

LIVING BENTHONIC FORAMINIFERA IN A TIDAL ENVIRONMENT: GULF OF KHAMBHAT (INDIA)

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ABSTRACT

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Living benthonic foraminifera from the top one centimetre layer from 23 surface sediment samples have been studied. Samples were collected from the tidally affected inner shelf off the Daman–Bombay sector of the Arabian Sea. The northern half of the study area is a high-energy environment, it is deep and it is bounded by a narrow, long shallow (at a submerged depth of 7–20 m) sand bar (Eastern Bank) which rises from 40–43 m depth and is separated from the coast by the parallel Sutherland Channel. The southern half of the study area has a smooth topography and low-energy environment.

A total of 60 species, of which 16 were living, were recorded in the study area. The diversity index (α) of the living assemblages is less than 3 and on the triangular diagram there is a greater concentration of points in the Rotaliina corner with some Textulariina and a general absence of Miliolina. *Ammobaculites persicus*, *Ammonia annectens*, *A. papillosus*, *Asterorotalia dentata* and *Pararotalia nipponica* are abundant in the living assemblage.

The eastern flank of the Eastern Bank is marked by extensive sand waves and an almost total absence of living individuals. There is a concentration of reworked Paleogene foraminifera derived from the nearby Surat–Broach outcrops. These two features are indicative of a possibly mobile substrate. The high tidal range and the high concentration of suspended matter and thus low penetration of light might also be the cause for the absence of living individuals in the samples from the eastern flank of the sand bar.

INTRODUCTION

In recent years, emphasis in the study of foraminifera has changed from systematics and distribution of dead foraminifera to the ecology and environment of the living ones. However, very little effort has been made to study the living foraminifera from the eastern margin of the Arabian Sea (Rao, 1974; Setty, 1976; Setty and Nigam, 1980; Nigam and Sarupria, 1981) and therefore, the available information is limited.

The objective of this paper is to present the variations in distribution and ecology of living benthonic foraminifera from the neritic regime off the Daman–Bombay sector of the Arabian Sea, West Coast of India, an area showing transition from high- to low-energy environmental conditions from

north to south. Some other aspects of these foraminiferal studies have already been published elsewhere (Nigam and Setty, 1980, 1982; Setty and Nigam, 1981).

MATERIAL AND METHODS

The twenty-three samples used in the present study were collected (January 1978) from the inner shelf within the depth range of 24–43 m off the Daman–Bombay sector during the 28th cruise of R.V. "Gaveshani". The samples were collected during the survey for the proposed pipeline route from Bassein to Gujarat for the Oil and Natural Gas Commission and as a part of the project "Distribution, Ecology and Significance of Foraminiferal Fauna on the Continental Shelf of the West Coast of India."

The sediment samples were collected by modified Peterson Grab (area 900 cm²). The top 1 cm layer was separated from each sample and fauna was preserved in a 10% buffered formalin solution and stained with Rose Bengal, as suggested by Walton (1952) for recognition of living individuals. Samples were sieved through a 63- μ m size sieve and the +63 fraction was dried. A number of 300–500 specimens or all foraminiferal tests were picked from the weighed sample (depending upon richness of fauna). The total foraminiferal numbers were then standardized to 1 g to study relative abundance.

The two statistical methods suggested by Murray (1973) were used for environmental analysis. In the first method, the percentage distribution of the three main suborders, Textulariina, Miliolina and Rotaliina in each sample, were plotted on a triangular diagram. In the second method, α index values were obtained from a graph based on the number of individuals and number of species. These results were then compared with the summary diagrams of Murray (1973, figs.101 and 102).

ENVIRONMENT

Bathymetry

The area studied is situated north of Bombay and off the gently curving coastline extending from Daman to Bombay. The submarine topography is shown in Fig.1. The southern half of the continental shelf has a smooth topography, whereas the northern half is a deeper region bounded by a narrow, long, shallow sand bar (Eastern Bank) which rises suddenly from 40–43 m depth; it is separated from the land by the Sutherland Channel (Fig.1) and reaches depths of 7–20 m. Extensive sand waves 2–4 m in height and 100–400 m in wave length were also observed from the eastern flank of the sand bar (Fig.2).

