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Planktonic foraminiferal assemblage in surface sediments from the Thukela Shelf, South Africa

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ABSTRACT

Twenty-three species of planktonic Foraminifera have been identified from surface sediments on the Thukela Shelf (KwaZulu-Natal Bight, South Africa). The assemblage is dominated by *Orbulina universa*, *Globigerinoides ruber* and *Neogloboquadrina dutertrei*, and is referred to the tropical–subtropical zone. Surface-water species (*Globigerinoides ruber*, *G. trilobus*, *G. sacculifer*, and *G. conglobatus*) dominate over deep-water species (*Globorotalia inflata*, *G. tumida*, *G. menardii*, and *Sphaeroidinella dehiscens*). Identification keys to species of *Globorotalia*, *Globigerina*, and *Globigerinoides* from the KwaZulu-Natal Bight are provided.

KEY WORDS: Foraminifera, planktonic, South Africa, Indian Ocean, Agulhas Current, KwaZulu-Natal Bight, Holocene, check list, identification keys.

INTRODUCTION

Planktonic Foraminifera are an important source of palaeoceanographic information (Schiebel & Hemleben 2005). Their long palaeontological record, good preservation in sediments and easy collection make them perfect indicators for studies on changes in sea-surface temperature, salinity, and nutrient content (e.g., Spezzaferri & Spiegler 2005; Fraile *et al.* 2009).

South African foraminifers have been studied for more than 150 years, but most studies, especially recent ones, have been of a geological nature, without any investigation of their distribution pattern (e.g., McMillan 2003; Toefy *et al.* 2005; and references therein). The diversity and distribution pattern of recent foraminifers, and their application to environmental analyses, have so far been largely ignored. Noteworthy studies on southern African planktonic foraminifers include those of Giraudeau (1993) on the south-western African continental margin and Rau *et al.* (2002) on the southern margin. Bé and Hutson (1977) provided a regional distribution of planktonic foraminifers in the Indian Ocean, but no systematic research has been undertaken on the eastern continental shelf of South Africa.

Recent interest was initiated by the proposed development of a dam on the Thukela River and the associated impacts on a unique marine ecosystem, the Thukela Shelf, comprising an uncharacteristically wide muddy continental shelf and an associated economically important prawn industry. This system depends on the interaction of fresh water and sediment from the Thukela River, the strong Agulhas Current, and a semi-permanent anti-cyclonic spinning gyre within the KwaZulu-Natal Bight (Bosman *et al.* 2007).

In this paper we provide results of the taxonomic study of planktonic foraminiferal assemblages from sediments across the KwaZulu-Natal Bight.

TABLE 1

General information from samples collected at the Thukela River and Thukela Shelf (TB).

Sample	Latitude (S)	Longitude (E)	Depth, m	Visual Description
2	29º15.5037'	31º38.6995'	-49	Light/medium mud. Some sand
4	29º17.0864'	31º36.4682'	-49	Medium/dark mud. Some sand
6	29º20.3382'	31º35.0655'	-52	Light brown medium/ coarse sand
8	29º19.1597'	31º38.8723'	-51	Dark brown medium/ coarse sand
10	29º20.3946'	31º40.5621'	-56	Dark brown fine to medium sand
12	29º22.1458'	31º35.8622'	-59	Medium/dark brown mud medium sand. Some mud
15	29º22.9755'	31º41.2241'	-65	Medium brown medium to fine sand and mud
19	29º24.3596'	31º41.2063'	-72	Light brown mud
22	29º28.3820'	31º39.2880'	-79	Dark brown. 90% mud. Some fine sand
23	29º27.9048'	31º41.3821'	-79	Light/medium brown medium sand. Little fine sand
25	29º25.6829'	31º46.4385'	-81	Dark brown 90% mud and fine sand
26	29º30.8352'	31º43.8446'	-112	Light/medium brown mud
30	29º33.9354'	31º38.2329'	-123	Dark brown. Fine sand. >90% mud
A	29°05.4032'	31°51.3783'	-43	Grey soft massive mud
B	29°11.3999'	31°42.7800'	-43	Grey mud, thin veneer of brown mud (soft)
C	29°26.6999'	31°42.4200'	-75	Dark grey mud, may be stiffer than A & B
TB 7	29°06.0540'	31°43.0592'	-20	Sand
TB 20	29°10.1995'	31°47.5863'	-45	Sand
TB 22	29°12.1894'	31°39.8004'	-37	Grey-brown mud
TB 32	29°18.4872'	31°32.5577'	-40	Grey-brown mud
TB 34	29°22.8134'	31°27.5618'	-42	Sand

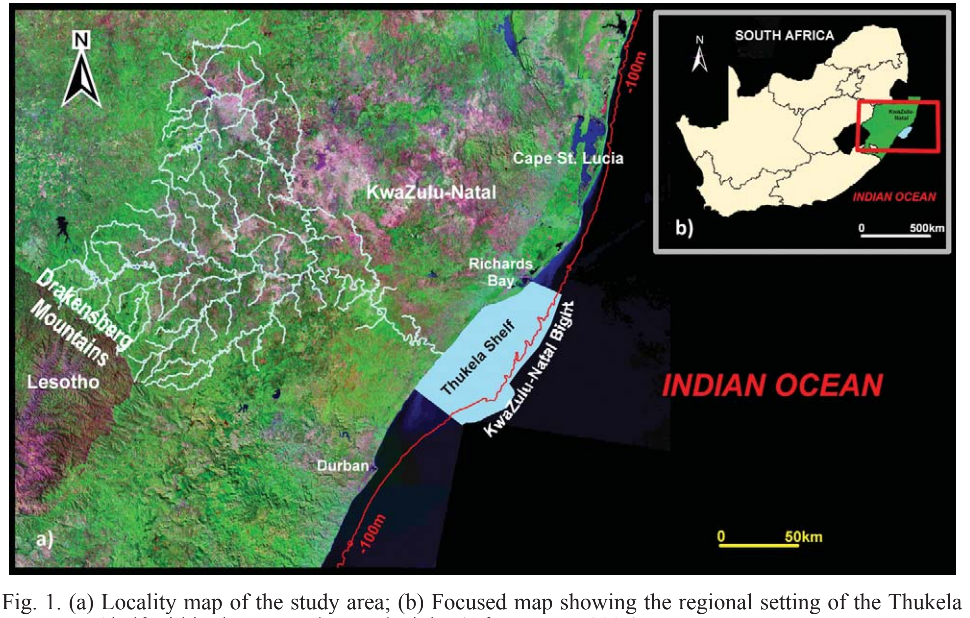

Fig. 1. (a) Locality map of the study area; (b) Focused map showing the regional setting of the Thukela Shelf within the KwaZulu-Natal Bight. (After Hunter 2007)

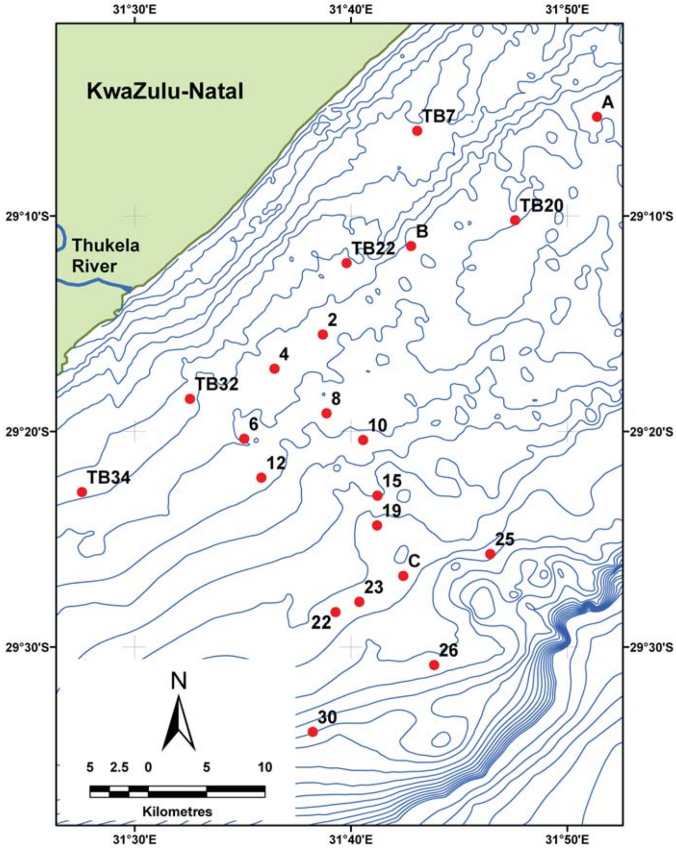

Fig. 2. Map showing the positions from which samples were collected on the Thukela Shelf. These were taken on the inner, mid and outer shelf, offshore of the Thukela River. Isobaths drawn at 5 m.

MATERIAL AND METHODS

The study area, approx. 18×25 km in extent, is located immediately offshore of the Thukela River on the Thukela Shelf and forms part of the KwaZulu-Natal Bight (Fig. 1). Surface sediment samples were collected by *Shipek* grab sampler in 2006 aboard the Marine and Coastal Management research vessel the FRS *Algoa* (Hunter 2007), and during the Oceanographic Research Institute (ORI) survey in 2008.

In total, 21 samples were analyzed for the foraminiferal fauna (Fig. 2). Samples were washed through 500, 125 and 63 μm sieves, were dried and the two fractions (>500, 500–125 μm) were analyzed. Due to the relative proximity of the sampling sites to the shore, foraminifers were found to be scarce and the required number of 300 specimens per sample could not be obtained for most samples. Thus this study presents results of a semi-quantitative approach.

The relative abundance of individual foraminiferal taxa is expressed as follows: R – rare (1–5 specimens/sample), C – common (6–10 specimens/sample), F – frequent (11–25 specimens/sample), A – abundant (>25 specimens/sample). The sample numbers, depth, location of each sample and sediment character are given in Table 1.

