EXCELLENT PUBLISHERS

International Journal of Current Research and Academic Review

ISSN: 2347-3215 Volume 2 Number 11 (November-2014) pp. 74-85

www.ijcrar.com

A note on *Globigerina helicina* (d'Orbigny) – A rare deep-sea planktic foraminifer from the Bay of Bengal

N. Rajeshwara Rao* and P. Kamatchi

Department of Applied Geology, University of Madras, Guindy Campus, Sardar Patel Road, Chennai 600 025, India

Corresponding author

KEYWORDS

Weather parameters, trend pattern, people perception, climate change

A B S T R A C T

Planktic foraminifera constitute a significant component of the deep-sea sediment and are of great utility for various applications in oceanographic and paleoceanographic studies. Although there are only ~40 extant planktic foraminiferal species in the present-day oceans and seas, only some of them are relatively more abundant. A few are very rare, with sporadic records over the last two centuries and more; one such taxon is *Globigerina helicina* (d'Orbigny) and is reported for the first time from deep-sea sediments from the Bay of Bengal. Two short cores were retrieved from off Chennai at water depths of 2,004 m and 3,042 m, respectively, and analysis of planktic foraminiferal content revealed the presence of *G. helicina* only in the latter core, suggesting its comparatively deeper abyssal habitat.

Introduction

Foraminifera are found in all marine environments, and they may be planktic or benthic in mode of life. The generally accepted classification of the foraminifera is based on that of Loeblich and Tappan (1987). The Order Foraminiferida (informally foraminifera) belongs to the Kingdom Protista, Subkingdom Protozoa, Phylum Sarcomastigophora, Subphylum Sarcodina, Superclass Rhizopoda, Class Granuloreticulosea. Foraminifera are testate (i.e. they possess a shell) protozoa, (single-celled organisms characterized by the absence of tissues and organs), which possess granuloreticulose pseudopodia (i.e. thread-like extensions of the ectoplasm, often including grains or tiny particles of various materials). Bi-directional cytoplasmic flow along these pseudopodia carries granules which may consist of symbiotic dinoflagellates, digestive vacuoles, mitochondria and vacuoles containing waste products. These processes are, however, still not fully understood. In the planktic foraminifera *Globigerinoides sacculifer*, dinoflagellate symbionts are transported out to the distal parts of rhizopodia in the morning and are returned back into the test at night. The name Foraminiferida is derived from the foramen, the connecting hole through the wall (septa) between each chamber.

Planktic foraminifera are unicellular organisms with a complex cell and genetic material within a cell nucleus. They live floating in the surface waters of the open ocean, and secrete a calcium carbonate test. Planktic foraminifera in the Recent oceans can be divided in two groups: one groups that bears very long, thin calcite spines, the other group that does not. Many of the spinose foraminifera have symbiotic algae living within their protoplasm. During the day time, they let these algae outside the shell, so that the algae photosynthesize, and the foraminifera can take up their waste products. At night, they haul them in again. All foraminifera, including the ones with symbionts, also eat pretty much all creatures smaller than themselves. Some foraminifera appear to prefer algae, other microscopic animals. Foraminifera have sticky pseudopods (long, thin streamers of protoplasm), with which they grab food and place it in contact with their protoplasm, which engulfs their prey and digests it.

Planktic foraminiferal studies in India

Studies on Recent foraminifers in the Indian region were initiated by Chapman (1895) who reported 274 species from the *Investigator* collections made off the Laccadives, in the Arabian Sea. Later, a monograph of foraminifers from the Arabian Sea was published by Hofker (1930). Setty and Guptha (1972) reported 15 species of planktic foraminifera from the sediments off Karwar and Mangalore. Kameswara Rao (1973) presented a quantitative distribution of planktic foraminifera in the south-west coast of India; he recorded 26 planktic foraminiferal taxa and concluded that the Arabian Sea has greater species diversity than the Bay of Bengal attributable, perhaps, to greater salinity in the former. Zhang (1985) opined that living planktic foraminifera are governed by upwelling seasonally and spatially than by sea temperature and latitude in the eastern Arabian Sea. The ecologic distribution of four abundant species of planktic foraminifers-*Globigerina bulloides*, *Globigerinoides ruber*, *Globigerinoides triloba* and *Neogloboquadrina dutertrei*- from the bottom sediments of the north-western part of the Bay of Bengal was studied by Elonee Pal (1988).

Divakar Naidu and Guptha (1989) analyzed a set of seven core tops from the western equatorial Indian Ocean for planktic foraminifera, and recorded 20 species, among which *Globorotalia menardii*, *Globigerinoides sacculifer* and *Gs. ruber* constituted the majority of the population. From the distribution of foraminifera, they observed that the tropical fauna gradually and progressively decreased from 6° N latitude to 21° S latitude from 98.9 to 58.2%, while the sub-polar fauna showed upward trend in its abundance from 38% at 21° S latitude to 0.8% at 6° N latitude. Three warm and two cold episodes were identified by Divakar Naidu *et al*. (1989) based on an investigation on planktic foraminifera and $CaCO_3$ content of a box core collected at a depth of 2,556 m from the southern part of the Arabian Sea, indicating faunal changes depicting Quaternary climatic fluctuations.