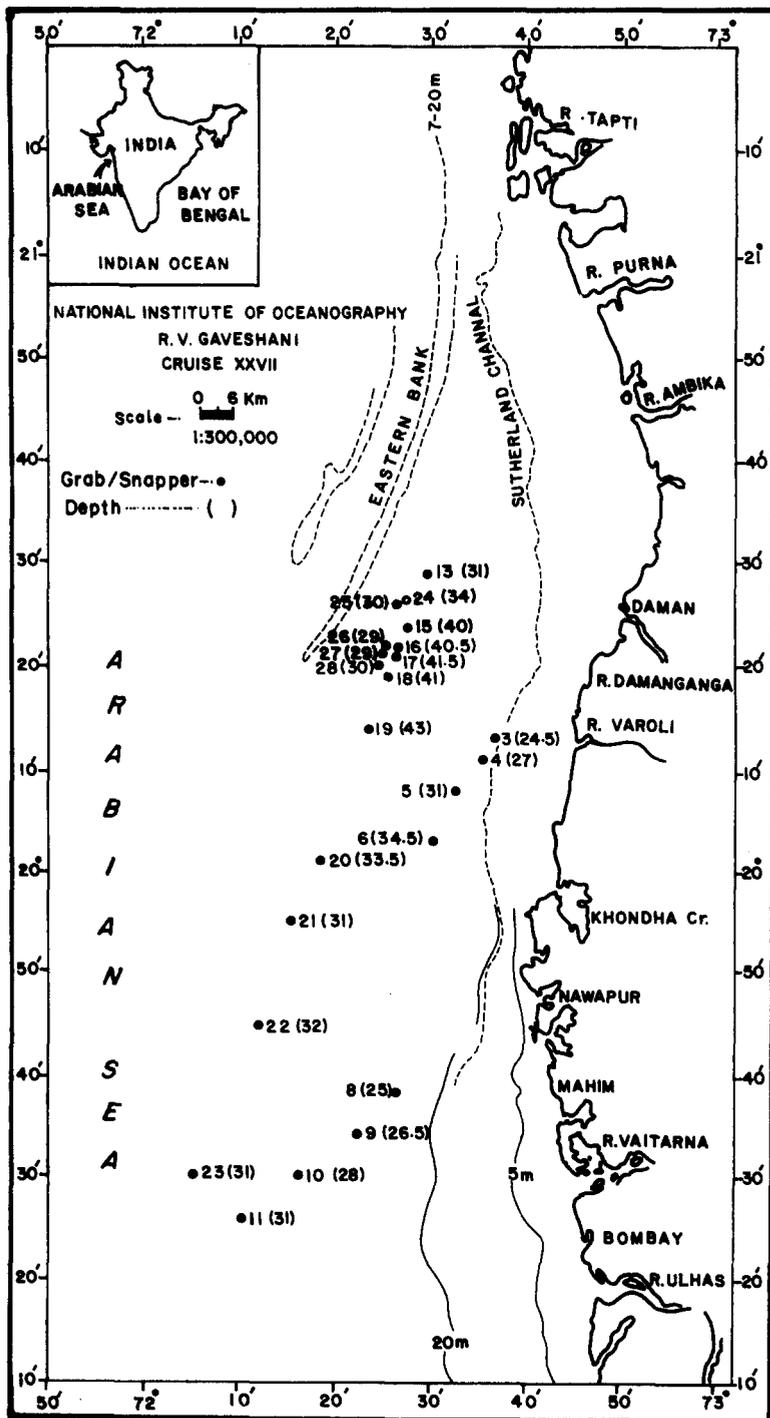


Fig.1. Map showing locations and bathymetry of the study area.

