were oven-dried overnight at approximately 60°C and weighed. After drying, they were dissolved in 1 L of alkaline solution containing 1 g sodium hexametaphosphate $(NaPO_3)_6$ and 5 g sodium hydroxide (NaOH). To assist the disintegration of the clay, occasionally 10 mL H_2O_2 was added. The solution was then subjected to an ultrasonic bath for 2 min to enhance disintegration. After this treatment, the samples were thoroughly washed with tap water over sieves of two sizes: ≥150 µm and ≥100 µm. The samples were left to dry at room temperature overnight. The dried residue of the two sizes was carefully transferred into three tubes that corresponded to 150 µm, 100 µm, and the base for mud collection for each sample.

2.3. Age model for Hole U1474A

A detailed paleomagnetic record was obtained from the shipboard investigation (**Hall et al.**, 2017) for Hole U1474A. Table **T1** lists the paleomagnetic events recorded for Hole U1474A along with their absolute ages, as derived from Ogg (2020).

This record was used to calculate the rate of sedimentation and estimate the approximate age of the samples under investigation, assuming a uniform rate of sedimentation. The rate of sedimentation was determined by dividing the depth of the core by the corresponding paleomagnetic age and was then multiplied by the depth of the samples to estimate their ages.

Table T1. Rate of sedimentation, Hole U1474A. **Download table in CSV format.**

3. Results

3.1. Foraminifera

The planktic foraminiferal assemblages from Hole U1474A spanning Late Neogene–Quaternary were analyzed for the taxonomic studies. We encountered 63 species belonging to 21 genera that were prominent in their occurrence in Hole U1474A. The list of the genera and species is provided in Table **T2**.

The processed samples were spread in a picking tray and were studied under the Zeiss Discovery V.8 Stereozoom microscope with camera facility. The planktic foraminifera were identified to the species level following the taxonomic work of Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Huber et al. (2016), and Lam and Leckie (2020a).

The details of surface ultrastructure, pores, spines, keel, and so on were studied using a Carl Zeiss EVO-18 scanning electron microscope at the Department of Geology at Banaras Hindu University (India). The specimens were mounted on stubs using carbon tape and were coated with gold-palladium alloy before being loaded in the SEM.

3.2. Diversity

The diversity of foraminiferal assemblages in Hole U1474A is quite high. We identified a total of 63 species from Late Miocene to recent comprising a mixture of warm tropical–subtropical and cool temperate–subpolar forms. Although the warm-water dwellers were dominant forms in the entire core, the Quaternary section showed an unprecedented rise in the cold-water species, which occasionally comprised more than half of the entire assemblage of planktic foraminifera.

3.3. Biostratigraphy

Hall et al. (2017) conducted low-resolution biostratigraphy aboard ship for Hole U1474A using core catcher samples supplemented with an additional one sample per section for the entire core. Although this study was preliminary and used Wade et al. (2011) as the reference for the ages, we revised the entire shipboard range charts and updated the biostratigraphy following Kennett (1973), Jenkins and Srinivasan (1986), and Lam and Leckie (2020b). The detailed biostratigraphy is presented in Singh et al. (2025). The stratigraphic range of the important planktic foraminiferal species is given in Figure **F2**.

3.4. Systematic paleontology

The systematic descriptions of the encountered species follow the existing understanding of Late Neogene–Quaternary planktic foraminiferal taxonomy as well as new taxonomic concepts developed and revised over the years (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985, Schiebel and Hemleben, 2017; Lam and Leckie, 2020a; Brummer and Kučera, 2022).

In this study, we have documented as many species as possible encountered from the Agulhas Current region to prepare a catalogue of the tropical and temperate forms from the mid-latitudes in the southwest Indian Ocean. We have elaborated the significant morphological features for each species to help with precise identification in each Remarks section. Although we tried to incorporate the minute and subtle observations used for identification, we do not claim that these are the complete descriptions of any species. These observations may be used along with the relevant literature for taxonomic identifications (e.g., Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Cifelli and Scott, 1986; Scott et al., 1990; Schiebel and Hemleben, 2017; Wade et al. 2018; Lam and Leckie, 2020a; Brummer and Kučera, 2022). Along with the published work, we also cite the website **https://www.mikrotax.org/pforams** (Huber et al., 2016) for latest concepts, SEM images, and references.

Table T2. List of Late Neogene–Quaternary planktic foraminiferal species encountered in the present work. **Download table in CSV format.**

The species that were excluded from the list are those with extremely rare occurrences in Hole U1474A. The basionyms, synonyms (if any), and original references for each species are included in the notes that follow. SEM images of specimens are designed to capture the range of morphological variability within a species concept.

The plates are arranged by the family in which the species occur, within which the taxa are listed alphabetically by genus and species name. The images of various morphotypes within a species are arranged in the stratigraphic order of occurrence with the core.

Order FORAMINIFERIDA d'Orbigny 1826
Superfamily GLOBIGERINOIDEA Carpenter, Parker and Jones 1862
Family CANDEINIDAE Cushman 1927
Genus *Candeina* d'Orbigny 1839
Type species *Candeina nitida* d'Orbigny 1839

***Candeina nitida* (d'Orbigny 1839)**
(Plate P1, figures 1–3)

Basionym: *Candeina nitida*
Synonym: *Candeina milletti* Dolfus (1905), *Candeina nitida praenitida* Blow (1969)
Type species: *Candeina nitida* d'Orbigny, 1839

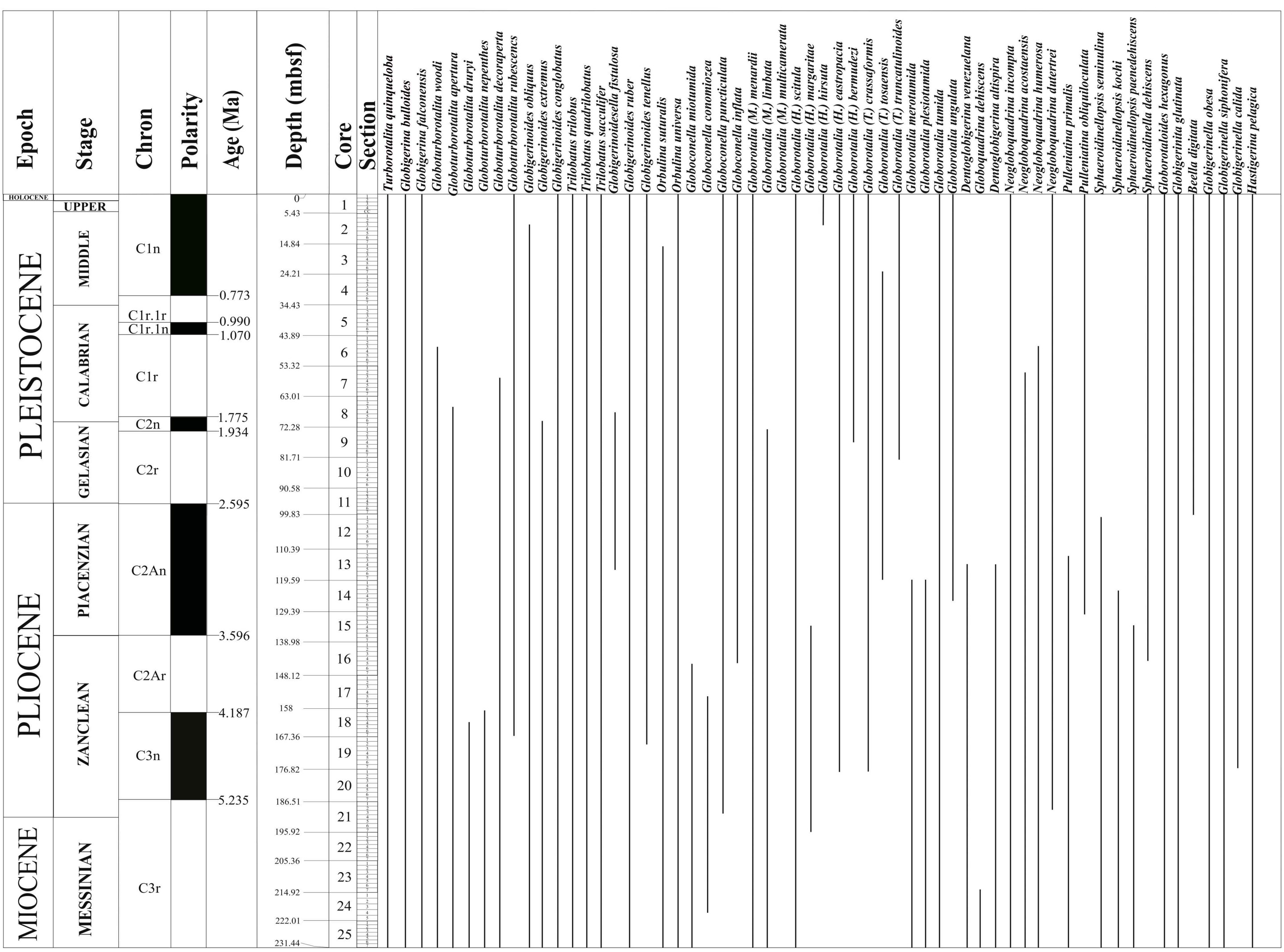

Figure F2. Stratigraphic ranges of planktic foraminifera, Hole U1474A.

References: d'Orbigny (1839), Kennett and Srinivasan (1983), Loeblich and Tappan (1994), Norris (1998), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Meilland et al. (2022), Brummer and Kučera (2022)

Observed stratigraphic range: 361-U1474A-23H-7, 54–56 cm, to 1H-1, 0–2 cm

Remarks. *C. nitida* is an extant species characterized by a high trochospiral compact test. The final whorl has three chambers. The surface is smooth and microperforate. The characteristic feature of *C. nitida* is the presence of sutural supplementary apertures, each of which is bordered by a rim.

This thermocline dweller (Lessa, 2020) is found in tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). This species is rare and shows irregular occurrence in Hole U1474A.

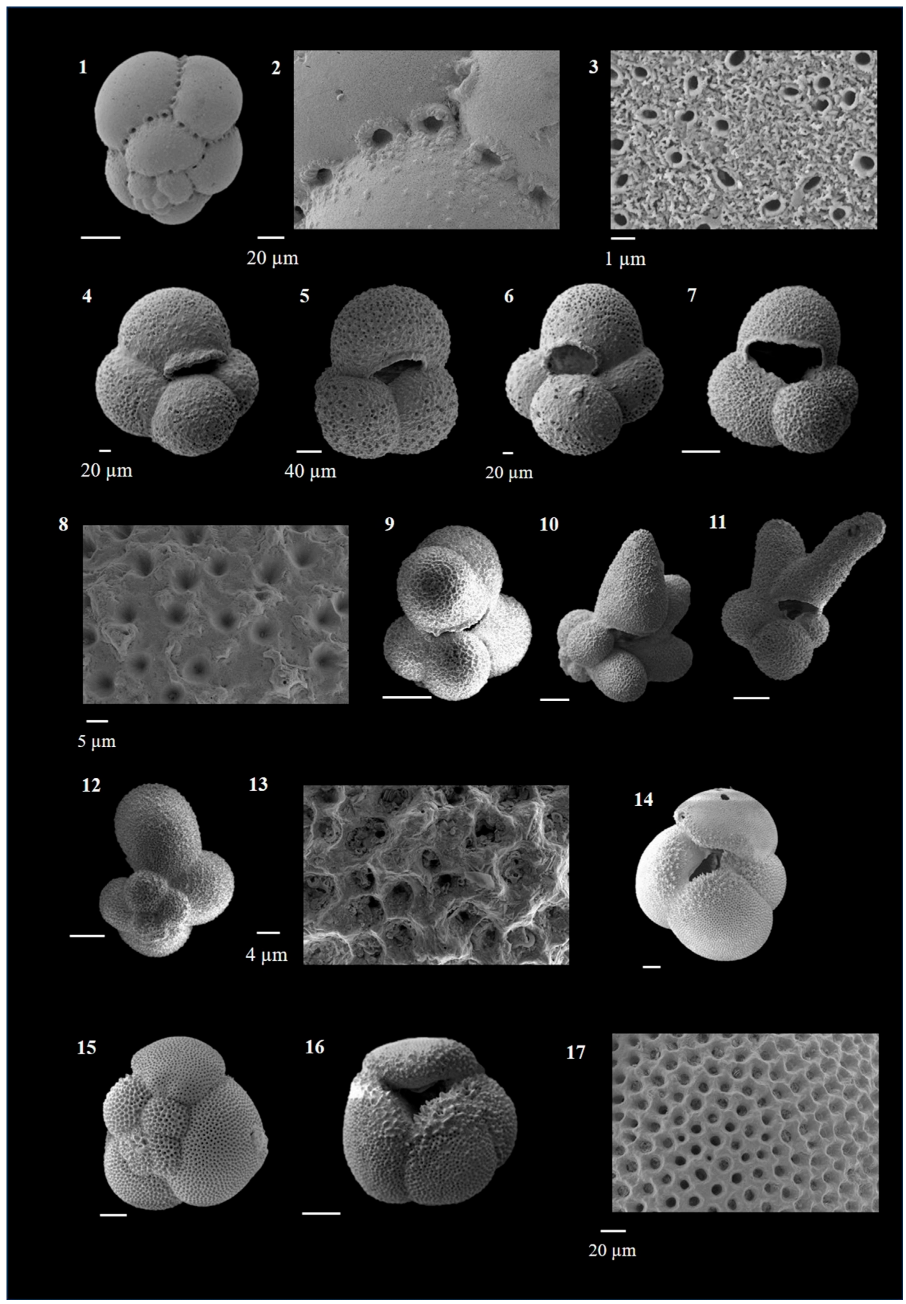

Plate P1. *Candeina nitida*, *Beella praedigitata*, *Beella digitata*, and *Dentoglobigerina venezuelana*, Hole U1474A. 1–3. *Candeina nitida* d'Orbigny (10H-2, 77–79 cm; 1. Spiral view; 2. Sutural apertures; 3. Surface ultrastructure). 4–8. *Beella praedigitata* Parker (20H-1, 83–85 cm; 4–7. Umbilical view; 8. Surface ultrastructure). 9–13. *Beella digitata* Brady (2H-4, 62–64 cm; 9–11. Umbilical view; 12. Spiral view; 13. Surface ultrastructure). 14–17. *Dentoglobigerina venezuelana* Hedberg (18H-3, 27–29 cm; 14, 16. Umbilical view; 15. Spiral view; 17. Surface ultrastructure). Scale bar = 100 µm unless otherwise mentioned.

Family GLOBIGERINIDAE Carpenter, Parker and Jones 1862
Genus *Beella* Banner and Blow 1960
Type species *Globigerina digitata* Brady 1879

***Beella praedigitata* (Parker 1967)**
(Plate **P1**, figures 4–8)

Basionym: *Globigerina praedigitata*
Synonym: *Beella megastoma* Earland (1934)
Type species: *Beella praedigitata* (Parker, 1967)
References: Parker (1967), Kennett (1973), Kennett and Srinivasan (1983), Lam and Leckie (2020a).
Observed stratigraphic range: 361-U1474A-23H-7, 54–56 cm, to 4H-1, 10–12 cm

Remarks. *B. praedigitata* has a low trochospiral test with four to five inflated chambers in the final whorl. The surface is spinose and smooth (Aze et al., 2011), consisting of circular pores and tubercles representing spine bases (Kennett and Srinivasan, 1983).

It evolved from *G. bulloides* in the Late Miocene (Kennett and Srinivasan, 1983) and evolved into *B. digitata* by giving rise to radially elongate chambers (Kennett and Srinivasan, 1983; Lam and Leckie, 2020a). *B. praedigitata* is a thermocline dweller (Aze et al., 2011) extending from tropical to temperate latitudes (Kennett and Srinivasan, 1983). It is extremely rare in Hole U1474A.

***Beella digitata* (Brady 1879)**
(Plate **P1**, figures 9–13)

Basionym: *Globigerina digitata*
Synonyms: *Beella chathamensis* McCulloch (1977), *Beella guadalupensis* McCulloch (1977), *Hastigerina frailensis* McCulloch (1977).
Type species: *Beella digitata* Brady, 1879
References: Brady (1879), Kennett (1973), Kennett and Vella (1975), Kennett and Srinivasan (1983), Lam and Leckie (2020a), Brummer and Kučera (2022).
Observed stratigraphic range: 361-U1474A-11H-7, 35–37 cm, to 1H-1, 0–2 cm

Remarks. *B. digitata* differs from *B. praedigitata* in having radially elongate chambers. It has a high trochospiral test, with four to five radially elongated chambers in the final whorl. The wall is spinose and irregularly cancellate (Aze et al., 2011).

B. digitata is a thermocline dweller (Aze et al., 2011) extending from tropical to temperate latitudes (Kennett and Srinivasan, 1983). It is a regularly occurring species in the Quaternary samples but very low in abundance.

Genus *Dentoglobigerina* Blow 1979
Type species *Globigerina galavisi* Bermúdez 1961

***Dentoglobigerina venezuelana* (Hedberg 1937)**
(Plate **P1**, figures 14–17)

Basionym: *Globigerina venezuelana*
Synonym: *Globoquadrina venezuelana*, *Globoquadrina conglomerata* (?)
Type species: *Dentoglobigerina venezuelana* Hedberg, 1937
References: Hedberg (1937), Postuma (1971), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Wade et al. (2018), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 13H-4, 77–79 cm

Remarks. *D. venezuelana* is characterized by a very large test with a wide umbilicus. There are four reniform chambers in the final whorl, and the wall is spinose to cancellate (Wade et al., 2018). The test is sometimes pustulose on the umbilical shoulders and may also show the presence of umbilical teeth, thereby closely resembling *Dentoglobigerina altispira*.

There has been considerable debate over the generic affinity of this species. Kennett and Srinivasan (1983) assigned it to *Globoquadrina*, which was also accepted by Bolli and Saunders (1985) and Aze et al. (2011). Later, Wade et al. (2018) determined that this species was spinose and thus transferred it to *Dentoglobigerina*. Lam and Leckie (2020a) have also included it in *Dentoglobigerina*. Another form, *Globoquadrina conglomerata* Schwager (1866) was considered a distinct species by Saito et al. (1981), Hemleben et al. (1989), and Lam and Leckie (2020a). Lam and Leckie (2020a) suggest that it is the extant form and a separate species that differs morphologically from *D. venezuelana*. Banner and Blow (1960), Parker (1962), and later Wade et al. (2018) considered *G. conglomerata* a synonym of *D. venezuelana*. Brummer and Kučera (2022) chose to retain *venezuelana* in *Globoquadrina* based on the genetic data by Morard et al. (2019), which does not show any affinity to the spinose clade. This thermocline dweller is globally found in low and mid latitudes (Wade et al., 2018). In Hole U1474A, it is a commonly occurring species during the Late Pliocene, although the abundance is quite low.

Dentoglobigerina altispira (Cushman and Jarvis 1936)
(Plate P2, figures 1–14)

Basionym: *Globigerina altispira*
Synonym: *Dentoglobigerina altispira altispira*, *Dentoglobigerina altispira conica*
Type species: *Dentoglobigerina altispira* Cushman and Jarvis, 1936
References: Cushman and Jarvis (1936), Postuma (1971), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Fox and Wade (2013), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 13H-4, 77–79 cm

Remarks. *D. altispira* is characterized by large, high trochospiral tests with four to five chambers in the final whorl. The chambers are appressed toward the umbilicus. The umbilicus is wide open and deep and shows umbilical teeth. The surface is cancellate with pores in pore pits.

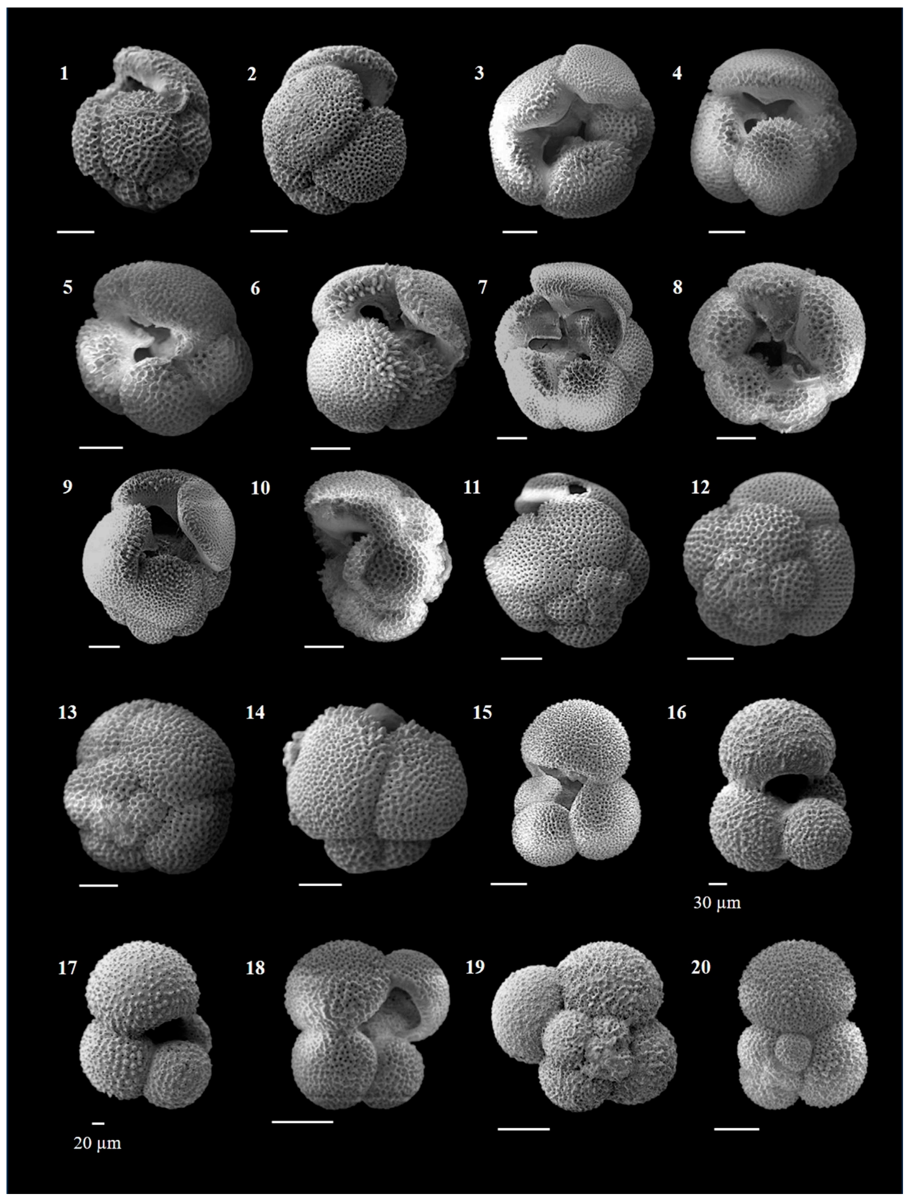

Plate P2. *Dentoglobigerina altispira* and *Globigerina bulloides*, Hole U1474A. 1–14. *Dentoglobigerina altispira* Cushman and Jarvis (1, 2. 19H-6, 133–135 cm [side view]; 3–6, 10, 14. 15H-3, 89–91 cm [3–6. Umbilical view; 10. Axial view; 14. Side view showing high spire]; 7–9, 11–13. 14H-6, 117–119 cm [7–9. Umbilical view; 11–13. Spiral view]. 15–20. *Globigerina bulloides* d'Orbigny (15, 16. 13H-3, 131–133 cm [umbilical view]; 17–20. 1H-2, 106–108 cm [17, 18. Umbilical view; 19, 20. Spiral view]). Scale bar = 100 µm unless otherwise mentioned.

Another species, *D. altispira globosa* Bolli (1957), differs from *D. altispira* in having five to six chambers in the final whorl and a low trochospiral test (Kennett and Srinivasan, 1983). It has not been differentiated in this work owing to the scope of the objectives.

D. altispira is a shallow mixed-layer dweller (Srinivasan and Sinha, 2000; Aze et al., 2011) and is commonly found in tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). It is a regularly occurring species in Hole U1474A in samples spanning the Pliocene and shows moderately high abundance, occasionally reaching up to 6%.

Genus *Globigerina* d'Orbigny 1826
Type species *Globigerina bulloides* d'Orbigny 1826

***Globigerina bulloides* (d'Orbigny 1826)**
(Plate **P2**, figures 15–20; Plate **P3**, figures 1–4)

Basionym: *Globigerina bulloides*
Type species: *Globigerina bulloides* d'Orbigny 1826
References: d'Orbigny (1826), Schwager (1866), Banner and Blow (1960), Lamb and Beard (1972), Kennett and Srinivasan (1983), Jenkins (1985), Shrivastav et al. (2016), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. bulloides* is a commonly occurring species in the eutrophic waters along the Equator, temperate regions, and in the-low latitude upwelling zones (Bé, 1977; Duplessy et al., 1981; Naidu et al., 1992; Naidu and Malmgren, 1996; Sinha et al., 2006; Shrivastav et al., 2016; Schiebel and Hemleben, 2017; Brummer and Kučera, 2022). It is characterized by a low trochospiral test with a characteristic *G. bulloides*-type wall texture. This wall texture is characterized by a hispid surface (Kennett and Srinivasan, 1983), which has thin and round spines, and an irregular pore pattern with a narrow space between pores (Hemleben and Olsson, 2006). The overall test morphology closely resembles quite a few other species like *Globigerinella calida*, *Globigerinella obesa*, *Globigerina falconensis*, and sometimes vaguely *Globigerinita glutinata* (without bulla). However, the umbilical aperture in *G. bulloides*, which is slightly eccentric, distinguishes it from *G. calida*, which has the aperture facing either left or right side (Schiebel and Hemleben, 2017); *G. obesa* differs from *G. bulloides* by its extraumbilical aperture (Shrivastav et al., 2016); the absence of apertural rim or lip separates it from *G. falconensis* (Kennett and Srinivasan, 1983); and the wide, high-arch aperture and surface ultrastructure distinguish *G. bulloides* from *G. glutinata* (Darling and Wade, 2008). The test of *G. bulloides* frequently exhibits the presence of a kummerform final chamber.

The considerable variability in the shape and number of chambers in *G. bulloides* has led to great confusion in taxonomic identification (Lamb and Beard, 1972) and the erection of several species by other authors, for example, *Globigerina bermudezi* Seiglie 1963, *Globigerina cariacoensis* Rögl and Bolli 1973, *Globigerina megastoma* Earland 1934, *Globigerina quadrilatera* Galloway and Wissler 1927, and *Globigerina riveroae* Bolli and Bermúdez 1965, all of which are morphotypes and closely resemble *G. bulloides* (Shrivastav et al., 2016). Kennett and Srinivasan (1983) dubbed these morphotypes phenotypic variants of *G. bulloides*.

The molecular genetic studies by various authors have distinguished 14 genetic types of *G. bulloides* (Darling et al., 2000; Darling and Wade, 2008; André et al., 2013; Morard et al., 2013; Schiebel and Hemleben, 2017). Later, André et al. (2014) suggested that only seven genotypes of *G. bulloides* qualify for a species status. Seears et al. (2012) showed bipolar distribution of a few genotypes of *G. bulloides*, suggesting a gene flow across the tropics, as suggested earlier by Darling et al. (2000). This species has attracted significant attention for its correct taxonomic identification owing to its importance as proxy for upwelling episodes in the low and mid latitudes.

This species is a temperate-latitude, mixed-layer dweller (Bé and Tolderlund, 1971) and thrives in high nutrient conditions, indicative of upwelling in lower latitudes (Thiede, 1975; Bé and Hutson, 1977; Naidu and Malmgren, 1996; Seears et al., 2012; Shrivastav et al., 2016; Schiebel and Hemleben, 2017) and seasonally enhanced primary production at mid and high latitudes (Bé and Tolderlund, 1971; Ottens, 1992; Chapman, 2010; Schiebel and Hemleben, 2017).

In the present study, this species is encountered throughout the Late Neogene–Quaternary span, with significantly high abundance in several samples representing episodes of enhanced productivity in Hole U1474A.