Twenty-one surficial sediment samples were analyzed for planktic foraminifera, radiolarians, $CaCO_3$ and organic carbon by Divakar Naidu (1990), who suggested that the sediments recorded an upwelling signature. Based on the relative abundance of planktic foraminifera and radiolarians, and the concentration of $CaCO_3$ and organic carbon, he concluded that the intensity of upwelling was greater on the upper slope

(>1,000 m) than on the lower slope region (<1,000 m).

Guptha *et al*. (1990) examined 39 vertical zooplankton hauls from the south-eastern Arabian Sea for living planktic foraminifera and reported 28 species, with the standing crop being highest off the Cape Comorin coast. They observed the presence of two assemblages indicative of upwelling off the Kerala coast and south of Cape Comorin, respectively. Divakar Naidu (1991) studied two cores collected in the eastern Arabian Sea for coarse fraction, $CaCO_3$ content and *Globorotalia menardii* complex abundance. Based on the fluctuations of $CaCO_3$ and *G. menardii* complex abundance, he placed the Holocene/Pleistocene boundary at 50 cm level from the top of the core and the Last Glacial Maximum (LGM) at 80 cm depth for the northern Arabian Sea core. He also suggested that the carbonate maxima with less abundance of *G. menardii* complex reflected glacials (cold periods), while carbonate minima with high abundance of *G. menardii complex* reflected inter-glacials (warm periods).

The ecology and distribution of Recent planktic foraminifera in the eastern part of the Arabian Sea were studied by Kameswara Rao *et al.* (1991); they recorded 30 living planktic foraminiferal taxa from 97 plankton tow samples. According to Curry *et al*. (1992), planktic foraminifera collected in sediment traps in the Arabian Sea during 1986 and 1987 responded to the southern Asian monsoon in the form of changes in productivity, relative abundance of species and isotopic shell chemistry. They observed that most of the species increased in flux shortly after the advent of the south-west monsoon. Analysis of 63 sediment samples from the western continental margin of India for planktic foraminifera, organic carbon, biogenic silica and calcium carbonate content showed higher frequency (30-40%) of *Globigerina bulloides* and high organic carbon (3%) coinciding with higher primary productivity (1 g C m^{-2} day^{-1}) in the south compared to lesser (20-30%) abundance of *G. bulloides* and organic carbon (1-2%) and moderate productivity (0.5-0.75 g C m^{-2} day^{-1}) in the north (Divakar Naidu *et al*., 1992). Kameswara Rao *et al.* (1992) recorded 25 planktic foraminiferal taxa from 36 plankton tows in the Arabian Sea, and observed that the fauna has, in general, a close affinity with that of equatorial waters of the world. Distribution patterns of Recent planktic foraminifera in surface sediments of the western continental margin of India, revealed the ecological preferences of the different planktic foraminifera species (Divakar Naidu, 1993). He observed that higher offshore absolute abundance of planktic foraminifera was associated with the lower frequencies of the productivity indicator *Globigerinoides bulloides*, while their lower nearshore absolute abundance coupled with higher frequencies of *G. bulloides*. He suggested productivity did not control the absolute abundance of planktic foraminifera in the area.

According to Divakar Naidu *et al*. (1999), variations in the abundances of *Globigerina bulloides* and *Neogloboquadrina dutertrei* in the sediment cores of Arabian Sea and Bay of Bengal can trace the intensity of paleoupwelling and river discharge and thereby associated summer monsoon intensity and productivity changes in the northern Indian Ocean. Divakar Naidu and Niitsuma (2003) performed oxygen and carbon isotopic analyses on the tests of *Globigerina bulloides* and *Pulleniatina obliquiloculata* to study the evolution of surface and bottom water hydrographic changes associated with summer monsoon upwelling process at the Oman Margin over the last 19,000 years. According to Nigam *et* *al*. (2003), the life spans of planktic foraminifera are vital in view of their increasing use for paleoclimatic studies. They proposed the use of sediment trap technique to get better estimates of life spans of planktic foraminifers and, on the basis of sediment trap results, they observed the life spans of planktic foraminiferal species to be of the order of few months instead of few days to few weeks, as reported earlier.