Photographs were taken using a Nikon AZ-100 stereomicroscope and 3-D Nikon imaging software. The classification of foraminifers in this study follows Loeblich and Tappan (1987, 1994), Saito *et al.* (1981) and *The Taxonomicon & Systema Naturae* (2000).

All examined material has been deposited in the palaeontological collection of the Department of Natural Sciences, Natal Museum, Pietermaritzburg, South Africa.

TAXONOMY

Order Globigerinida Lankester, 1885
Superfamily Globorotaliacea Cushman, 1927
Family Globorotaliidae Cushman, 1927
Genus *Globorotalia* Cushman, 1927
Globorotalia cultrata (d'Orbigny, 1839)

Figs 3A, 3D

Rotalina cultrata: d'Orbigny 1839*a*: 76, pl. 5, figs 7–9.
Globorotalia cultrata (d'Orbigny): Parker 1962: 235–236, pl. 5, figs 3–5; Pflaumann & Krasheninnikov 1978: 891, pl. 5, figs 2–4; Loeblich & Tappan 1994: 100, pl. 184, figs 8–10; Bylinskaya *et al.* 2002: 132, pl. VIII, figs 7–9.
Globorotalia menardii cultrata (d'Orbigny): Bolli & Saunders 1985: 226, figs 32.3, 34.8–10.

Remarks: *G*. *cultrata* is very similar to *G*. *menardii*, but differs in having a thinner, more delicate test wall and a narrower peripheral keel. Saito *et al*. (1981) considered *G*. *cultrata* a synonym of *G*. *menardii*, whereas Bolli and Saunders (1985) recognized it as a subspecies, *G*. *menardii cultrata.*

Distribution: A tropical species, abundant in warm-water regions, but isolated specimens could appear up to 56°N in the Atlantic. Quite rare in our material.

Globorotalia inflata (d'Orbigny, 1839)

Figs 4A–C

Globigerina inflata: d'Orbigny 1839*b*: 134, pl. 2, figs 7–9.
Turborotalia inflata (d'Orbigny): Bermúdez 1961: 1323–1324, pl. 18, figs 2a–b.
Globorotalia inflata (d'Orbigny): Parker 1962: 236, pl. 5, figs 6–9; Saito *et al.* 1981: 124, pl. 41, figs 1a–d; Bylinskaya *et al.* 2002: 133, pl. XI, figs 1–3.

Test size variable, usually medium-sized, low trochospiral with 4 subglobular chambers in the final whorl. On umbilical side chambers more inflated than on spiral side, increasing moderately in size as added. Aperture interiomarginal, a high, wide arch.

Remarks: *G*. *inflata* differs from other *Globorotalia* species encountered in having subglobular chambers and in lacking a keel.

Distribution: This species characterizes cool-temperate waters. It is uncommon in the tropical region (Bylinskaya *et al.* 2002) and very rare in our material.

Globorotalia menardii (Parker, Jones & Brady, 1865)

Figs 3B, 3E

Rotalia menardii: Parker *et al.* 1865: 20, pl. 3, fig. 81.
Pulvinulina menardii (Parker *et al.*): Brady, 1884: 690, pl. 103, figs 1, 2.
Globorotalia menardii: Cushman 1927*b*: 175; 1931: 91, pl. 17, fig. 1; Bé *et al.* 1966: 885–896, pls 1–17; Saito *et al.* 1981: 147, pl. 50, figs 1a–d; Loeblich & Tappan 1987: 475, pl. 516, figs 4–11; 1994: 101, pl. 183, figs 1–6; Basov & Krasheninnikov 1995: pl. I, figs 3, 4.
Globorotalia menardii menardii (Parker *et al.*): Bolli & Saunders 1985: 226, figs 32.4, 34.5–7.

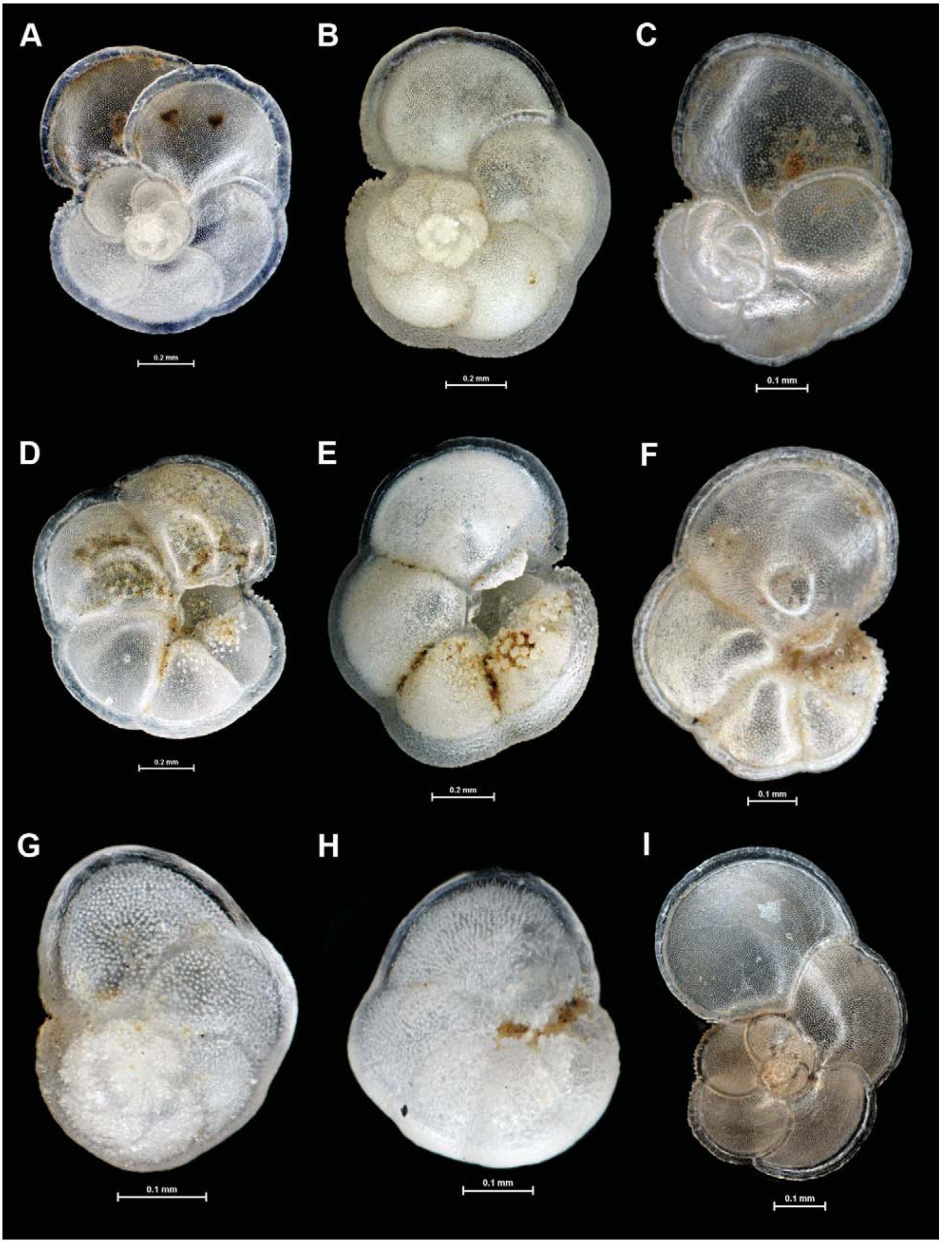

Fig. 3. (A, D) *Globorotalia cultrata* (d'Orbigny, 1839), sample 25; (B, E) *Globorotalia menardii* (Parker, Jones & Brady, 1865), sample 30; (C, F) *Globorotalia ungulata* Bermúdez, 1961, sample 25; (G, H) *Globorotalia tumida* (Brady, 1877), sample 26; (I) *Globorotalia ungulata* Bermúdez, 1961, sample 30.

Medium to large biconvex trochospiral test with 5–6 wedge-shaped chambers in the final whorl. On spiral side chambers semi-circular, nearly flat, with curved sutures; on umbilical side triangular, slightly inflated, with radial sutures. Peripheral keel wide. Aperture interiomarginal, umbilical, a low arch with a large plate-like umbilical tooth.

Remarks: *G. menardii* differs from *G. cultrata* in being generally larger and in having a robust, thicker test wall with a wider peripheral keel. It differs from *G. tumida* in having a more circular equatorial outline and a larger diameter, and in being narrower.

Distribution: Equatorial to tropical waters. Only four specimens were found in our material.

Globorotalia tumida (Brady, 1877)

Figs 3G, 3H

Pulvinulina menardii (d'Orbigny) var. *tumida*: Brady 1877: 535; Banner & Blow 1960: 26–27, pl. 5, fig. 1.
Pulvinulina tumida Brady: Brady 1884: 692, pl. 103, figs 4–6.
Globorotalia tumida (Brady): Cushman 1927*a*: 91, pl. 19, fig. 12; Bolli *et al.* 1957: 41–42, pl. 10, figs 2a–c; Parker 1962: 239–240, pl. 6, figs 8–10; Todd 1965: 71–72, pl. 28, fig. 1; Saito *et al.* 1981: 148, pl. 50, figs 2a–d; Loeblich & Tappan 1987: 475, pl. 515, figs 4–6; 1994: 101, pl. 183, figs 7–12; Bylinskaya *et al.* 2002: 137, pl. IX, figs 13, 14.
Globorotalia tumida tumida (Brady): Bolli & Saunders 1985: 227, figs 33.8, 34.11–13; Basov & Krasheninnikov 1995: pl. I, figs 8, 9.

Medium to large; biconvex trochospiral test with 5–6 wedge-shaped chambers in the final whorl. On the spiral side chambers reniform, slightly inflated, sutures curving, thickened; on the umbilical side chambers subtriangular, more inflated, with radial sutures. Peripheral keel distinct, thick. Aperture interiomarginal, extraumbilical, a low arch with a large, plate-like lip.