***Globigerina falconensis* (Blow 1959)**
(Plate **P3**, figures 5–10)

Basionym: *Globigerina falconensis*
Synonym: *Globorotalia (Turborotalia) palpebra* Brönnimann and Resig (1971)
Type species: *Globigerina falconensis* Blow, 1959

References: Blow (1959), Kennett and Srinivasan (1983), Jenkins (1985), Iaccarino (1985), Shrivastav et al. (2016), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022), Fabbrini et al. (2023)

Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. The test of *G. falconensis* closely resembles *G. bulloides* in its appearance, with *G. bulloides*-type wall structure, globular chambers, and the slightly eccentric umbilical aperture. The main difference lies in the presence of a distinct apertural lip. Although the apertural area is usually smaller than *G. bulloides* (Schiebel and Hemleben, 2017), it is not very distinct unless the test is morphometrically analyzed. Kennett and Srinivasan (1983) mentioned that the final chamber of *G. falconensis* is distinctly smaller than the penul-

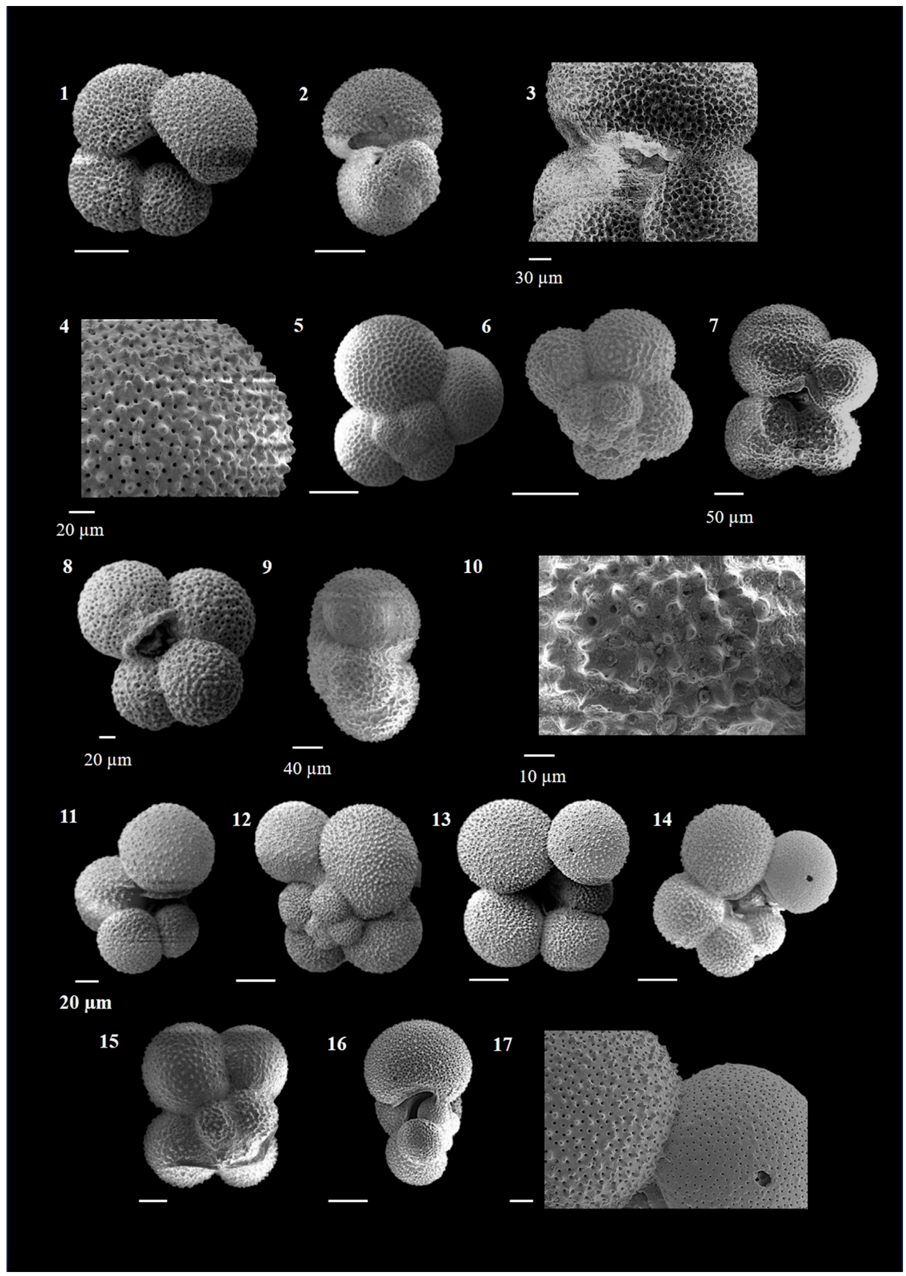

Plate P3. *Globigerina bulloides*, *Globigerina falconensis*, and *Globigerinella calida*, Hole U1474A. 1–4. *Globigerina bulloides* d'Orbigny (1. 1H-1, 0–2 cm [umbilical view]; 2. 1H-1, 96–98 cm [axial view]; 3. 13H-3, 131–133 cm [enlarged view of the aperture]; 4. 1H-2, 106–108 cm [surface ultrastructure]. 5–10. *Globigerina falconensis* Blow (5. 1H-2, 106–108 cm [spiral view]; 6, 9, 10. 1H-1, 32–34 cm [6. Spiral view; 9. Axial view; 10. Surface ultrastructure]; 7, 8. 12H-7, 23–25 cm [umbilical view]). 11–17. *Globigerinella calida* Parker (11. 14H-3, 21–23 cm [umbilical view]; 13, 14, 17. 3H-4, 64–66 cm [13, 14. Umbilical view; 17. Surface ultrastructure]; 12, 15, 16. 5H–1, 12–14 cm [12, 15. Spiral view; 16. Axial view]. Scale bar = 100 µm unless otherwise mentioned.

timate chamber, but this feature was not observed in all the specimens. There were several forms that did not adhere to this observation by Kennett and Srinivasan (1983). Thus, the presence of lip in the last chamber wall becomes an essential criterion for its distinction.

Fabbrini et al. (2023), on the basis of morphometric analysis, reported the presence of interpore ridges in *G. falconensis* and opined that the wall structure was more pseudocancellate than *G. bulloides*-type. Fabbrini et al. (2023) described a new morphotype, *Globigerina neofalconensis*, distinguished from *G. falconensis* by its more lobate profile, more loosely coiled test, and wider umbilicus.

In the present study, all morphotypes with lobate outline, globular chambers, *G. bulloides*-type wall, and aperture with a prominent lip have been identified as *G. falconensis*. It is a commonly occurring species in Hole U1474A, but its abundance has mostly stayed within 5%.

Genus *Globigerinella* Cushman 1927
Type species *Globigerina aequilateralis* Brady 1879

***Globigerinella calida* (Parker 1962)**
(Plate **P3**, figures 11–17)

Basionym: *Globigerina calida*
Synonym: *Globigerina calida calida*, *Bolliella calida calida*
Type species: *Globigerina calida* Parker, 1962
References: Parker (1962), Kennett and Srinivasan (1983), Chaproniere et al. (1994), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-19H-7, 47–49 cm, to 1H-1, 0–2 cm

Remarks. *G. calida* has a smaller, less planispiral test, which separates it from *G. siphonifera*, and the radially elongated chambers in the final whorl distinguish it from *G. obesa* (Brummer and Kučera, 2022). It has a *G. bulloides*-type wall, characteristic of this lineage.

This thermocline dweller is commonly found in tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011). In Hole U1474A, *G. calida* occurs regularly with higher abundance in Quaternary samples than Pliocene samples.

***Globigerinella obesa* (Bolli 1957)**
(Plate **P4**, figures 1–9)

Basionym: *Globorotalia obesa*
Synonym: *Globigerina praebulloides* Blow (1959)
Type species: *Globigerinella obesa* Bolli, 1957
References: Bolli (1957), Kennett (1973), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Spezzaferri et al. (2018), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 32–34 cm

Remarks. *G. obesa* is characterized by a strongly lobulate test with four chambers in the final whorl. The surface is densely perforated and spinose with spine bases coalescing into regular ridges (Kennett and Srinivasan, 1983).

G. obesa very closely resembles *G. bulloides*, but it can be distinguished on the basis of flat spiral side and extraumbilical aperture (Lam and Leckie, 2020a). It is commonly found in low to mid latitudes (Spezzaferri et al., 2018). In Hole U1474A, it is extremely low in abundance.

***Globigerinella siphonifera* (d'Orbigny 1839)**
(Plate **P4**, figures 10–14)

Basionym: *Globigerina siphonifera*
Synonym: *Globigerina aequilateralis* Brady (1879), *Globigerina aequilateralis involuta* Cushman (1917), *Hastigerina aequilateralis*
References: d'Orbigny (1839), Brady (1879), Kennett (1973), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Pearson (1995), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. siphonifera* is characterized by an irregular planispiral test. Five to six chambers are present in the final whorl. The surface is spinose with *G. bulloides*-type wall and rounded spines. The aperture is wide arch and extends from umbilicus to spiral side, without rim or lip.

G. siphonifera is a thermocline dweller, living in low to mid latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011). It occurs regularly in Hole U1474A in moderate abundance.

Genus *Globigerinoides* Cushman 1927
Type species *Globigerina rubra* d'Orbigny 1839

***Globigerinoides conglobatus* (Brady 1879)**
(Plate **P4**, figures 15–18; Plate **P5**, figures 1–3)

Basionym: *Globigerina conglobatus*
Synonym: *Globigerinoides carimanensis* Bermúdez (1960)
Type species: *Globigerinoides conglobatus* Brady, 1879

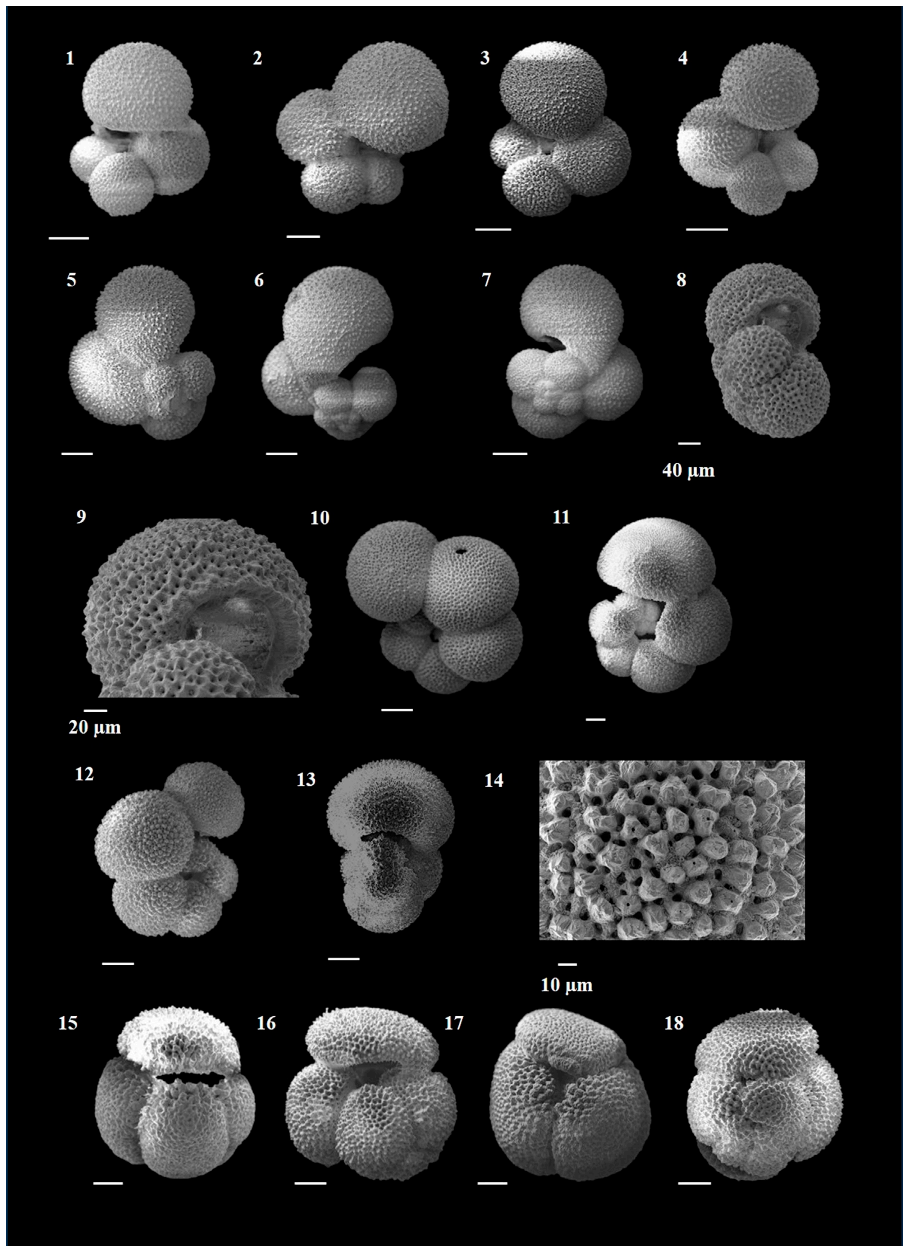

Plate P4. *Globigerinella obesa*, *Globigerinella siphonifera*, and *Globigerinoides conglobatus,* Hole U1474A. 1–9. *Globigerinella obesa* Bolli (1–3, 5–7. 8H-6, 129–131 cm [1–3. Umbilical view; 5–7. Spiral view]; 4. 4H-4, 8–10 cm [umbilical view]; 8, 9. 5H-1, 76–78 cm [8. Axial view; 9. Enlarged view of the aperture]). 10–14. *Globigerinella siphonifera* Brady (1H-2, 106–108 cm [10–12. Equatorial view; 13. Axial view; 14. Surface ultrastructure]). 15–18. *Globigerinoides conglobatus* Brady (15, 16. 4H-2, 84–86 cm [umbilical view]; 17. 19H-2, 123–125 cm [umbilical view]; 18. 2H-1, 0–2 cm [spiral view]). Scale bar = 100 µm unless otherwise mentioned.

References: Brady (1879), Banner and Blow (1960), Jenkins (1971), Kennett (1973), Fleisher (1974), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Schiebel and Hemleben (2017), Lam and Leckie (2020a)

Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. conglobatus* is characterized by its compact, large test with three to four flattened chambers, giving a subquadrate outline to the test. It can be distinguished by its tight coiling and an unusually flat final chamber. The test is often very thick and has a *G. ruber*-type wall. The surface has large pores, triangular spines and spine holes, which are often obscured by a thick calcite crust (Schiebel and Hemleben, 2017). The umbilicus is small, and the primary aperture varies from a low slit to a low arch centered on the previous chambers. The spiral side bears two or more sutural supplementary apertures. An interesting observation in the present work was a higher abundance of morphotypes with three chambers during the Late Miocene–

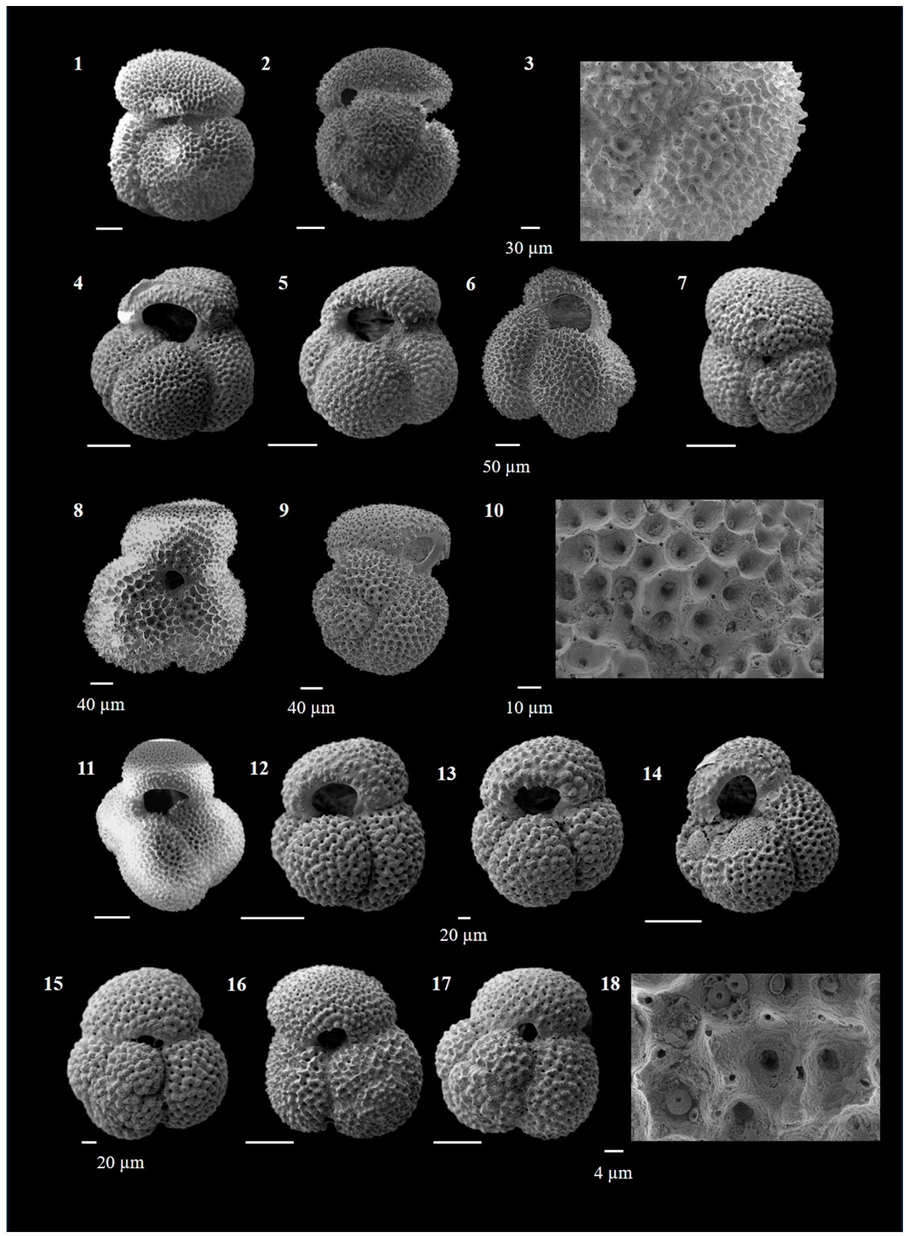

Plate P5. *Globigerinoides conglobatus*, *Globigerinoides extremus*, and *Globigerinoides obliquus,* Hole U1474A. 1–3. *Globigerinoides conglobatus* Brady (1. 4H-2, 84–86 cm [spiral view]; 2, 3. 2H-1, 0–2 cm [2. Axial view; 3. Surface ultrastructure]; 4–10. *Globigerinoides extremus* Bolli (4, 5. 21H-1, 83–85 cm [umbilical view]; 6–8. 9H-2, 121–123 cm [6. Umbilical view; 7, 8. Spiral view]; 9, 10. 10H-5, 139–141 cm [9. Axial view; 10. Surface ultrastructure]). 11–18. *Globigerinoides obliquus* Bolli (11, 16–18. 15H-1, 69–71 cm [11. Umbilical view; 16, 17. Spiral view; 18. Surface ultrastructure]; 12–15. 21H-5, 113–115 cm [12–14. Umbilical view; 15. Spiral view]). Scale bar = 100 µm unless otherwise mentioned.

Early Pliocene, whereas four-chambered forms dominated Late Pliocene–Quaternary. *G. conglobatus* is an extant species that prefers open ocean mixed-layer habitat (Aze et al., 2011) and extends from tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983; Schiebel and Hemleben, 2017) and is often transported by ocean currents to lower mid latitudes (Schmuker and Schiebel, 2002).

This species is found across Late Neogene–Quaternary and rarely exceeds 1.5% abundance in Hole U1474A.

Globigerinoides extremus (Bolli and Bermúdez 1965)
(Plate **P5**, figures 4–10)

Basionym: *Globigerinoides obliquus extremus*
Type species: *Globigerinoides extremus* Bolli and Bermúdez, 1965
References: Bolli and Bermúdez (1965), Postuma (1971), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 8H-6, 4–6 cm

Remarks. *G. extremus* evolved from *G. obliquus* by the development of laterally compressed four chambers in the final whorl and distinctly flattened final chamber (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985), resembling a beret (Lam and Leckie, 2020a). The surface is distinctly pitted, and has *G. ruber/T. sacculifer*-type wall. The surface exhibits tubercles with spine holes, which were formed when the spine was shed. The primary aperture is oblique in shape, umbilical, and there is one supplementary aperture opposite the primary one.

G. extremus extends from tropical to cool subtropical latitudes (Kennett and Srinivasan, 1983), preferring open ocean mixed-layer habitat (Aze et al., 2011). It occurs in extremely low abundance in the upper part of the core compared to the lower part, where it is common to abundant.

Globigerinoides obliquus (Bolli 1957)
(Plate **P5**, figures 11–18)

Basionym: *Globigerinoides obliqua*
Type species: *Globigerinoides obliqua* Bolli (1957)
References: Bolli (1957), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Spezzaferri (1994), Lam and Leckie (2020a), Singh et al. (2021)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 2H-3, 52–54 cm

Remarks. *G. obliquus* shows a lobate test with four ovate chambers in the final whorl, and the last chamber is obliquely compressed. The surface is spinose, distinctly pitted and perforate, exhibiting *G. ruber/T. sacculifer*-type wall (Spezzaferri et al., 2018). The primary aperture is umbilical, high and wide arch. There is one supplementary aperture on the spiral side, opposite the primary aperture.

This cosmopolitan species occurs commonly at middle and high latitudes (Spezzaferri et al., 2018) and prefers mixed-layer habitat (Chaisson and Ravelo, 1997).

The lowest occurrence (LO) of *G. obliquus* is an important biostratigraphic event and has been assigned a mid-Pleistocene age by several authors (Kennett and Srinivasan, 1983; Aze et al., 2011; Wade et al., 2011; Brummer and Kučera, 2022) and Late Pleistocene by others (Sinha and Singh, 2008, 2022; Lam and Leckie, 2020b; Kaushik et al., 2020). In the present study, the LO of this species was found in the samples of the Late Quaternary. In Hole U1474A, *G. obliquus* occurs in high abundance in the lower part of the core spanning the Pliocene, and the Quaternary section has extremely low abundance.

Globigerinoides ruber (d'Orbigny 1839)
(Plate **P6**, figures 1–10)

Basionym: *Globigerina rubra*
Type species: *Globigerinoides ruber* d'Orbigny (1839)
References: d'Orbigny (1839), Banner and Blow (1960), Postuma (1971), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Loeblich and Tappan (1994), Wang (2000), Numberger et al. (2009), Spezzaferri et al. (2015), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Jayan et al. (2021), Latas et al. (2023)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. ruber* can be distinguished by a three-chambered, low to high trochospiral test with its primary and supplementary sutures symmetrically placed above the suture between the earlier chambers of the final whorl. The suture line seems to bisect the primary aperture. The surface is spinose with a *G. ruber*-type wall.

This species exhibits several morphotypes during its entire stratigraphic range, especially during the Quaternary, during which it shows a wide range of variation in the height of the spire and tightness of the test coiling (Kennett and Srinivasan, 1983). These variations led to the recognition of several taxa: forms with a high trochospiral test were named *Globigerinoides pyramidalis* (Van den Broeck, 1876), forms with tightly coiled tests were named *Globigerinoides elongatus* (d'Orbigny, 1826), and those with a compact test and smaller aperture were called *Globigerinoides cyclostomus* (Galloway and Wissler, 1927). All these forms were considered phenotypic variants by Kennett and Srinivasan (1983).

Two chromotypes of *G. ruber* were identified as phenotypes: a white variety, also referred to as *G. ruber* subspecies *albus* (Morard et al., 2019), and a pink variety, *G. ruber* subspecies *ruber* (d'Orbigny, 1839). The name of this species is actually derived from the pink color of its tests (Aurahs et al., 2009; Morard et al.,

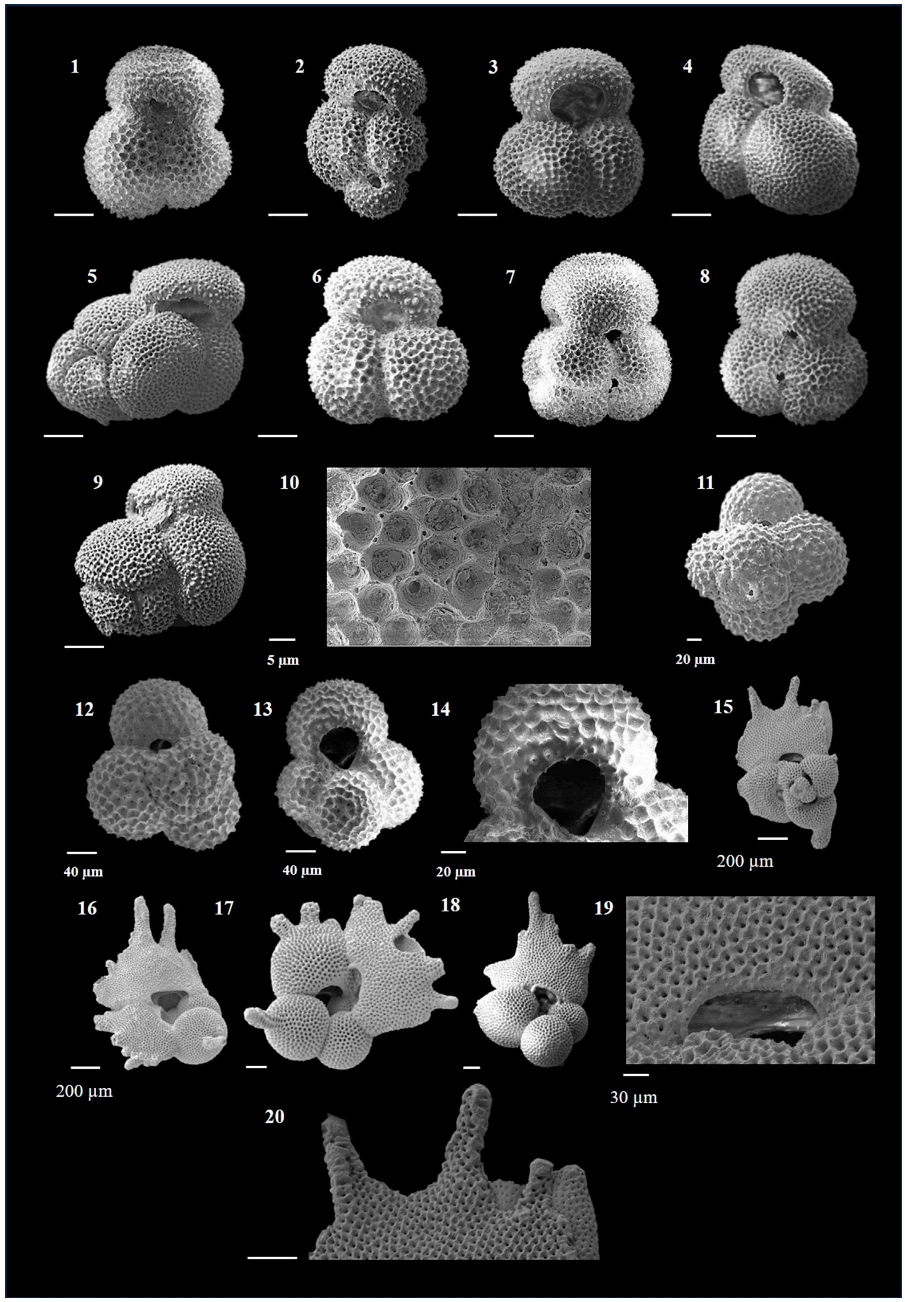

Plate P6. *Globigerinoides ruber*, *Globigerinoides tenellus*, and *Globigerinoidesella fistulosa*, Hole U1474A. 1–10. *Globigerinoides ruber* d'Orbigny (1–3, 7, 10. 1H-3, 52–54 cm [1–3. Umbilical view; 7. Spiral view; 10. Surface ultrastructure]; 4–6. 13H-32, 121–123 cm [umbilical view]; 8–9. 16H-7, 19–21 cm [spiral view]). The various morphotypes designated by Numberger et al. (2009) are also displayed: type-a (normal) represented by figures 1, 3, 6, 7 and 8; type-b (platys) shown by figure 4; type-c (elongate) shown by figures 5 and 9; and type-d (twin) represented by figure 2. 11–14. *Globigerinoides tenellus* Parker (2H-4, 94–96 cm [11, 12. Spiral view; 13. Umbilical view; 14. Aperture]). 15–20. *Globigerinoidesella fistulosa* Schubert (8H-3, 11–13 cm [15. Spiral view; 16–18. Umbilical view; 19. Surface ultrastructure; 20. Fistulose protuberance]). Scale bar = 100 µm unless otherwise mentioned.

2019). The white variety was originally given the name *G. ruber* forma *albus* by Boltovskoy (1968) and was later differentiated into *G. ruber* sensu stricto (s.s.) and *G. ruber* sensu lato (s.l.) by Wang (2000) on the basis of their morphometry and stable isotopic compositions.

The white variety of *G. ruber* is extant in all the ocean basins and dominates in the tropical and subtropical water masses (Bé and Hamlin, 1967; Hemleben et al., 1989), and the pink variety of *G. ruber* became extinct in the Indian and Pacific Oceans during Late Pleistocene (Schiebel and Hemleben, 2017) and preferred warmer habitats than white variants (Bé and Hamlin, 1967, Hemleben et al.1989). The LO of *G. ruber* (pink) is an important biostratigraphic event in the Indian and Pacific oceans (Wade et al., 2011). Numberger et al. (2009) recognized four morphotypes of *G. ruber* (white) on the basis of morphometric analysis and named them "type a or normal, type b or platys, type c or elongate, and type d or kummerform."

G. ruber is an important species inhabiting the top mixed layer (Aze et al., 2011). It exhibits oligotrophic behavior and serves as an important proxy for the thickness of the mixed layer (Sinha et al., 2006). This species has been effectively used for the stable oxygen isotope as well as Mg/Ca ratios for reconstruction of past sea-surface temperatures. *G. ruber* is a characteristic species for the Agulhas Current and constitutes 40%–60% of the modern Agulhas fauna (Simon et al., 2013). The average abundance of *G. ruber* in Hole U1474A is higher during the Late Pliocene to recent and rare during the Early Pliocene.

Globigerinoides tenellus **(Parker 1958)**
(Plate **P6**, figures 11–14)

Type species: *Globigerinoides tenella* Parker (1958)
Reference: Parker (1958), Frerichs (1971), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-16H-5, 77–79 cm, to 1H-1, 0–2 cm

Remarks. *G. tenellus* can be distinguished by its small, compact test with spinose and cancellate wall (Kennett and Srinivasa, 1983; Aze et al., 2011). The primary aperture is large and circular, with a distinct rim, and placed centrally. It has one supplementary aperture on the spiral side. This species closely resembles *Globoturborotalita rubescens*, but for its supplementary aperture. In many modern analyses it was included in *Globoturborotalita* despite having a supplementary aperture (Schiebel and Hemleben, 2017). Kennett and Srinivasan (1983) included this species in *Globigerinoides* and considered *G. rubescens* as the ancestor. Morard et al. (2019), on the basis of molecular genetics, included it in *Globigerinoides* and assigned *G. elongatus* as its ancestor.

G. tenellus can be distinguished from *G. rubescens* by the presence of a supplementary aperture. It is a mixed-layer dweller (Aze et al., 2011), present in tropical to temperate latitudes (Kennett and Srinivasan, 1983). In the present study, this species has occurred from Late Pliocene to recent, but is quite low in abundance.