Similar analyses were performed by Divakar Naidu (2004) on the tests of *Globigerina bulloides*, *Globigerinoides sacculifer*, *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata* to study $\delta^{18}O$ and $\delta^{13}C$ of shallow and deeper-living planktic foraminiferal species. He suggested that both $\delta^{18}O$ and $\delta^{13}C$ of surface and subsurface living foraminifera could be used as isotope indices of upwelling in the Arabian Sea. Divakar Naidu and Malmgren (2005) reconstructed the annual, summer, and winter sea surface temperatures (SSTs) in the western Arabian Sea over the last 22,000 years using artificial neural networks (ANNs) based on quantitative analyses of planktic foraminifera. Down-core SST estimates revealed that annual, summer, and winter SSTs were 2.0, 1.2, and 2.6° C cooler, respectively, during the last glacial period than in the Holocene.

Divakar Naidu (2007) summarized the influence of monsoon-driven upwelling on the planktic foraminiferal species abundances, coiling directions of *Globigerinoides bulloides* and *Neogloboquadrina pachyderma* and size variations of selected planktic foraminiferal species, and carbon isotopic composition of *G. bulloides*. Calcite dissolution in marine sediments is known to be driven by the degree of saturation state with respect to $CaCO_3$, of overlying bottom waters. Three paleocarbonate ion proxies – planktic foraminifer size index, shell weight and calcite crystallinity – were applied to a set of core top samples by Naik and Divakar Naidu (2008). Their studies revealed commencement of calcite dissolution from 2,250 m onwards and its intensification ~3,900 m water depth in the western tropical Indian Ocean.

Anand *et al*. (2008) studied two sedimentary cores from the western (water depth of 1,586 m) and eastern Arabian Sea (840 mm) to study past (SSTs) and seawater $\delta^{18}O$ ($\delta^{18}O_w$) variations for the past 35,000 years by coupling Mg/Ca-$\delta^{18}O$ calcite variability in two planktic foraminiferal species: *Globigerinoides ruber*, which thrives throughout the year, and *Globigerina bulloides*, which occurs mainly when surface waters contain high nutrients during upwelling or convective mixing. Based on Mg/Ca in *G. ruber*, they inferred that SSTs in both areas were 3 to 4° C lower during the Last Glacial Maximum (~21,000 years ago) than today and the Holocene period. The SST records based on *G. bulloides* also indicated general cooling, down to 18° C in both areas. Moreover, the SSTs in the western Arabian Sea based on *G. bulloides* were always lower than those based on *G. ruber*, indicating the presence of strong seasonal temperature contrast during the Holocene and LGM.

Shell weights of *Globigerinoides sacculifer* and Mg/Ca ratios in *G. ruber* were measured from an Arabian Sea sediment core by Naik *et al*. (2010), who recorded an inverse relationship between the two parameters. The results revealed that shell weights are mainly controlled by surface water $[CO_3^{=}]$ rather than calcification temperature. Based on the excellent correspondence between shell weight and CO_2 concentrations in an Antarctic ice core, they suggested that shell weights of *G. sacculifer* could be used as a proxy to reconstruct atmospheric CO_2 concentrations in the past.

Paired measurements of $\delta^{18}O$ and SST utilizing *Globigerinoides sacculifer*, an upper mixed layer dwelling foraminifer, were used by Mahesh *et al*. (2011) to report changes during the last 32,000 years in the Lakshadweep Sea (south-eastern Arabian Sea). The 552 cm long core was retrieved at a water depth of 2,300 m, and the upper 150 cm of it was studied by them. Based on census counts of planktic foraminifers by using the ANN technique, Godad *et al*. (2011) estimated downcore variations in SST during May and August in a core, and showed that the timing of intense upwelling in the western Arabian Sea has varied over the last 22,000 years. Naik *et al*. (2013) estimated the shell weights of *Globigerinoides ruber* in the size range of 300–355 μm from sediment traps in the western and eastern Arabian Sea, which represent upwelling and non-upwelling conditions, respectively. Their results revealed that shell weights of *G. ruber* versus flux showed significant correlation at both the sites, implying that shell calcification mainly depends on optimal growth conditions.

Recently, Naik *et al*. (2014) have reported coeval increase in productivity and denitrification from ~7 to 0 kyr in the eastern Arabian Sea, coinciding with minimum dissolved O_2 levels in bottom waters, increased $CaCO_3$ dissolution, diminishing shell weights of *G. ruber* with well-marked dissolution features on its tests. Based on their results, they emphasized the role of OMZ in governing $CaCO_3$ dissolution and contributing to an increase in atmospheric CO_2. In another recent study, specimens of *G. ruber* from the last 22,000 years were analyzed by Naik and Divakar Naidu (2014) for B/Ca, $\delta^{18}O$ and Mg/Ca. B/Ca was compared to reconstructed salinity and sea surface temperature (SST) records, to gain insight into the processes controlling the incorporation of boron. They have concluded that that temperature governs the incorporation of boron in *G. ruber* to some extent, but have seriously doubted utility of B/Ca ratio as a pH or CO_2 proxy.