Remarks: *G. tumida* has a more elongate and thick test than *G. menardii*, with a less lobulate periphery and an angular final chamber.

Distribution: An equatorial/tropical species, appearing in warm-water regions only. A single specimen was found in our material.

Globorotalia ungulata Bermúdez, 1961

Figs 3C, 3F, 3I

Globorotalia ungulata: Bermúdez 1961: 1304, pl. 15, figs 6a–b; Blow, 1969: 371, pl. 8, figs 13–15; Pflaumann & Krasheninnikov 1978: 892, pl. 5, figs 5–7; Saito *et al.* 1981: 155–156, pl. 53, figs 2a–b, 3a–b; Bolli & Saunders 1985: 230, figs 32.2; Loeblich & Tappan 1994: 101, pl. 182, figs 1–12.
Globorotalia menardii ungulata Bermúdez: Todd 1964: 1093, pl. 295, fig. 3; Todd 1965: 71, pl. 28, fig. 3.

Small to medium biconvex trochospiral test with about 5 wedge-shaped chambers in the final whorl. On the spiral side chambers slightly reniform, nearly flat; on the ventral side, subtriangular, inflated. The final chamber has a high umbilical shoulder. Peripheral keel thin. Aperture interiomarginal, a very low slit-like opening at the base of umbilical shoulder with a large plate-like umbilical lip.

Remarks: This species can be easily recognized by its high umbilical face and its thin, shiny, elliptical test. Because of its elongate, somewhat inflated test *G. ungulata* was occasionally considered to be related to *G. tumida*; however, we believe it to be closer to the *G. menardii*–*G. cultrata* complex.

Distribution: Equatorial and tropical waters. Quite rare in our material.

Key to the species of *Globorotalia* from the Thukela Shelf

1	Test low trochospiral with subglobular chambers in final whorl	**inflata**
–	Test biconvex trochospiral with wedge-shaped chambers in final whorl	2
2	Test wall thin with delicate, thin peripheral keel	3
–	Test wall thick with thick peripheral keel	4
3	Test rounded in outline..	**cultrata**
–	Test more elliptical in outline..	**ungulata**
4	Test rounded in outline..	**menardii**
–	Test elliptical in outline..	**tumida**

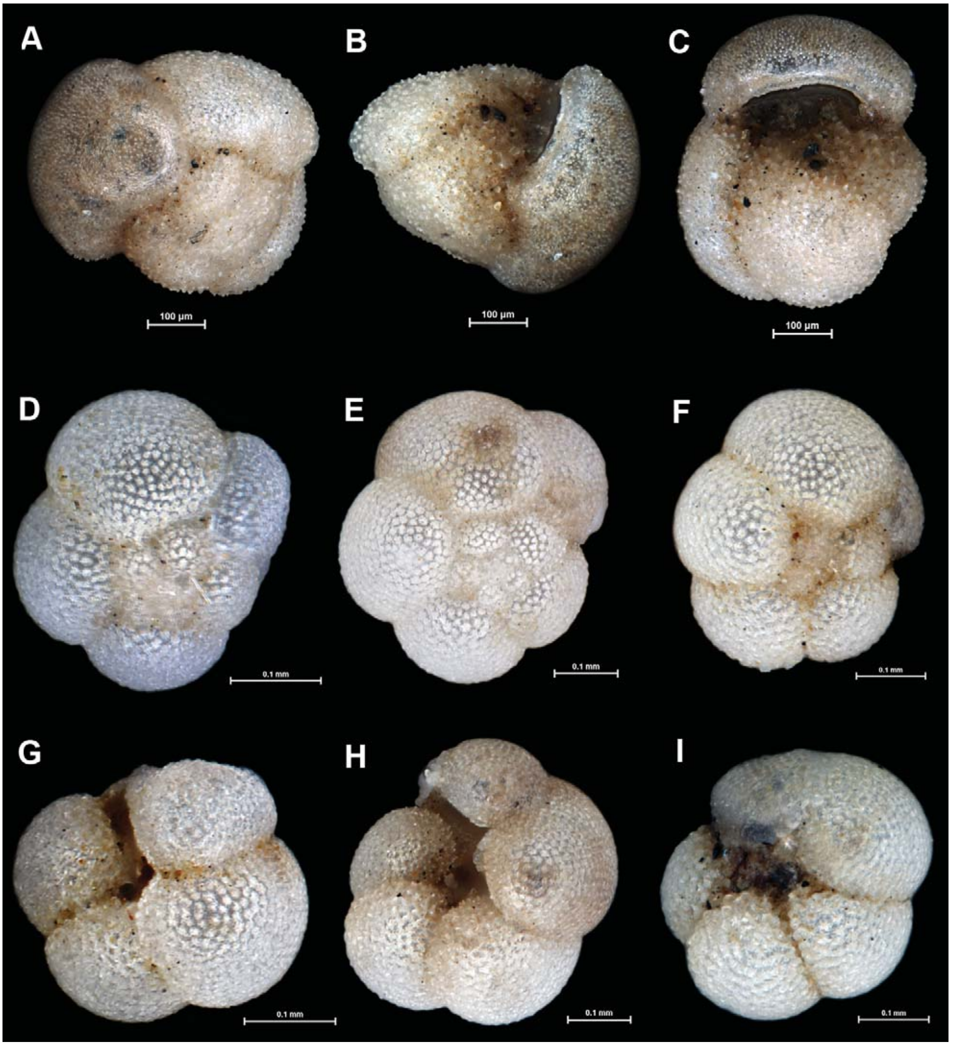

Fig. 4. (A–C) *Globorotalia inflata* (d'Orbigny, 1839), sample 26; (D, G) *Neogloboquadrina incompta*, sample 15; (E, H) *N. dutertrei* (d'Orbigny, 1839), sample 30; (F, I) *N. dutertrei*, a low trochospiral specimen with more umbilical aperture from sample 30.

Genus *Neogloboquadrina* Bandy, Frerichs & Vincent, 1967
Neogloboquadrina dutertrei (d'Orbigny, 1839)

Figs 4E, 4F, 4H, 4I

Globigerina dutertrei: d'Orbigny 1839*a*: 84, pl. 4, figs 19–21; Brady 1879: 286; Banner & Blow 1960: 11, pl. 2, fig. 1.
Globigerina eggeri Rhumbler, 1901: 19, text-fig. 20; Banner & Blow 1960: 11–12, pl. 2, figs 4a–c.
Globoquadrina dutertrei (d'Orbigny): Parker 1962: 242, 244, pl. 7, figs 1–13; pl. 8, figs 1–4.
Neogloboquadrina dutertrei dutertrei (d'Orbigny): Rögl & Bolli 1973: 570, pl. 9, figs 3, 6, pl. 10, figs 1–10, pl. 17, fig. 12.
Neogloboquadrina dutertrei (d'Orbigny): Saito *et al.* 1981: 111, pl. 36, figs 1a–c, 2; Cimerman & Langer 1991: 57, pl. 60, fig. 1.

Test variable in size, usually medium, a medium-height trochospire with 4–6 subspherical to radially slightly flattened chambers in the final whorl. Chambers increase slowly in size as added, sutures depressed. Aperture a wide and deep opening directly into umbilicus.

Remarks: A few individuals with a lower trochospire and more umbilical aperture were found (Figs 4F, 4I) in our material. These forms may be identified as *N. eggeri* (Rhumbler, 1901). Saito *et al.* (1981) separate these species on the basis of a higher spire in *N. dutertrei*, but Kennett and Srinivasan (1983) suppose that *N. eggeri* is a junior synonym of *N. dutertrei*. We tend to agree with the latter opinion at this stage.

N. dutertrei differs from *N. incompta* in having a bigger and less compact test, and in having more chambers in the final whorl.

Distribution: Equatorial and tropical waters. A common species in our material.

Neogloboquadrina incompta (Cifelli, 1961)

Figs 4D, 4G

Globigerina incompta: Cifelli 1961: 83, pl. 4, figs 1–7.
Globigerina pachyderma incompta (Cifelli): Cifelli 1965: 11, pl. 1, figs 4–6.

Test small with partly embracing chambers, 4 or 4.5 globular chambers in the final whorl. Aperture umbilical, interiomarginal but extending almost to the periphery, a low arch with a thin projecting rim. Wall thin, finely porous, granular.

Remarks: Differs from *N. dutertrei* in being smaller and in having a more compact test.

Distribution: North Atlantic (surface plankton), latest Pliocene and Pleistocene sediments from northern Japan. Only two specimens were recorded in our material.

Family Pulleniatinidae Cushman, 1927
Genus *Pulleniatina* Cushman, 1927
Pulleniatina obliquiloculata (Parker & Jones, 1865)

Figs 5A, 5D

Pullenia obliquiloculata: Parker & Jones 1865: 183.
Pulleniatina obliquiloculata (Parker & Jones): Parker 1962: 234, pl. 4, figs 13–16, 19, 22; Todd 1965: 67, pl. 27, figs 2–4; Saito *et al.* 1981: 96, 98, pl. 30, figs 1a–d, 2a–d; pl. 31, figs 3a–d; Bolli & Saunders 1985: 247, figs 40.4, 41.9–12; Loeblich & Tappan 1987: 480, pl. 524, figs 4–12; 1994: 103, pl. 187, figs 8–13; pl. 188, figs 1–6; Basov & Krasheninnikov 1995: pl. III, figs 7, 8.

Test size variable, rounded in outline, initially a low trochospiral becoming a streptospiral. Spherical chambers becoming radially flattened, very embracing with sutures weak. Aperture a very low, ventrally interiomarginal arch.

Remarks: This species can easily be identified by its rounded polished (glossy) test, being very compact, with embracing chambers.

Distribution: Equatorial and tropical waters. Rare in our material.