Genus *Globigerinoidesella* El-Naggar 1971
Type species *Globigerina fistulosa* Schubert 1910

Globigerinoidesella fistulosa **(Schubert 1910)**
(Plate **P6**, figures 15–20)

Basionym: *Globigerina fistulosa*
Synonyms: *Globigerinoides fistulosus*, *Globigerinoides sacculifera fistulosus*, *Globigerinoides quadrilobatus hystricosus*
Type species: *Globigerinoidesella fistulosa* Schubert (1910)
References: Schubert (1910), Parker (1967), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Poole and Wade (2019)
Observed stratigraphic range: 361-U1474A-13H-5, 87–89 cm, to 8H-4, 77–79 cm

Remarks. *G. fistulosa* differs from its ancestor *T. sacculifer* (Kennett and Srinivasan, 1983; Spezzaferri et al., 2015) in having a large test and fistulose proturbances on the chambers in the final whorl. It has a cancellate surface and differs from a *T. sacculifer*-type wall in being spinose (Aze et al., 2011). The primary aperture is large, rimmed, and interiomarginal, and there are multiple supplementary sutural apertures on the spiral side.

G. fistulosa is considered to be of great importance in biostratigraphic studies. The LO event of *G. fistulosa* has been used to mark the top of the Olduvai Normal Event (Srinivasan and Sinha, 1991, 1992; Berggren et al., 1995). Earlier, this event was also used to demarcate the Pliocene/Pleistocene boundary (Berggren et al., 1995; Sinha and Singh, 2008) when the age of the boundary was considered to be 1.8 Ma (Gradstein et al., 2004). After the age of the Pliocene/Pleistocene boundary was lowered to 2.588 Ma (Hilgen et al., 2009; Gibbard et al., 2010; Raffi et al., 2020), this event lost its utility as the boundary marker. This event is still utilized to identify the Gelasian/Calabrian boundary in the sedimentary record. The LO of *G. fistulosa* has also been used to mark the base of Zone PT1 by Wade et al. (2011), and Singh and Sinha (2022) identified this event close to the Olduvai base in Ocean Drilling Program Hole 762B.

G. fistulosa exhibits several morphotypes. Kennett and Srinivasan (1983) considered the forms with elongated digitations on the last few chambers in the final whorl as *G. fistulosa*. Belford (1962) erected a new subspecies, *Globigerinoides quadrilobatus hystricosus*, for the forms that had elongated final chambers with digitations. It was considered a primitive phylogenetically related form to *G. fistulosa* (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Poole and Wade, 2019). Bolli and Saunders (1985) identified the forms resembling *G. fistulosa* as *Globigerinoides trilobus fistulosus*, *Globigerinoides trilobus* cf. *fistulosus*, and *Globigerinoides trilobus* A on the basis of the extension of peripheral ends of the last few chambers in fistule-like projections.

The generic assignment of *G. fistulosa* also underwent revision. Schubert (1910) included this species in the genus *Globigerina*, which was later included in *Globigerinoides*. A new genus *Globigerinoidesella* was introduced by El-Naggar (1971) to differentiate the forms with radially elongated digitate protuberances on chambers from the other species of *Globigerinoides* (Spezzaferri et al., 2015), with *Globigerina fistulosa* Schubert as its type species. Schiebel and Hemleben (2017), following André et al. (2013), identify this species as *Globigerinoides sacculifer* forma *fistulosus*, a rarely occurring morphotype in the modern plankton. They opine that a clear distinction between morphotypes forming the fistulose and sac-like chambers may be impossible.

Poole and Wade (2019) refrained from classifying the transitional forms with fistulose protuberances occurring until recent as *G. fistulosa*, and considered them extreme variants of *T. sacculifer* to maintain the biostratigraphic utility of *G. fistulosa*. In Hole U1474A, this species occurs in extremely low abundance and was observed intermittently.

Genus *Globoquadrina* Finlay 1947
Type species *Globorotalia dehiscens* Chapman, Parr and Collins, 1934

***Globoquadrina dehiscens* (Chapman, Parr and Collins 1934)**
(Plate **P7**, figures 1–6)

Basionym: *Globorotalia dehiscens*
Synonym: *Globoquadrina dehiscens*
Type species: *Globoquadrina dehiscens* Chapman, Parr and Collins, 1934
References: Chapman et al. (1934), Bolli et al. (1957), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Fox and Wade (2013), Wade et al. (2018), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 23H-7, 54–56 cm

Remarks. *G. dehiscens* is an important biostratigraphic marker in both tropical and temperate waters (Jenkins, 1971; Srinivasan and Kennett, 1981b). It has a compact test with a flat spiral and strongly convex umbilical side. There are three to four compressed chambers with a triangular outline and wide umbilicus surrounded by the steep walls of the chambers (Wade et al., 2018), which are also referred to as umbilical shoulders (Kennett and Srinivasan, 1983). The surface is cancellate with circular pores and polygonal ridges. The umbilicus is deep and has apertural tooth.

This cosmopolitan species (Wade et al., 2018) is considered an intermediate dweller by Keller (1985). *G. dehiscens* is extremely rare in Hole U1474A and is present only in the samples spanning the Late Miocene.

Genus *Globorotaloides* Bolli, 1957
Type species *Globorotaloides variabilis* Bolli, 1957

***Globorotaloides hexagonus* (Natland 1938)**
(Plate **P7**, figures 7–12)

Basionym: *Globigerina hexagona*
Synonyms: *Globorotaloides hexagona*, *Globoquadrina hexagona*, *Globorotalia extans* Jenkins (1960), *Globorotaloides permicrus* Blow and Banner (1962), *Globigerina clippertonensis* McCulloch (1977).
Type species: *Globorotaloides hexagonus* Natland, 1938
References: Natland (1938), Parker (1962), Lipps (1964), Kennett (1973), Keller (1978), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. hexagonus* is an extant form typified by a low trochospiral test with flat spiral side, four to five chambers in the final whorl, and a typical cancellate surface (Kennett and Srinivasan, 1983; Schiebel and Hemleben, 2017) showing honeycomb-like structure (Coxall and Spezzaferri, 2018). It typically consists of five chambers in the final whorl (Kennett and Srinivasan, 1983; Lam and Leckie, 2020a), but in the present study the four-chambered forms were dominant and five-chambered forms were rare. The surface is coarsely cancellate with *T. sacculifer*-type wall, with pores in hexagonal pore pits (Kennett and Srinivasan, 1983).

G. hexagonus is an extremely rare form restricted to the Indian and Pacific Oceans (Bé and Tolderlund, 1971). It is a deep subthermocline dweller (Ortiz et al., 1996; Birch et al., 2013), commonly occurring in the tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). In Hole U1474A, *G. hexagonus* is extremely rare in occurrence.

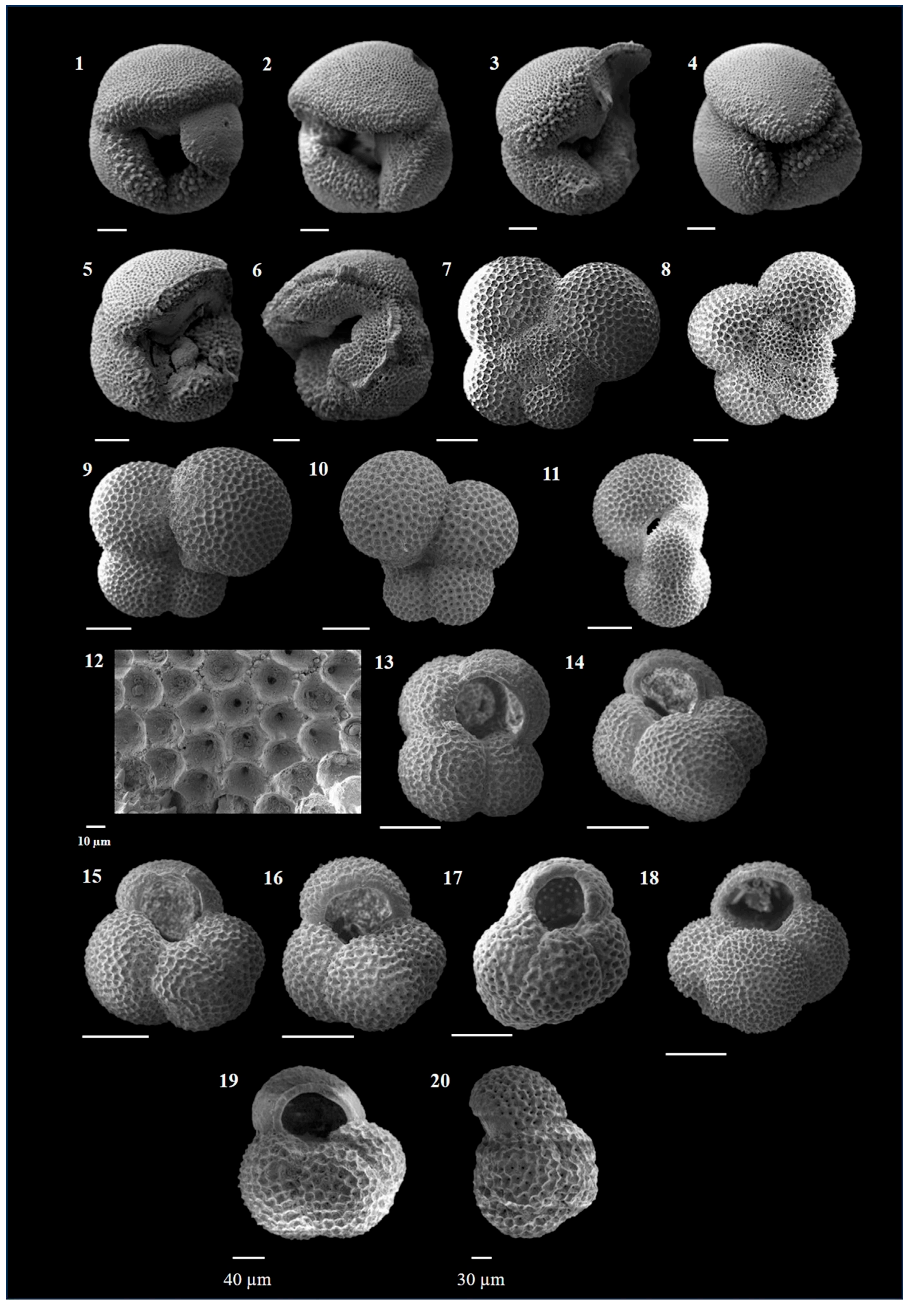

Plate P7. *Globoquadrina dehiscens*, *Globorotaloides hexagonus*, and *Globoturborotalita apertura*, Hole U1474A. 1–6. *Globoquadrina dehiscens* Chapman, Parr and Collins (1–3. 23H-7, 54–56 cm [umbilical view]; 4–6. 23H-7, 22–24 cm [4, 5. Umbilical view; 6. Axial view]. 7–12. *Globorotaloides hexagonus* Natland (11H-5, 81–83 cm [7, 8. Spiral view; 9, 10. Umbilical view; 11. Axial view; 12. Surface ultrastructure]). 13–20. *Globoturborotalita apertura* Cushman (13–16. 20H-3, 39–41 cm [umbilical view]; 17–20. 19H-3, 135–137 cm [17–19. Umbilical view; 20. Axial view]. Scale bar = 100 µm unless otherwise mentioned.

Genus *Globoturborotalita* Hofker 1976
Type species *Globigerina rubescens* Hofker 1956

***Globoturborotalita apertura* (Cushman 1918)**
(Plate **P7**, figures 13–20)

Basionym: *Globigerina apertura*
Synonym: *Globigerina (Zeaglobigerina) apertura*
Type species: *Globoturborotalita apertura* Cushman, 1918
References: Cushman (1918), Kennett and Vella (1975), Kennett and Srinivasan (1983), Iaccarino (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 8H-3, 3–5 cm

Remarks. *G. apertura* is characterized by a large, low trochospiral test with quadrilobate outline, and a large semicircular aperture with a distinct rim. It has a cancellate surface ultrastructure resembling *G. woodi*. Blow (1969) considered *G. bulloides* as the ancestor of *G. apertura*, but the lack of *G. bulloides*-type wall and rimmed aperture phylogenetically links it with *G. woodi* (Kennett and Srinivasan, 1983).

G. apertura preferred open ocean mixed-layer habitat (Aze et al., 2011) and ranged from subtropical to temperate latitudes (Kennett and Srinivasan, 1983). In the present study, it is a rarely occurring species.

***Globoturborotalita decoraperta* (Takayanagi and Saito 1962)**
(Plate **P8**, figures 1–4)

Basionym: *Globigerina druryi decoraperta*
Synonym: *Globigerina (Zeaglobigerina) decoraperta*
Type species: *Globoturborotalita decoraperta* (Takayanagi and Saito, 1962)
References: Takayanagi and Saito (1962), Kennett (1973), Kennett and Vella (1975), Kennett and Srinivasan (1983), Iaccarino (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 7H-3, 131–133 cm

Remarks. *G. decoraperta* closely resembles *G. woodi* but for its high-spired test, which also distinguishes it from *G. apertura* because both have a large aperture bordered by a rim. *G. decoraperta* has a compact test with cancellate surface and wide and deep umbilicus with a large, rimmed aperture. This tropical–subtropical species is a mixed-layer dweller (Kennett and Srinivasan, 1983; Aze et al., 2011).

It is an important biostratigraphic marker but has a quite variable recorded stratigraphic range. The LO of *G. decoraperta* has been assigned a Late Pliocene age by Kennett and Srinivasan (1983), Kaushik et al. (2020), and Lam and Leckie (2020b). Jenkins and Srinivasan (1986), Sinha and Singh (2008), and Singh and Sinha (2022) have reported the LO as Quaternary. The LO of *G. decoraperta* was observed during the late Early Quaternary in the present study. It is a prominently occurring species in the present work, with a higher relative abundance during the Late Miocene and Pliocene than the Pleistocene in Hole U1474A.

***Globoturborotalita druryi* (Akers 1955)**
(Plate **P8**, figures 5–8)

Basionym: *Globigerina druryi*
Synonym: *Globigerina (Zeaglobigerina) druryi*
Type species: *Globoturborotalita druryi* Akers, 1955
References: Akers (1955), Kennett (1973), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 18H-4, 133–135 cm

Remarks. *G. druryi* is characterized by a small, compact test with lobate periphery and coarsely pitted surface. It has a distinct low arch aperture with a rim, which distinguishes it from *G. woodi* (Kennett and Srinivasan, 1983; Lam and Leckie, 2020a).

G. druryi was a mixed-layer dweller (Aze et al., 2011) and inhabited lower latitudes (Kennett and Srinivasan, 1983).

In the present study, it is a commonly occurring species in the lower part of the core, with high relative abundance (>10%) in the Late Miocene–Early Pliocene part of the core.

***Globoturborotalita nepenthes* (Todd 1957)**
(Plate **P8**, figures 9–16)

Basionym: *Globigerina nepenthes*
Synonym: *Globigerina (Zeaglobigerina) nepenthes*
Type species: *Globoturborotalita nepenthes* Todd, 1957

References: Todd (1957), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Hornibrook et al. (1989), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 18H-1, 39–41 cm

Remarks. *G. nepenthes* shows a compactly coiled test with a characteristic thumb-like protruding final chamber, cancellate wall, and broad aperture with distinct rim (Kennett and Srinivasan, 1983). Its final chamber resembles the tropical insectivorous pitcher plant *Nepenthes*, from which it derives its name. *G. nepenthes* differs from its ancestor *G. druryi* in its final chamber and relatively large test. The wide range of variations in *G. nepenthes* led to the erection of some other species like *Globigerina picassiana* (Perconig, 1968) and *Globigerina nepenthes delicatula* (Brönnimann and Resig, 1971), which were later considered phenotypic variants of *G. nepenthes* by Kennett and Srinivasan (1983).

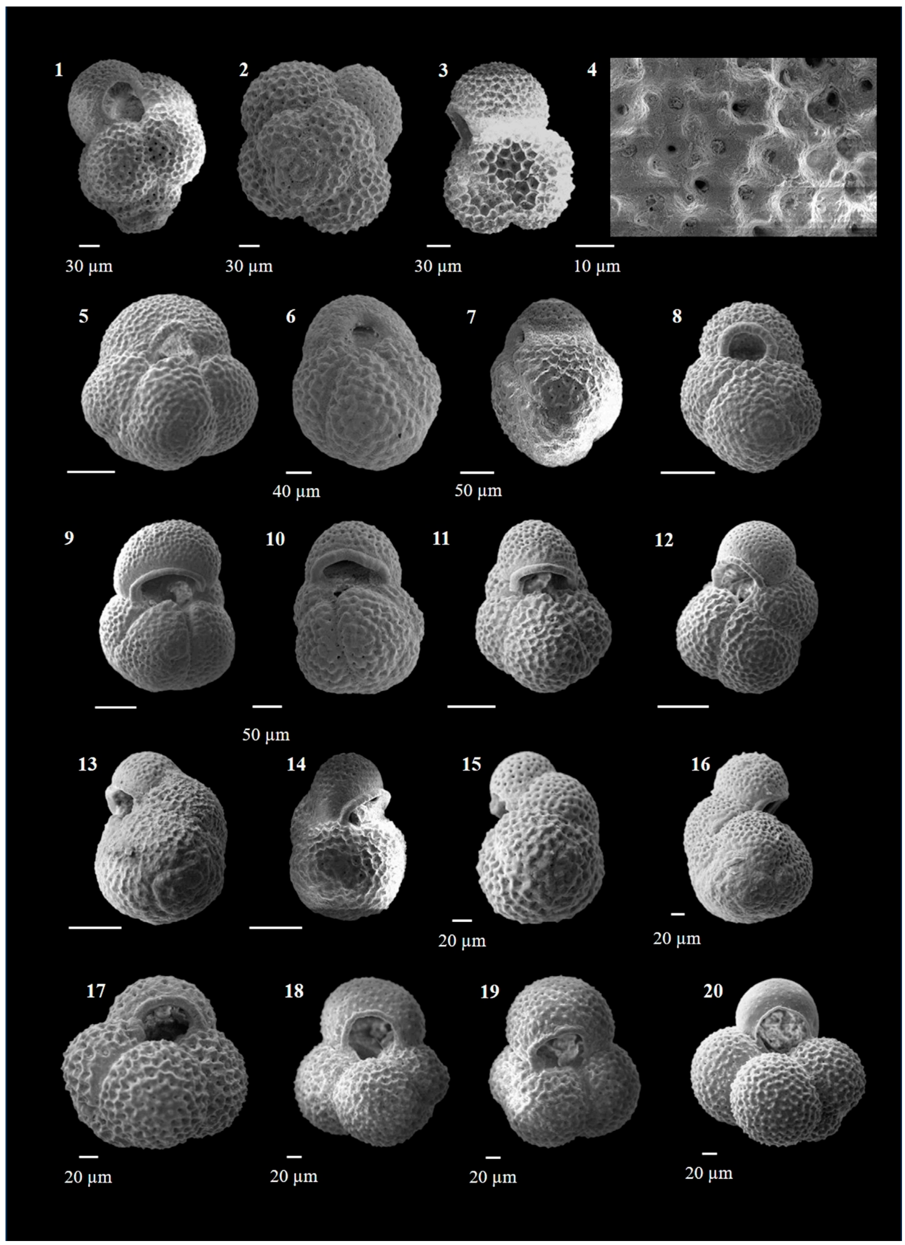

Plate P8. *Globoturborotalita decorpaerta*, *Globoturborotalita druryi*, *Globoturborotalita nepenthes*, and *Globoturborotalita rubescens*, Hole U1474A. 1–4. *Globoturborotalita decorpaerta* Takayanagi and Saito (22H-2, 10–12 cm [1. Umbilical view; 2. Spiral view; 3. Axial view; 4. Surface ultrastructure]). 5–8. *Globoturborotalita druryi* Akers (5–7. 23H-6, 82–84 cm; 8. 19H-4, 145–147 cm [5, 6, 8. Umbilical view; 7. Axial view]). 9–16. *Globoturborotalita nepenthes* Todd (9, 10. 23H-6, 146–148 cm [umbilical view]; 11–13, 16. 21H-1, 115–117 cm [11, 12. Umbilical view; 13, 16. Side view]). 17–20. *Globoturborotalita rubescens* Hofker (17–19. 7H-6, 33–35 cm [umbilical view]; 20. 1H-2, 42–44 cm [umbilical view]). Scale bar = 100 µm unless otherwise mentioned.

This mixed-layer dweller (Aze et al., 2011) lived in warm low latitudes (Kennett and Srinivasan, 1983). *G. nepenthes* is a frequently occurring species in the lower part of the core and has an average relative abundance of 3%–5%.

***Globoturborotalita rubescens* (Hofker 1956)**
(Plate **P8**, figures 17–20; Plate **P9**, figures 1–5)

Basionym: *Globigerina rubescens*
Synonyms: *Globigerina (Zeaglobigerina) rubescens*, *Globigerina rosacea* Bermúdez and Seiglie (1963)
Type species: *Globoturborotalita rubescens* Hofker (1956)

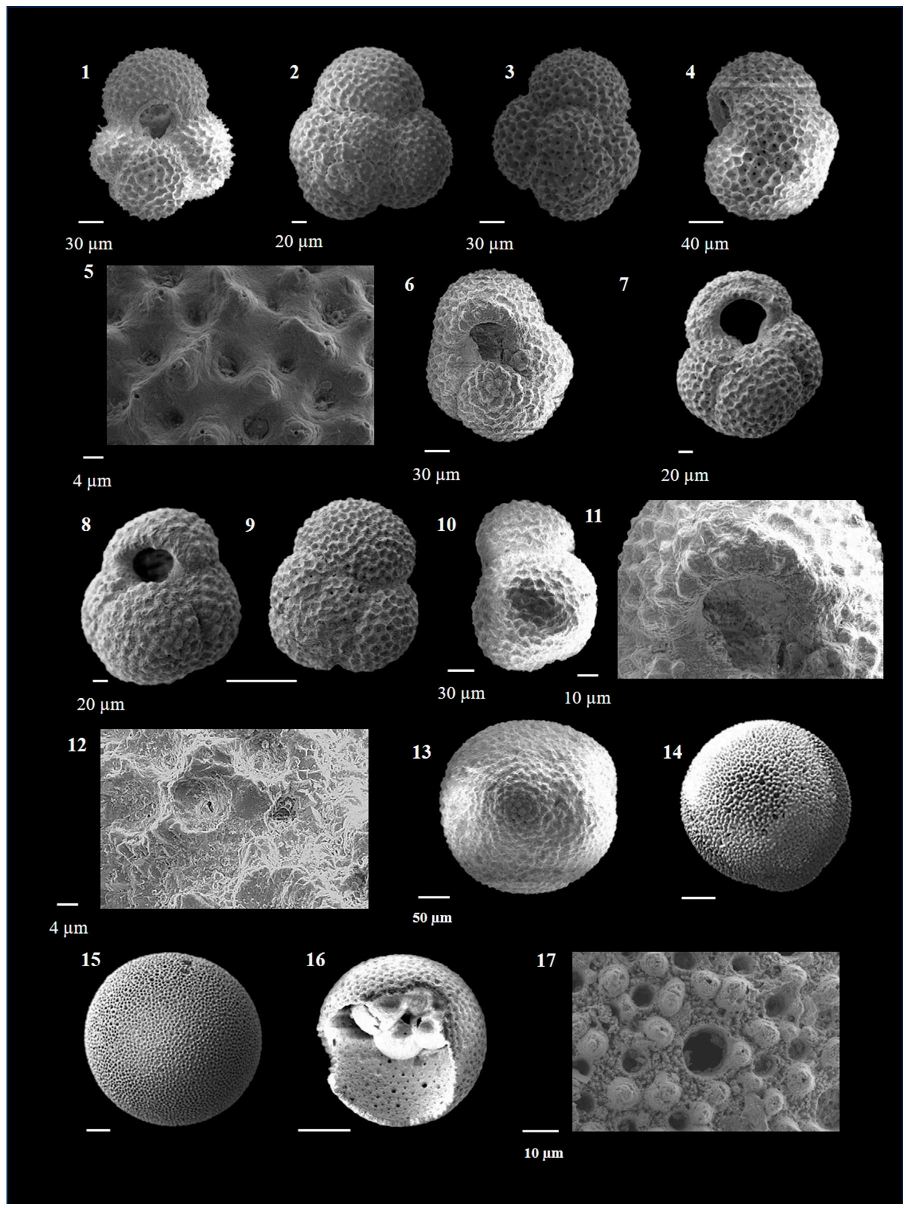

Plate P9. *Globoturborotalita rubescens*, *Globoturborotalita woodi*, *Orbulina suturalis*, and *Orbulina universa,* Hole U1474A. 1–5. *Globoturborotalita rubescens* Hofker (1, 5. 1H-2, 42–44 cm [1. Umbilical view; 5. Surface ultrastructure]; 2–4. 7H-6, 33–35 cm [2, 3. Spiral view; 4. Axial view]). 6–12. *Globoturborotalita woodi* Jenkins (6, 7, 11, 12. 20H-6, 69–71 cm [6, 7. Umbilical view; 11. Aperture; 12. Surface ultrastructure]; 8–10. 10H-2, 141–143 cm [8. Umbilical view; 9. Spiral view; 10. Axial view]). 13, 14. *Orbulina suturalis* Brönnimann (21H-3, 39–41 cm). 15–17. *Orbulina universa* d'Orbigny (5H-6, 126–128 cm [15. Final chamber enveloping the rest of the chambers; 16. Broken test showing the globigerine chambers; 17. Surface ultrastructure. Scale bar = 100 µm unless otherwise mentioned.

References: Hofker (1956), Kennett and Srinivasan (1983), Iaccarino (1985), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-18H-7, 35–37 cm, to 1H-1, 0–2 cm

Remarks. *G. rubescens* is the only extant species of genus *Globorotalita* (Brummer and Kučera, 2022). It evolved from *G. decoraperta* and is distinguished by its small size, relatively delicate test, and small circular aperture. The aperture is bordered by a rim. The surface ultrastructure is cancellate, as well as spinose (Aze et al., 2011). *G. rubescens* often exhibits pink-pigmented tests, especially in modern waters and Late Quaternary sediments.

G. rubescens prefers open ocean mixed-layer habitat (Aze et al., 2011) and is a tropical to subtropical dweller (Kennett and Srinivasan, 1983). Parker (1962) and Hemleben et al. (1989) suggested that white tests of *G. rubescens* are frequently found in bottom sediments underlying temperate waters and suggested that this species is ubiquitous in tropical to temperate surface waters.

In the present work, the relative abundance of this species is very significant and often exceeds 15% of the total faunal composition.

Globoturborotalita woodi **(Jenkins 1960)**
(Plate **P9**, figures 6–12)

Basionym: *Globigerina woodi*
Synonym: *Globigerina (Zeaglobigerina) woodi*
Type species: *Globoturborotalita woodi* Jenkins, 1960
References: Jenkins (1960), Kennett and Srinivasan (1983), Jenkins (1985), Chaproniere (1988), Spezzaferri (1994), Li and McGowran (2000), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 6H-3, 34–36 cm

Remarks. *G. woodi* is distinguished by its quadrilobate outline, with a centrally placed, high-arched symmetrically rounded aperture bordered by a distinct rim. It has a cancellate surface ultrastructure with pores located in subhexagonal pore pits.

Pearson et al. (1997), based on isotope studies, assigned surface mixed-layer habitat for *G. woodi*, whereas Keller (1985) suggested a deeper habitat for this species. *G. woodi* had a wide latitudinal range from temperate to warm subtropical (Kennett and Srinivasan, 1983). It was a commonly occurring species at mid latitudes in both hemispheres (Lam and Leckie, 2020a; present study). In the present work, *G. woodi* was a rare species, showing sporadically high abundance in the lower part of the core spanning the Pliocene.

Genus *Orbulina* d'Orbigny 1839
Type species *Orbulina universa* d'Orbigny, 1839

Orbulina suturalis **(Brönnimann 1951)**
(Plate **P9**, figures 13–14)

Basionym: *Orbulina suturalis*
Synonym: *Candorbulina universa* Jedlitschka (1934)
Type species: *Orbulina suturalis* Brönnimann (1951)
References: Brönnimann, (1951), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Norris 1998), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 3H-1, 41–43 cm

Remarks. *O. suturalis* is a distinct species with a spherical test, areal apertures, and supplementary apertures located along a suture line that joins the previous chambers of the *Globigerina* stage with the final chamber. The surface ultrastructure is hispid. The large final chamber does not completely envelop the previous chambers, which are visible as low, round projections. The sutural supplementary apertures may sometimes become obscured due to heavy encrustation or secondary infilling, which makes it difficult to identify because the specimen looks like *O. universa*. Therefore, it sometimes becomes important to locate the projections of the chambers of the *Globigerina* stage by using a dark-colored dye dripped on the specimen to identify this species.

It has a wide latitudinal range, from tropics to temperate region (Kennett and Srinivasan, 1983). It is widely regarded as a mixed-layer dweller, but Aze et al. (2011) classify it as an open ocean thermocline dweller based on its heavy $\delta^{18}O$ signatures.

This species shows sporadic occurrence in Hole U1474A, with abundance rarely exceeding 1% during the Quaternary and Late Pliocene, whereas the Early Pliocene witnessed quite high abundance, occasionally exceeding 15% of the total population.