Methodology

The National Institute of Ocean Technology (NIOT) has developed an automated, remotely operable submersible that has the capability to retrieve short cores up to 40 cm length at water depths ranging up to 6,000 m. The ROSUB-6000 retrieved two short cores of lengths of 12 cm and 30 cm; the first was collected at a water depth of 2,004 m (Core A), while the second was retrieved from 3,042 m (Core B). Both these cores have been used in the present study. The locations of the drilling sites in the Bay of Bengal, off Chennai, are shown in Figure 1. All the cores were sub-sampled at 2 cm intervals and the sub-samples were obtained from the National Institute of Ocean Technology (NIOT) with the kind co-operation of Dr. G. A. Ramadass, Project Director, Scientist-F, and Dr. S. Ramesh, Scientist-E, of the Submersibles Division. Dissolved oxygen (DO in $ml.l^{-1}$) and temperature (in °C) profiles (raw data) were also provided by the NIOT.

Each sub-sample was subjected to deflocculation (made to stand overnight) using sodium hexametaphosphate (Calgon) solution. The sub-samples were then wet-sieved through ASTM 230 mesh (opening = 63 μm) to remove the mud content (silt + clay). The sub-samples were then oven-dried at 50° C. It was observed that the residue had very little sediment (sand content) and was almost entirely comprised of several foraminiferal tests, few ostracod carapaces, diatoms and radiolarians. There was, therefore, no need for grain size-based fractionation of the sub-samples. The dried sub-samples were examined under a stereo zoom binocular microscope (NIKON SMZ-1B), and foraminifers were hand-picked using a soft-bristled brush (preferably a 0.00 brush).

The handpicked foraminiferal tests from each sub-sample were transferred to 24-chambered micropaleontological slides and mounted over a thin layer of tragacanth gum according to the family, genus and species, wherever possible. The different genera and species were identified; type specimens of each species were selected and transferred to single or double round punch microfaunal slides with cover slips. The taxa were identified using the widely utilized generic classification proposed by Loeblich and Tappan (1987).

Systematic paleontology

A species has been regarded as the sum-total of specimens sharing all test characters, with such measurable, countable, or otherwise observable, variation in size and shape of some elements or of proportions between the latter in different ontogenic stages, which fits a pattern of normal distribution and whereby these specimens are separable from other similar groupings regarded as distinct species (Hottinger *et al.*, 1993). Twenty-one planktic foraminiferal taxa have been identified, but this research paper is devoted one very rarely recorded species, *Globigerina helicina* (d'Orbigny), with a peculiar morphology.

Suborder GLOBIGERININA Delage and Hérouard, 1896
Superfamily GLOBIGERINACEA Carpenter, Parker and Jones, 1862
Family GLOBIGERINIDAE Carpenter, Parker and Jones, 1862
Subfamily GLOBIGERININAE Carpenter, Parker and Jones, 1862
Genus GLOBIGERINA d'Orbigny, 1826
Globigerina helicina (d'Orbigny)

Original citation: *Polymorpha globulifera* SOLDANI, 1791, v. 1, pt. 2, p. 119, pl.130, figs. rp, qq, rr.
Globigerina helicina d'Orbigny, 1826, Ann. Sci. Nat., v. 7, p. 277, no. 5;– Weaver, 1841, v. 18, no. CXIX, pp. 452, 453;– Parker, Jones and Brady, 1871, Ann. and Mag. Nat. Hist., ser. 4, v. 8, p. 175, p1. 11, fig. 113;– Brady, 1879, Quart. Jour. Micr. Sci., v. 19, N. S., p. 287;– Brady, 1884, p. 605, pl. 81, figs. 4, 5; pl. 11, fig. 15;– Bagg, 1908, Proc. U. S. Natl. Mus., v. 34, p. 154;– Cushman *et al*., 1910, FNP 1914, p.12, pl. 3, figs. 1, 2;– Heron-Allen and Earland, 1922, British Antarctic Expedition (Terra Nova), Nat. Hist. Rept., Zool., v. 6, no. 2, pp. 190, 192;– Barker, 1960, p. 168, pl. 81, figs, 4, 5;– Banner and Blow, 1962, p. 98; – Todd and Low, 1976, U.S.G.S. Prof. Paper, no. 863, p. 18, 19, pl. 11, fig. 15a, b;- Banchetti, Gradoni and Dini, 2008, Biol. Mar. Mediterr., v. 15 (suppl.), p. 21.

Remarks: The type material for this species came from the beach sands of Rimini in Italy (d'Orbigny, 1826). According to Barker (1960), "the *Globigerina helicina* of d'Orbigny possesses characters which entitle it to rank as a zoological variety, and whether the forms it includes would not be better treated as examples of monstrous or abnormal development. Nevertheless the peculiar features of the test are tolerably constant. It most resembles an ordinary small Globigerine shell of the "rubra" type, with the addition of an inflated chamber at two opposite points of its periphery. The superior face is obscurely spiral, and shows two, three, or more apertures; the inferior has four visible segments, two large and oblong, laid side by side, and two small and rounded, one at each end of the test; and the latter have inferior apertures. Of the figures in Soldani's Testaceographia, referred to by d'Orbigny, that marked *qq*, which gives both the superior and inferior aspects of the shell, is the most characteristic, and leaves nothing to be desired in point of definition. It is interesting to note that examples precisely analogous, from a morphological point of view, to those upon which this variety is founded, occur in other genera of the Globigerinidæ, notably in *Pullenia* and *Candeina* (Pl. LXXXIV. fig. 19, and Pl. LXXXII, fig. 19)".