Family Candeinidae Cushman, 1927
Subfamily Globigerinitinae Bermúdez, 1961
Genus *Globigerinita* Brönnimann, 1951
Globigerinita glutinata (Egger, 1893)

Figs 5B, 5E

Globigerina glutinata: Egger 1893: 371, pl. 13, figs 19–21.
Globigerinita glutinata (Egger): Parker 1962: 246–249, pl. 9, figs 1–16; 1967: 146, pl. 17, figs 3–5; Pflaumann & Krasheninnikov 1978: 890, pl. 2, figs 4–6; Saito *et al.* 1981: 77, pl. 22, figs 1–7; Bylinskaya *et al.* 2002: 125, pl. I, figs 4–6.
Tinophodella ambitacrena (Loeblich & Tappan, 1957): Bolli & Saunders 1985: 188, fig. 17.6; Loeblich & Tappan 1987: 481, pl. 525, figs 10–15.

Small to medium trochospiral test with 4 globular chambers in the final whorl; chambers spherical to slightly flattened radially. Primary aperture umbilical, a low arch with a thin lip. Bulla of variable configuration may cover sutures on umbilical side.

Distribution: Cosmopolitan, equatorial to subpolar latitudes. This species is most abundant in subtropical and temperate sediments (Bylinskaya *et al.* 2002), but is quite rare in our material.

Superfamily Globigerinaceae Carpenter, Parker & Jones, 1862
Family Globigerinidae Carpenter, Parker & Jones, 1862
Subfamily Globigerininae Carpenter, Parker & Jones, 1862
Genus *Globigerina* d'Orbigny, 1826
Globigerina bulloides d'Orbigny, 1826

Figs 5G–I

Globigerina bulloides: d'Orbigny 1826: 277, list no. 1; Parker *et al.* 1865: 21, 31, pl. II, figs 55, 56; Brady 1879: 285; Banner & Blow 1960: 3–4, pl. 1, figs 1a–c, 4; Parker 1962: 221, pl. 1, figs 1–8; Loeblich & Tappan 1987: 489, pl. 535, figs 1–7; Saito *et al.* 1981: 40, pl. 7, figs 1a–d; Loeblich & Tappan 1994: 105–106, pl. 197, figs 1–9; Basov & Krasheninnikov 1995: pl. IV, figs 5, 6; Bylinskaya *et al.* 2002: 126, pl. I, figs 9–11.

Test size variable, trochospiral, well lobulated, with 4 chambers in the final whorl slowly increasing in size. Chambers spherical or slightly ovoid. Aperture umbilical, interiomarginal, a high arch. Wall smoothly perforated.

Remarks: The species differs from *G. falconensis* in having a high aperture without a lip. *G. bulloides* has a more hispid and thicker wall than does *Globigerinella calida*.

Distribution: A cosmopolitan species, equatorial to subpolar waters. Most abundant in the temperate Atlantic. It is also known for its association with upwelling zones (Bylinskaya *et al.* 2002). This species is very rare in our material.

Globigerina falconensis Blow, 1959

Figs 6A–C

Globigerina falconensis: Blow 1959: 177, pl. 9, figs 40a–c, 41; Parker 1962: 224, pl. 1, figs 14, 16–19; Brönnimann & Resig 1971: 1295–1296; Saito *et al.* 1981: 40, 42, pl. 7, figs 2a–d.

Small to medium trochospiral test, with 4 spherical chambers in the final whorl. The last chamber is typically smaller than the previous one and ovoid in shape. Aperture umbilical, interiomarginal, a low arch with a thick lip.

Remarks: The species is characterized by a very large variation, and does not always have a reduced last chamber. It can easily be separated from *G. bulloides* by the smaller aperture with a lip on the last chamber.

Distribution: Subtropical to temperate waters. Very rare in our material.

Globigerina quinqueloba Natland, 1938

Figs 5C, 5F

Globigerina quinqueloba: Natland 1938: 149, pl. 6, fig. 7; Parker 1962: 225–226, pl. 2, figs 7–16; Pflaumann & Krasheninnikov 1978: 888, pl. 2, figs 10–12; Saito *et al.* 1981: 48, pl. 10, figs 1, 2; Bylinskaya *et al.* 2002: 127, pl. II, figs 9–11.

Small, low trochospiral test, with 5 subglobular chambers, slightly flattened radially, in the final whorl. The last chamber is elongated and can partially cover the umbilicus like a bulla. Aperture umbilical, interiomarginal with rim-like basal lip.

Remarks: *G. quinqueloba* differs from other *Globigerina* species encountered in having five subglobular chambers, slightly flattened radially, in the final whorl.

Distribution: Temperate, subarctic and subantarctic. This species is an indicator of cold-water conditions (Bé & Hutson 1977; Bylinskaya *et al.* 2002). A single specimen was found in our material.

Globigerina rubescens Hofker, 1956

Figs 6D–F

Globigerina rubescens: Hofker 1956: 234, pl. 32, figs 18–21; Parker 1962: 226, pl. 2, figs 17–18; Pflaumann & Krasheninnikov 1978: 889, pl. 1, figs 11–13; Saito *et al.* 1981: 50, pl. 11, figs 1a–d; Bylinskaya *et al.* 2002: 127, pl. II, figs 6–8.

Globoturborotalita rubescens (Hofker): Loeblich & Tappan 1987: 490–491, pl. 537, figs 7–15; 1994: 108, pl. 208, figs 1–12.

Small trochospiral test with 4 globular chambers in final whorl. Subspherical chambers closely packed, sutures distinct. Aperture umbilical, a high open arch with an imperforate thin rim-like lip. Wall coarsely perforated.

Remarks: This species occasionally has a distinctive pink to red pigmentation in the Late Pleistocene and younger sediments of the Atlantic (Saito *et al.* 1981; Bylinskaya *et al.* 2002). Red-coloured forms have not yet been found in surface sediments of the Indian Ocean. The species differs from *Globigerinoides tenellus* and *Globigerinoides ruber* in having a more lobulate periphery and in the absence of supplementary apertures; and from other *Globigerina* species in having a coarsely perforate wall.

Distribution: Temperate to equatorial waters. Very rare in our material.

Key to the species of *Globigerina* from Thukela Shelf

1 Test with 5 subglobular, slightly flattened radially, chambers in final whorl.......... .... **quinqueloba**

– Test with 4 globular or spherical chambers in final whorl....................................2

2 Aperture a low arch with thick lip .... **falconensis**

– Aperture a high open arch without lip or with an imperforate thin rim-like lip 3

3 Aperture without lip, test wall smoothly perforated .... **bulloides**

– Aperture with an imperforate thin rim-like lip, test wall coarsely perforated ....**rubescens**

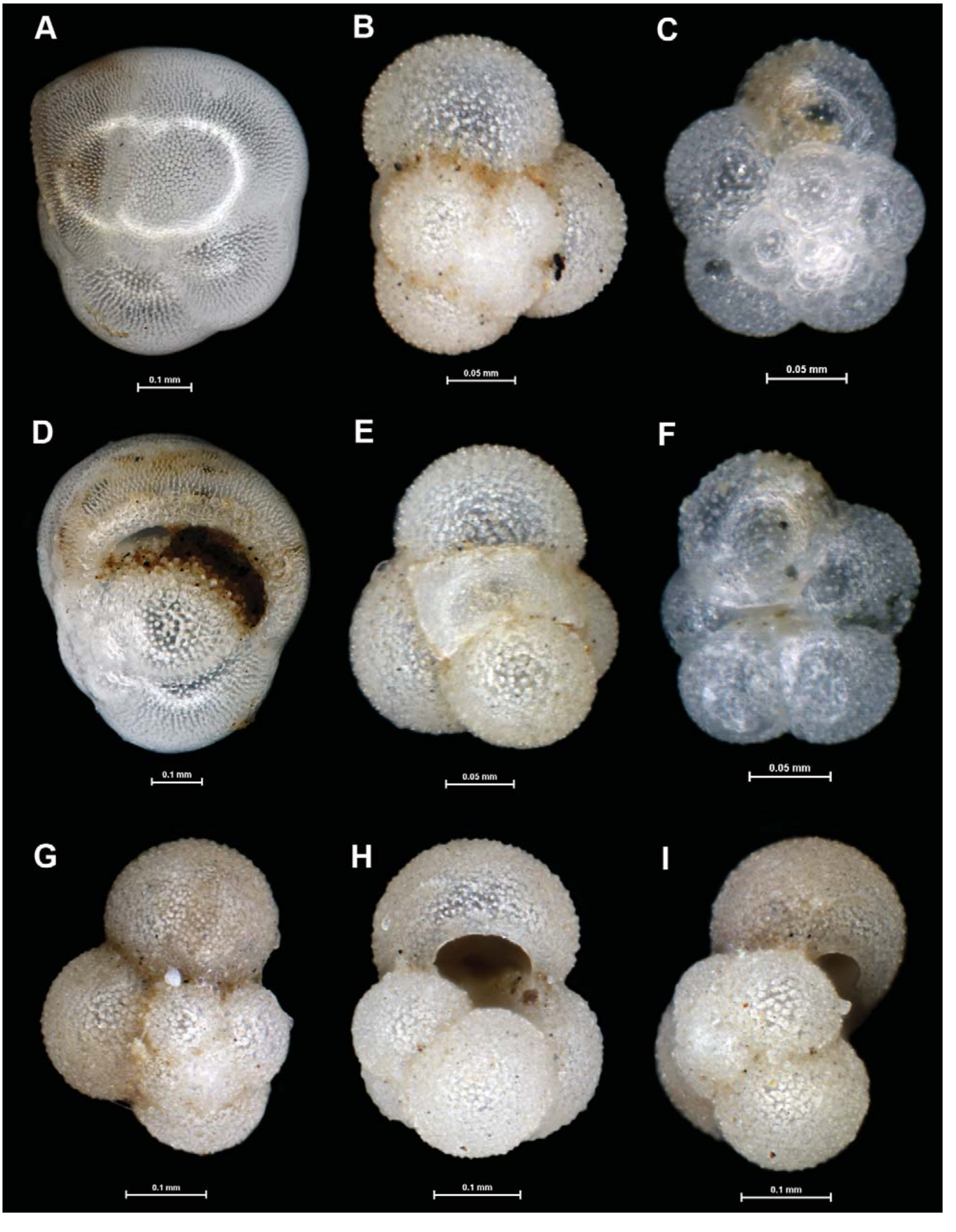

Fig. 5. (A, D) *Pulleniatina obliquiloculata* (Parker & Jones, 1865), sample 26; (B, E) *Globigerinita glutinata* (Egger, 1893), sample 26; (C, F) *Globigerina quinqueloba* Natland, 1938, sample 2; (G–I) *Globigerina bulloides* d'Orbigny, 1826, sample 6.