Orbulina universa (d'Orbigny 1839)
(Plate **P9**, figures 15–17; Plate **P10**, figures 1–2)

Type species: *Orbulina universa* d'Orbigny, 1839
Variant: *Orbulina bilobata* d'Orbigny (*Biorbulina bilobata*)
References: d'Orbigny (1839), d'Orbigny (1846), Blow (1956), Postuma (1971), Stainforth et al. (1975), Saito et al. (1981), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Loeblich and Tappan (1994), de Vargas et al. (1999), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

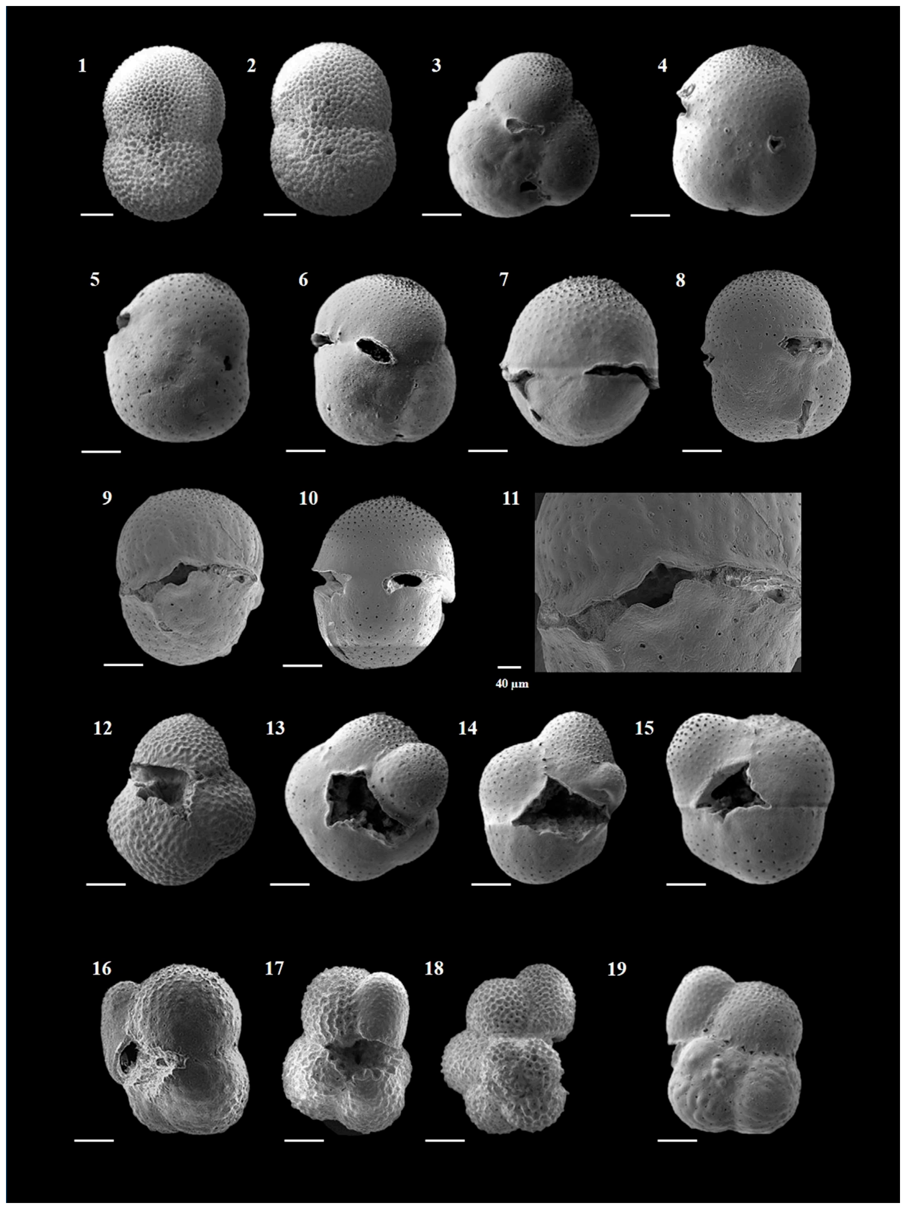

Plate P10. *Orbulina universa*, *Sphaeroidinella dehiscens*, and *Sphaeroidinellopsis kochi*, Hole U1474A. 1, 2. *Orbulina universa* d'Orbigny (25H-5, 113–115 cm; test with second terminal spherical chamber, previously referred to as *Orbulina bilobata* or *Biorbulina bilobata*, an aberrant form of *O. universa*). 3–11. *Sphaeroidinella dehiscens* Parker and Jones (3–5. 18H-2, 17–19 cm [spiral view showing the minute secondary aperture formed in the early phase of evolution]; 6–8, 10. 2H-2, 42–44 cm [6–8. Spiral view; 10. Side view]; 9, 11. 16H-5, 108–110 cm [9. Umbilical view; 11. Aperture]). 12–19. *Sphaeroidinellopsis kochi* Caudri (12. 23H-1, 62–64 cm [umbilical view]; 13–15, 18, 19. 20H-3, 105–107 cm [13–15. Umbilical view; 18, 19. Spiral view]; 16, 17. 17H-6, 85–87 cm [umbilical view]). Scale bar = 100 µm unless otherwise mentioned.

Remarks. *O. universa*, a commonly encountered species inhabiting the surface waters of the world oceans from the Subarctic to Subantarctic latitudes (de Vargas et al., 1999), is easily distinguishable by its spherical test formed at the terminal ontogenetic stage (Schiebel and Hemleben, 2017). The development of a completely spherical form in *O. universa* is believed to be the result of rapid anagenesis at the early/middle Miocene boundary, followed by morphological stasis (Jenkins, 1968; de Vargas et al., 1999). It consists of a single spherical chamber, which is the final chamber enveloping the early part of the test that represents the preadult *Globigerina* stage (Schiebel and Hemleben, 2017). The surface has hispid wall (Aze et al., 2011) and is densely perforate with two distinct pore sizes, of which the larger ones act as the aperture. The size and frequency of pores in *O. universa* have been used in paleotemperature studies and it has been observed in laboratory experiments that increases in temperature correlate with larger pore diameter (Caron et al., 1987; Bijma et al., 1990). The tests with large diameter and higher porosities occur in tropical latitudes, whereas those with smaller test diameter and lower porosities are characteristic of mid to high latitudes (Bé and Tolderlund, 1971). Molecular genetic data have revealed three cryptic species of *O. universa* whose distribution is related to hydrographic provinces and sea-surface total chlorophyll-a concentration (de Vargas et al., 1999). The three cryptic species are regionally separated by their dominance as Caribbean species (Type I), Mediterranean species (Type II), and Sargasso species (Type III), with varying pore density and pore/aperture sizes (de Vargas et al., 1999; Morard et al., 2009; Schiebel and Hemleben, 2017).

O. universa has largely been considered a mixed-layer dweller, although Aze et al. (2011) marked it as an open ocean thermocline species based on its stable oxygen isotope signatures.

Another variant, *O. bilobata*, which was previously considered an extant species by Kennett and Srinivasan (1983), has been disregarded as a separate species and included in *O. universa* (Stainforth et al., 1975; Saito et al., 1981; Rossignol et al., 2011; Schiebel and Hemleben, 2017; Brummer and Kučera, 2022). It is an aberrant form of *O. universa* that develops a second terminal chamber in response to higher food availability (Robbins, 1988; Hemleben et al., 1989). The relative abundance of *O. universa* is higher during the Pliocene as compared to Quaternary, occasionally exceeding 10% during the Pliocene.

Genus *Sphaeroidinella* Cushman 1927
Type Species *Sphaeoridina bulloides* d'Orbigny *var. dehiscens* Parker and Jones, 1865

Sphaeroidinella dehiscens (Parker and Jones 1865)
(Plate **P10**, figures 3–11)

Basionym: *Sphaeroidina bulloides* var. *dehiscens*
Synonyms: *Sphaeroidinella dehiscens immatura* Cushman (1919), *Sphaeroidinella dehiscens excavata* Banner and Blow (1965), *Sphaeroidinella dehiscens ionica ionica* Cita and Ciaranfi (1972), *Sphaeroidinella ionica evoluta* Cita and Ciaranfi (1972)
Type species: *Sphaeroidinella dehiscens* Parker and Jones, 1865
References: d'Orbigny (1865), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Pearson (1995), Malmgren et al. (1996), Kučera (1998), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-16H-4, 67–69 cm, to 1H-1, 0–2 cm

Remarks. *S. dehiscens* is an extant species characterized by a large, ovoid test with three chambers in the final whorl. It has a deep umbilicus, a large primary aperture, and a secondary sutural aperture. The apertures are bordered by crenulated lip. It has a nonspinose cancellate wall with cortex (Aze et al., 2011). *S. dehiscens* differs from *S. paenedehiscens* in having secondary apertures (Kennett and Srinivasan, 1983).

The development of a secondary aperture in the test of *S. dehiscens* is considered an important event in Late Neogene biostratigraphy. Berggren et al. (1985) assigned an age of 5.1 Ma to the evolutionary appearance of secondary apertures, which was revised by Malmgren et al. (1996) to 5.5 Ma. The evolution of *S. dehiscens* from *S. paenedehiscens* by development of minute secondary apertures in the latest Miocene (Malmgren et al., 1996; Kučera, 1998) was used to define the base of Zone N19 (Kennett and Srinivasan, 1983). These forms with minute secondary apertures were referred to as *S. dehiscens* forma *immatura* (Kučera, 1998). Such forms were also encountered in the lower part of the studied core in the present study (Plate **P25**, figures 17–19). The transition from such minute secondary aperture to a large secondary aperture covering the spiral side occurred after the mid Pliocene (Malmgren et al., 1996) and marked the appearance of *S. dehiscens* sensu stricto (Bandy, 1964).

Sphaeroidinella is a monospecific genus that develops the cortex at the terminal stage of its life cycle, which makes the preadult specimens similar to *T. sacculifer* (Schiebel and Hemleben, 2017; Brummer and Kučera, 2022).

S. dehiscens is an open ocean thermocline dweller (Aze et al., 2011), ranging from tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). It occurs in extremely low abundance in Hole U1474A.

Genus *Sphaeroidinellopsis* Banner and Blow 1959
Type species *Globigerina seminulina* Schwager 1866

***Sphaeroidinellopsis kochi* (Caudri 1934)**
(Plate **P10**, figures 12–19; Plate **P11**, figures 1–5)

Basionym: *Globigerina kochi*
Synonym: *Sphaeroidinella rutschi* Cushman and Renz (1941), *Sphaeroidinella multiloba* LeRoy (1944), *Globigerina grimsdalei* Keijzer (1945), *Sphaeroidinellopsis hancocki* Bandy (1975).
Type species: *Sphaeroidinellopsis kochi* Caudri, 1934

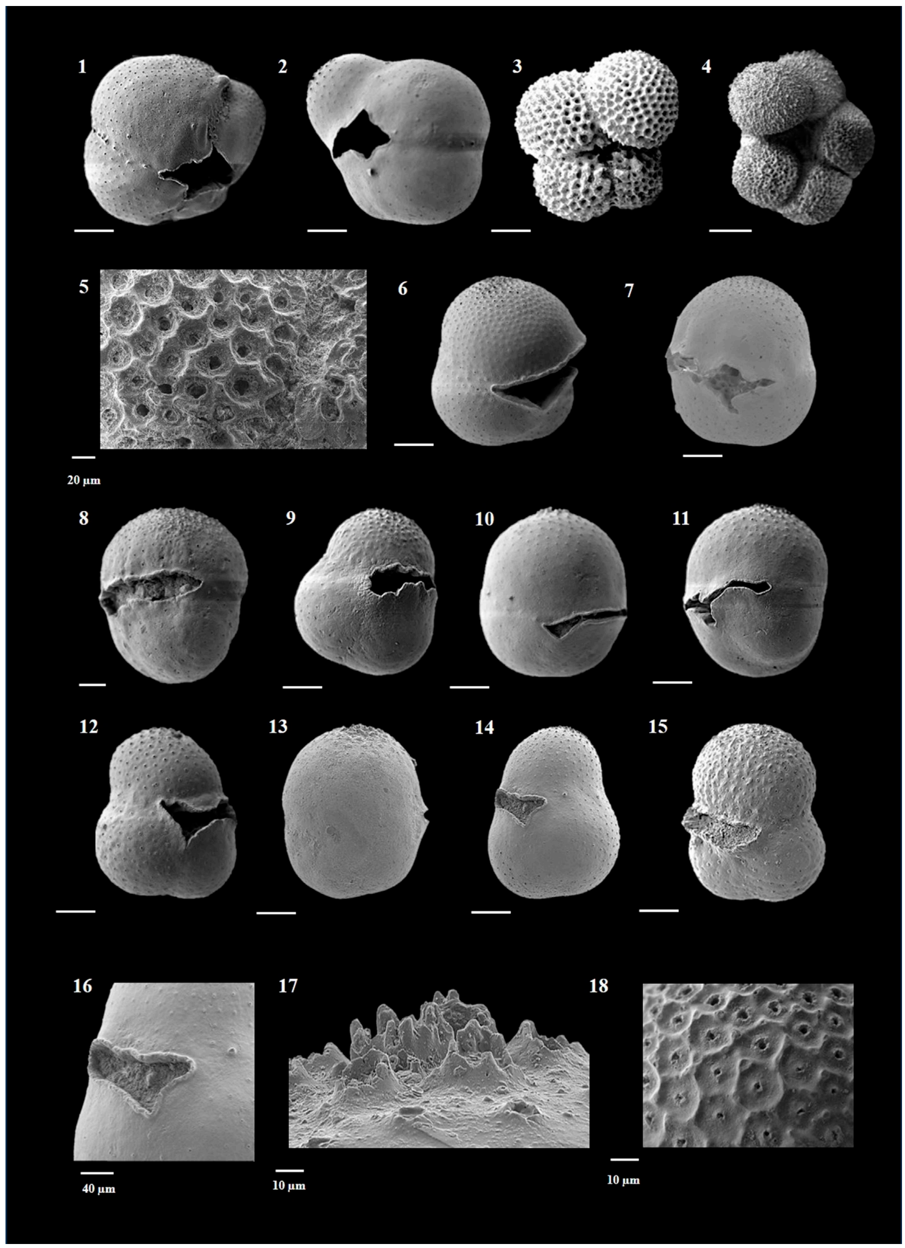

Plate P11. *Sphaeroidinellopsis kochi*, *Sphaeroidinellopsis paenedehiscens*, and *Sphaeroidinellopsis seminulina*, Hole U1474A. 1–5. *Sphaeroidinellopsis kochi* Caudri (1, 2. 17H-6, 85–87 cm [umbilical view]; 3–5. 23H-1, 62–64 cm [3, 4. Umbilical view; 5. Surface ultrastructure]). 6–8. *Sphaeroidinellopsis paenedehiscens* Blow (21H-7, 5–7 cm; umbilical view). 9–18. *Sphaeroidinellopsis seminulina* Schwager (9, 10, 17. 17H-7, 33–35 cm [9, 10. Umbilical view; 17. Spines]; 11–16, 18. 17H-1, 3–5 cm [11, 12, 14, 15. Umbilical view; 13. Spiral view; 16. Aperture; 18. Surface ultrastructure]). Scale bar = 100 µm unless otherwise mentioned.

References: Caudri (1934), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Pearson (1995), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 14H-3, 21–23 cm

Remarks. *S. kochi* differs from *Sphaeroidinellopsis seminulina* in having more than three chambers (Kennett and Srinivasa, 1983), a wide open umbilicus, and a larger aperture. It has four to five chambers in the final whorl, with last chamber of characteristic sacculiferid shape (Bolli and Saunders, 1985). The wall is distinctly cancellate in the specimens that lack a cortex, whereas those with cortex exhibit smooth surface. The aperture has crenulated margin like *S. seminulina*. In some specimens of *S. kochi*, series of supplementary sutural apertures were visible on the spiral side, but these appear to be more of a diagenetic signature rather than a distinguishing morphological feature.

S. kochi was a thermocline dweller (Aze et al., 2011) found in tropical latitudes (Kennett and Srinivasan, 1983). In Hole U1474A, it is found in low abundance.

***Sphaeroidinellopsis paenedehiscens* (Blow 1969)**
(Plate **P11**, figures 6–8)

Basionym: *Sphaeroidinella subdehiscens paenedehiscens*
Synonym: *Sphaeroidinellopsis sphaeroides* Lamb (1969).
Type species: *Sphaeroidinellopsis paenedehiscens* Blow, 1969
References: Blow (1969), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 15H-4, 67–69 cm

Remarks. *S. paenedehiscens* has a large test with rounded periphery, with three inflated chambers in the final whorl, and a heavy cortex that obscures the pores and sutures. The wall is cancellate with smooth cortex (Aze et al., 2011). The aperture is elongate and has a crenulated lip. *S. paenedehiscens* differs from *S. seminulina* in having a large test, more spherical outline, and a more elongated aperture. Another important distinguishing feature is the compactness of the test that gives the impression of two chambers in the final whorl, unlike *S. seminulina*, in which the three chambers are distinct.

S. paenedehiscens was an open ocean thermocline dweller (Aze et al., 2011) found in tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). In Hole U1474A, *S. paenedehiscens* occurs in extremely low abundance in the Pliocene samples.

***Sphaeroidinellopsis seminulina* (Schwager 1866)**
(Plate **P11**, figures 9–18)

Basionym: *Globigerina seminulina*
Synonym: *Sphaeroidinellopsis seminulina seminulina*, *Sphaeroidinella spinulosa* Subbotina (1958), *Sphaeroidinellopsis subdehiscens* Blow (1959).
Type species: *Sphaeroidinellopsis seminulina* Schwager, 1866
References: Schwager (1866), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 12H-1, 71–73 cm

Remarks. *S. seminulina* is characterized by a compact test with a broadly ovate to trilobulate outline and is covered with a heavy cortex (Kennett and Srinivasan, 1983). It has three chambers in the final whorl, a cancellate wall that shows smooth texture due to the cortex, and an elongate umbilical aperture with crenulated margin. The coarsely perforate surface has cancellate wall, which is covered by a heavy cortex giving it a glossy appearance (Kennett and Srinivasan, 1983). In almost all the specimens encountered, the surface of the last chamber of the final whorl showed blunt, spine-like extensions of the cortex.

A lot has been discussed about the number of chambers in the final whorl of *S. seminulina*, and several species/subspecies have been proposed. The original description of *S. seminulina* by Schwager (1866) indicates three-chambered form, which was different from the four-chambered neotype selected by Banner and Blow (1960). Another species, *S. subdehiscens*, was erected by Blow (1959) for three-chambered forms. Later, Srinivasan and Kennett (1981b), on comparison of both the forms, concluded that *S. subdehiscens* was a junior synonym of *S. seminulina*. Lam and Leckie (2020a) included the forms with three to three and a half chambers in *S. seminulina*. In the present work, we have adhered to the concept of Kennett and Srinivasan (1983) and included only three-chambered forms in *S. seminulina*. The forms with more than three chambers in the final whorl were included in *S. kochi*.

S. seminulina was a thermocline dweller (Aze et al., 2011) extending in the tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). In Hole U1474A, *S. seminulina* showed extremely high abundance during the Late Miocene–Early Pliocene, often exceeding 10% of the faunal population, whereas during the Late Pliocene it showed extremely low abundance.

Genus *Trilobatus* Spezzaferri et al. 2015
Type species *Trilobatus trilobus*

***Trilobatus quadrilobatus* (d'Orbigny 1846)**
(Plate **P12**, figures 1–4)

Basionym: *Globigerina quadrilobata*
Synonym: *Globigerinoides quadrilobatus*, *Globigerinoides primordius*
Type species: *Trilobatus quadrilobatus* d'Orbigny (1846)
References: d'Orbigny (1846), Banner and Blow (1960), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Spezzaferri et al. (2018), Poole and Wade (2019)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

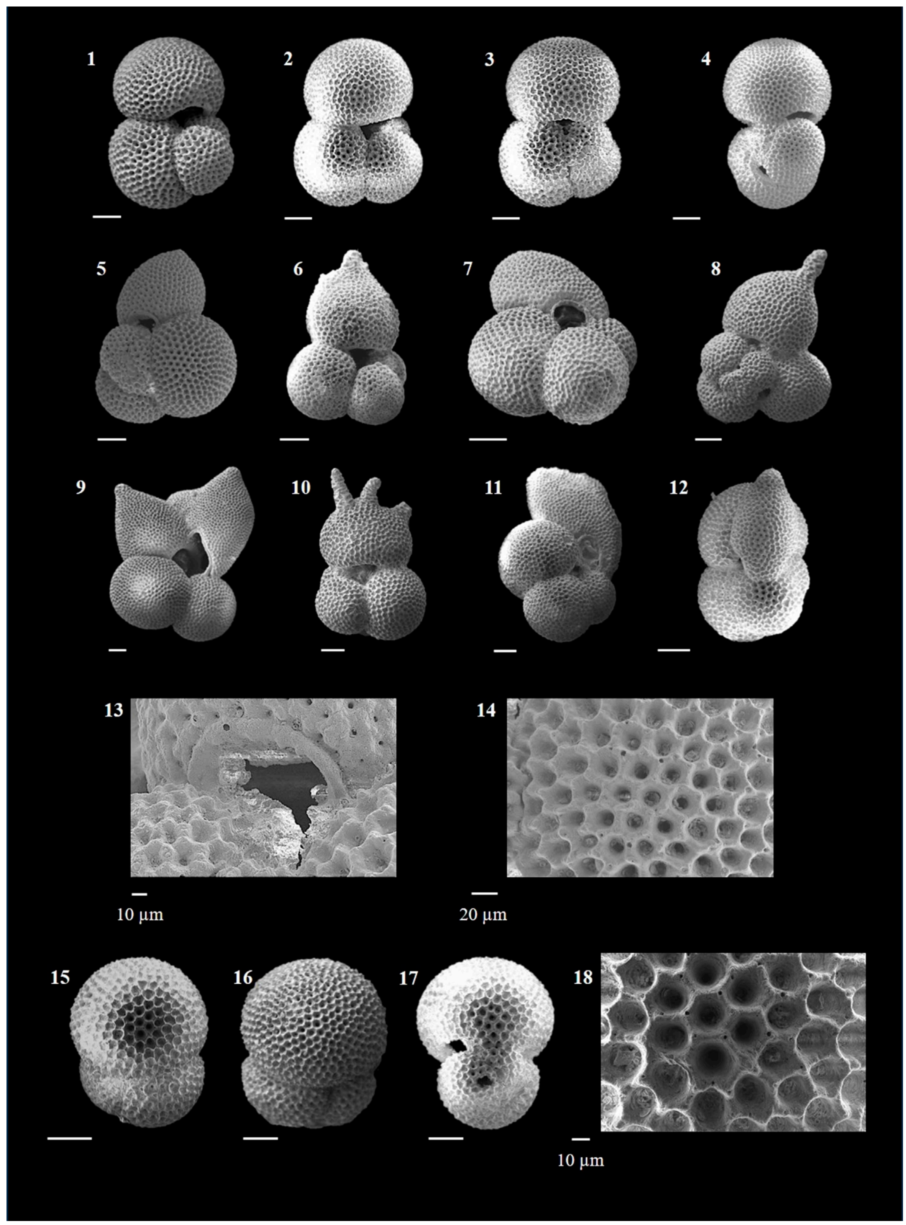

Plate P12. *Trilobatus quadrilobatus*, *Trilobatus sacculifer*, and *Trilobatus trilobus*, Hole U1474A. 1–4. *Trilobatus quadrilobatus* d'Orbigny (4H-3, 94–96 cm [1, 2. Umbilical view; 3. Spiral view; 4. Axial ultrastructure]). 5–14. *Trilobatus sacculifer* Brady (5, 12–14. 8H-7, 11–13 cm [5. Spiral view; 12. Axial view; 13. Supplementary aperture; 14. Surface ultrastructure]; 6, 7. 12H-4, 89–91 cm [umbilical view]; 8, 10, 11. 15H-2, 111–113 cm [8. Spiral view; 10, 11. Umbilical view]; 9. 4H-1, 138–140 cm [umbilical view]). 15–18. *Trilobatus trilobus* Reuss (4H-1, 138–140 cm [15. Spiral view; 16. Umbilical view; 17. Axial view; 18. Surface ultrastructure]). Scale bar = 100 µm unless otherwise mentioned.

Remarks. *T. quadrilobatus* is characterized by three and a half to four chambers, a *T. sacculifer*-type wall, and a low arch primary aperture bordered by a thin rim centered over the antepenultimate chamber (Schiebel and Hemleben, 2017). There are two supplementary apertures on the spiral side.

This species closely resembles *Trilobatus immaturus* but for its higher aperture (Kennett and Srinivasan, 1983). In the present work, both species are clubbed into *T. quadrilobatus*. André et al. (2013) included it in *T. sacculifer* based on molecular genetic studies.

T. quadrilobatus is a cosmopolitan species (Kennett and Srinivasan, 1983; Spezzaferri et al., 2018) and prefers mixed-layer habitat (Chaisson and Ravelo, 1997). It is a consistently occurring species with low abundance in Hole U1474A.

***Trilobatus sacculifer* (Brady 1877)**

(Plate **P12**, figures 5–14)

Basionym: *Globigerina sacculifera*
Synonyms: *Globigerinoides sacculifer*, *Globigerina bulloides* var. *recumbens* Rhumbler (1901)
Type species: *Trilobatus sacculifera* Brady (1877)
References: Brady (1877), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Spezzaferri et al. (2018), Poole and Wade (2019), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *T. sacculifer* is an important mixed-layer dwelling species, abundant in tropical–subtropical latitudes (Kennett and Srinivasan, 1983; Schmuker and Schiebel, 2002; Aze et al., 2011; Schiebel and Hemleben, 2017). It has a unique morphological appearance and can be distinguished by its compressed, sac-like final chamber, which shows several modifications. The test has a *T. sacculifer*-type wall, a high arch, and rimmed primary aperture. There are numerous supplementary apertures on the spiral side.

T. sacculifer has been studied in great detail by several authors for its micropaleontological as well as molecular genetic aspects (e.g., Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; André et al., 2013; Spezzaferri et al., 2015, 2018; Schiebel and Hemleben, 2017; Poole and Wade, 2019; Lam and Leckie, 2020a). It was considered a descendant of the lineage *triloba-immaturus-quadrilobatus-sacculifer* by Kennett and Srinivasan (1983) and included in the Group B stock of their classification of *Globigerinoides*. As previously discussed, André et al. (2013) grouped *triloba*, *immaturus*, *quadrilobatus*, and *sacculifer* as the morphospecies of *T. sacculifer*. Lam and Leckie (2020a) have preferred the biological definition of this species and grouped *T. triloba* with *T. sacculifer* due to their similar stratigraphic ranges in the northwest Pacific Ocean. Schiebel and Hemleben (2017) opine that of the various morphotypes, *sacculifer* is the valid species name because it best includes the entire range of the morphotypes and have assigned terminology like forma *trilobus*, forma *quadrilobatus* and forma *sacculifer* to express their concept of genotype. Poole and Wade (2019) encountered several forms of *T. sacculifer* with an elongate fistulose projection from the final chamber and considered it to be the plexus form of *T. sacculifer*.

Although in modern plankton, all these morphotypes are considered conspecific (André et al., 2013), in the fossil record they are still regarded as distinct species due to their different stratigraphic ranges (Spezzaferri et al., 2018). The census data suggest low abundance of this commonly occurring species in Hole U1474A.

***Trilobatus trilobus* (Reuss 1850)**

(Plate **P12**, figures 15–18)

Basionym: *Globigerina triloba*
Synonym: *Globigerinoides triloba*, *Globigerinoides trilobus* Spezzaferri (1994)
Type species: *Trilobatus triloba* Reuss (1850)
References: Reuss (1850), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Spezzaferri (1994), Fox and Wade (2013), Spezzaferri et al. (2015), Schiebel and Hemleben (2017), Poole and Wade (2019)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *T. trilobus* is characterized by its low trochospiral test with three chambers in the last whorl, with the final chamber being larger than the previous two. The surface ultrastructure is cancellate with *T. sacculifer*-type wall. The primary aperture is a narrow slit-like, sometimes low arch, and there are two to three secondary apertures on the spiral side.

There has been a large debate on the status of *T. trilobus* as a separate species. Earlier, this species was considered under the genus *Globigerinoides*, which was later included in the genus *Trilobatus* (Spezzaferri et al., 2015). Spezzaferri et al. (2015), using stratophenetic and molecular genetic data, proved the polyphyletic origin of the genus *Globigerinoides*, a trait previously discussed by several authors, for example, Takayanagi and Saito (1962), Keller (1981), Kennett and Srinivasan (1983), Jenkins (1985), Spezzaferri and Premoli Silva (1991), and Spezzaferri (1994). André et al. (2013) conducted molecular genetic studies on modern forms and concluded that the species *trilobus*, *immaturus*, *quadrilobatus*, and *sacculifer* are the morphotypes of the same species, which are not separated by the biologists and included in *T. sacculifer*. However, the fossils of these forms are still considered separate species and used exclusively for paleoceanographic and biostratigraphic studies (Spezzaferri et al., 2018; Poole and Wade, 2019; Lam and Leckie, 2020a, 2020b). Schiebel and Hemleben (2017) described four common morphotypes of the modern *T. sacculifer* (*Globigerinoides sacculifer*, as mentioned by the authors): forma *trilobus*, forma *quadrilobatus*, forma *immaturus*, and forma *sacculifer*. All these forms are considered morphotypes of *T. sacculifer* due to its range that includes the entire range of morphotypes including the plexus forms (Schiebel and Hemleben, 2017). The focus of the present work is on the paleoceanographic reconstruction of the Agulhas Current, so these forms are considered as separate distinct species.

T. trilobus is very abundant in the tropics as well as commonly found in the mid latitudes (Spezzaferri et al., 2018) and prefers mixed-layer habitat (Pearson et al., 1997). In the present work, this species is found consistently, with an abundance of 2%–3%.

Genus *Turborotalita* Blow and Banner, 1962
Type Species *Truncatulina humilis* Brady 1884

***Turborotalita quinqueloba* (Natland 1938)**
(Plate **P13**, figures 1–7)

Basionym: *Globigerina quinqueloba*
Synonym: *Globigerina quinqueloba*
Type species: *Turborotalita quinqueloba* Natland, 1938
References: Natland (1938), Kennett and Srinivasan (1983), Jenkins (1985), Pearson and Wade (2009), Schiebel and Hemleben (2017), Pearson and Kučera (2018), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *T. quinqueloba* shows wide morphological variability and resembles many forms with ampullate final chambers (Brummer and Kučera, 2022). The test consists of four and a half to five chambers in the final whorl, with the final chamber modified in a flap-like extension, which resembles a lip in some morphotypes and is modified like a bulla in others. The surface ultrastructure consists of a primarily smooth wall with the development of *G. ruber/T. sacculifer*-type wall, also known as *Turborotalita*-type wall ultrastructure (Hemleben and Olsson, 2006). Another important feature is the distinctly spinose surface of the last chamber, with short, stunted triangular spines. It is a species inhabiting subpolar latitudes (Bé and Tolderlund, 1971). *T. quinqueloba* is rare in Hole U1474A and occurs sporadically, with the relative abundance below 0.5%.