Results and Discussion

A thorough review of literature shows that *Globigerina helicina* (d'Orbigny) has had only sporadic records since as far back as 1791. According to Weaver (1841), this species was found "living in the Adriatic Sea and the Ocean"; he observed it to be present as fossil in the white chalk of Cattolica and remarked, "Ehrenberg had referred, with a mark of interrogation, four species of calcareous-shelled Polythalamia to the white chalk of Cattolica, in which they are very extensively distributed: *Globigerina bulloides*, *Globigerina helicina*, *Rosalina globularis* and *Textularia aciculata*".

On *Globigerina helicina*, Brady (1879) had remarked, "is an anomalous oblong form and one rarely met with. It is not easy to describe it intelligibly without the aid of figures. It most resembles an ordinary small Globigerine shell, with the addition of a little inflated chamber at two opposite points if its periphery.

The superior surface is obscurely spiral and shows two, three, or more apertures. The inferior side has four visible segments; two large and oblong, laid side by side, and two small and inflated, one at each end of the test; the latter have inferior apertures. It is possible that *Gl. helicina* may represent a monstrous condition rather than one of the more permanent varieties of this type". Bagg (1908) reported it to be rare in both the North and South Atlantic and the South Pacific oceans; in fact, he recorded it at only one hydrographic station at a water depth of ~671 m.

In their monumental work on Protozoa, Heron-Allen and Earland (1922) remarked, "At the dominant Stations large numbers of abnormal and wild growing specimens occur, ranging between double individuals inseparable from *G. helicina* to 'sports' in which individual chambers are malformed and tubular, in fact the species seems more subject to these biological malformations than any other Globigerinae". "The specimens at Station 6 are poor, at the others much more distinctive, especially at Station 18.

Brady has already questioned the specific value of this species, which he was inclined to regard as merely a monstrous variety of other species. The evidence from this material strongly supports this. At Stations where *G. helicina* occurs *G. dutertrei* is a predominant form, and nearly all our specimens of *G. helicina* show at least one character characteristic of *G. dutertrei*. Brady's figures, on the other hand, suggest a *G. conglobata* origin". They recorded this species at variable water depths, ranging from 70 to 2,216 fathoms off the east coast of New Zealand (~128 to ~4,053 m).

Barker (1960) also observed this species to be relatively rare, with tests of this species recovered from sediment samples dredged at 9–10 stations scattered over the North and South Atlantic and the South Pacific oceans, as well as in the Mediterranean and the Adriatic seas.