Genus *Globigerinella* Cushman, 1927
Globigerinella calida (Parker, 1962)

Figs 6G–I

Globigerina calida: Parker 1962: 221–222, pl. 1, figs 9–13, 15; 1967: 149, pl. 18, fig. 11, 12 (not figs 6–10); Bé 1967: 3, figs 15a–c; Cimerman & Langer 1991: 57, pl. 60, figs 2, 3.

Globigerina calida calida Parker: Blow 1969: 317, pl. 13, figs 9, 10; Bolli & Saunders 1985: 256, fig. 5.13; Basov & Krasheninnikov 1995: pl. IV, figs 7–9; Bylinskaya *et al.* 2002: 126, pl. II, figs 1–3.

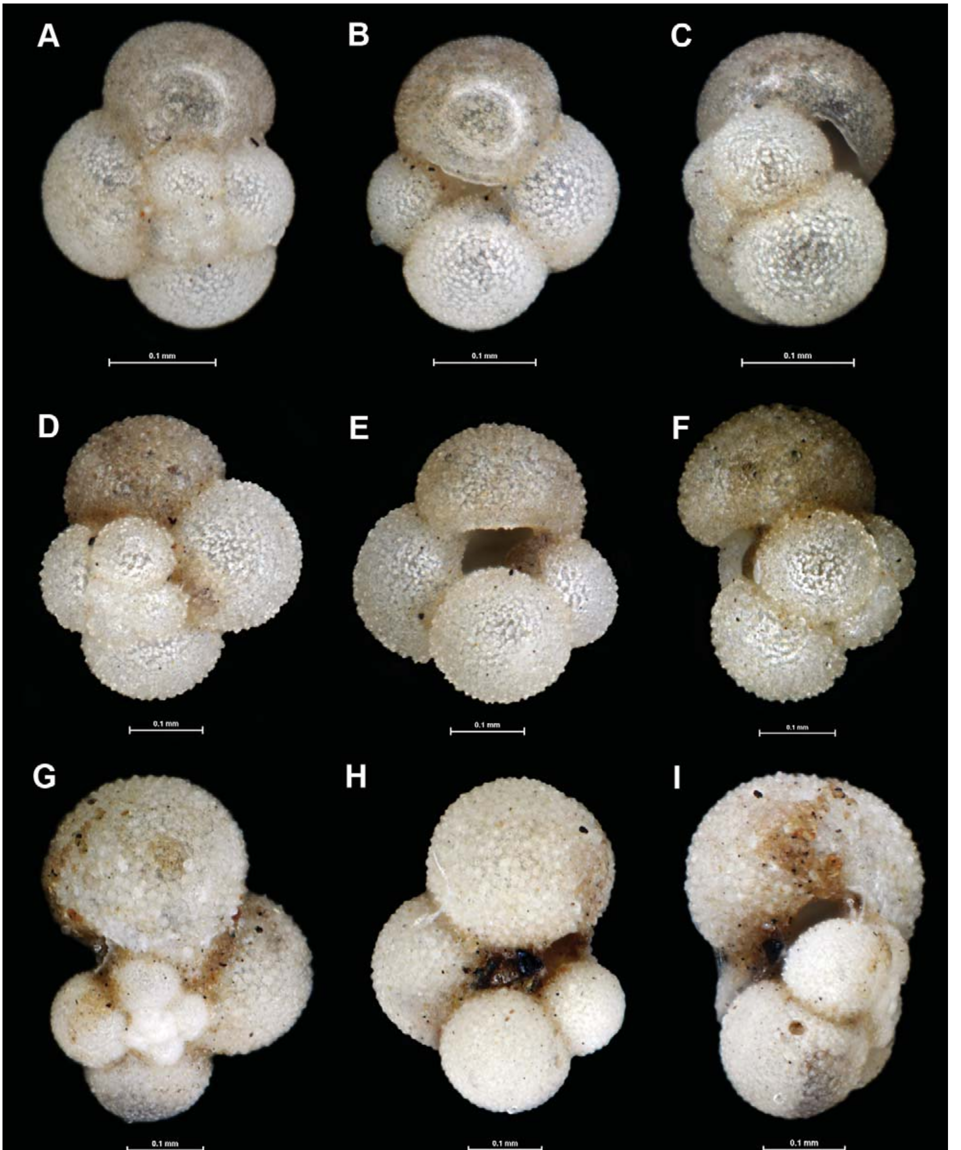

Fig. 6. (A–C) *Globigerina falconensis* Blow, 1959, sample 30; (D–F) *Globigerina rubescens* Hofker, 1956, sample 25; (G–I) *Globigerinella calida* (Parker, 1962), sample 4.

Globigerinella calida (Parker): Saito *et al.* 1976: 282, pl. 1, fig. 2; pl. 6, fig. 2; pl. 8, fig. 1; 1981: 32, pl. 4, figs 2a–d; Loeblich & Tappan 1994: 106, pl. 201, figs 7–11; pl. 202, figs 1–10.

Size variable. Low trochospiral test with about 4 initially spherical to slightly radially elongate chambers. Embracing loose so that the final chamber is almost completely detached from the previous whorl and the aperture is visible from the lateral and even spiral side (appears as slit); sutures deep. The aperture is developed as a large umbilical arch.

Remarks: Differs from *Globigerina bulloides* in loose embracing, radial elongation of the final chambers, visible aperture (slit) on the spiral side, and in having a thinner and less hispid wall. It also differs from juvenile trochoid *Globigerinella siphonifera* in having less involute chambers and a less hispid surface of the wall.

Distribution: *G. calida* appears in most of the climatic areas from equatorial to temperate, but is never abundant in assemblages (Bylinskaya *et al.* 2002). This species is rare in our material.

Globigerinella siphonifera (d'Orbigny, 1839)

Figs 7A, 7B, 7D, 7E

Globigerina siphonifera: d'Orbigny 1839*a*: 83, pl. 4, figs 15–18.
Globigerina aequilateralis Brady, 1879: 285; 1884: 605, pl. 80, figs 18–21.
Globigerinella aequilateralis (Brady): Cushman 1927*a*: 87; Todd 1965: 64–65, pl. 25, figs 4, 5; Saito *et al.* 1976: 281–282, pl. 3. figs 1, 2; pl. 6, fig. 7; pl. 8, figs 3, 8; 1981: 26, pl. 2, figs 2a–d; Bolli & Saunders 1985: 253, figs 42.6; 43.5–7, 9, 10; Loeblich & Tappan 1987: 489, pl. 535, figs 8–12; Cimerman & Langer 1991: 57, pl. 60, figs 4, 5.
Hastigerina siphonifera (d'Orbigny): Bolli & Saunders 1985: 251, figs 42.1, 4; 43.1, 2, 8.
Globigerinella siphonifera (d'Orbigny): Parker 1962: 228, pl. 2, figs 22–28; Loeblich & Tappan 1994: 106, pl. 200, figs 7–10; pl. 201, figs 1–3; Bylinskaya *et al.* 2002: 125, pl. I, figs 1–3.

This species is very variable, with the test varying from very low trochospiral to planispiral. The test is medium to large. Chambers are spherical to ovate, rapidly enlarging in the adult whorl. Sutures distinct and depressed. The aperture appears as a low, wide symmetrical equatorial arch in the interiomarginal position.

Remarks: *G. siphonifera* is more hispid than *Hastigerina pelagica*, and more tightly coiled and planispiral than *Globigerinella calida*.

Distribution: Tropical – subtropical waters. It appears in practically all our samples, in low abundance.

Genus *Globigerinoides* Cushman, 1927
Globigerinoides bulloideus Crescenti, 1966

Figs 7C, 7F

Globigerinoides bulloideus: Crescenti 1966: 43, pl. 9, figs 9a–c; Bolli & Saunders 1985: 194, fig. 20.9.

Test medium trochospiral, well lobulated, with 4 spherical chambers in the final whorl slowly increasing in size. Primary aperture umbilical, interiomarginal, a wide arch with very thin lip; only one small supplementary aperture.

Remarks: The test of this species is very similar to that of *Globigerina bulloides*, and it is normally characterized by a wide primary aperture (Bolli & Saunders 1985). Our specimen has an atypically small primary aperture with a thin lip, similar to that of *Globigerina falconensis*. However, it differs from both *G. bulloides* and *G. falconensis* in having a supplementary aperture. *G. bulloideus* differs from *Globigerinoides tenellus* in being larger and in having slowly increasing non-embracing chambers.