***Turborotalita humilis* (Brady 1884)**
(Plate **P13**, figure 8)

Basionym: *Truncatulina humilis*
Synonym: *Turborotalita humilis*, *Turborotalita cristata*
Type species: *Turborotalita humilis* Brady, 1884
References: Brady (1971), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Brummer and Kučera (2022)

Remarks. *T. humilis* is an extant form (Schiebel and Hemleben, 2017), characterized by a small, compact test with circular equatorial outline and six chambers in the final whorl. The last chamber is characteristically modified in the form of tongue-like extension over the umbilicus and has several infralaminal apertures (Kennett and Srinivasan, 1983). The extension of the last chamber also resembles bulla that wraps the umbilicus and ends in a series of finger-like extensions over the umbilical sutures (Bolli and Saunders, 1985). The wall is spinose and shows cancellate structure (Aze et al., 2011), which is often obscured due to encrusting.

T. humilis is a mixed-layer dweller found in tropical–subtropical latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011). It is extremely rare in Hole U1474A and occurred sporadically.

Family GLOBIGERINITIDAE Bermúdez 1961, revised Li 1987; Pearson and Wade 2009
Genus *Globigerinita* Brönnimann 1951
Type species *Globigerinita naparimaensis* Brönnimann 1951

Globigerinita glutinata (Egger 1893)
(Plate **P13**, figures 9–19)

Basionym: *Globigerina glutinata*
Synonyms: *Globigerinita glutinata glutinata*, *Globigerinita naparimaensis* Brönnimann (1951), *Globigerinita incrusta* Akers (1955), *Globigerinita parkerae* Bermúdez (1961), *Globigerinita flparkerae* Brönnimann and Resig (1971)

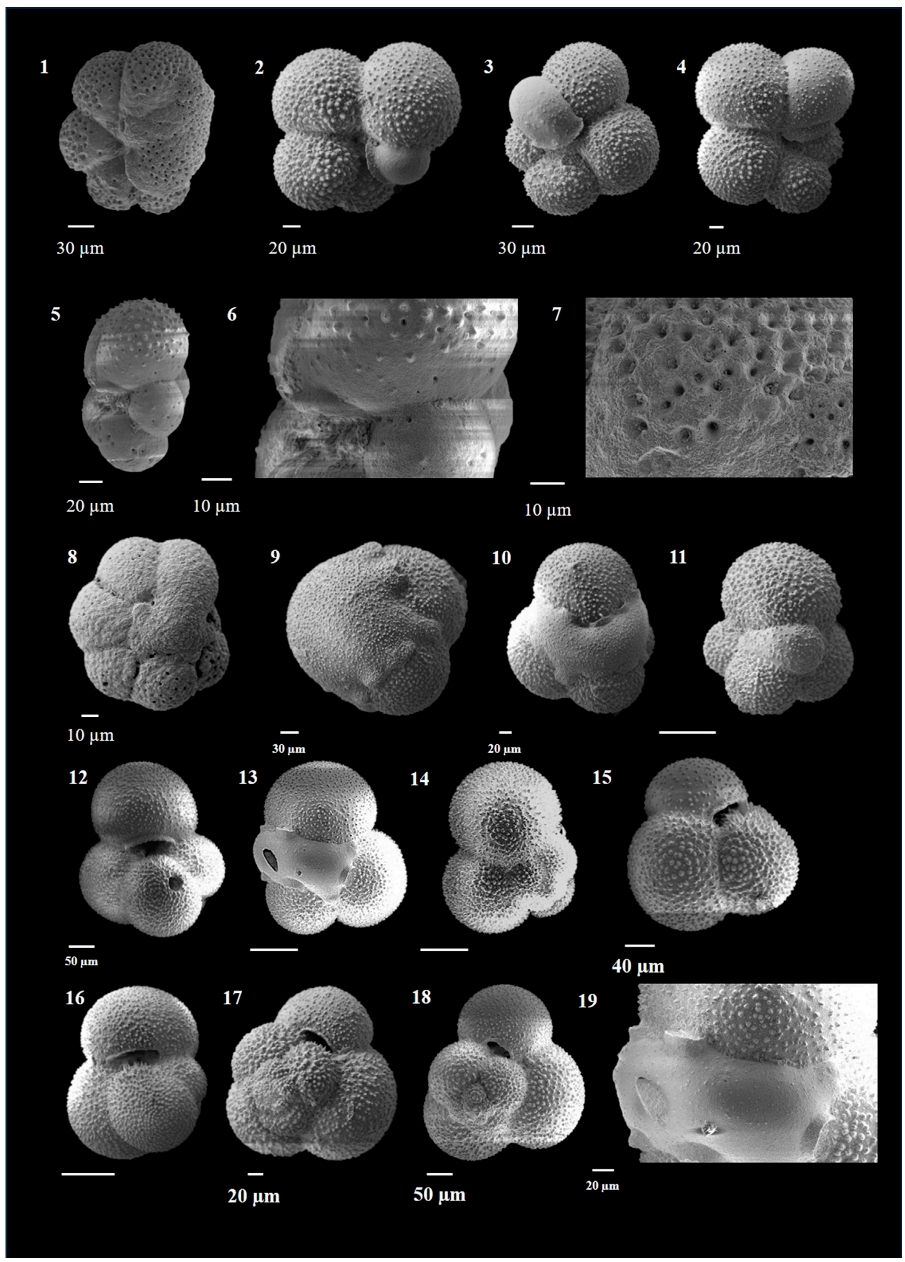

Plate P13. *Turborotalita quinqueloba*, *Turborotalita humilis*, and *Globigerinita glutinata*, Hole U1474A. 1–7. *Turborotalita quinqueloba* Natland (1, 2, 5-7. 10H-6, 117–119 cm [1, 2. Umbilical view; 5. Axial view; 6. Apertural lip; 7. Surface ultrastructure]; 3, 4. 2H-6, 106–108 cm [umbilical view]). 8. *Turborotalita humilis* Brady (2H-1, 32–34 cm). 9–19. *Globigerinita glutinata* Egger (9. 18H-7, 67–69 cm [umbilical view with bulla]; 10, 11, 13, 15, 16, 19. 1H-1, 96–98 cm [10, 11, 13. Umbilical view with bulla; 15, 16. Umbilical view without bulla; 19. Aperture covered with bulla, showing infralaminal supplementary apertures]; 12, 14, 17, 18. 7H-2, 57–59 cm [12. Umbilical view without bulla; 14. Spiral view; 17, 18. Spiral view with secondary aperture]). Scale bar = 100 µm unless otherwise mentioned.

Type species: *Globigerinita glutinata* Egger, 1893

References: Egger (1893), Parker (1962), Lipps (1964), Fleisher (1974), Keller (1978), Kennett and Srinivasan (1983), Chaisson and Leckie (1993), Spezzaferri (1994), Pearson (1995), Schiebel and Hemleben (2017), Pearson, Wade and Huber (2018), Lam and Leckie (2020a), Brummer and Kučera (2022)

Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. glutinata* is a ubiquitous species in the modern ocean, most abundant in subtropical to temperate waters (Schiebel and Hemleben, 2017). It is an important upwelling indicator in the lower latitudes (Sinha et al., 2006).

G. glutinata is characterized by a small compact test, with four chambers in the last whorl. The surface is smooth, with irregularly distributed fine perforations covered by crystallites. It has umbilical aperture with a characteristic inflated bulla that covers the umbilicus. The inflation of bulla along the umbilical sutures shows numerous infralaminal supplementary apertures bordered by tubulose openings (Kennett and Srinivasan, 1983).

There is considerable morphological variability in the development of bulla in *G. glutinata* and its genetic diversity (André et al., 2014; Schiebel and Hemleben, 2017; Morard et al., 2019; Brummer and Kučera, 2022).

Another morphotype, *Globigerinita parkerae* Bermúdez (1961), which was previously considered a distinct species (Kennett and Srinivasan, 1983), is now a synonym of *G. glutinata* (Brummer and Kučera, 2022). *G. parkerae* differs from *G. glutinata* by secondary apertures on the spiral side. It was considered the ancestor of *Candeina nitida* (Kennett and Srinivasan, 1983). Following Brummer and Kučera (2022), it is lumped with *G. glutinata* in the present work.

It is an important species in paleoceanographic reconstructions, as it is used as an upwelling indicator. *G. glutinata* is a shallow mixed-layer dweller (Pearson and Wade, 2009) and shows a global occurrence (Pearson et al., 2018).

In Hole U1474A, *G. glutinata* is a prominent species that occurs in high abundance. It is present throughout the core and has higher abundance during Quaternary than Pliocene.

Family GLOBOROTALIIDAE Blow 1979
Genus *Globoconella* Bandy 1975
Type species *Globorotalia conomiozea* Kennett 1966

***Globoconella conomiozea* (Kennett 1966)**
(Plate **P14**, figures 1–10)

Basionym: *Globorotalia conomiozea*

Type species: *Globoconella conomiozea* Kennett (1966)

References: Kennett (1966, 1973), Chaproniere (1973), Kennett and Vella (1975), Hornibrook (1982), Kennett and Srinivasan (1983), Jenkins (1985), Jenkins and Srinivasan (1986), Cifelli and Scott (1986), Lam and Leckie (2020a)

Observed stratigraphic range: 361-U1474A-24H-4, 56–58 cm, to 17H-5, 107–109 cm

Remarks. *G. conomiozea* is characterized by a thick, planoconvex test, with a highly vaulted umbilical side, strong marginal keel, and high arched aperture. A lot of confusion has prevailed over the differences between *G. miotumida* and *G. conomiozea* because of the subtle variation in the vaulted umbilical side. Kennett (1966) described this species as having a planoconvex test with a flat spiral side and a strongly vaulted umbilical side. This characteristic is also exhibited by *G. miotumida* tests lacking secondary calcification, which can show a strongly pronounced keel and vaulted umbilical side (Lam and Leckie, 2020a). It makes *G. miotumida* gradational with *G. conomiozea*. Lam and Leckie (2020a) attempted to differentiate the two species by projecting a line from either side of the test on the axial view. They have assigned the forms in which the angle made between the lines is less than 90° to *G. conomiozea* suggesting the umbilical side is more highly vaulted than *G. miotumida* in which the angle was equal to or greater than 90°. This approach is quite cumbersome when it comes to working with a large number of samples, using a light microscope, like in the present study. Also, if the *G. miotumida* tests are encrusted with secondary calcite, it would for sure show an angle close to *G. conomiozea*.

In the present study, differentiation between the two species is done taking into account the test thickness and aperture height. The test of *G. conomiozea* is thicker and more vaulted on the umbilical side, resulting in an elongate and relatively lower aperture than *G. miotumida*, which has a less thick test, less vaulted umbilical side, and a higher aperture.

The presence of keel is a distinguishing feature of *G. conomiozea* among the *Globoconella* lineage. There was a distinct loss of keel in the course of evolution of this genus during the evolution from *G. conomiozea* to *G. puncticulata*. The loss of keel in the *Globoconella* lineage is an important morphological change that occurred in the Miocene in response to cooling (Malmgren and Kennett, 1981). The keel, almost universally present in the globorotalid taxa with compressed chambers, is like a crimp in a wall that acts a support to the periphery, and is not present in forms with inflated chambers (Scott et al., 1990). There was a rapid loss of keel in the forms that descended from *G. conomiozea* (Malmgren and Kennett, 1981; Kennett and Srinivasan, 1983; Scott et al., 1990). Walters (1965) erected a new species *Globoconella sphericomiozea* descending from *G. conomiozea*, distinguished by small its small, compact test and rapid loss of keel (Kennett and Srinivasan, 1983). Later, Scott et al. (2007) considered *G. sphericomiozea* as a subspecies of *G. puncticulata*, whereas Lam and Leckie (2020a) synonymized it with *G. puncticulata*.

In the present work, the forms with even a remnant of keel are included in *G. conomiozea*, thereby leading to nonrecognition of *G. sphericomiozea* as a separate species and synonymizing it with *G. puncticulata*. A detailed discussion is presented in the remarks section of *G. puncticulata*.

G. conomiozea is a temperate species (Kennett and Srinivasan, 1983) and prefers thermocline habitat (Aze et al., 2011). It is an important indicator of events of incursion of the cold Southern Ocean water to Hole U1474A in the present study. It showed an average abundance of 1%–3% in the samples spanning Early Pliocene, occasionally exceeding 7% of the total assemblage.

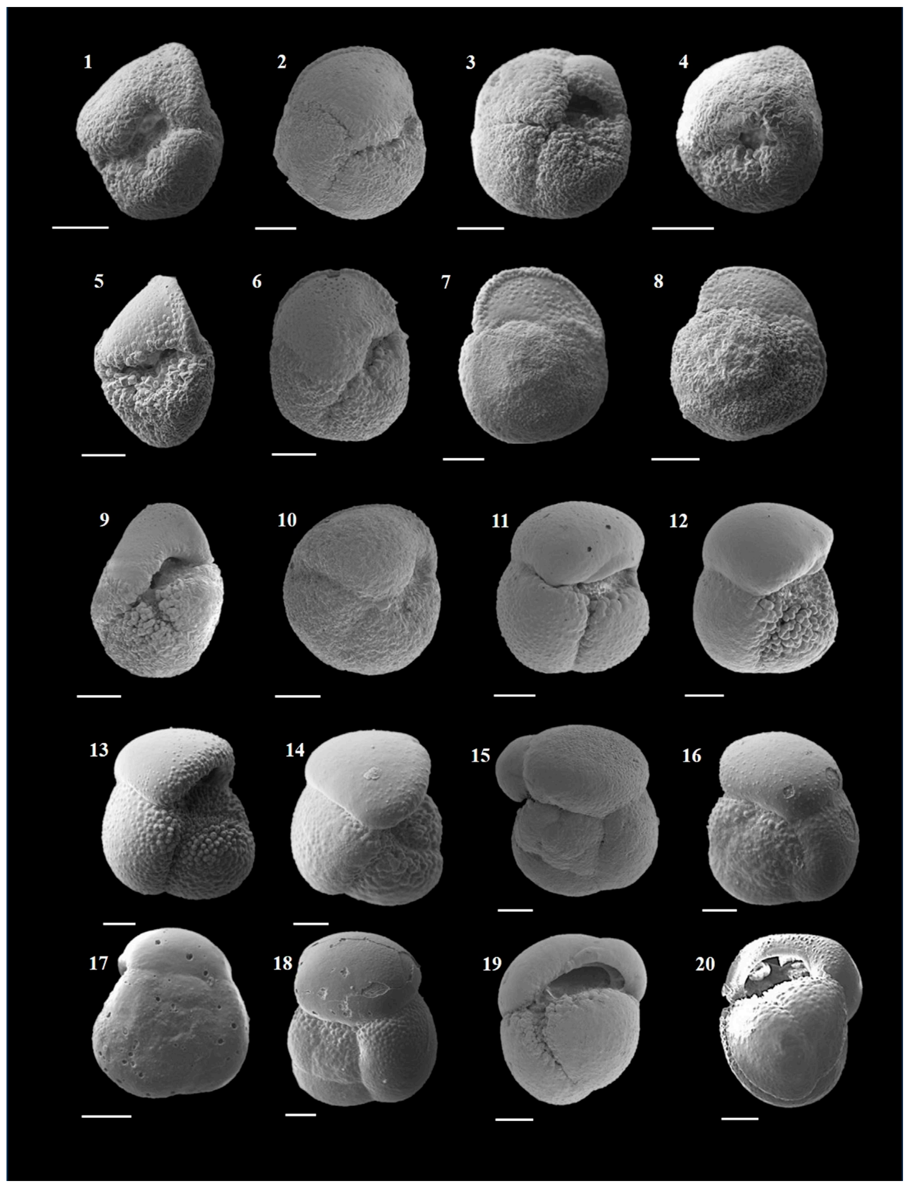

Plate P14. *Globoconella conomiozea* and *Globoconella inflata*, Hole U1474A. 1–10. *Globoconella conomiozea* Kennett (1. 23H-3, 78–80 cm [1. Axial view; 7, 8. Spiral view]; 2, 3, 5, 9. 22H-1, 0–2 cm [2, 3. Umbilical view; 5, 9. Axial view]; 4, 6, 10. 18H-7, 35–37 cm [4. Axial view; 6, 10. Umbilical view]. 11–20. *Globoconella inflata* d'Orbigny (11, 12. 2H-1, 136–138 cm [umbilical view]; 13, 14, 19, 20. 16H-2, 79–81 cm [13, 14. Umbilical view; 19, 20. Axial view]; 15–18. 12H-3, 91–93 cm [spiral view]). Scale bar = 100 µm unless otherwise mentioned.

Globoconella inflata (d'Orbigny 1839)

(Plate **P14**, figures 11–20; Plate **P15**, figures 1–7)

Basionym: *Globigerina inflata*
Synonym: *Globorotalia inflata*
Type species: *Globoconella inflata* d'Orbigny (1839)
References: d'Orbigny (1839), Jenkins (1971), Kennett (1973), Kennett and Vella (1975), Maiya et al. (1976), Keller (1978), Kennett and Srinivasan (1983), Iaccarino (1985), Hornibrook et al. (1989), Scott et al. (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-16H-5, 77–79 cm, to 1H-1, 0–2 cm

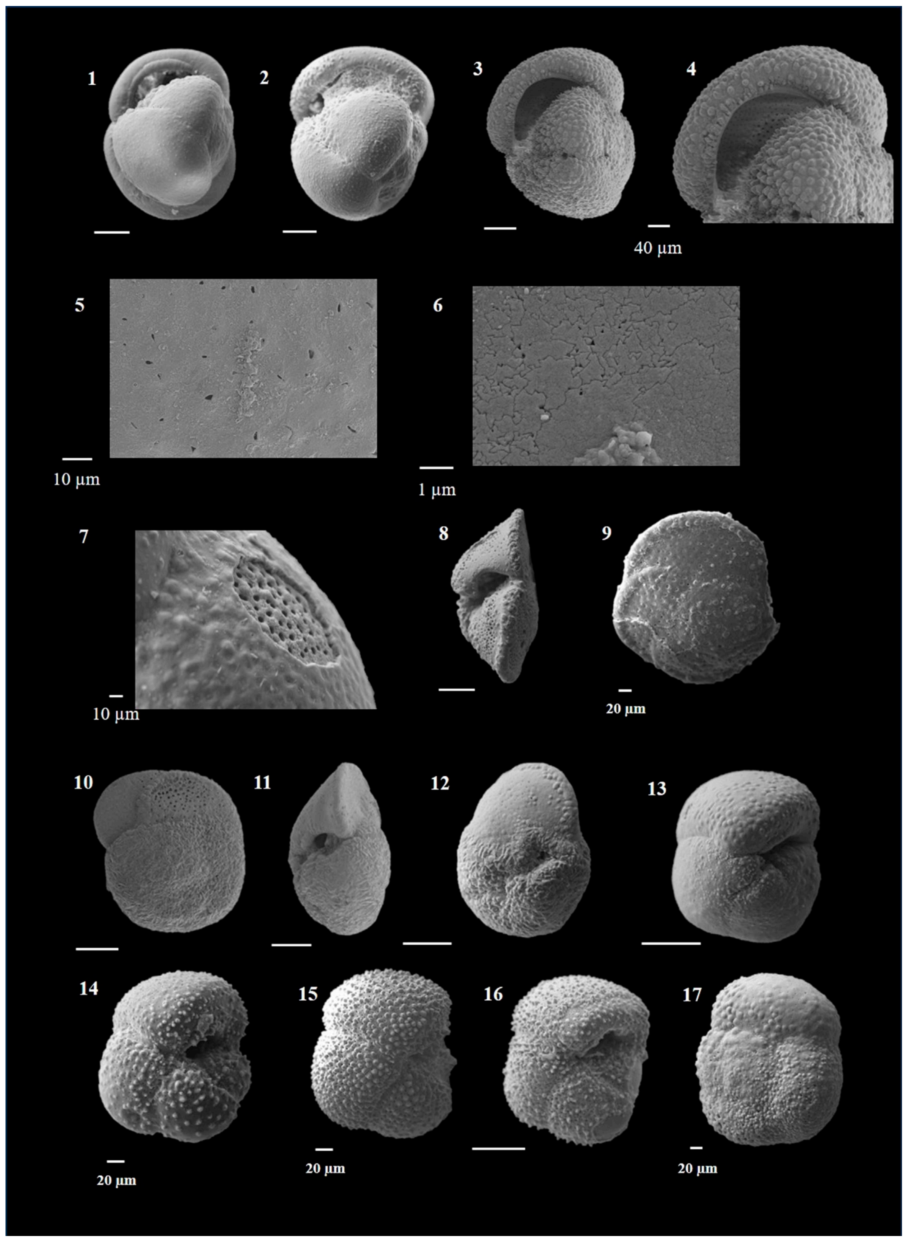

Plate P15. *Globoconella inflata*, *Globoconella miotumida*, and *Globoconella puncticulata*, Hole U1474A. 1–7. *Globoconella inflata* d'Orbigny (1, 2, 5–7. 12H-3, 91–93 cm [1, 2. Axial view; 5, 6. Surface of the cortex; 7. Surface ultrastructure]; 3, 4. 2H-1, 136–138 cm [3. Axial view; 4. Aperture]). 8–12. *Globoconella miotumida* Jenkins (8. 22H-2, 10–12 cm [axial view]; 9–11. 17H-2, 45–47 cm [9, 10. Spiral view; 11. Axial view]; 12. 23H-3, 78–80 cm [umbilical view]). 13–17. *Globoconella puncticulata* Deshayes (13–15. 20H-5, 59–61 cm [umbilical view]; 16. 14H-4, 196.5–198.5 cm [umbilical view]; 17. 1H-1, 64–66 cm [spiral view]). Scale bar = 100 µm unless otherwise mentioned.

Remarks. *G. inflata* is an extant species (Brummer and Kučera, 2022), characterized by its globose test, with three to three and a half inflated chambers in the final whorl, high arch aperture, and a pustulose surface, often covered with a cortex giving it a porcelaneous texture. The cortex is formed of interlocking calcitic plates, sometimes with irregular pores distributed on it. Although Aze et al. (2011) have marked a cancellate surface of the wall, it was not observed in the specimens in the present work. Rather, the wall structure beneath the cortex is porous with ridges in a crisscross manner, giving it a mesh-like appearance (refer to Plate **P15**, figure 7). The highly globose and tight forms sometimes resemble *Pulleniatina obliquiloculata*, from which it is distinguished by having a low trochospiral coiling, unlike the latter, which has streptospiral coiling.

There have been several views about the number of chambers in the final whorl of *G. inflata*. Kennett and Srinivasan (1983) mentioned the presence of three to three and a half chambers, whereas Scott et al. (1990), Schiebel and Hemleben (2017), and Lam and Leckie (2020a) mention the presence of three to four chambers. Kennett and Vella (1975), Malmgren and Kennett (1981), and Kennett and Srinivasan (1983) have categorically mentioned that *G. inflata* evolved from *G. puncticulata* by a reduction in the number of chambers and increase in the degree of inflation of the chambers. This warrants unanimity over the number of chambers in the final whorl of *G. inflata*. In the present work, the name *G. inflata* has been strictly applied to the forms with three to three and a half chambers only. All the forms with more than three and a half chambers were excluded from *G. inflata* and were identified on the basis of other associated morphological characteristics.

A few species were identified over the past several decades: *Neoacarinina blowi* Thompson 1973, *Globigerina nipponica* Asano 1957, and *Globorotalia oscitans* Todd 1957, which were later rejected by Brummer and Kučera (2022) as variants of *G. inflata*. Another species, *Globoconella triangula* Theyer 1973, is a very closely resembling form with *G. inflata*. Kennett and Srinivasan (1983) and Chaisson and Pearson (1997) considered it as a variant of *G. inflata*, whereas Scott et al. (1990) described it as a form normally intergrading with *G. inflata* yet being distinct in some collections. Lam and Leckie (2020a) consider it a separate species on the basis of a distinct triangular outline in the axial view given by highly vaulted umbilical chambers. In the present work, we refrained from distinguishing *G. triangula* from *G. inflata* following Kennett and Srinivasan (1983).

G. inflata prefers subpolar to transitional water mass (Bé, 1977; Hilbrecht, 1996; Sinha et al., 2006; Morard et al., 2011) and has been widely used in tracing the oceanic fronts migration (Peeters et al., 2004; Caley et al., 2014; Morard et al., 2016; Singh et al., 2023; Dwivedi et al., 2024). It has two genetically distinct morphotypes, Type I occurring between the subtropical to subpolar latitudes and Type II occurring mainly southward of subpolar front (Morard et al., 2011, 2013).

G. inflata is a thermocline dweller (Aze et al., 2011) which frequently occurs in the vicinity of hydrologic fronts and eddies (Schiebel and Hemleben, 2017). The increasing abundance of *G. inflata* at lower latitudes may sometimes indicate selective dissolution of solution-prone species (Bé, 1977; Sinha et al., 2006).

This species has shown significant variation in the present study during the Late Pliocene, with the relative abundance reaching up to 5%, although its variability during the Quaternary was extremely important, with abundance often exceeding 15% during the events of the northward migration of the subtropical front.

Globoconella miotumida (Jenkins 1960)

(Plate **P15**, figures 8–12)

Synonym: *Globorotalia miozea conoidea* Walters 1965
Type species: *Globoconella miotumida* Jenkins (1960)
References: Jenkins (1960, 1985), Walters (1965), Kennett and Vella (1975), Keller (1980), Kennett and Srinivasan (1983), Cifelli and Scott (1986), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 16H-5, 77–79 cm

Remarks. *G. miotumida* is characterized by a large test with four and a half to five chambers in the final whorl, with a highly conical umbilical side and a cord like peripheral keel. The surface has a nonspinose, finely perforate wall and a distinctly arch aperture. The earlier chambers show secondary thickening on the periphery and umbilical surface, which makes the periphery on the earlier chambers bluntly rounded and thickened, as compared to the later chambers, which are more sharply angled (Kennett and Srinivasan, 1983).

G. miotumida has undergone taxonomic revision following the discussion by several authors. Kennett and Srinivasan (1983) considered *Globorotalia conoidea* Walters (1965) as a distinct species, and were of the opinion that *Globorotalia miotumida* may represent a thin-walled form of *G. conoidea* and should be given a priority. Cifelli and Scott (1986), Scott et al. (1990), and later Lam and Leckie (2020a) synonymized *Globorotalia conoidea* with *Globoconella miotumida*. In the present work, *G. miotumida* has been given priority over *G. conoidea* following the modern taxonomic concepts. Sometimes the secondary calcification over the test of *G. miotumida* may obscure its keel and increase the test thickness, making it appear like *G. conomiozea*.

It is a thermocline dweller, occurring in the temperate to warm subtropical latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011). In the present study it is a rarely occurring form in the Pliocene samples.

Globoconella puncticulata **(Deshayes 1832)**
(Plate **P15**, figures 13–17; Plate **P16**, figures 1–8)

Basionym: *Globigerina puncticulata*
Synonym: *Globorotalia puncticulata*
Type species: *Globoconella puncticulata* Deshayes (1832)

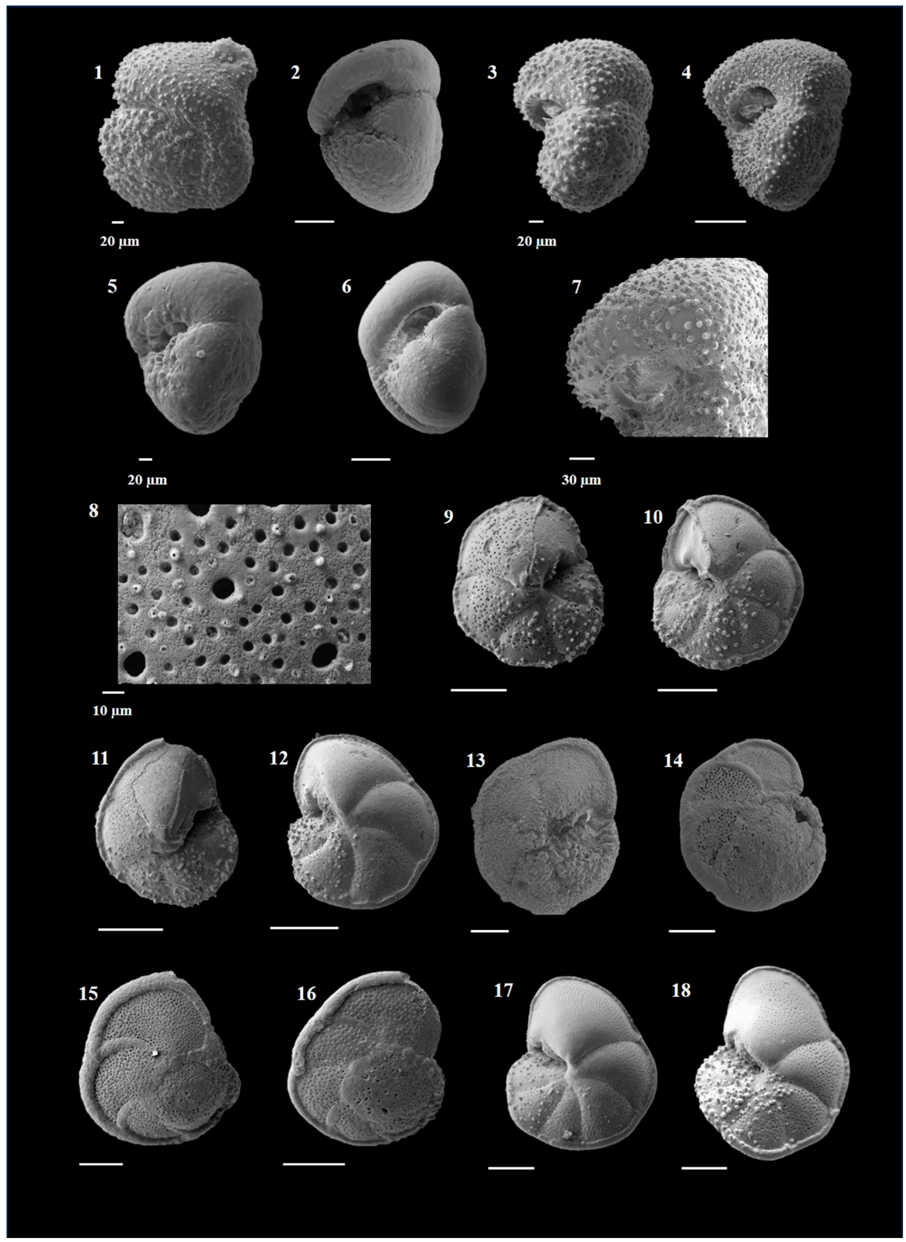

Plate P16. *Globoconella puncticulata*, *Globorotalia merotumida*, and *Globorotalia plesiotumida*, Hole U1474A. 1–8. *Globoconella puncticulata* Deshayes (1, 5, 6. 14H-4, 196.5–198.5 cm [axial view]; 2. 1H-1, 64–66 cm [axial view]; 3, 4, 7, 8. 20H-5, 59–61 cm [3, 4. Axial view; 7. Aperture; 8. Surface ultrastructure]). 9–14. *Globorotalia merotumida* Blow and Banner (9, 10, 14. 21H-5, 17–19 cm [9, 10. Umbilical view; 14. Spiral view]; 11, 13. 16H-3, 57–59 cm [umbilical view]). 15–18. *Globorotalia plesiotumida* Blow and Banner (15, 16. 19H-4, 81–83 cm [spiral view]; 17, 18. 21H-1, 83–85 cm [umbilical view]). Scale bar = 100 µm unless otherwise mentioned.