Figure.1 Map showing the locations of the two cores, A and B

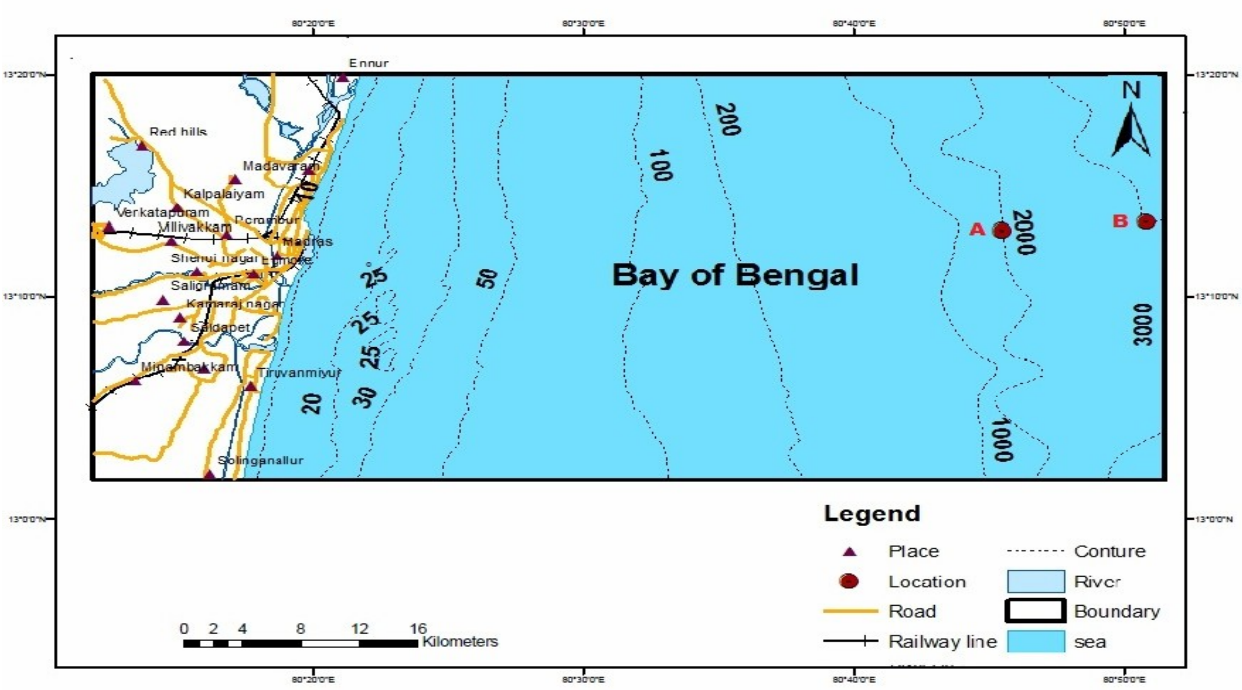

Table.1 Downcore populations of *G. helicina* (d'Orbigny) in Core B

S. no.	Depth (cm)	No. of tests
1	0–2	3
2	2–4	0
3	4–6	0
4	6–8	2
5	8–10	0
6	10–12	0
7	12–14	0
8	14–16	2
9	16–18	0
10	18–20	1
11	20–22	0
12	22–24	0
13	24–26	0
14	26–28	0
15	28–30	0

According to Banner and Blow (1962), the only known members of the Globigerinidae which grossly resemble *Globigerina turrilitina turrilitina* are *Globigerina praeturritlina*, *Globigerina helicina* d'Orbigny and *Globigerinoides mitrus* (Todd, 1957) from the Burdigalian Tagpochau Limestone of Saipan. *Globigerina helicina* (d'Orbigny) has less globular chambers, a less lobulate periphery, a lower dorsal spire, and a less hispid test than *G. turrilitina turrilitina* (Blow and Banner, 1962).

Dabrio *et al*. (1972) recorded this species and remarked, "We believe that this form can be identified, with certain reserve, with *Globigerina helicina* d'Orbigny, as per Banner and Blow (1960). There is, however, the presence of a lip and relatively more oval chambers". Todd and Low (1976) found this species to be rare as well, occurring as scattered specimens at various water depths off St. Croix Island in the Caribbean Sea. Perhaps the most recent mention of *Globigerina helicina* (d'Orbigny) is that of Ovechkina *et al*. (2010), who examined planktic foraminiferal assemblages in surface sediments from the Thukela Shelf, off South Africa, and stated, "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 sub-globular 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".

In concurrence with the few existing records of *Globigerina helicina* (d'Orbigny), it is not surprising to note that only few specimens of this species were obtained (Table 1) and only from the core collected at 3,042 m water depth (Core B); no specimens were observed in Core A (2,004 m water depth). No records of this species are available from the Bay of Bengal or the Arabian Sea, and the results presented in this article suggest it to be a comparatively deeper abyssal species in the Bay of Bengal. The presence of a few tests in the core top sub-sample (0–2 cm) indicates that this species is extant in the bay.

References

Anand, P., Kroon, D., Singh, A. D., Ganeshram, R. S., Ganssen, G. and Elderfield, H. 2008. Coupled sea surface temperature–seawater $\delta^{18}O$ reconstructions in the Arabian Sea at the millennial scale for the last 35 ka. *Paleoceanogr*. 23 (4): PA4207.

Bagg, R. M. 1908. Foraminifera collected near the Hawaiian Islands by the *Steamer Albatross* in 1902. Proc. *U.S. Natl. Mus*. 34 (1603): 113–175.

Banchetti, R., Gradoni, L. and Dini, F. 2008. Protozoa. *Biol. Mar. Mediterr*. 15: 1–41.

Banner, F. T. and Blow, W. H. 1960. The taxonomy, morphology and affinities of the genera included in the subfamily Hastigerininae. *Micropal.* 6: 19–31.

Banner, F. T. and Blow, W. H. 1962. In: Eames, F. E., Banner, F. T., Blow, W. H. And Clarke, W. J. (Eds.), Fundamentals of Mid-Tertiary Stratigraphical Correlation. Part 1. Cambridge Univ. Press.

Barker, R. W. 1960. Taxonomic notes on the species figured by H.B. Brady in his report on the Foraminifera dredged by H.M.S. Challenger during the year 1873-1876. *Soc. Econ. Palaeont. Mineral. Spec. Publn.* 9: 238 p.

Blow, W. H. And Banner, F. T. 1962. In: Eames, F. E., Banner, F. T., Blow, W. H. And Clarke, W. J. (Eds.), Fundamentals of Mid-Tertiary Stratigraphical Correlation. Part 2. The Mid-Tertiary (Upper Eocene to Aquitanian). Globigerinaceae, Cambridge Univ. Press.