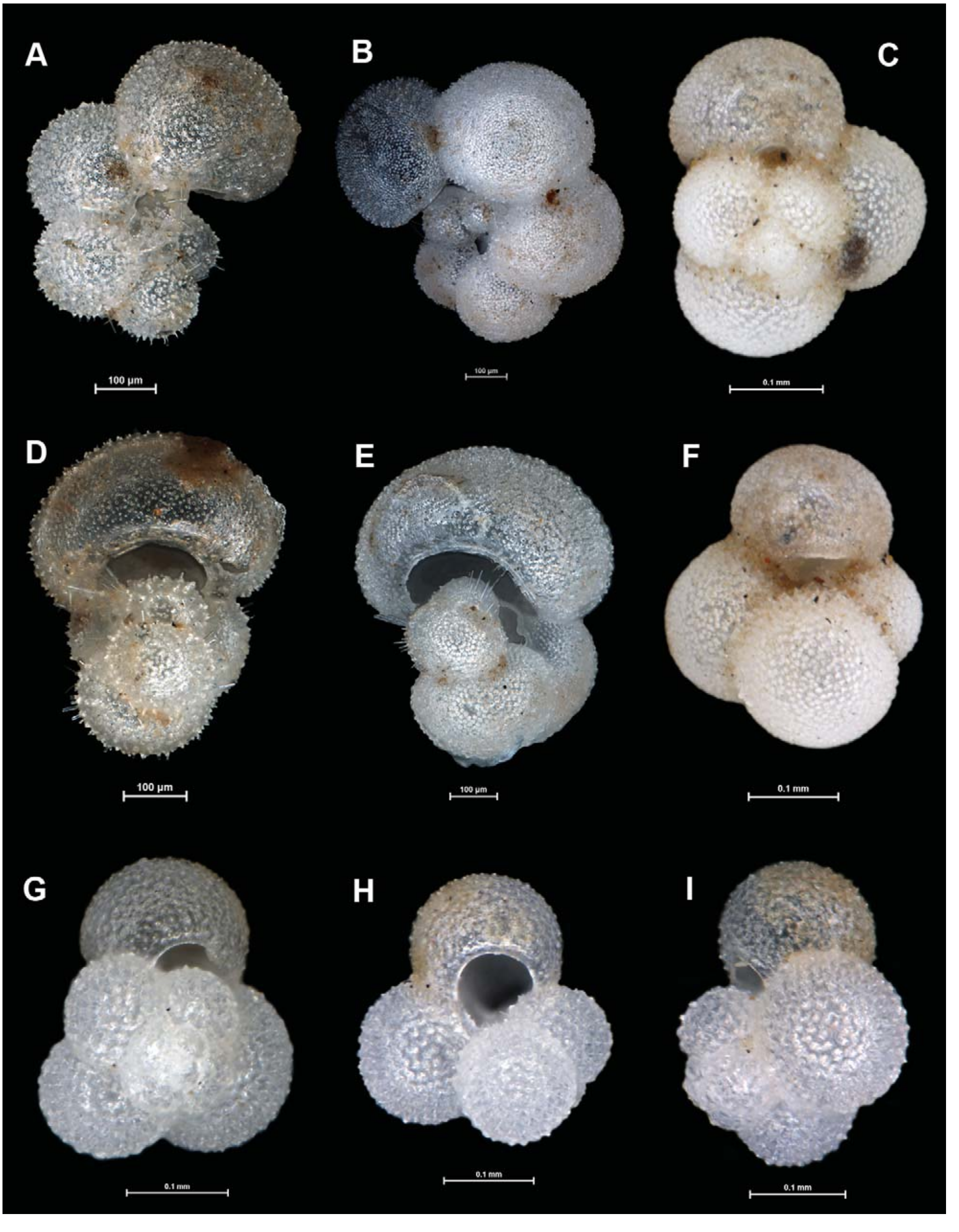

Fig. 7. (A, D) *Globigerinella siphonifera* (d'Orbigny, 1839), sample 26; (B, E) *G. siphonifera*, another specimen from sample 26; (C, F) *Globigerinoides bulloideus* Crescenti, 1966, sample 30; (G–I) *Globigerinoides tenellus* Parker, 1958, sample 6.

Distribution: Known from the Middle Miocene of Italy (Bolli & Saunders 1985). Temperate waters, found in Atlantic Quaternary cores (Bylinskaya, unpubl. data). Very rare, two specimens in our material.

Globigerinoides conglobatus (Brady, 1879)

Figs 8A–D

Globigerina conglobata: Brady 1879: 286; 1884: 603, pl. 80, figs 1–5; pl. 82, fig. 5; Banner & Blow 1960: 6, pl. 4, fig. 4.

Globigerinoides conglobatus (Brady): Drooger 1953: 142; Parker 1962: 229, pl. 3, figs 1–5; Todd 1965: 62, pl. 25, fig. 3; Pflaumann & Krasheninnikov 1978: 889, pl. 4, figs 4–6; Saito *et al.* 1981: 56, pl. 14, figs 1a–d; Cimerman & Langer 1991: 57, pl. 60, figs 6, 7; Bylinskaya *et al.* 2002: 127, pl. III, figs 4, 5.

Alloglobigerinoides conglobatus (Brady): Loeblich & Tappan 1994: 105, pl. 193, figs 5–10; pl. 194, figs 1–3.

Test large, medium to high trochospire, subglobular or subquadrate in outline. In the final whorl there are about 3.5 subspherical chambers, rapidly increasing as added but greatly embracing. Primary aperture umbilical, interiomarginal, a long, low asymmetrical arch; secondary supplementary apertures smaller, arch-shaped openings on spiral side.

Remarks: *G. conglobatus* has a larger and more compact test in adults, and more embracing chambers in juveniles, than does *G. ruber*.

Distribution: Equatorial to temperate waters. It appears in practically half of our samples, in low abundance.

Globigerinoides ruber (d'Orbigny, 1839)

Figs 9A–E

Globigerina rubra: d'Orbigny 1839*a*: 82, pl. 4, figs 12–14; Brady 1879: 286; Banner & Blow 1960: 19, pl. 3, figs 8a–b.

Globigerinoides ruber (d'Orbigny): Parker 1962: 230, 232, pl. 3, figs 11–14, pl. 4, figs 1–10; Todd 1965: 63, pl. 25, fig. 6; Pflaumann & Krasheninnikov 1978: 889, pl. 3, figs 1–6; Saito *et al.* 1981: 59, pl. 15, figs 1a–d; Bolli & Saunders 1985: 196, figs 20.1, 2, 6; Cimerman & Langer 1991: 58, pl. 60, fig. 9; Loeblich & Tappan 1994: 107, pl. 203, figs 1–9; pl. 206, figs 10–12; Basov & Krasheninnikov 1995: pl. V, figs 3, 4; Bylinskaya *et al.* 2002: 128, pl. III, figs 6, 7.

Test small to medium, variable, low or high trochospiral, with 3 characteristic globular chambers in the final whorl and a drop-shaped primary aperture situated symmetrically above suture between two previous chambers. Secondary supplementary apertures are smaller openings on the spiral side. Test may have pink to red pigmentation.

Remarks: The pink-colored forms have not been found in surface sediments of the Indo-Pacific area (Bé & Hutson, 1977; Saito *et al.* 1981), where they have disappeared at about 120 ka (Thompson *et al.* 1979). Many specimens in the Indo-Pacific area which could be considered pink varieties have an early whorl or two of light pink chambers and gradually become white in later chambers (Saito *et al.* 1981).

In our material we also found seven individuals that show aberrant features (Figs 9D, 9E; Table 2). Their tests are medium to large, medium–high trochospiral, very loosely embracing, with 4–5 subglobular slightly flattened chambers in the final whorl. The last chamber is completely detached from the previous whorl and is connected with the penultimate chamber only. The test wall is spinose, strongly perforated. The primary aperture is umbilical, in the form of a broad and deep arch. Secondary apertures are smaller, semicircular or drop-shaped. This form was mentioned as *G. ruber* forma *helicina* (Saito *et al.* 1981: 165, pl. 56, fig. 7), but coiling in our material is markedly looser than illustrated in the aforementioned work.

Distribution: Equatorial to temperate waters, most abundant in the tropical and subtropical areas; it is indicative of warm-water conditions. The species is abundant in our material.

Globigerinoides sacculifer (Brady, 1877)

Figs 8G–I

Globigerina sacculifera: Brady 1877: 535; 1879: 287; 1884: 604, pl. 80, figs 11–17; pl. 81, fig. 2; pl. 82, fig. 4; Banner & Blow 1960: 21, pl. 4, figs 1, 2.
Globigerinoides quadrilobatus sacculifer (Brady): Parker 1962: 229, pl. 3, figs 6–10.
Globigerinoides sacculifer (Brady): Todd 1965: 63–64, pl. 26, fig. 4; Parker 1967: 156–158, pl. 21, figs 1, 2, 4, text-fig. 5; Saito *et al.* 1981: 65–66, pl. 17, fig. 2; Basov & Krasheninnikov 1995: pl. V, figs 8, 9; Bylinskaya *et al.* 2002: 128, pl. IV, figs 1, 2.
Globigerinoides trilobus sacculifer (Brady): Bolli & Saunders 1985: 196, figs 20.13.
Globigerinoides sacculiferus (Brady): Loeblich & Tappan 1994: 107, pl. 205, figs 1–9.

Medium to large, low trochospiral test with 3 to 4 globular chambers in the final whorl. Chambers spherical to slightly flattened radially, very rapidly increasing, partly embracing. Final chamber usually incompletely inflated, having a sac-like appearance. Primary aperture interiomarginal, umbilical, a low but quite wide symmetrical arch; supplementary apertures elliptical or subtriangular.

Remarks: The species differs from *G. trilobus* in the characteristic sac-like shape of the last chamber and in being generally larger.

Distribution: A tropical species, it is an indicator of warm-water conditions. It appears in practically all our samples, in small numbers.

Globigerinoides tenellus Parker, 1958

Figs 7G–I

Globigerinoides tenella: Parker 1958: 280, pl. 6, figs 7–11.
Globigerinoides tenellus: Parker 1962: 232, pl. 4, figs 11, 12; Pflaumann & Krasheninnikov 1978: 890, pl. 4, figs 1–3; Saito *et al.* 1981: 50, pl. 11, figs 2a–d; Bolli & Saunders, 1985: 196, fig. 20.7.
Globoturborotalita tenella (Parker): Loeblich & Tappan 1994: 108, pl. 198, figs 7–15; pl. 204, figs 9–11.