References: Deshayes (1832), Banner and Blow (1960), Kennett (1973), Hornibrook (1982), Kennett and Srinivasan (1983), Jenkins (1985), Jenkins and Srinivasan (1986), Cifelli and Scott (1986), Scott et al. (1990), Lam and Leckie (2020a)

Observed stratigraphic range: 361-U1474A-21H-3, 71–73 cm, to 1H-1, 0–2 cm

Remarks. *G. puncticulata* can be distinguished by its planoconvex test, with a highly vaulted umbilical side and absence of keel. It has four chambers in the final whorl and a high arch aperture with a rim. The periphery is angular–subangular to subrounded. The surface exhibits a smooth, perforate wall, which is densely pustulose on earlier chambers.

The main distinguishing criteria of *G. puncticulata* from *G. conomiozea* is the absence of keel and height of the aperture, which is lower in the latter. It was also observed that the tests of *G. conomiozea* were more robust than *G. puncticulata*.

The increase in the roundness of the peripheral margin of the test and inflation of the chambers, making them globose, led to the evolution of *Globoconella inflata* from *G. puncticulata*. The main features that separate *G. inflata* from *G. puncticulata* are the rounded margin, three to three and a half (fewer than four) chambers in the final whorl, and the cortex on the test, giving it a smooth texture.

There have been several discussions about the ancestry and lineage of *G. puncticulata* with many species. Barbieri (1967) considered it to be closely related to *Globorotalia crassaformis*, whereas Blow (1969) and later Stainforth et al. (1975) suggested it to have descended from *Globorotalia subscitula*. Berggren (1977) was of the opinion that it descended from *Globorotalia cibaoensis*. Later, Kennett (1973) and Malmgren and Kennett (1981) showed that *G. puncticulata* evolved from *G. conomiozea* via an intermediate form *G. puncticulata sphericomiozea*, later giving rise to *G. inflata* during the Late Pliocene. Jenkins (1985) considered *G. puncticulata* to have descended from *G. sphericomiozea*. Kennett (1973) included *G. puncticulata* in *G. sphericomiozea*, whereas Walters (1965) considered *G. sphericomiozea* to have graded into *G. inflata*, making *G. puncticulata* an intermediate form between these two species. Thus, large confusion over the ancestry of *G. puncticulata* has prevailed over several decades. After analyzing all these literatures and the specimens recovered from Hole U1474A, we are of the opinion that *G. puncticulata* evolved from *G. conomiozea* by developing more rounded peripheral margin, complete loss of keel, and reduction in the vaulting of the umbilical side.

Walters (1965) erected a new species, *G. puncticulata sphericomiozea*, which was an intermediate form between *G. conomiozea* and *G. puncticulata*. It was distinguished by a small test and rapid loss of keel from its ancestor *G. conomiozea* (Kennett and Srinivasan, 1983), although a weak keel on the last chamber in many specimens has also been reported (Scott et al., 1990). Another method of distinction was suggested by Scott (1980) based on population approach in which the appearance of *G. sphericomiozea* would occur if the nonkeeled tests comprised at least 5% of a sample, and *G. puncticulata* occurred if all the tests were nonkeeled. Although this approach was suggested for biostratigraphy (Scott, 1980), it is our opinion that the population-based approach for taxonomic and biostratigraphic studies does not serve the purpose accurately, as the morphological variations are not dependent on the relative abundance.

Lam and Leckie (2020a) synonymized *G. sphericomiozea* with *G. puncticulata* following difficulty in consistent recognition and differentiation of this species due to strong similarities in the test features. The various studies concerning the loss of keel from *G. conomiozea* and its evolution to *G. puncticulata* and *G. inflata* (Kennett, 1966; Kennett and Vella, 1975; Scott, 1979, 1980; Scott et al., 1986, 1990; Kennett and Srinivasan, 1983; Jenkins, 1985) considered it an important event in the course of evolution of this genus, but confusion always loomed whether to include the forms with remnant of keel in *G. conomiozea* or *G. sphericomiozea*. Lam and Leckie (2020a) have reported that the original description of Walters (1965), along with the holotype and paratype images are gradational with *G. puncticulata* and *G. conomiozea*, and a specimen even had visible keel on the last chamber with more vaulted umbilical chambers. These forms, which had even a part of the keel, were included in *G. conomiozea* by Lam and Leckie (2020a). In the present work also, this approach is accepted and followed, leading to classifying all the forms with even partial keel as *G. conomiozea*, whereas only those forms which completely lacked keel were included in *G. puncticulata*. Other than the absence of keel, some factors like overlapping metrics of globoconellid shape measurements between *G. puncticulata* and *G. sphericomiozea* (Malmgren and Kennett, 1981) and the nearly identical signal in the isotopic values in paleoecological study during the Neogene (Schneider and Kennett, 1996), also support synonymizing *G. sphericomiozea* and *G. puncticulata*. This resolves the issue of identification of forms with weak/partial keel.

The taxonomic concept pertaining to *G. puncticulata* s.s. has changed several times over the last few decades. Banner and Blow (1960) comprehensively described this species and assigned a lectotype. Although the definition of this species was accepted by Barbieri (1971), the lectotype was repudiated on the pretext that the lectotype showed fairly high arch aperture, whereas the original description by Deshayes considers it as a small apertura rotunda. This issue of variability in the shape of the aperture from rounded to arched has been dealt with in detail (Stainforth et al., 1975; Jenkins, 1985). The rounded periphery and rounded aperture became the main criteria to classify the forms as *G. puncticulata*, whereas the forms with rounded periphery and umbilical-extraumbilical elongated apertures were included in *Globorotalia crassaformis* by Barbieri (1967), which was later supported by Iaccarino (1967), Barbieri and Petrucci (1967), and Barbieri (1971). Jenkins (1985) included all such forms in *G. puncticulata,* as it showed features consistent with the lectotype description and the variation in the species.

It is a temperate to warm subtropical latitude dweller (Kennett and Srinivasan, 1983) and prefers an open ocean thermocline habitat (Aze et al., 2011).

It is a consistently occurring species in Hole U1474A from Early Pliocene (5.37 Ma) onward, although in lower abundance. It is a surprising observation that this species is constantly found in all the samples of Quaternary to the top of the core.

Genus *Globorotalia* Cushman 1927
Subgenus *Globorotalia* Bandy 1972
Type species *Pulvinulina menardii var. tumida* Brady 1877

***Globorotalia (Globorotalia) merotumida* (Blow and Banner 1965)**
(Plate **P16**, figures 9–14)

Synonym: *Globorotalia merotumida*
Type species: *Globorotalia merotumida* Blow and Banner, 1965
References: Blow and Banner (1965), Keller (1980), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 15H-2, 79–81 cm

Remarks. *G. merotumida* is characterized by a small biconvex test, with more inflated umbilical side. It has five to six wedge-shaped chambers in the final whorl and a distinct marginal keel. The surface is densely perforate with a smooth wall and limbate sutures. The distinctive feature of *G. merotumida* is the last chamber of the final whorl, which is as tall as wide (Bolli and Saunders, 1985).

G. merotumida is an open ocean thermocline dweller (Aze et al., 2011) that extends from tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). It is an important biostratigraphic marker in the Late Neogene. In Hole U1474A, it is regularly present in the samples spanning Early to Middle Pliocene but show very low abundance.

***Globorotalia (Globorotalia) plesiotumida* (Blow and Banner 1965)**
(Plate **P16**, figures 15–18; Plate **P17**, figures 1–2)

Synonym: *Globorotalia plesiotumida*
Type species: *Globorotalia plesiotumida* Blow and Banner, 1965
References: Blow and Banner (1965), Postuma (1971), Kennett and Srinivasan (1983), Cifelli and Scott (1986), King et al. (2020), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 15H-2, 79–81 cm

Remarks. *G. plesiotumida* differs from *G. merotumida* by its relatively larger test, an elongate equatorial outline, and the width and height of the last chamber, which is taller than wide in this case. Other features are quite similar to *G. merotumida*.

G. plesiotumida is an open ocean thermocline dweller (Aze et al., 2011) that extends from tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). It descended from *G. merotumida* and acts as an important biostratigraphic marker in the Late Neogene. The evolutionary appearance of *G. plesiotumida* is used to mark the base of the Zone N17, and its evolution to *G. tumida tumida* approximates Zone N17–N18 (Kennett and Srinivasan, 1983).

In Hole U1474A, it is regularly present in the samples spanning Early to Middle Pliocene but shows very low abundance.

***Globorotalia (Globorotalia) tumida* (Brady 1877)**
(Plate **P17**, figures 3–11)

Basionym: *Pulvinulina menardii var. tumida*
Synonym: *Globorotalia tumida tumida*
Type species: *Globorotalia tumida* Brady, 1877
References: Brady (1877), Blow (1969), Kennett (1973), Keller (1980), Saito et al. (1981), Hornibrook (1982), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Scott et al. (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-23H-5, 40–42 cm, to 1H-1, 0–2 cm

Remarks. *G. tumida* has a large, robust biconvex test with a tumid base. The marginal keel is very heavy and cord-like. The surface is densely perforate with pores of uniform size and smooth. The degree of convexity of the test and the thickness of the tumid base shows variation with latitudes, with the tropical forms being tumider than their subtropical counterparts (Chaisson and Leckie, 1993; Lam and Leckie, 2020a).

Often this species has been confused and lumped with *G. menardii* based on the census counts of the Quaternary assemblages (Brummer and Kučera, 2022). Lam and Leckie (2020a) found that in the Kuroshio Current Extension region, *G. tumida* showed morphologically similar features to *G. menardii*. In the present work, the tests of *G. tumida* were distinct from *G. menardii*. Another species, *G. tumida flexuosa* Koch, which was identified as a distinct species by Kennett and Srinivasan (1983) and Bolli and Saunders (1985), has been considered an aberrant form of *G. tumida* by Brummer and Kučera (2022). The robust and thick test makes *G. tumida* highly resistant to dissolution, which results in its higher abundance in sediments than the water column (Schiebel and Hemleben, 2017).

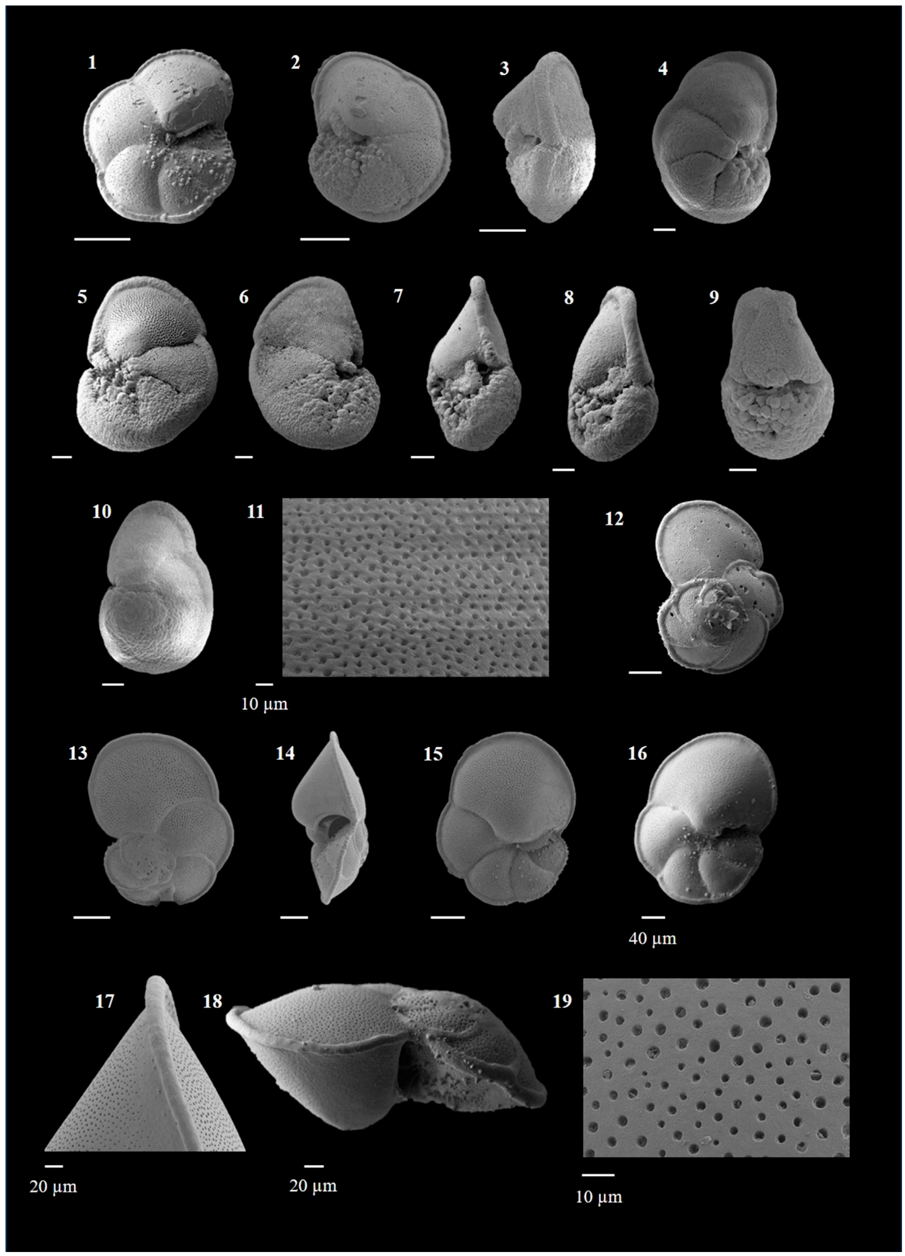

Plate P17. *Globorotalia plesiotumida*, *Globorotalia tumida*, and *Globorotalia ungulata*, Hole U1474A. 1, 2. *Globorotalia plesiotumida* Blow and Banner (19H-4, 81–83 cm [umbilical view]). 3–11. *Globorotalia tumida* Brady (3, 4, 6, 11. 13H-3, 67–69 cm [3. Axial view; 4–6. Umbilical view; 11. Surface ultrastructure]; 7–10. 7H-4, 45–47 cm [7–9. Axial view; 10. Spiral view]). 12–19. *Globorotalia ungulata* Bermúdez (12–14, 17, 19. 1H-1, 96–98 cm [12, 13. Spiral view; 14. Axial view; 17. Cord-like keel; 19. Surface ultrastructure]; 15, 16, 18. 2H-6, 106–108 cm [15, 16. Umbilical view; 18. Side view]). Scale bar = 100 µm unless otherwise mentioned.

G. tumida is an open ocean thermocline dweller (Aze et al., 2011) and occurs in preferably tropical, warm subtropical latitudes (Kennett and Srinivasan, 1983). Berggren (1973) and Fleisher (1974) considered the evolutionary appearance of *G. tumida* at the base of Zone N18 as an important marker for Miocene/Pliocene boundary.

Globorotalia (Globorotalia) ungulata (Bermúdez 1961)
(Plate **P17**, figures 12–19)

Synonym: *Globorotalia ungulata*
Type species: *Globorotalia ungulata* Bermúdez, 1961
References: Bermúdez (1961), Kennett and Srinivasan (1983), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-14H-5, 109–11 cm, to 1H-1, 0–2 cm

Remarks. *G. ungulata* is considered to resemble *G. tumida* due to its tumid and elongate test (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Lam and Leckie, 2020a) but has a delicate test with thin keel (Bolli and Saunders, 1985). It showed a preference for the sinistral coiling. Lamb and Beard (1972) considered *G. ungulata* as a shallow-water, thin-walled growth form of *G. tumida*. Morard et al. (2015) confirmed the phylogenetic relationship of *G. ungulata* with *G. tumida* on the basis of molecular genetic data.

Shackleton and Vincent (1978) considered *G. ungulata* as a mixed-layer dweller, whereas Aze et al. (2011) assigned it open ocean thermocline habitat. It prefers tropical to subtropical latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011; Schiebel and Hemleben, 2017) but has a very sporadic appearance.

It showed sporadic and very low abundance in Hole U1474A in samples spanning Late Pliocene to recent.

Subgenus _Hirsutella_ Bandy 1972
Type Species _Rotalina hirsuta_ d'Orbigny 1839

Globorotalia (Hirsutella) bermudezi (Rögl and Bolli 1973)
(Plate **P18**, figures 1–5)

Synonym: *Globorotalia bermudezi*
Type species: *Globorotalia bermudezi* Rögl and Bolli, 1973
References: Rögl and Bolli (1973), Kennett and Srinivasan (1983), Loeblich and Tappan (1994), Aze et al. (2011)
Observed stratigraphic range: 361-U1474A-9H-4, 77–79 cm, to 1H-1, 0–2 cm

Remarks. *G. bermudezi* has been considered a junior synonym of *G. scitula* by many authors (Saito et al., 1981; Schiebel and Hemleben, 2017; Lam and Leckie, 2020a), although Kennett and Srinivasan (1983) and Aze et al. (2011) considered it as a distinct species. Brummer and Kučera (2022) consider *G. bermudezi* as the small extant forms of *G. scitula* with open umbilicus.

G. bermudezi is characterized by a very small, lobulate test, consisting of five to six chambers in the final whorl. The axial periphery is subangular, with umbilical side more convex than spiral side. The surface is smooth and irregularly perforated, a character that distinguishes *G. bermudezi* from *G. scitula* (Kennett and Srinivasan, 1983).

G. bermudezi is a thermocline dweller that ranges from tropical to temperate latitudes.

In the present work, it occurs in extremely low abundance and shows intermittent appearance in the samples restricted to the Quaternary Period.

Globorotalia (Hirsutella) eastropacia (Boltovskoy 1974)
(Plate **P18**, figures 6–11)

Basionym: *Globorotalia hirsuta eastropacia*
Synonym: *Globorotalia eastropacia*, *Globorotalia theyeri* (Fleisher 1974)
Type species: *Globorotalia eastropacia* Boltovskoy, 1974
References: Boltovskoy (1974), Fleisher (1974), Saito et al. (1981), Kennett and Srinivasan (1983), Vincent and Toumarkine (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-20H-1, 19–21 cm, to 1H-1, 0–2 cm

Remarks. *G. eastropacia* was earlier synonymized with *G. theyeri*. Kennett and Srinivasan (1983) considered *G. eastropacia* as a junior synonym of *G. theyeri*, but Brummer and Kučera (2022) showed that *G. eastropacia* has priority over *G. theyeri* and should be used as the correct name. *G. eastropacia* is characterized by large, thin test with a sharp outline and differs from *G. margaritae* in having a flat spiral side. There are four to five flaring chambers in the final whorl. The wall is smooth and finely perforate. There is a thin discontinuous keel on the periphery. The marginal keel and flaring chambers distinguish it from *G. scitula*.

G. eastropacia is a subthermocline dweller (Aze et al., 2011; Schiebel and Hemleben, 2017) and prefers low latitudes (Kennett and Srinivasan, 1983). It occurs rarely in Hole U1474A and only in extremely low abundance.

Globorotalia (Hirsutella) hirsuta (d'Orbigny 1839)
(Plate **P18**, figures 12–19)

Basionym: *Rotalina hirsuta*
Synonym: *Globorotalia hirsuta*, *Globoquadrina patriciae* McCulloch 1977
Type species: *Globorotalia hirsuta* d'Orbigny, 1839

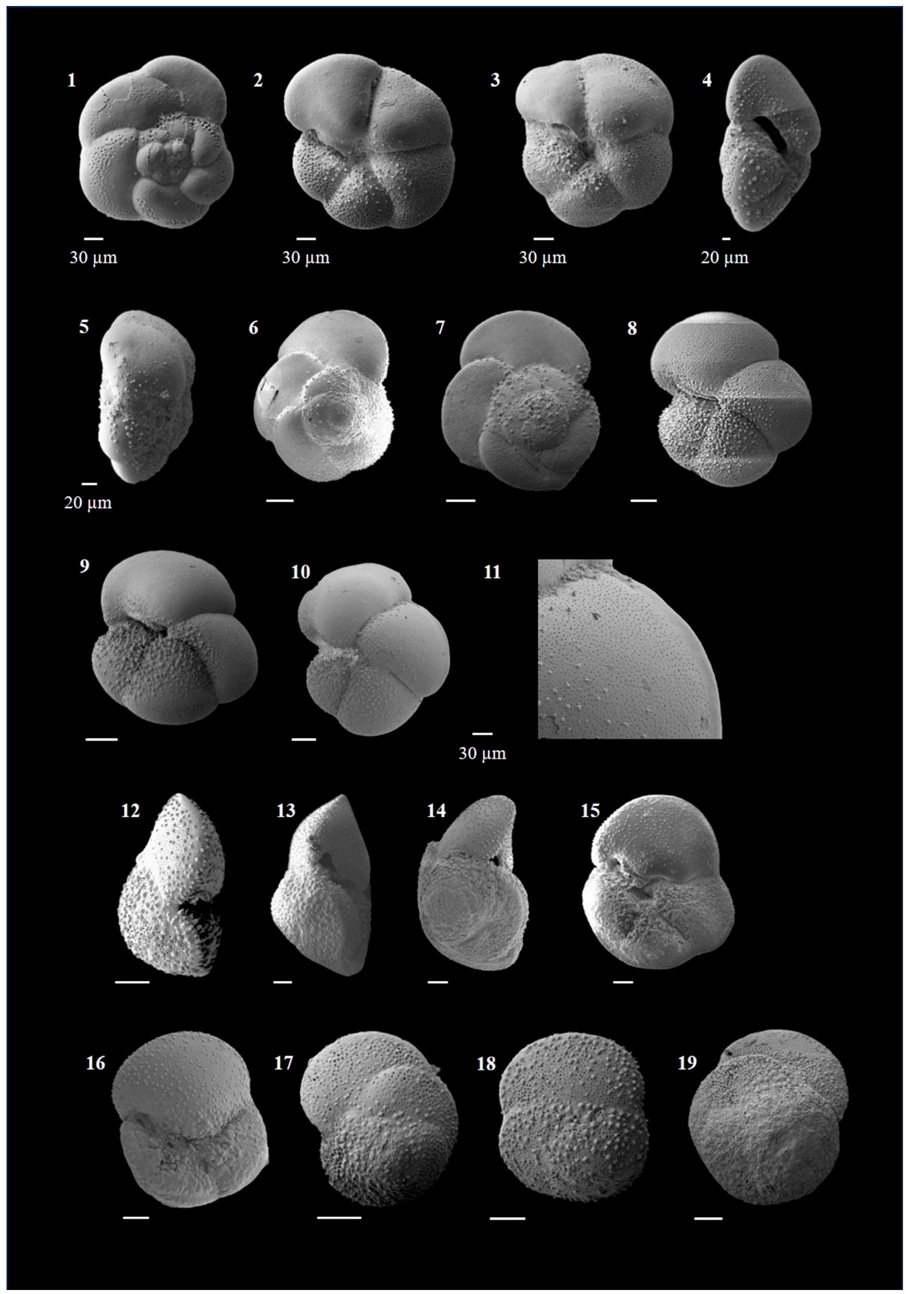

Plate P18. *Globorotalia (H.) bermudezi*, *Globorotalia (H.) eastropacia*, and *Globorotalia (H.) hirsuta*, Hole U1474A. 1–5. *Globorotalia (H.) bermudezi* Rögl and Bolli (6H-3, 131–133 cm [1. Spiral view; 2, 3. Umbilical view; 4, 5. Axial view]). 6–11. *Globorotalia (H.) eastropacia* Fleisher (6, 7. 15H-5, 13–15 cm [spiral view]; 8–11. 6H-2, 89–91 cm [8–10. Umbilical view; 11. Peripheral keel]). 12–19. *Globorotalia (H.) hirsuta* d'Orbigny (12–14, 17–19. 1H-1, 96–98 cm [12–14. Axial view; 17–19. Spiral view]; 15, 16. 2H-6, 42–44 cm [umbilical view]). Scale bar = 100 µm unless otherwise mentioned.

References: d'Orbigny (1839), Banner and Blow (1960), Bolli and Bermúdez (1965), Kennett (1973), Hornibrook (1982), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Scott et al. (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-2H-3, 52–54 cm, to 1H-1, 0–2 cm

Remarks. *G. hirsuta* is characterized by a large test with an extremely convex and tumid spiral side and a concave umbilical side, giving it a spiroconical outline. It differs from *G. margaritae* in having a robust test with four crescent-shaped chambers in the final whorl and a pustulose surface. The wall is smooth and finely perforate (Aze et al., 2011).

Scott et al. (1990) mentioned that the spiroconical form tends to develop better in *G. margaritae* than *G. hirsuta* because of the extremely concave umbilical side in the latter.

G. hirsuta prefers thermocline habitat (Aze et al., 2011) and ranges from tropical to temperate latitudes (Kennett and Srinivasa, 1983; Schiebel and Hemleben, 2017). Kennett and Srinivasan (1983) assigned its first appearance age as Late Pliocene, whereas Wade et al. (2011) and Lam and Leckie (2020b) gave its a first appearance age in the Late Pleistocene. It is an extant species that is found often in plankton (Schiebel and Hemleben, 2017). In Hole U1474A, it is a commonly occurring species in the Late Quaternary samples, and is an important biostratigraphic marker.

Globorotalia (Hirsutella) margaritae (Bolli and Bermúdez 1965)
(Plate **P19**, figures 1–14)

Basionym: *Globorotalia margaritae*
Type species: *Globorotalia margaritae* Bolli and Bermúdez, 1965
References: Bolli and Bermúdez (1965), Kennett (1973), Hornibrook (1982), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Scott et al. (1990), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-21H-7, 5–7 cm, to 15H-4, 35–37 cm

Remarks. *G. margaritae* is an important Early Pliocene index fossil (Srinivasan and Kennett, 1981a). It is characterized by its spiroconical test (Scott et al., 1990), which has a convex spiral side and concave umbilical side. The test is delicate with five compressed chambers in the final whorl, and has a thin marginal keel. The surface is densely perforate and smooth, with pustules on the earlier chambers. Aperture is low slit, with a pronounced lip. The wall is nonspinose and smooth (Aze et al., 2011) and is sometimes covered with secondary calcite, which obscures the surface texture (Lam and Leckie, 2020a). Lam and Leckie (2020a) observed that the width of the last chamber is almost equal to the length of the shell, a feature that was also observed in several specimens in this work.

Three subspecies of *G. margaritae* have been identified: *G. margaritae primitiva*, *G. margaritae margaritae*, and *G. margaritae evoluta* (Cita, 1973; Bolli and Saunders, 1985). They have very subtle differences in their morphology, which makes it difficult to assign the morphotypes to these subspecies. In the present work, this scheme was not followed and all such forms were included in *G. margaritae*. It differs from *G. scitula* in having concavo-convex test with marginal keel.

G. margaritae is a thermocline dweller (Aze et al., 2011) that occurs from tropical to temperate latitudes (Kennett and Srinivasan, 1983). It occurs in quite low abundance in Hole U1474A.

Globorotalia (Hirsutella) scitula (Brady 1882)
(Plate **P19**, figures 15–22; Plate **P20**, figures 1–3)

Basionym: *Pulvinulina scitula*
Synonym: *Globorotalia scitula*
Type species: *Globorotalia scitula* Brady, 1882
References: Brady (1882), Fleisher (1974), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Hornibrook et al. (1989), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. scitula* is characterized by a medium-sized test with four to five crescentic chambers in the final whorl. The outline is lobulate and subcircular and completely lacks keel. The wall is porous and smooth, bearing pustules in the earlier chambers. The umbilical side is more porous than the spiral side (Schiebel and Hemleben, 2017). The slit-like aperture is umbilical-extraumbilical and bears a pronounced lip. *G. scitula* shows a preference for the dextral coiling.

It closely resembles *Globorotalia (Hirsutella) bermudezi*. Saito et al. (1981) have considered *G. bermudezi* as the junior synonym of *G. scitula*. Lam and Leckie (2020a) have included the concept of *G. bermudezi* in *G. scitula*, although they haven't synonymized the two species. On the other hand, Kennett and Srinivasan (1983) have considered *G. bermudezi* as a distinct species on the basis of its smaller size and more number of chambers.

G. scitula is a cosmopolitan species, more abundant in the mid latitudes (Schiebel and Hemleben, 2017) that prefers open ocean thermocline habitat (Aze et al., 2011). *G. scitula* occurs in extremely low abundance in Hole U1474A.