Brady, H. B. 1879. Notes on some of the Reticularian Rhizopoda of the *Challenger* Expedition. Memoirs. *Ann. Sci. Nature* 19: 261–299.

Brady, H. B. 1884. Report on the foraminifera dredged by *H.M.S. Challenger* during the years 1873-1876. Report on the Scientific Results of the Voyage of the *H.M.S. Challenger* during the years 1873-1876 (Zoology) 9: 1–814.

Chapman, F. 1895. On some foraminifera obtained by the Royal Indian Marine Survey's *S.S. Investigator* from the Arabian Sea, near the Laccadive Islands. *Proc. Zool. Soc. London*: 4–55.

Curry, W. B., Ostermann, D. R., Guptha, M. V. S. and Ittekkot, V. 1992. Foraminiferal production and monsoon upwelling in the Arabian Sea: Evidence from sediment traps, In: Upwelling Systems: Evolution Since the Early Miocene, Summerhayes, C. P., Prell, W. L. and Emeis, K. C. (Eds.), *Geol. Soc. Spl. Publn*. 64: 93–106.

Cushman, J. A. 1910. A Monograph of the Foraminifera of the North Pacific Ocean. *U.S. Natl. Mus*. 71: 1–62.

Dabrio, C. J., Garcia-Yebra, R., Gonzales-Donoso, J. M. and Vera, J. A. 1972. Turbiditas Asociadas a Evaporitas (Mioceno, La Mala, Depresion de Granada. *Cuad. Geol*. 3: 139–164.

Divakar Naidu, P. 1990. Distribution of upwelling index planktonic foraminifera in the sediments of the western continental margin of India. *Oceanologica Acta* 13: 327–333.

Divakar Naidu, P. 1991. Glacial to interglacial contrasts in the calcium carbonate content and influence of Indus discharge in two eastern Arabian Sea cores. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 86: 255–263.

Divakar Naidu, P. 1993. Distribution patterns of Recent planktonic foraminifera in surface sediments of the western continental margin of India. *Mar. Geol.* 110: 403–418.

Divakar Naidu, P. 2004. Isotopic evidences of past upwelling intensity in the Arabian Sea. *Global Planet. Change* 40 (3-4): 285–293.

Divakar Naidu, P. 2007. Influence of monsoon upwelling on the planktonic foraminifera off Oman during Late Quaternary. *Ind. J. Mar. Sci*. 36 (4): 322–331.

Divakar Naidu, P. and Guptha, M. V. S. 1989. Recent geoscientific studies in the Arabian Sea off India: Planktonic foraminifera from (core tops) the western equatorial Indian Ocean. *Geol. Surv. Ind. Spl. Publn.* 24: 133–135.

Divakar Naidu, P. Malmgren, B. A. 2005. Seasonal sea surface temperature contrast between the Holocene and last glacial period in the western Arabian Sea (Ocean Drilling Project Site 723A): Modulated by monsoon upwelling. *Paleoceanogr*. 20 (1): PA001078.

Divakar Naidu, P. and Niitsuma, N. 2003. Carbon and oxygen isotope time series records of planktonic and benthic foraminifera from the Arabian Sea: Implications on upwelling processes. *Palaeogeogr*. *Palaeoclimatol*. *Palaeoecol*. 202 (1-2): 85–95.

Divakar Naidu, P., Babu, C. P. and Rao, Ch. M. 1992. The upwelling record in the sediments of the western continental margin of India. *Deep-Sea Res.* 39: 715–723.

Divakar Naidu, P., Ramesh Kumar, M. R. and Ramesh Babu, V. 1999. Time and space variations of monsoonal upwelling along the west and east coasts of India. *Cont. Shelf Res*. 19 (4): 559–572.

Divakar Naidu, P., Rao, P. S. and Pattan, J. N. 1989. Planktonic foraminifera from a Quaternary deep sea core from the southern Arabian Sea. *J. Geol. Soc. India* 34: 393–397.

Elonee Pal. 1988. Ecologic distribution of planktonic foraminifera in the bottom sediments of the north-western part of the Bay of Bengal. *J. Geol. Soc. India*, v. 32: 320–326.

Godad, S. P., Divakar Naidu, P. and Malmgren, B. A. 2011. Sea surface temperature changes during May and August in the western Arabian Sea over the last 22 kyr: Implications as to shifting of the upwelling season. *Mar. Micropaleontol*. 78 (1-2): 25–29.

Guptha, M. V. S., Divakar Naidu, P. and Muralinath, A. S. 1990. Pre-monsoon living planktonic foraminifera from the Southeastern Arabian Sea. *J. Geol. Soc. India*. 36: 654–660.

Heron-Allen, E. and Earland, A. 1922. British Antarctic (“Terra Nova”) Expedition, 1910. *British Mus. Nat. Hist. Rept*. (Zool.) 6 (2): 25–268.