Small trochospiral test with strongly lobate equatorial outline, with 4 globular chambers in final whorl. Subspherical chambers greatly embracing without distinct sutures, rapidly enlarging. Primary aperture umbilical, an open and high arch (almost circular in outline) with a thin lip, secondary aperture(s) small and narrow, but visible on even the smallest specimens.

Remarks: The species differs from *G. rubescens* in having supplementary aperture(s) and a smoother wall, and from *G. ruber* by its more lobulate periphery and low trochospire.

Distribution: Equatorial to temperate waters. The species is never numerous in assemblages, and very rare in our material.

Globigerinoides trilobus (Reuss, 1850)

Figs 8E, 8F

Globigerina triloba: Reuss 1850: 374, pl. 47, figs 11a–c.
Globigerinoides trilobus trilobus (Reuss): Bolli & Saunders 1985: 196, fig. 20.15.
Globigerinoides trilobus immaturus LeRoy: Bolli & Saunders 1985: 196, fig. 20.14.
Globigerinoides sacculifer (Brady): Saito *et al.* 1981: 65, pl. 17, figs 1a–d.
Globigerinoides trilobus (Reuss): Loeblich & Tappan 1994: 107, pl. 206, figs 1–6; Basov & Krasheninnikov 1995: pl. V, figs 5–7; Bylinskaya *et al.* 2002: 129, pl. IV, figs 3, 4.

Test medium in size, with 3–3.5 globular chambers in the final whorl. The primary aperture is in the form of a low, quite wide symmetrical arch.

Remarks: Differs from *G. sacculifer* by its globular last chamber, and from *G. ruber* in the general chamber arrangement and the form of the primary aperture.

Distribution: A tropical species, indicative of warm-water conditions. It appears in practically all our samples, in low abundance.

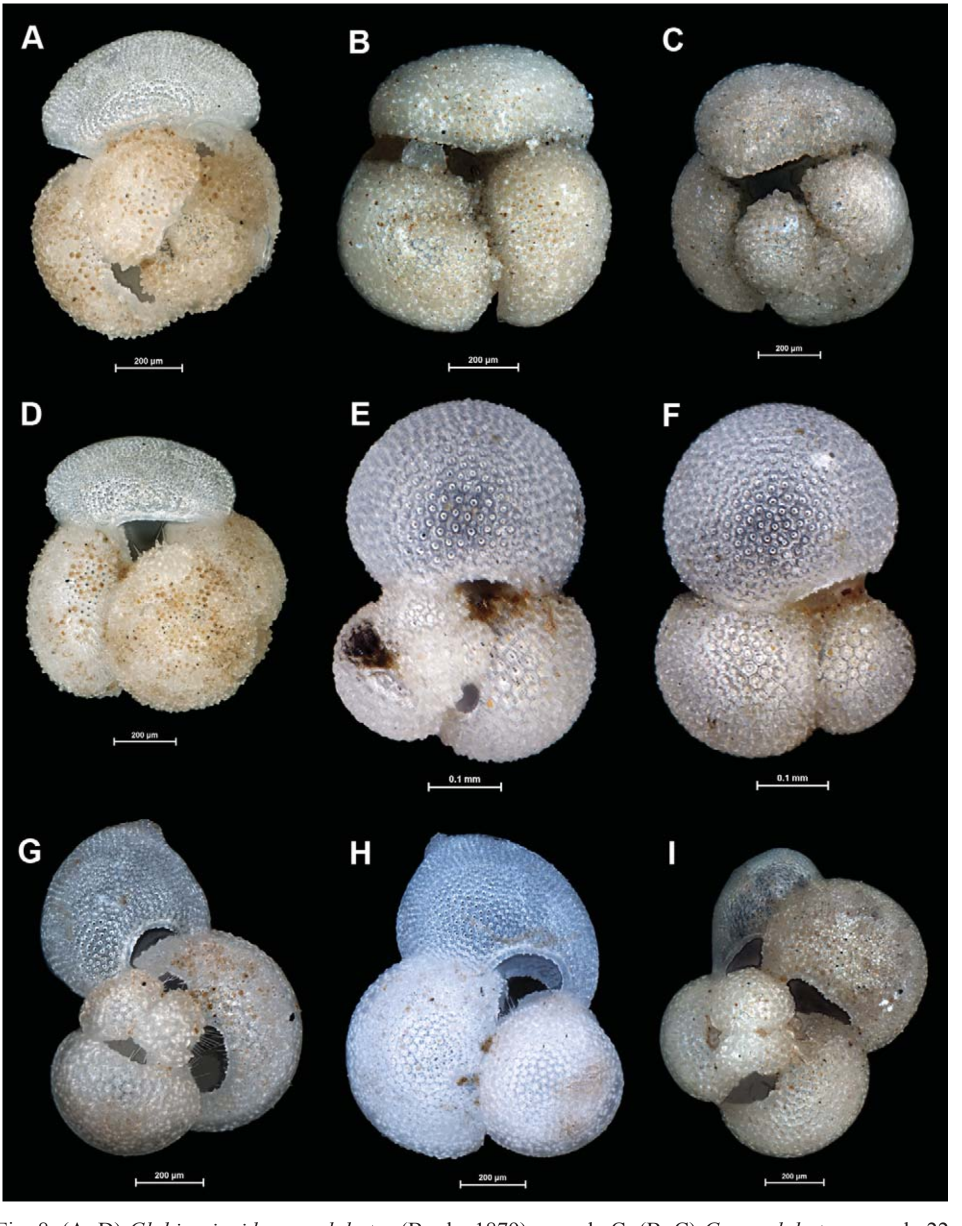

Fig. 8. (A, D) *Globigerinoides conglobatus* (Brady, 1879), sample C; (B, C) *G. conglobatus*, sample 22; (E, F) *Globigerinoides trilobus* (Reuss, 1850), sample 22; (G, H) *Globigerinoides sacculifer* (Brady, 1877), sample 22; (I) *G. sacculifer*, sample 22.

Key to the species of *Globigerinoides* from the Thukela Shelf

1 Test very loosely embracing, with 4–5 subglobular slightly flattened chambers in final whorl; last chamber completely detached from previous whorl (Figs 9D, 9E)..aberrant form of **ruber**
– Test not so loosely embracing or sometimes closely embracing , with at most 4 globular chambers in final whorl; last chamber at least partly attached to previous whorl 2

2 Chambers in final whorl greatly embracing..3
– Chambers in final whorl partly embracing or non-embracing 4

3 Test small with 4 globular chambers in final whorl ....**tenellus**
– Test large or medium with 3.5 subspherical chambers in final whorl......................
.... **conglobatus**

4 One small secondary aperture .... **bulloideus**
– More than one secondary aperture 5

5 Primary aperture characteristically drop-shaped, situated symmetrically above suture between 2 previous chambers ....**ruber**
– Primary aperture as low, quite wide symmetrical interiomarginal arch.................6

6 Final chamber globular .... **trilobus**
– Final chamber subglobular, sac-like... **sacculifer**

Genus *Sphaeroidinella* Cushman, 1927

Sphaeroidinella dehiscens (Parker & Jones, 1865)

Figs 9F, 9G

Sphaeroidinella bulloides d'Orbigny var. *dehiscens*: Parker & Jones 1865: 369, pl. 19, figs 5a–b.
Sphaeroidina dehiscens Parker & Jones: Brady 1884 (part): 621, pl. 84, figs 9–11 (not fig. 8).
Sphaeroidinella dehiscens (Parker & Jones): Cushman 1927a, 90, pl. 19, fig. 2; Parker 1962: 234, pl. 5, figs 1, 2; Todd 1965: 67–68, pl. 26, figs 5, 6; Saito *et al.* 1981: 72, 74, pl. 20, figs 2a–d; Bolli & Saunders 1985: 244, figs 39.1–8; Basov & Krasheninnikov 1995: pl. V, figs 11, 12; Bylinskaya *et al.* 2002: 137, pl. IV, fig. 10.

Remarks: This species demonstrates a very wide variation in the size and shape of the test, and in the development of apertures.

Distribution: Equatorial to tropical waters, warm-water species. We found three specimens in our material.

Subfamily Orbulininae Schultze, 1854

Genus *Orbulina* d'Orbigny, 1839

Orbulina universa (d'Orbigny, 1839)

Fig. 9H

Orbulina universa: d'Orbigny 1839*a*: 3, pl. 1, fig. 1; Brady 1879: 289; Saito *et al.* 1981: 70, pl. 19, figs 1a–d, 2a–b, 3a–b, 4–6; Loeblich & Tappan 1987: 494, pl. 541, figs 1–6, 8–11 (not fig. 7); Cimerman & Langer 1991: 58, pl. 60, fig. 8; Loeblich & Tappan 1994: 109, pl. 211, figs 4–7; Basov & Krasheninnikov 1995: pl. V, fig. 10.
Globigerina bilobata d'Orbigny, 1846: 164, pl. 9, figs 11–14; Brady 1879: 290; Banner & Blow 1960: 2–3, pl. 3, fig. 9.

Test large, spherical. Wall very thin, coarsely perforated with pores of two distinct sizes.

Remarks: This species is very distinctive in having two life stages, viz. a multichambered trochospiral stage followed by a single-chambered spherical stage (Bé *et al.* 1973). However, the trochospiral form was not found in our material.

Distribution: Equatorial to temperate waters. Exceptionally abundant in our material.