Subgenus *Menardella* Bandy 1972
Type Species *Pulvinukina menardii* Parker, Jones and Brady, 1865

***Globorotalia (Menardella) limbata* (Fornasini 1902)**
(Plate **P20**, figures 4–7)

Basionym: *Rotalia limbata*
Synonym: *Globorotalia limbata*
Type species: *Rotalia limbata* Fornasini, 1902

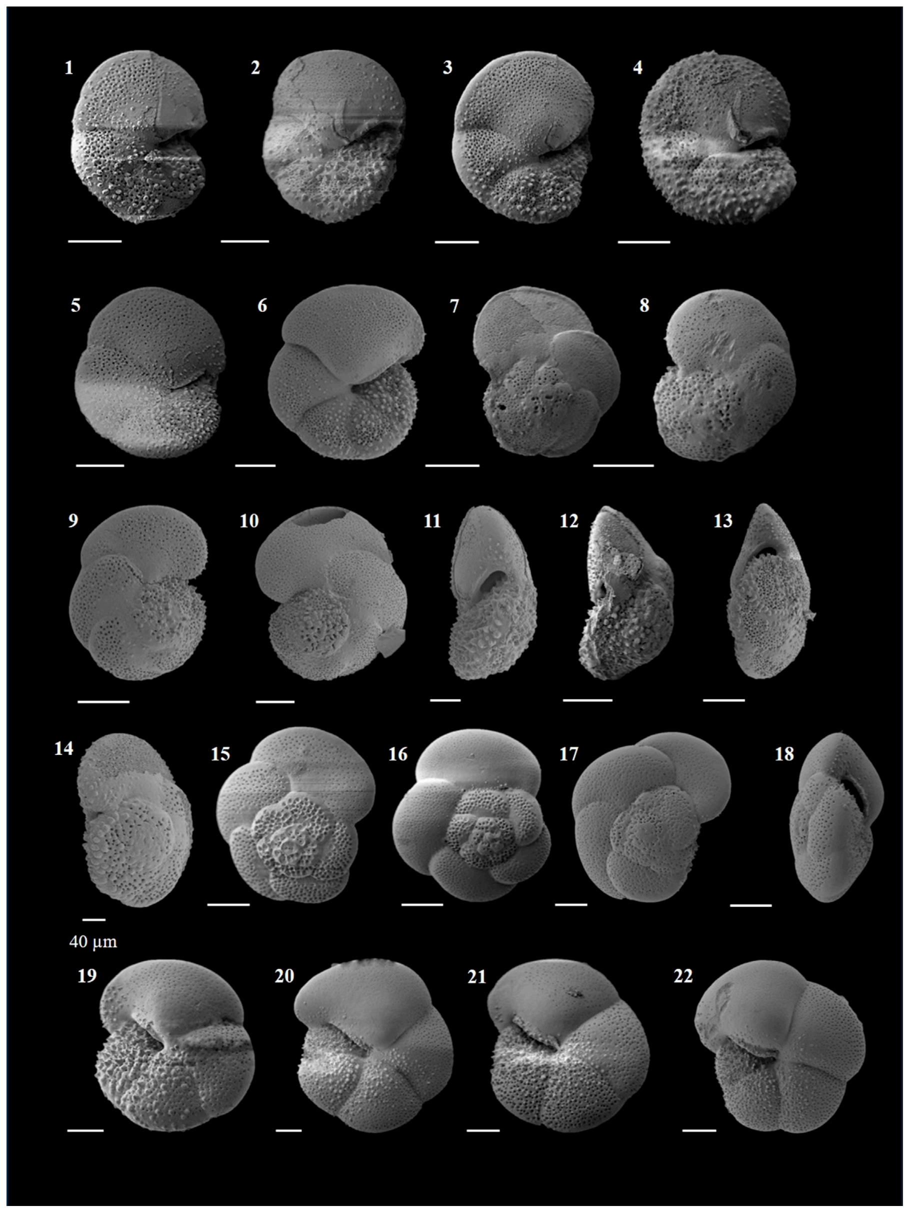

Plate P19. *Globorotalia (H.) margaritae* and *Globorotalia (H.) scitula*, Hole U1474A. 1–14. *Globorotalia (H.) margaritae* Bolli and Bermúdez (1–3. 20H-2, 29–31 cm [umbilical view]; 4–10. 19H-1, 115–117 cm [4–6. Umbilical view; 7–10. Spiral view]; 11–14. 17H-5, 13–15 cm [axial view]). 15–22. *Globorotalia (H.) scitula* Brady (15–17, 21, 22. 3H-3, 54–56 cm [15–17. Spiral view; 21, 22. Umbilical view]; 18–20. 7H-1, 15–17 cm [18. Axial view; 19, 20. Umbilical view]). Scale bar = 100 µm unless otherwise mentioned.

References: Fornasini (1902), Kennett and Srinivasan (1983), Norris (1998), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 9H-1, 79–81 cm

Remarks. *G. limbata* differs from *G. menardii* by having at least seven chambers in the final whorl, a less pronounced keel, and a lenticular outline in the axial view. The limbate spiral sutures are straight for most of their length, curving just before merging into the peripheral keel, giving a hockey stick shape (Blow, 1969). The sutures are thickened toward the periphery. The surface is smooth and densely perforate. *G. limbata* is a low-latitude dweller (Kennett and Srinivasan, 1983) and prefers open ocean thermocline (Aze et al., 2011). It is extremely low in abundance and shows irregular appearance in Hole U1474A.

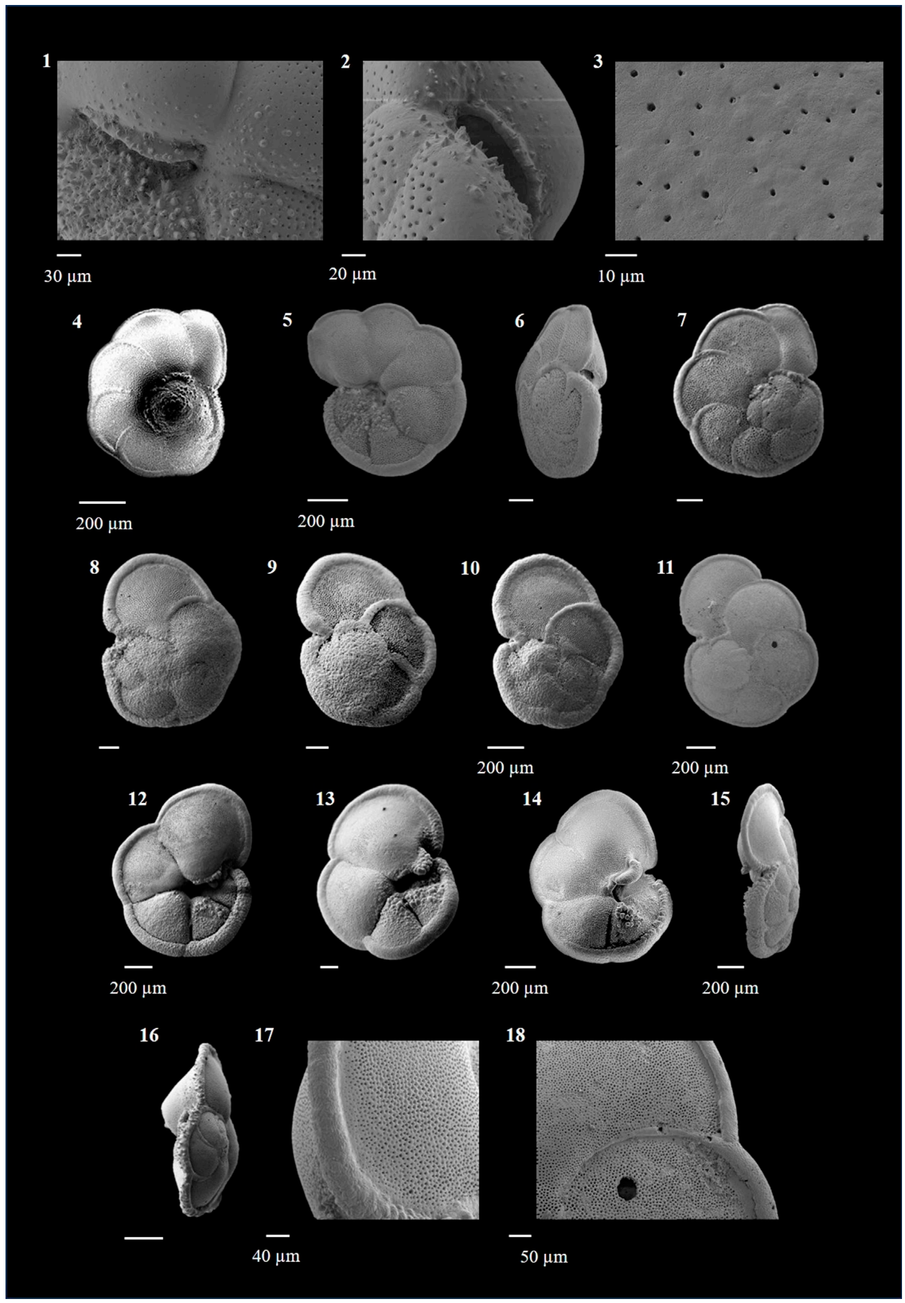

Plate P20. *Globorotalia (H.) scitula*, *Globorotalia (M.) limbata*, and *Globorotalia (M.) menardii*, Hole U1474A. 1–3. *Globorotalia (H.) scitula* Brady (3H-3, 54–56 cm [1, 2. Aperture; 3. Surface ultrastructure]). 4, 5. *Globorotalia (M.) limbata* Fornasini (18H-7, 3–5 cm [4. Spiral view; 5. Umbilical view; 6. Axial view]. 7–18. *Globorotalia (M.) menardii* Parker, Jones and Brady (7–11, 16, 18. 1H-CC, 3–5 cm [7–11. Spiral view; 16. Axial view; 18. Wall texture]; 12–15, 17. 10H-2, 77–79 cm [12–14. Umbilical view; 15. Axial view; 17. Keel]). Scale bar = 100 µm unless otherwise mentioned.

Globorotalia (Menardella) menardii **(Parker, Jones and Brady 1865)**

(Plate **P20**, figures 7–18)

Basionym: *Rotalia menardii*
Type species: *Globorotalia menardii* Parker, Jones and Brady (1865)
References: Parker, Jones and Brady (1865), Kennett (1973), Hornibrook (1982), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Scott et al. (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

Remarks. *G. menardii* is an extant species characterized by a low trochospiral, compressed test, with a circular outline and a prominent peripheral keel. It has five to six chambers in the final whorl, with strongly curved, limbate sutures on the spiral side merging into the keel. The wall is nonspinose and smooth and is densely perforate.

There is a lot of variation in the degree of convexity of the test, which has led to a lot of confusion in the identification. The test outline of *G. menardii* in the axial view ranges from flat, as seen in *G. cultrata* (e.g., Bolli and Saunders, 1985; Knappertbusch, 2007; Brummer and Kučera, 2022), to biconvex, as seen in *G. menardii* (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Brummer and Kučera, 2022).

Another feature that adds to this confusion is the spiral sutures which are limbate. Kennett and Srinivasan (1983) mention that *G. menardii* has five to six wedge-shaped chambers with strongly curved raised spiral sutures. Brummer and Kučera (2022) have reported limbate sutures in *G. menardii* that are more thickened toward periphery, whereas those in *G. cultrata* show uniform thickness. Kennett and Srinivasan (1983) described *Globorotalia limbata*, which has six to eight chambers in the final whorl and limbate spiral sutures that are thickened where they merge into the keel. This is a cause for concern because if a six-chambered test of *G. menardii* and *G. limbata* are compared, there will be striking similarity between the two as per the description of Kennett and Srinivasan (1983) and Brummer and Kučera (2022). To avoid this confusion in the present work, *G. menardii* has been used for the tests with not more than six chambers and limbate spiral sutures which have a uniform thickness.

Past authors have reported a number of morphotypes of *G. menardii*. The Miocene to Early Pliocene forms were named *G. menardii* A, having five to six chambers in the final whorl, and *G. menardii* B, which had seven to seven and a half chambers in the final whorl (Bolli, 1970). Bolli and Saunders (1985) have illustrated two forms ranging from Pleistocene to Holocene: *G. menardii menardii* showing a robust, thick-walled test with more circular equatorial outline and *G. menardii cultrata* with a more delicate, thin test with more elongate equatorial outline. Another morphotype with peripheral spines was identified by Brady (1884) as *G. menardii fimbriata*. Both *G. menardii cultrata* and *G. menardii fimbriata* were often used as distinct species.

There has been a huge debate over the usage of the name *G. menardii* and *G. cultrata* that has been discussed at length by Banner and Blow (1960), Parker (1962), Stainforth et al. (1975), Knappertbusch (2007, 2016, 2022), and Brummer and Kučera (2022). Stainforth et al. (1975) recommended that the name *G. menardii* be retained for Miocene and younger menardiform species. This view was supported by Kennett and Srinivasan (1983). Knappertbusch (2007) identified four morphotypes of *G. menardii*, namely *alpha*, *beta*, *gamma*, and *delta*, of which the *alpha* morphotype was identified as *G. menardii menardii*, and the *beta* morphotype was considered *G. menardii cultrata*. A recent review by Brummer and Kučera (2022) argues for using *G. menardii* strictly for the forms that have gone extinct during Late Miocene and advocates usage of *G. cultrata* for the extant forms. These morphotypes have also been encountered in the present work but are very low in abundance. We agree with Kennett and Srinivasan (1983) for the use of the name *G. menardii* for all such forms.

G. menardii is a cosmopolitan species most frequent in tropical to subtropical waters (Kennett and Srinivasan, 1983; Schiebel and Hemleben, 2017). It prefers open ocean thermocline (Aze et al., 2011). *G. menardii* is a major component of surface and Pleistocene sediments due to its large size and occasionally thick calcite crust (Schiebel and Hemleben, 2017).

In the present study, *G. menardii* occurs in fairly high abundance during the Pliocene occasionally reaching >10% of the total assemblage.

Globorotalia (Menardella) miocenica **(Palmer 1945)**

(Plate **P21**, figures 1–3)

Basionym: *Globorotalia menardii* var. *miocenica*
Synonym: *Globorotalia miocenica*
Type species: *Globorotalia miocenica* Palmer, 1945
References: Palmer (1945), Kennett and Srinivasan (1983), Norris (1998)
Observed stratigraphic range: 361-U1474A-17H-4, 65–67 cm, to 11H-1, 41–43 cm (?)

Remarks. *G. miocenica* is characterized by a menardiform test with a flat spiral side and strongly convex umbilical side, giving it a planoconvex appearance in the axial view. It has six to seven chambers in the final whorl, with limbate spiral sutures.

It is a thermocline dweller (Aze et al., 2011) and preferred low latitudes (Kennett and Srinivasan, 1983; Aze et al., 2011).

G. miocenica is extremely rare in the present work.

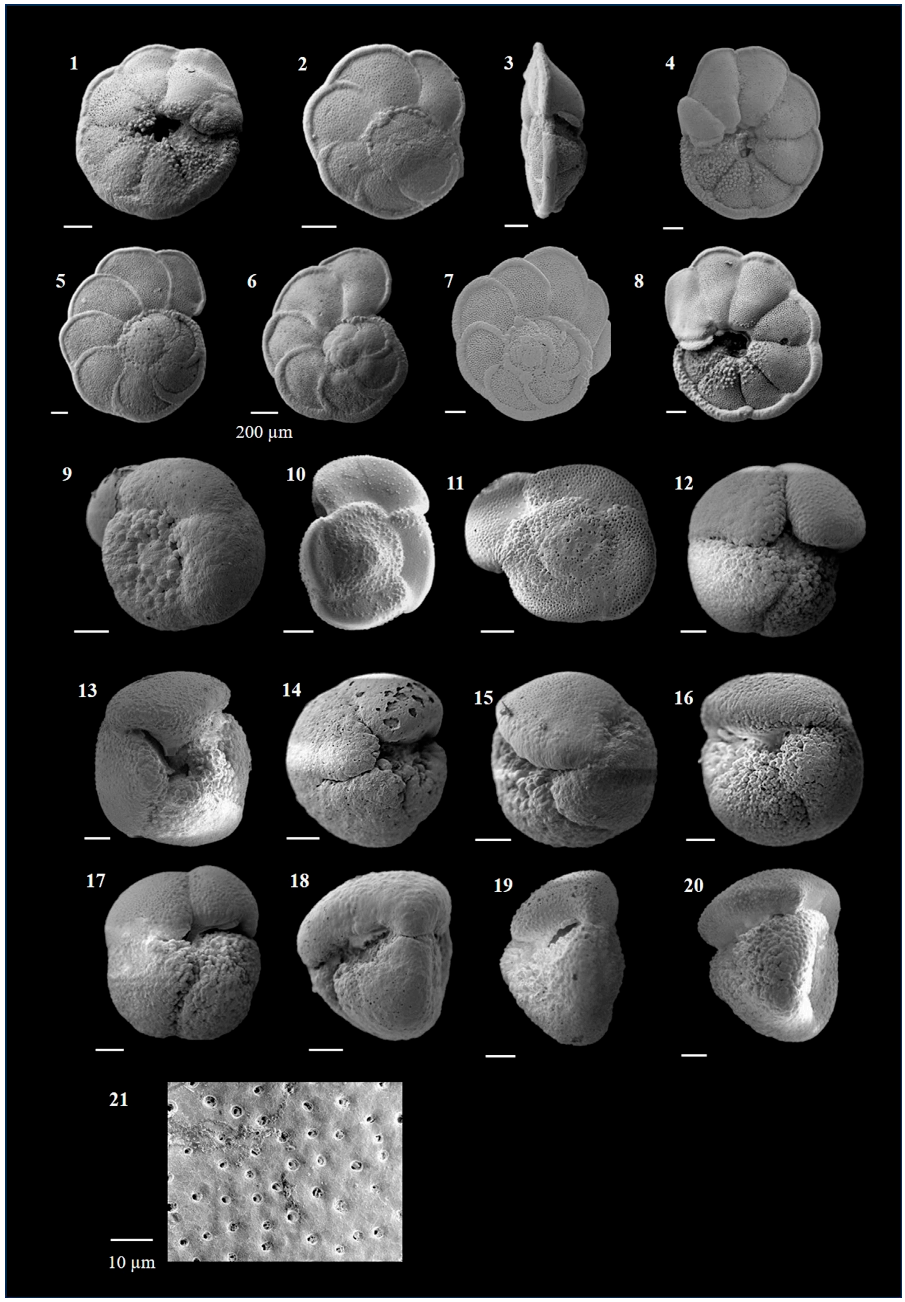

Plate P21. *Globorotalia (M.) miocenica*, *Globorotalia (M.) multicamerata*, *Globorotalia (T.) crassaformis*, Hole U1474A. 1–3. *Globorotalia (M.) miocenica* Palmer (15H-6, 23–25 cm [1. Umbilical view; 2. Spiral view; 3. Axial view]). 4–8. *Globorotalia (M.) multicamerata* Cushman and Jarvis (4–7. 14H-2, 139–141 cm [4. Umbilical view; 5–7. Spiral view]; 8. 13H-1, 141–143 cm [umbilical view]). 9–21. *Globorotalia (T.) crassaformis* Galloway and Wissler (9–11, 15, 16, 21. 13H-6, 1–3 cm [9–11. Spiral view; 15, 16. Umbilical view; 21. Surface ultrastructure]; 12–14. 4H-4, 8–10 cm [umbilical view]; 18–20. 3H-1, 2–4 cm [axial view]). Scale bar = 100 µm unless otherwise mentioned.

Globorotalia (Menardella) multicamerata (Cushman and Jarvis 1930)
(Plate **P21**, figures 4–8)

Basionym: *Globorotalia menardii* var. *multicamerata*
Synonym: *Globorotalia multicamerata*
Type species: *Globorotalia multicamerata* Cushman and Jarvis, 1930
References: Cushman and Jarvis (1930), Postuma (1971), Kennett and Srinivasan (1983), Norris (1998), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 9H-6, 129–131 cm

Remarks. *G. multicamerata* has a large test with a circular outline, with eight to ten chambers, limbate spiral sutures, and smooth surface. It very closely resembles *G. limbata* but for number of chambers in the final whorl (eight to ten versus seven to eight). Sometimes the intergradation between these two species is so subtle that it becomes difficult to differentiate between them. An important characteristic is the umbilicus in form of a distinct circular pit (Kennett and Srinivasan, 1983).

This open ocean thermocline dweller (Aze et al., 2011) is found in tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983).

G. multicamerata is not a frequently occurring species and has been found in extremely low abundance in Hole U1474A.

Subgenus *Truncorotalia* Cushman and Bermúdez 1949
Type Species *Rotalia truncatulinoides* d'Orbigny, 1839

Globorotalia (Truncorotalia) crassaformis (Galloway and Wissler 1927)
(Plate **P21**, figures 9–21)

Basionym: *Globigerina crassaformis*
Synonym: *Globorotalia crassaformis*
Type species: *Globorotalia crassaformis* Galloway and Wissler, 1927
References: Galloway and Wissler (1927), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Scott et al. (1990), Bylinskaya (2005), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-20H-1, 19–21 cm, to 1H-1, 0–2 cm

Remarks. *G. crassaformis* very closely resembles *G. puncticulata*, but for its low, slit-like aperture, which in the latter case is high arched. It is characterized by a robust test with a subquadrate to subrounded equatorial profile and a lack of keel. The test has a flat to slightly convex spiral side, and the umbilical side is strongly convex, giving a planoconvex axial outline. It has four to four and a half chambers in the final whorl, sometimes five chambers in the variant *G. crassaformis hessi*. The wall is smooth, finely perforate, and heavily pustulose on both sides.

G. crassaformis is morphologically quite diverse and several names have been given for the different morphotypes (Saito et al., 1981). It was regarded as end form of evolutionary development by some authors, whereas certain others considered it as initial species from which other morphologically distinguishable taxa had developed (Bolli and Saunders, 1985). Several morphotypes of *G. crassaformis* have been identified: *Globorotalia crassaformis oceanica* Cushman and Bermúdez (1949), *Globorotalia crotonensis* Conato and Follador (1967), *Globorotalia crassacrotonensis* Conato and Follador (1967), *Globorotalia crassaformis ronda* Blow (1969), *Globorotalia crassaformis viola* Blow (1969), *Globorotalia crassaformis hessi* Bolli and Premoli Silva (1973), *Globorotalia crassaconica* Hornibrook (1981), *Globorotalia crassaformis imbricata* Krasheninnikov et al. (2002). Most of the authors have considered these as variants of *G. crassaformis* (Kennett and Srinivasan, 1983; Lam and Leckie, 2020a; Brummer and Kučera, 2022). Parker (1962) has considered *G. crassaformis* as the senior synonym of *G. crassula*. The common morphological feature in all the morphotypes/variants is the quadrate arrangement of the quasi-scituline shaped chambers (Cifelli and Glacon, 1979), suggesting a close phylogenetic relationship among them (Kennett and Srinivasan, 1983).

G. crassaformis extends from warm subtropical to temperate latitudes (Kennett and Srinivasan, 1983) and prefers open ocean subthermocline habitat (Aze et al., 2011; Brummer and Kučera, 2022). In Hole U1474A, *G. crassaformis* has occurred consistently from Pliocene to recent, although the abundance was not very high.

Globorotalia (Truncorotalia) tosaensis (Takayanagi and Saito 1962)
(Plate **P22**, figures 1–9)

Synonym: *Globorotalia tosaensis*
Type species: *Globorotalia tosaensis* Takayanagi and Saito, 1962

References: Takayanagi and Saito (1962), Kennett (1973), Keller (1978), Hornibrook (1982), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Scott et al. (1990), Lam and Leckie (2020a)

Observed stratigraphic range: 361-U1474A-13H-7, 29–31 cm, to 3H-7, 30–32 cm

Remarks. *G. tosaensis* is an important biostratigraphic marker for the Pleistocene. It can be distinguished by the test with a circular outline, five chambers in the final whorl, and lack of keel. The umbilical side is extremely convex, giving it a planoconvex outline in the axial view. The wall is smooth and surface is perforate, sometimes with a crust that obscures the surface. It can be differentiated from *G. crassaformis* by circular outline and five chambers in the final whorl.

Blow (1969) considered the forms with and without crust as members of separate lineages, following which Rögl (1976) recognized four taxa branching from the crust-free *G. tosaensis*. These forms, however, were considered variants among the intergrading morphotypes (Berggren et al., 1967; Phillips et al., 1968; Hornibrook, 1976).

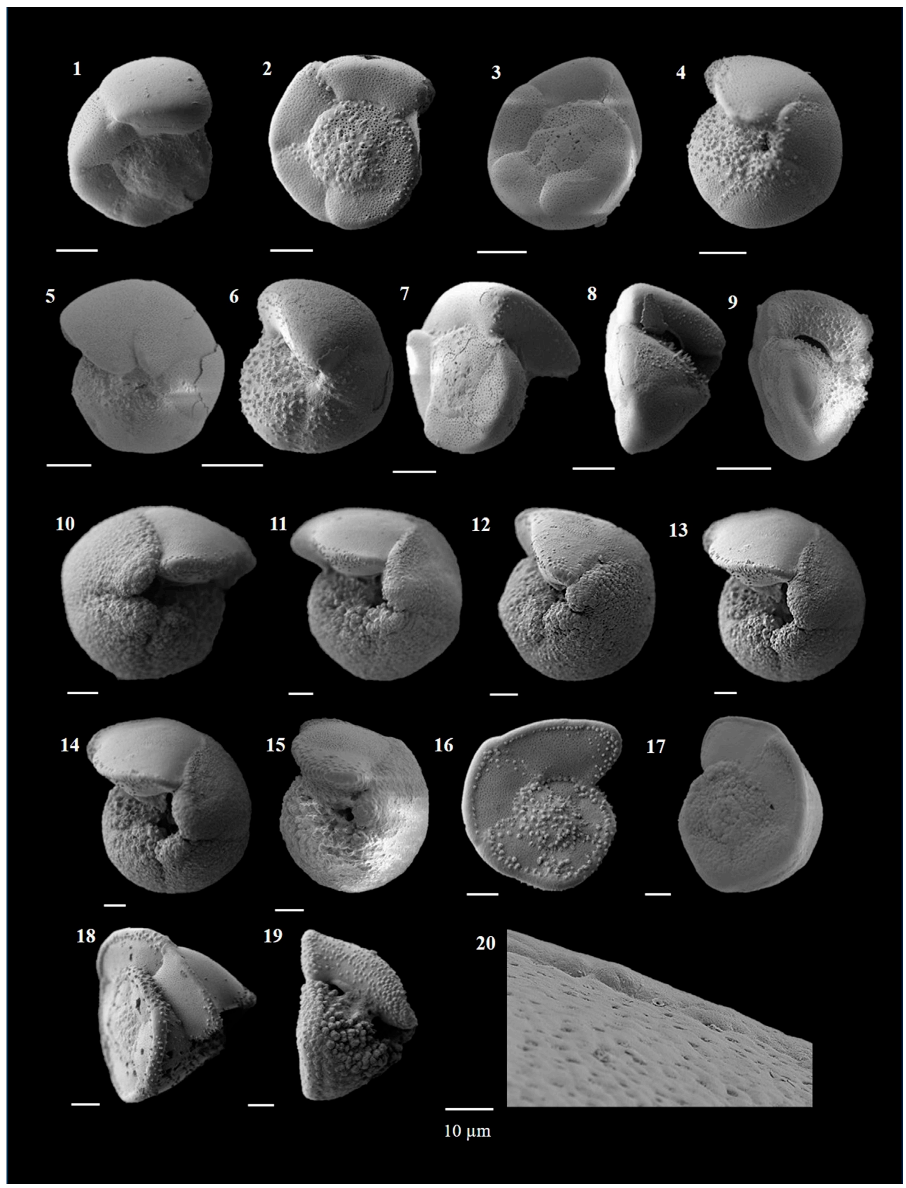

Plate P22. *Globorotalia (T.) tosaensis* and *Globorotalia (T.) truncatulinoides*, Hole U1474A. 1–9. *Globorotalia (T.) tosaensis* Takayanagi and Saito (1–3. 4H-2, 20–22 cm [spiral view]; 4, 5, 7. 6H-2, 121–123 cm [4, 5. Umbilical view; 7. Axial view]; 6, 8, 9. 11H-2, 51–53 cm [6. Umbilical view; 8, 9. Axial view]). 10–20. *Globorotalia (T.) truncatulinoides* d'Orbigny (10, 11. 7H-2, 25–27 cm [umbilical view]; 12–15, 18, 19. 5H-6, 126–128 cm [12–15. Umbilical view; 18, 19. Axial view]; 16, 17, 20. 1H-1, 0–2 cm [16, 17. Spiral view; 20. Peripheral keel]). Scale bar = 100 µm unless otherwise mentioned.

G. tosaensis is an open ocean subthermocline dweller (Aze et al., 2011), ranging from tropical to subtropical latitudes. In Hole U1474A, this species has a low abundance in the samples spanning Late Pliocene.

***Globorotalia (Truncorotalia) truncatulinoides* (d'Orbigny 1839)**
(Plate **P22**, figures 10–20)

Basionym: *Rotalia truncatulinoides*
Synonym: *Globorotalia truncatulinoides*
Type species: *Globorotalia truncatulinoides* d'Orbigny, 1839
References: d'Orbigny (1839), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Cifelli and Scott (1986), Scott et al. (1990), Schiebel and Hemleben (2017), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-10H-1, 67–69 cm, to 1H-1, 0–2 cm

Remarks. *G. truncatulinoides* evolved from *G. tosaensis* by developing a marginal keel and more wide open umbilicus (Kennett and Srinivasan, 1983). The morphological features are very similar to *G. tosaensis* except for the presence of a marginal keel. The surface is encrusted with secondary calcite, obscuring the ultrastructure.

G. truncatulinoides is distinguished from *G. tosaensis* by the presence of a pronounced peripheral keel. In the present study, a few forms were encountered that had circular equatorial profile with five chambers, but the keel was present only on the final chamber. Such forms have been identified as *G. tosaensis-truncatulinoides* plexus forms (Kennett and Geitzenauer, 1969), but for the paleoceanographic reconstructions, such forms were counted as *G. truncatulinoides*. Some other forms like *G. truncatulinoides pachytheca* Blow (1969) and *G. excelsa* Sprovieri and Ruggieri (1980) were considered variants of *G. truncatulinoides* by Kennett and Srinivasan (1983) and Brummer and Kučera (2022), whereas Aze et al. (2011) considered them as separate species. Another species, *G. cavernula* Bé (1967), was considered a cryptic species of *G. truncatulinoides* by (Quillévéré et al., 2013), whereas Kennett and Srinivasan (1983) retained it as a distinct species.