Hofker, J. 1930. Foraminifera of the Siboga Expedition. Part 2. Families Astrorhizidae, Rhizamminidae, Reophacidae, Anomalinidae, Peneroplidae in Siboga Expeditie. Monographie Iva. Leiden: E. J. Brill: 79–170.

Hottinger, L., Halicz, E. and Reiss, Z. 1993. Recent Foraminiferida from the Gulf of Aqaba, Red Sea. Ljubljana: Slovenska Akademija znanosti in umetnisti: 179 p.

Kameswara Rao, K. 1973. Quantitative distribution of planktonic foraminifera in the south-west coast of India. *Ind. J. Mar. Sci.* 2: 54–61.

Kameswara Rao, K., Jayalakshmy, K. V. and Balasubramaniam, T. 1992. Distribution of planktonic foraminifera in waters of the submarine coral banks in south-east Arabian Sea during winter. *Ind. J. Mar. Sci.* 21: 233–245.

Kameswara Rao, K., Jayalakshmy, K. V. and Krishna Kutty, M. 1991. Ecology and distribution of Recent planktonic foraminifera in eastern part of Arabian Sea. *Ind. J. Mar. Sci.* 20: 25–35.

Loeblich, A.R. and Tappan, H. 1987. Foraminiferal Genera and their Classification. Von Nostrand Reinhold, New York: 970 p.

Mahesh, B., Banakar, V. and Burr, G. 2011. Paired measurements of foraminiferal delta $\delta^{18}O$ and Mg/Ca ratios of Indian monsoons reconstructed from Holocene to Last Glacial record. *Acta Geol. Sinica* 85: 950–956.

Naik, S. S. and Divakar Naidu, P. 2008. Possible factors that control calcite dissolution in the western tropical Indian Ocean. *Curr. Sci*. 95 (1): 22–23.

Naik, S. S. and Divakar Naidu, P. 2014. Boron/calcium ratios in *Globigerinoides ruber* from the Arabian Sea: Implications for controls on boron incorporation. *Mar. Micropaleontol*. 107: 1–7.

Naik, S. S., Divakar Naidu, P., Govil, P. and Godad, S. P. 2010. Relationship between weights of planktonic foraminifer shell and surface water

$CO_3^{=}$ concentration during the Holocene and Last Glacial Period. *Mar. Geol*. 275 (1-4): 278–282.

Naik, S. S., Godad, S. P., Divakar Naidu, P. and Ramaswamy, V. 2013. A comparison of *Globigerinoides ruber* calcification between upwelling and non-upwelling regions in the Arabian Sea. *J. Earth Syst. Sci*. 122 (4): 1153–1159.

Naik, S. S., Godad, S. P., Divakar Naidu, P., Tiwari, M. and Paropkari, A. L. 2014. Early- to late-Holocene contrast in productivity, OMZ intensity and calcite dissolution in the eastern Arabian Sea. *Holocene* 24 (6): 749–755.

Nigam, R., Saraswat, R. and Mazumder, A. 2003. Life spans of planktonic foraminifers: New insight through sediment traps. *J. Palaeontol. Soc. India* 48: 129–133.

d'Orbigny, A. 1826. Tableau methodique de la classes des Cephalopodes. *Ann. Sci. Natur*. 7: 245–314.

Ovechkina, M. N., Bylinskaya, M. E. and Uken, R. (2010) Planktonic foraminiferal assemblage in surface sediments from the Thukela Shelf, South Africa. *African Invertebrates* 51 (2): 231–254.

Parker, W. K., Jones, T. R. and Brady, H. B. (1871) On the Nomenclature of the Foraminifera. Part 14. The species enumerated by d'Orbigny in the "Annales des Sciences Naturelles", 1826. *Ann. Mag. Nat. Hist*. 4 (8): 145–266.

Saito, T., Thompson, P. R. and Breger, D. 1981. Systematic index of Recent and Pleistocene Planktonic Foraminifera. Univ. of Tokyo Press, Tokyo: 190 p.

Setty, M. G. A. P. and Guptha, M. V. S. 1972. Recent planktonic foraminifera from the sediments off Karwar and Mangalore. *Proc. Ind. Natl. Sci. Acad.* 38: 148–160.

Todd, R. 1957. Geology of Saipan, Mariana Islands: Smaller Foraminifera. *U.S.G.S. Prof. Paper* 280-H: 261–320.

Todd, R. and Low, D. 1976. Smaller Foraminifera from Deep wells on Puerto Rico and St. Croix. *U.S.G.S. Prof. Paper* 863: 1–32.

Weaver, T. 1841. On the Composition of Chalk Rocks and Chalk Marl by invisible Organic Bodies: from the Observations of Sr. Ehrenberg. *The London, Edinburgh and Dublin Phil. Mag. J. Sci*. 18 (119): 443–464.

Zhang, J. 1985. Living planktonic foraminifera from the eastern Arabian Sea. *Deep-Sea Res.* 32: 789–798.