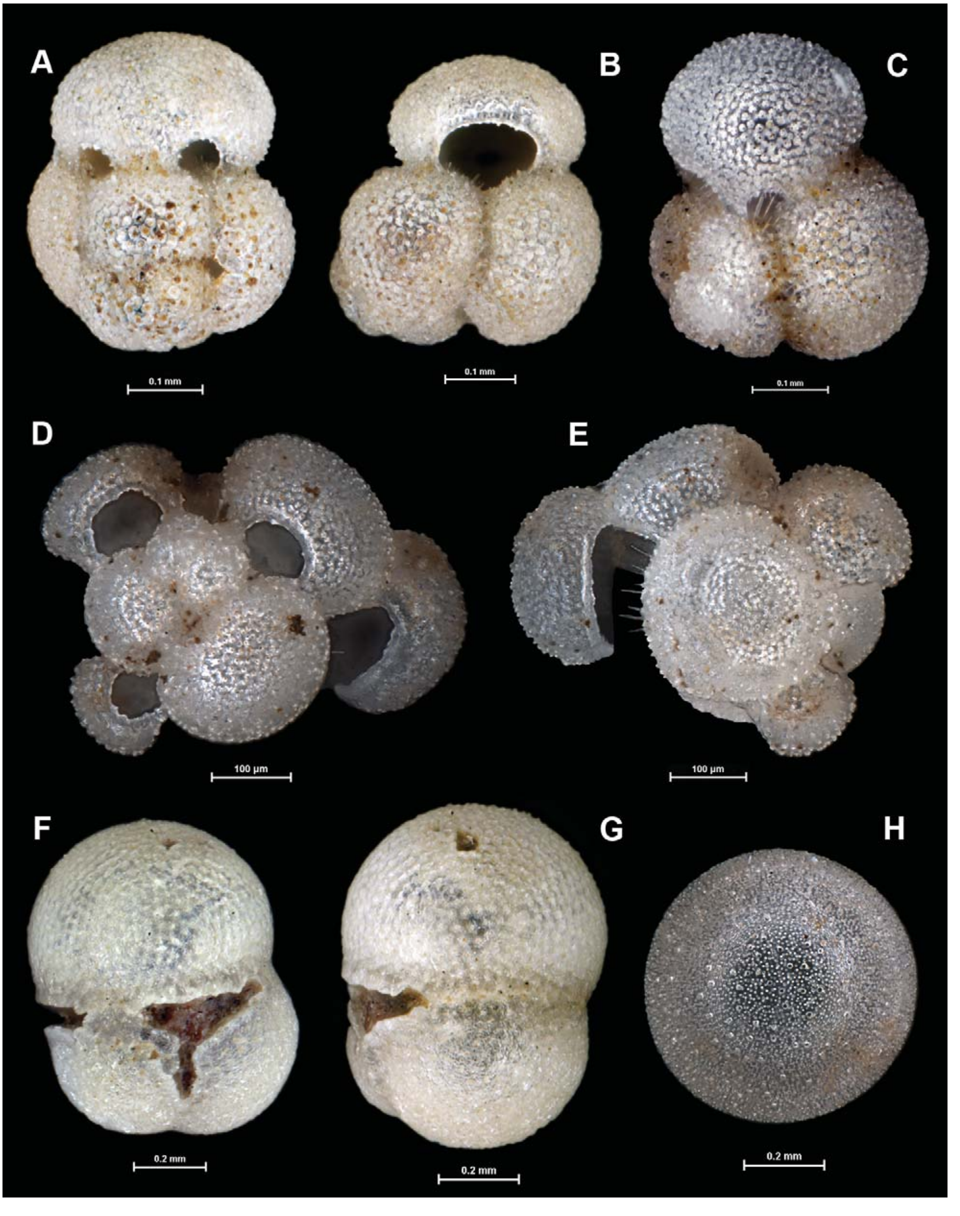

Fig. 9. (A, B) *Globigerinoides ruber* (d'Orbigny, 1839), sample 22; (C) *G. ruber*, sample TB34; (D, E) *G. ruber* (aberrant form), sample 8; (F, G) *Sphaeroidinella dehiscens* (Parker & Jones, 1865), sample 30; (H) *Orbulina universa* (d'Orbigny, 1839), sample C.

DISCUSSION

With a total of 23 species identified in this study from a small area of the subtropic/tropic fauna (Bé & Hutson 1977) (Table 2), the assemblage of planktonic foraminifers in surface sediments on the Thukela Shelf is as rich as assemblages from the south-western continental margin of the whole of southern Africa. Giraudeau (1993) reported 23 species off South Africa and Namibia, a region which includes two different biogeographic zones, i.e. transitional and subtropical (Bé & Hutson 1977).

In the identified assemblage, warm-water species are dominant (*Orbulina universa*, *Globigerinoides ruber* and *Neogloboquadrina dutertrei*) or subdominant (*Globigerinoides trilobus* and *Globigerinella siphonifera*). This is characteristic of tropical–subtropical areas (Bé & Tolderlund 1971). *G. ruber* prevails over *Globigerinoides sacculifer* in subtropical waters and along continental margins (Bé & Hutson 1977).

Although all our samples represent shallow-water sediments, species with very different depth preferences have been found. The studied assemblage is characterized by a high proportion of *Globigerinoides ruber* (>20 %), with *G. trilobus*, *G. sacculifer* and *G. conglobatus* being less abundant. These species prefer the upper part of the euphotic zone (Venéc-Peyré *et al*. 1995; Schiebel *et al*. 2004). Although *Globigerina quinqueloba* and *G. rubescens* are known as surface species as well, they are very rare in our material. Deep-water species (*Globorotalia menardii*, *G. tumida*, *G. inflata*, and *Sphaeroidinella dehiscens*) are generally exceptionally scarce, with the exception of *Neogloboquadrina dutertrei* that reaches over 11 % in the assemblage. *Orbulina universa*, *Globigerinella siphonifera*, *Globigerina bulloides*, *Globigerinita glutinata*, and *Pulleniatina obliquiloculata* do not show a strong preference for particular depths within 300 m of water column (Bé & Tolderlund 1971).

The taxonomic diversity of the planktonic foraminifers generally increases toward the outer shelf across the Thukela Shelf. This is hardly surprising, as these unicellular organisms prefer normal marine conditions.

In general, the planktonic foraminiferal assemblage of the Thukela Shelf agrees with the distributional pattern of species drawn by Bé and Hutson (1977), with several insignificant exceptions. Thus, the proportion of *Globigerinella siphonifera* is approximately the same as expected, whereas the proportions of *Globigerinita glutinata*, *Globigerinoides sacculifer* and *Globorotalia inflata* are slightly lower than those shown by Bé and Hutson (1977), although these authors analysed a different size fraction. These variations are most probably of little value, since the distribution of planktonic forams often demonstrates patchiness (Boltovskoy 1971).

The most striking oddity is a proportion of *O. universa*, which constitutes over 32 % of the total Thukela Shelf assemblage. Earlier researchers (Bé *et al.* 1973; Bé & Hutson 1977) reported much lower occurrences of this species east of South Africa, with its share not exceeding 5 % in sediment ("fossil") assemblages. *O. universa* is considerably more abundant (up to 10 %) in live plankton assemblages east of Kenya and south of Madagascar, and is believed to be associated with water temperatures between 18 and 24 °C, surface salinities 35.5–36.0 ‰, dissolved oxygen 4.8–5.1 ml/l, and low phosphate concentration (*ca* 0.3 µg/l) (Bé *et al.* 1973; Bé & Hutson 1977).

Our results may reflect changes in ocean conditions since the previous study (Bé & Hutson 1977), or may show the influence of the Agulhas Current, which brings pools of *O. universa* to the KwaZulu-Natal waters. On a smaller scale, *O. universa* is substantially

TABLE 2
Quantitative distribution of planktonic foraminifer species from the Thukela Shelf.

species/samples	**2**	**4**	**6**	**8**	**10**	**12**	**15**	**19**	**22**	**23**	**25**	**26**	**30**	**A**	**B**	**C**	**TB7**	**TB20**	**TB22**	**TB32**	**TB34**
Globorotalia cultrata			R	R		R		R	R	R	C	F	C	R	R	R					
G. inflata											R	R	R							R	R
G. menardii											R	R	R								
G. tumida												R									
G. ungulata								R	R	R	C	R	R	R		R		R			
Neogloboquadrina dutertrei	R	R	C	R	R	C	F	F	C	C	C	F	C	C	R	F	R	C	F	C	C
N. incompta							R				R										
Pulleniatina obliquiloculata			R			R	R	R	R	R	R	R	R			R	R		R	R	R
Globigerinita glutinata	C	R				R		R		C	R	C	R		R	R		R	R	R	
Globigerina bulloides		R					R		R		R		R		R			R	R	R	
G. falconensis									R		R		R	R	R			R	R		
G. quinqueloba	R																				
G. rubescens											R		R			R	R	R	R	R	
Globigerinella calida		R	R		R	R				C		R	C	R	R		R	R	C	C	R
G. siphonifera	R	R	F		R	R	F	F	F	C	C	A	A	A	R	C	R	R	R	C	R
Globigerinoides bulloideus											R		R								
G. conglobatus			R		R	R	R	R	C	R	R	F	R			R					
G. ruber	C	F	F	C	C	F	F	F	C	A	F	A	A	F	F	A	F	F	A	F	F
G. ruber (aberrant form)		R		R			R			R	R			R							R
G. sacculifer		R	R	R		R	R	R	C	R	C	F	C		R	C		R	R	R	R
G. tenellus			R	R				R					R						R	R	
G. trilobus	R	R	C	C	R	R	R	R	R	R	R	R	F	R	R	R	R	R	C	C	C
Sphaeroidinella dehiscens											R		R		R						
Orbulina universa	C	C	R			F	A	A	A	A	A	A	A	R	F	A	R	R	R	R	R

more abundant at sampling sites on the outer Thukela Shelf (e.g., samples 15, 19, 22, 23, 25, 26, 30, and C; Fig. 2), away from fresh water influx. This agrees well with the ecological requirements of the species, which prefers cooler temperatures and normal/elevated salinities, and again, may reflect the direct influence of the Agulhas Current.

The Agulhas Current may also be responsible for the appearance of *Globorotalia menardii* (Figs 3B, 3E) in sediments on the Thukela Shelf, although as isolated specimens. This species occurs predominantly in the equatorial region, the Arabian Sea, the Gulf of Aden, and the Bay of Bengal (Bé & Hutson 1977), but may be transported by currents over large distances (Schiebel & Hemleben 2005).

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