G. truncatulinoides is considered to be an open ocean subthermocline dweller by Aze et al. (2011), whereas Schiebel and Hemleben (2005) suggest that of all extant species it lives in the deepest habitat. It extends from tropical to subtropical latitudes (Kennett and Srinivasan, 1983).

In Hole U1474A, *G. truncatulinoides* occurred in significant abundance and is an important proxy to track the migration of the Subtropical Front north and south during Quaternary in the Agulhas Current and Agulhas leakage region (Peeters et al., 2004).

Genus *Neogloboquadrina* Bandy, Frerichs and Vincent, 1967
Type Species *Globigerina dutertrei* d'Orbigny, 1839

***Neogloboquadrina acostaensis* (Blow 1971)**
(Plate **P23**, figures 1–11)

Basionym: *Globorotalia acostaensis*
Synonym: *Globorotalia (Turborotalia) acostaensis tegillata* Brönnimann and Resig, 1971
Type species: *Neogloboquadrina acostaensis* Blow, 1959
References: Blow (1959), Postuma (1971), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 7H-2, 57–59 cm

Remarks. *N. acostaensis* has a small test, with five to five and a half chambers in the final whorl, and straight spiral and umbilical sutures. The wall is nonspinose and shows cancellate structure Aze et al., 2011; Lam and Leckie, 2020a), although Kennett and Srinivasan (1983) called it a reticulate. The last chamber has a characteristic lip extending up to the umbilicus.

Another subspecies *Globorotalia acostaensis trochoidea* was erected by Bizon and Bizon (1965) for forms with a slightly more convex spiral side but was later included in *N. acostaensis* for stratigraphic purposes (Bolli and Saunders, 1985).

N. acostaensis is an open ocean thermocline dweller (Aze et al., 2011), extending from tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983).

In Hole U1474A, it was found as commonly occurring species during the Pliocene, where it showed fairly high abundance, becoming rare during the Early Quaternary.

***Neogloboquadrina humerosa* (Takayanagi and Saito 1962)**
(Plate **P23**, figures 12–14)

Basionym: *Globorotalia humerosa*
Synonym: *Neogloboquadrina humerosa*
Type species: *Neogloboquadrina humerosa* Takayanagi and Saito, 1962

References: Takayanagi and Saito (1962), Keller (1978), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 6H-3, 131–133 cm

Remarks. *N. humerosa* has morphological features, largely those of *N. acostaensis*, except for the larger test with six chambers and reduced/no apertural lip (Bolli and Saunders, 1985). It has a low arch, interiomarginal aperture that lacks umbilical tooth, which separates it from *N. dutertrei*.

N. humerosa is an open ocean thermocline dweller (Aze et al., 2011) that thrives in tropical–subtropical latitudes (Kennett and Srinivasan, 1983).

In Hole U1474A, it occurs irregularly and has low abundance.

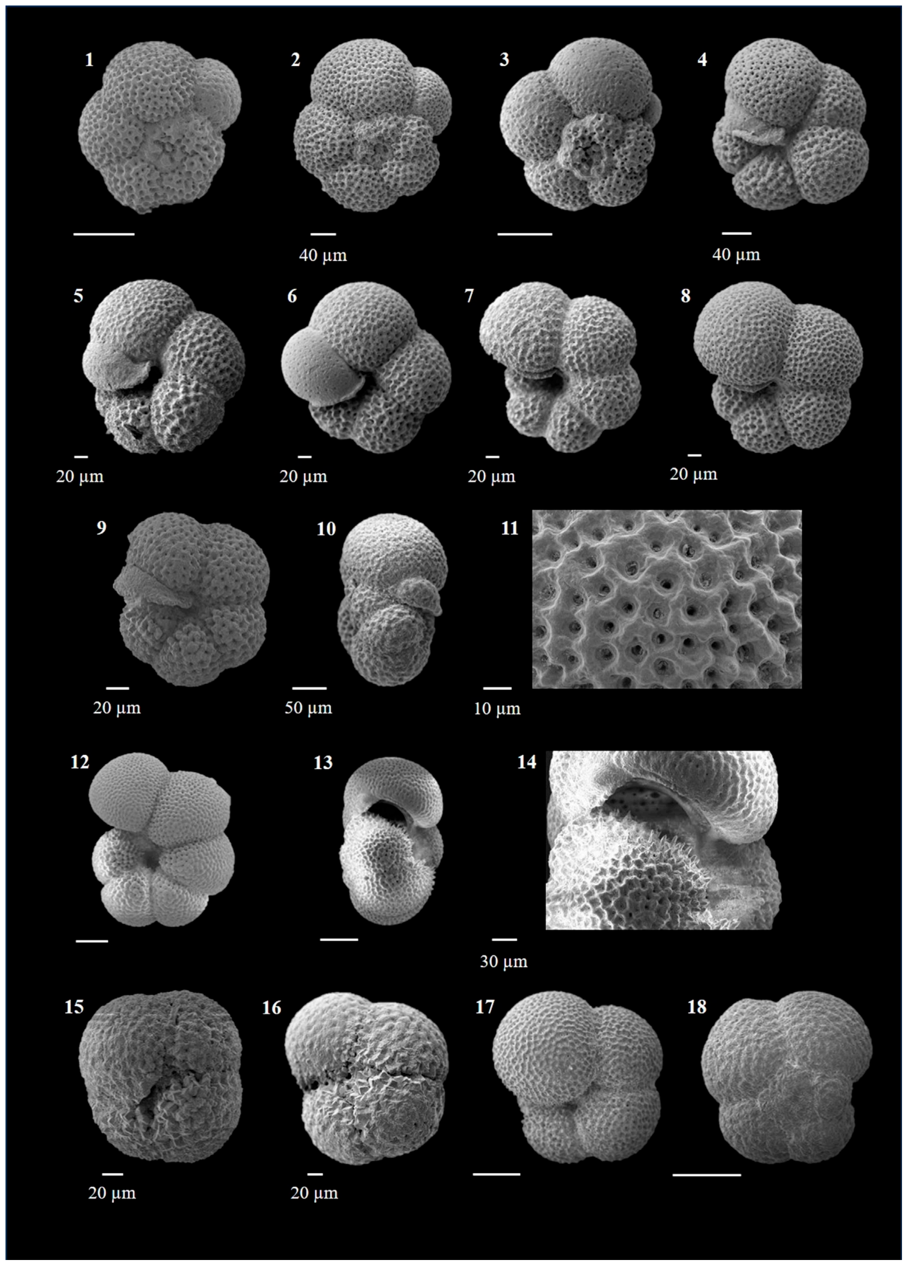

Plate P23. *Neogloboquadrina acostaensis*, *Neogloboquadrina humerosa*, and *Neogloboquadrina incompta*, Hole U1474A. 1–11. *Neogloboquadrina acostaensis* Blow (1, 2, 5. 21H-6, 59–61 cm [1, 2. Spiral view; 5. Umbilical view]; 3, 6–8, 10. 18H-1, 39–41 cm [3. Spiral view; 6–8. Umbilical view; 10. Axial view]; 9, 11. 14H-4, 129–131 cm [9. Umbilical view; 11. Surface ultrastructure]). 12–14. *Neogloboquadrina humerosa* Takayangi and Saito (15H-2, 15–17 cm [12. Umbilical view; 13. Axial view; 14. Aperture]). 15–18. *Neogloboquadrina incompta* Cifelli (15, 16. 7H-2, 89–91 cm [umbilical view]; 17, 18. 1H-1, 32–34 cm [17. Umbilical view; 18. Spiral view]). Scale bar = 100 µm unless otherwise mentioned.

Neogloboquadrina incompta (Cifelli 1961)
(Plate **P23**, figures 15–18; Plate **P24**, figures 1–3)

Basionym: *Globigerina incompta*
Synonym: *Neogloboquadrina pachyderma* (dextral)
Type species: *Neogloboquadrina incompta* Cifelli, 1961
References: Cifelli (1961), Kennett (1973), Kennett and Vella (1975), Keller (1978), Kennett and Srinivasan (1983), Darling et al. (2006), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 1H-1, 0–2 cm

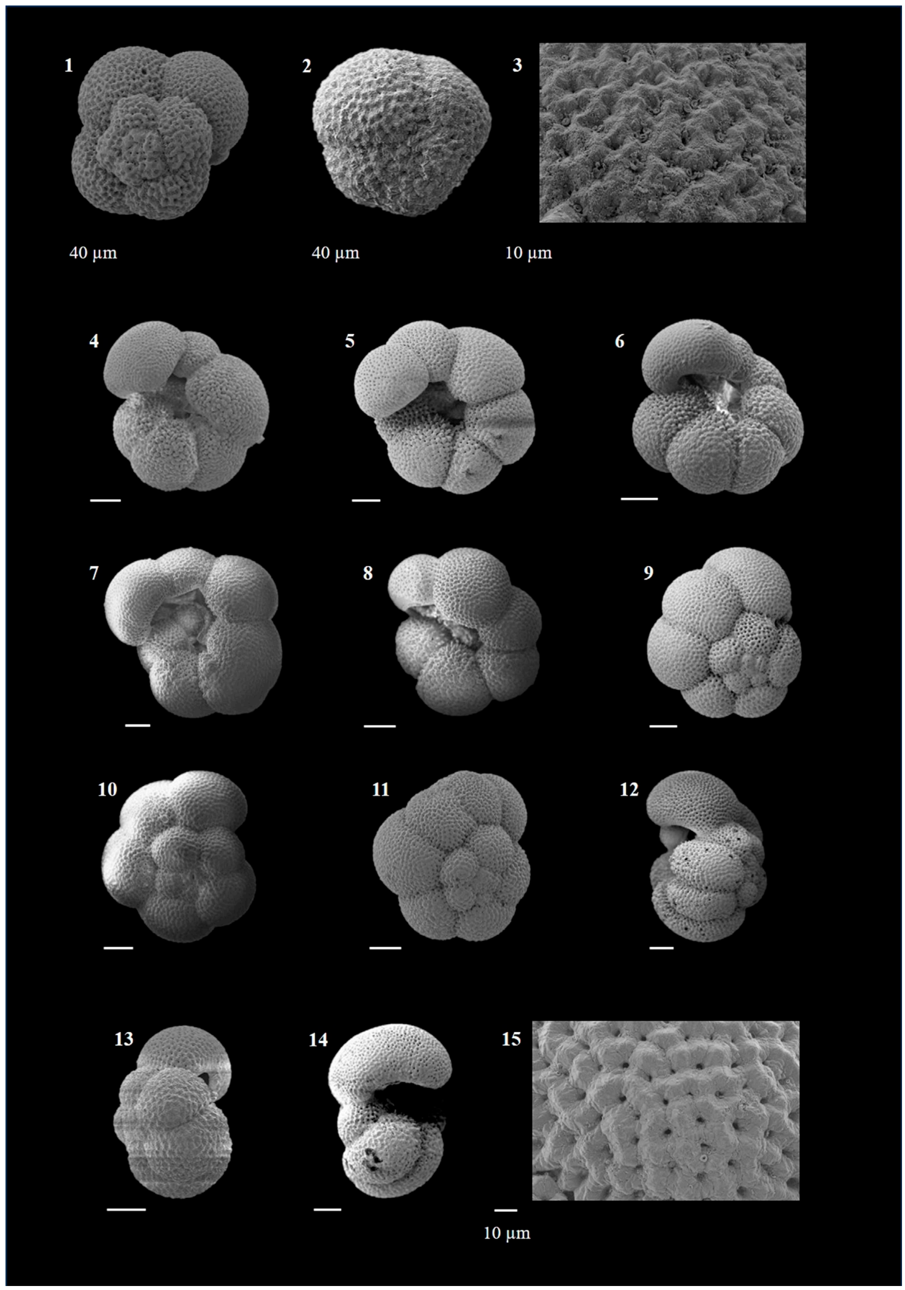

Plate P24. *Neogloboquadrina incompta* and *Neogloboquadrina dutertrei*, Hole U1474A. 1–3. *Neogloboquadrina incompta* Cifelli (7H-2, 89–91 cm [1, 2. Spiral view; 3. Surface ultrastructure]). 4–15. *Neogloboquadrina dutertrei* d'Orbigny (4–6, 9, 10, 13, 14. 10H-4, 97–99 cm [4–6. Umbilical view; 9, 10. Spiral view; 13, 14. Axial view]; 7, 8, 12. 3H-5, 10–12 cm [7, 8. Umbilical view; 12. Axial view]; 11, 15. 1H-1, 0–2 cm [11. Spiral view; 15. Surface ultrastructure]). Scale bar = 100 µm unless otherwise mentioned.

Remarks. *N. incompta* is characterized by a test with quadrate outline, four to five chambers in the final whorl, and dextral coiling. It has a very similar morphology to *N. pachyderma*, but the two species are distinct on the basis of genetic data (Darling et al., 2006). *N. pachyderma* and *N. incompta* are of morphological similarity, except coiling; *N. incompta* is typically dextral, and *N. pachyderma* is characterized by sinistral coiling.

N. incompta was synonymized with *N. pachyderma* by Parker (1962), whereas another species was identified as *N. pachyderma dextralis* by Setty (1977), later lumped with *N. incompta*. Kipp (1976) used the name *N. pachyderma-dutertrei* intergrade (P/D intergrade), which was also included in the *N. incompta* (Brummer and Kučera, 2022).

Darling et al. (2006) showed that the coiling direction is a genetic trait, and not a morphological feature reflecting ecophenotypic variation. The two opposite coiling morphotypes appear to have diverged during the late Miocene, and they have distinctly different ecologies (Darling et al., 2006). The molecular genetic data, fossil evidence, biogeography, and ecology together call for separating the two coiling types of *N. pachyderma* as distinct species (Darling et al., 2000, 2006; André et al., 2014). Since then, *N. incompta* has been in popular use for naming the dextrally coiled form of the erstwhile *N. pachyderma* (dextral).

N. incompta is a thermocline dweller that thrives in cold water. In Hole U1474A it is an important indicator of the northward migration of the Subtropical Front. It shows very low abundance except the episodes of cooling when its often exceeds 5%–10% of the total faunal population.

***Neogloboquadrina dutertrei* (d'Orbigny 1839)**
(Plate **P24**, figures 4–15)

Basionym: *Globigerina dutertrei*

Synonyms: *Neogloboquadrina dutertrei*, *Neogloboquadrina eggeri* Rhumbler (1901), *Neogloboquadrina subcretacea* Lomnicki (1901), *Neogloboquadrina blowi* Rögl and Bolli (1973), *Neogloboquadrina himiensis* Maiya et al. (1976), *Neogloboquadrina kagaensis* Maiya et al. (1976), *Globigerina eggeriformis* McCulloch (1977)

Type species: *Neogloboquadrina dutertrei* d'Orbigny, 1839

References: d'Orbigny (1839), Parker (1962), Kennett (1973), Keller (1980), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Schiebel and Hemleben (2017), Lam and Leckie (2020a), Brummer and Kučera (2022)

Observed stratigraphic range: 361-U1474A-21H-2, 123–125 cm, to 1H-1, 0–2 cm

Remarks. *N. dutertrei* is characterized by globose test with five to six chambers, slightly convex spiral side, and deep umbilicus with umbilical tooth. It is an important extant species that is used in paleoceanographic and paleoclimatic studies. It differs from *N. acostaensis* by its larger test and curved, radial sutures, and *N. humerosa* by its aperture and presence of umbilical teeth. The wall is nonspinose and cancellate (Aze et al., 2011).

Several attempts have been made to correlate variation in the morphological features of *N. dutertrei* and water-mass conditions. The high-spired forms were regarded as warm-water variants, and low-spired forms were considered to prefer cold water (Bradshaw, 1959; Bolli, 1970). Bandy et al. (1967) differentiated *N. dutertrei* in two subspecies on the basis of the umbilical tooth-like plates: (1) forms with umbilical plates, called as *N. dutertrei dutertrei*, and (2) forms without umbilical plates, termed as *N. dutertrei subcretacea*. Srinivasan and Kennett (1976) identified two kinds of surface ultramicrostructures restricted to different latitudinal ranges and identified two groups: *N. dutertrei* Group A, with relatively thin-walled test, high pore concentration, and pitted wall surface with microcrystals, and *N. dutertrei* Group B, with the characteristic rosette pattern formed by concentric arrangement of euhedral crystals on each chamber, characteristic of cool subtropical areas. Kipp (1976) classified forms with four to four and a half chambers in the final whorl and surface ultrastructure resembling that of *N. dutertrei* as *N. pachy-duter* (P-D intergrade). P-D intergrade was defined by Kipp (1976) as an informal group of *pachyderma-dutertrei* intergrades, which includes: (a) *N. incompta* that have more than four chambers per whorl when viewed from umbilical side (Parker, 1962), and (b) immature specimens of *N. dutertrei* without umbilical tooth (Boltovskoy, 1968). The P-D intergrades were later included in *N. incompta* (Kučera et al., 2005). These are characteristic of cooler waters and subtropical–subpolar latitudes and prefer a temperature ~20°C (Hilbrecht, 1996).

N. dutertrei is an important species in the tropical–subtropical zone, and sometimes also appears in the temperate zones during summer (Schiebel and Hemleben, 2017). It is considered as a salinity and productivity indicator in the tropical latitudes (Thunell, 1978; Cullen, 1981). Bijma et al. (1990) observed that under laboratory conditions, *N. dutertrei* can tolerate a wide range of salinity, 25–46 psu, and a temperature range of 13°–33°C. *N. dutertrei* is an important upwelling indicator (Thiede, 1983) and is indicative of mid to late phases of upwelling (Thunell and Sautter, 1992). Portilho-Ramos et al. (2017) used the relative abundance of *N. dutertrei*, *N. pachyderma*, and *G. glutinata* to track the intertropical convergence zone over Atlantic Ocean and observed the opposing pattern of abundance of *N. dutertrei* and *G. glutinata* during an upwelling episode.

In Hole U1474A, this species has fairly moderate abundance, with higher abundance during the Quaternary than during the Pliocene.

Genus *Pulleniatina* Cushman, 1927
Type Species *Pullenia obliquiloculata* Parker and Jones, 1865

Pulleniatina obliquiloculata (Parker and Jones 1865)
(Plate **P25**, figures 1–6)

Basionym: *Pullenia sphaeroides* var. *obliquiloculata*
Synonym: *Pulleniatina obliquiloculata*, *Pulleniatina antillensis* Bermúdez (1960), *Pulleniatina trochospira* Hartono (1964), *Pulleniatina finalis* Banner and Blow (1967), *Pulleniatina okinawaensis* Natori (1976)

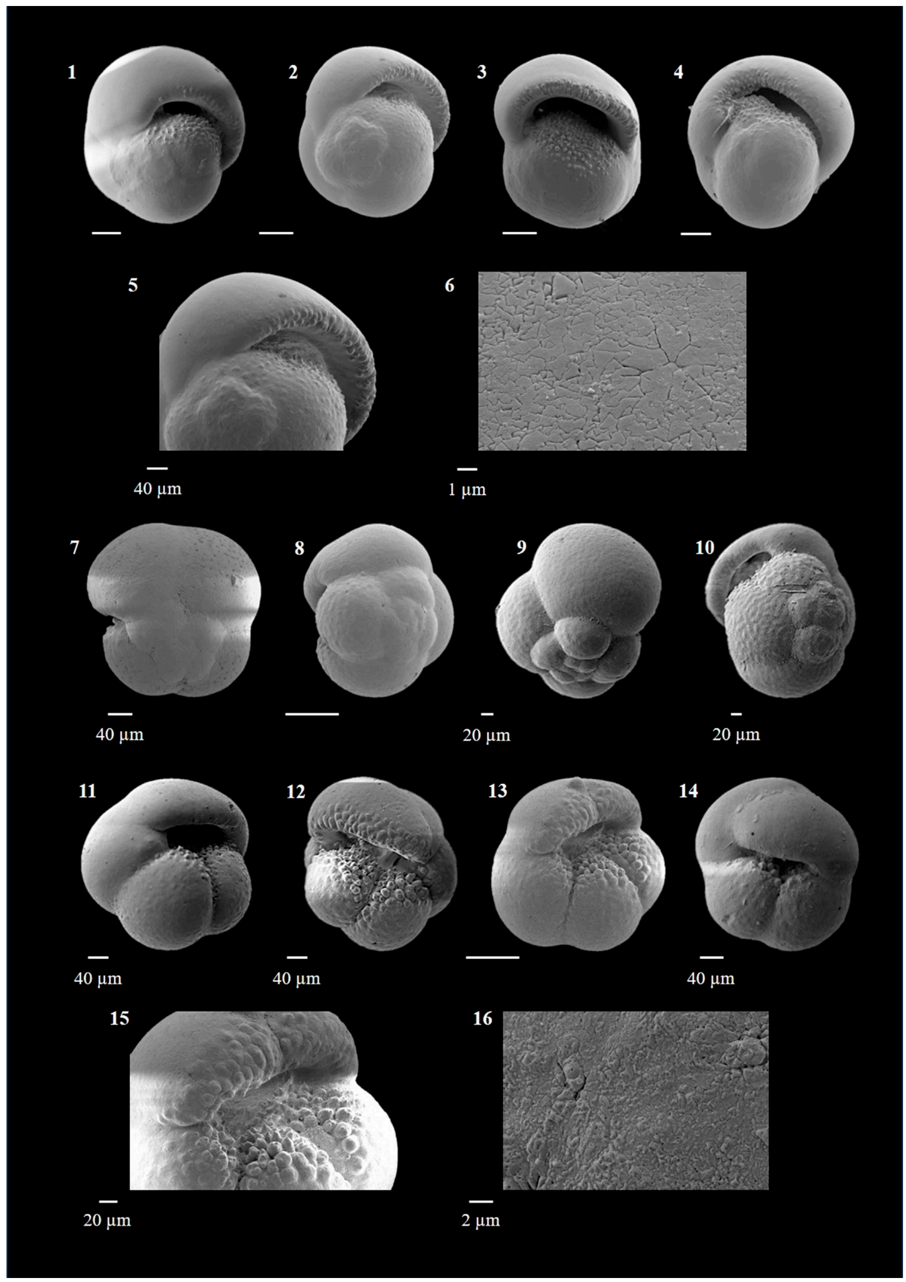

Plate P25. *Pulleniatina obliquiloculata* and *Pulleniatina primalis*, Hole U1474A. 1–6. *Pulleniatina obliquiloculata* Parker and Jones (1, 2, 5, 6. 5H-5, 20–22 cm [1, 2. Spiral view; 5. Aperture; 6. Cortex]; 3, 4. 2H-3, 148–150 cm [apertural view]). 7–16. *Pulleniatina primalis* Banner and Blow (7–9, 11, 12. 24H-5, 2–4 cm [7–9. Spiral view; 11, 12. Umbilical view]; 10, 16. 20H-1, 51–53 cm [10. Axial view; 16. Cortex surface]; 13–15. 16H-2, 47–49 cm [13, 14. Umbilical view; 15. Aperture]). Scale bar = 100 µm unless otherwise mentioned.

Type species: *Pulleniatina obliquiloculata* Parker and Jones, 1865
Observed stratigraphic range: 361-U1474A-15H-1, 133–135 cm, to 1H-1, 0–2 cm

Remarks. *P. obliquiloculata* is an extant species characterized by a globose, streptospiral test, with a low arch aperture extending from the umbilical area to periphery and onto the spiral side (Kennett and Srinivasan, 1983). The wall is smooth due to a heavy cortex made of interlocking calcite plates. The apertural area is granular.

P. obliquiloculata has undergone several morphological variations. The test of *P. finalis* appears to show planispiral coiling due to an involute spiral side, with a very broadly rounded periphery, and high arch, entirely extraumbilical aperture (Bolli and Saunders, 1985). The variation in the coiling direction of *P. obliquiloculata* was an important event in the geological history (Saito, 1977; Pearson and Penny, 2021).

P. obliquiloculata is a tropical to warm subtropical species (Kennett and Srinivasan, 1983; Schiebel and Hemleben, 2017), and prefers thermocline habitat (Aze et al., 2011). It is an important species in the Pacific Ocean realm and is known as indicator of the Kuroshio Current (Lam and Leckie, 2020a).

In Hole U1474A, it is a regularly occurring species, with low to moderate abundance.

Pulleniatina primalis **(Banner and Blow 1967)**
(Plate **P25**, figures 7–16)

Basionym: *Pulleniatina primalis*
Synonyms: *Pulleniatina praepulleniatina* Brönnimann and Resig (1971)
Type species: *Pulleniatina primalis* Banner and Blow, 1967
References: Banner and Blow (1967), Parker (1962), Kennett (1973), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Chaisson and Leckie (1993), Lam and Leckie (2020a)
Observed stratigraphic range: 361-U1474A-25H-7, 26–28 cm, to 13H-2, 89–91 cm

Remarks. *P. primalis* is characterized by a medium test with streptospiral coiling, with four to five chambers in the final whorl. The surface is smooth and porcelaneous with a cortex. The distinguishing feature of *P. primalis* is its final chamber, which is more embracing, and the aperture, which is restricted to the umbilical side and doesn't reach the periphery of the previous whorl, unlike *P. obliquiloculata,* in which the aperture is extended over the umbilical area (Kennett and Srinivasan, 1983).

P. primalis was an open ocean thermocline dwelling species (Aze et al., 2011) and extended in the tropical to warm subtropical latitudes (Kennett and Srinivasan, 1983). It is an important biostratigraphic marker for the Pliocene in the lower latitudes.

In Hole U1474A, it was found to occur regularly in the Pliocene samples, in lower abundance.

Family HASTIGERINIDAE Bolli, Loeblich and Tappan, 1957
Genus *Hastigerina* Thomson, 1876
Type Species *Nonionina pelagica* d'Orbigny, 1839

Hastigerina pelagica **(d'Orbigny 1839)**
(Plate **P26**, figures 1–8)

Basionym: *Nonionina pelagica*
Synonym: *Hastigerina murrayi* Thomson (1876)
Type species: *Hastigerina pelagica* d'Orbigny, 1839
References: d'Orbigny (1839), Saito et al. (1976), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Loeblich and Tappan (1994), Schiebel and Hemleben (2017)
Observed stratigraphic range: 361-U1474A-25H-7, 26–29 cm, to 1H-1, 0–2 cm

Remarks. *H. pelagica* is distinguished by its almost planispiral test, with four to five rapidly enlarging chambers in the final whorl and characteristic triradiate spines. In spinose forms, it is the only species that produces entirely triradiate spines (Schiebel and Hemleben, 2017).

H. pelagica is found in tropical to temperate latitudes (Kennett and Srinivasan, 1983).

This species occurs regularly in Hole U1474A in extremely low abundance.

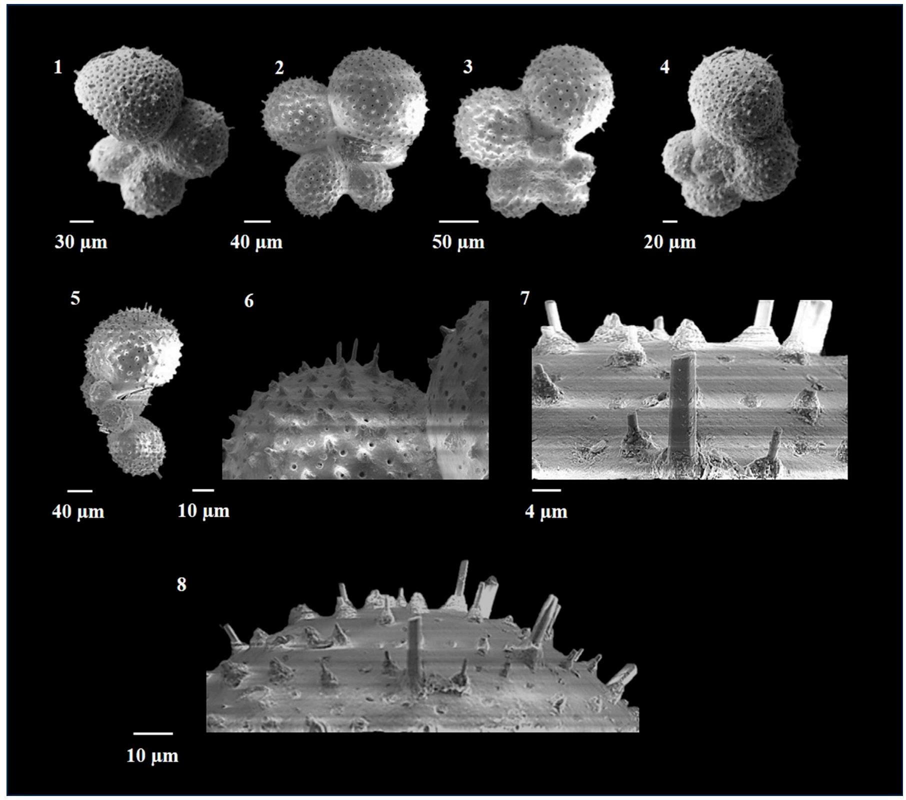

Plate P26. *Hastigerina pelagica* d'Orbigny, Hole U1474A (1H-1, 96–98 cm). 1, 2. Umbilical view; 3, 4. Spiral view; 5. Axial view; 6. Surface; 7, 8. Triradiate spines. Scale bar = 100 µm unless otherwise mentioned.

4. Acknowledgments

At the outset, we thank IODP and Kochi Core Center for providing the samples from Hole U1474A. V.P. Singh thanks the National Centre for Polar and Ocean Research (NCPOR) (India) for providing financial assistance through Project Grant NCPOR/IODP/E.3947/2021. R. Dwivedi thanks NCPOR for support in the form of a Junior Research Fellowship. S. Pathak thanks Indira Gandhi National Tribal University (IGNTU) (India) for financial support in the form of a Junior Research Fellowship. We extend our thanks to Dr. Rohit Pandey with the Department of Geology at Banaras Hindu University for extending the SEM facilities. V.P. Singh greatly appreciates the discussion on taxonomy with Professor Bridget Wade, Dr. Tracy Aze, Dr. Hellen Coxall, and Dr. Alessio Fabbrini during various meetings of the Neogene Quaternary Planktic Foraminiferal Working Group. The authors thankfully acknowledge the logistical support given by IGNTU.

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