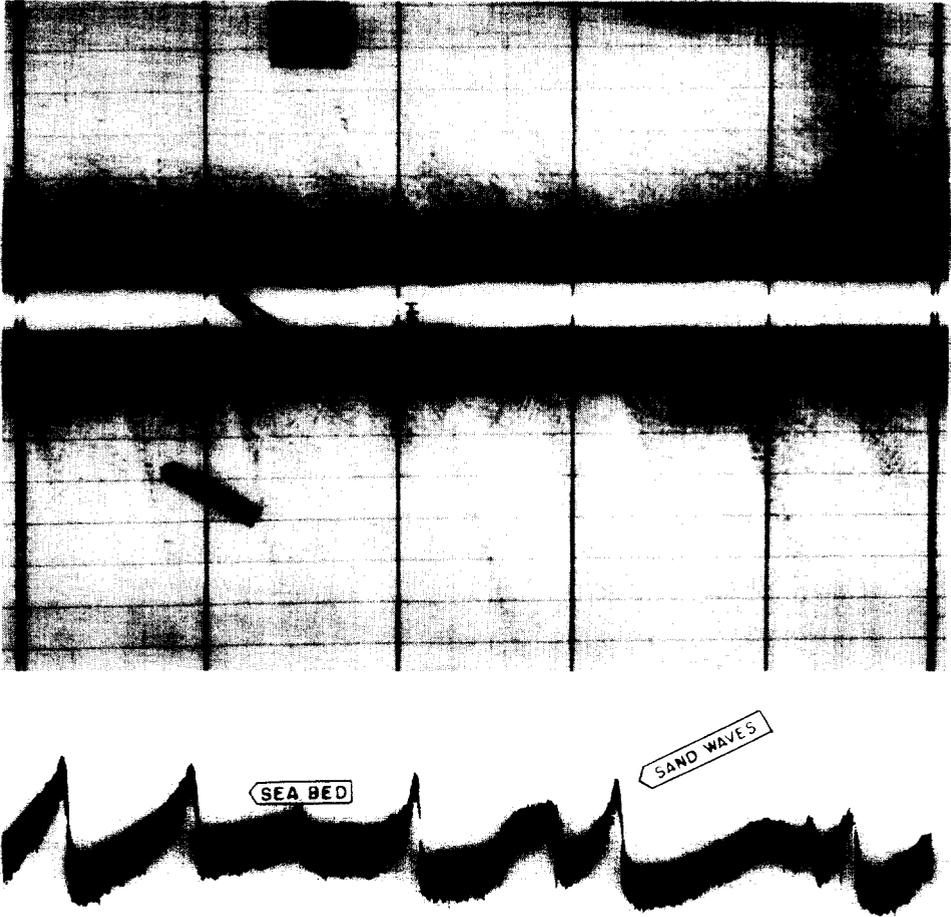


Fig. 2. Sonograph and echogram showing sand waves near sand bar within the study area.

Physical setting

The study area receives a large input of fresh water from the Narmada, Mahi, Kim, Tapti, Purna, Ambica and Damanganga rivers. Of these, the Narmada and Tapti are the two main rivers and their average monthly discharge exceeds $2000 \text{ m}^3 \text{ s}^{-1}$. (Unesco Report, 1971). These rivers also bring huge quantities of terrigenous material. High concentrations of suspended matter ($>4 \text{ mg l}^{-1}$ in surface waters and $>8 \text{ mg l}^{-1}$ and even 13 mg l^{-1} in the bottom waters) were reported by Rao and Rajamanickam (1976).

The high tidal range, of the order of 10 m (at Bhavnagar) to 5 m (at Daman), has already been noted (Indian Tide Table, 1978). The direction of currents changes and even reverses from southwest to northeast and vice versa. Surface current speeds of up to 2–5 knots have been recorded (Naval Hydrographic Chart No. 254).

Sediments

The study area is covered largely by clay except stations 3 and 4 (cobble- pebble shell fragments) 13–18 and 21 (clay with admixture of sand) and 24–28 (sand).

Chemistry of sea water and sediment

The salinity of the surface water ranges from 35.77 to 36.20‰ and from 35.7 to 36.1‰ at 15–30 m depth. Similarly, dissolved oxygen of the surface water varies from 4.82 to 5.14 and at a depth of 15–30 m, from 4.72 to 5.10 (Initial Report INS “Darshak” Expedition, 1974). Organic carbon in sediments ranges from 0.7 to 2.06% (dry weight) and the values are lowest in sands.

RESULTS AND DISCUSSION

Composition of foraminiferal assemblages

A total of 60 species of foraminifera were recorded from 23 samples, among these 16 species are living, and these have been studied in detail (Appendix I).

The total foraminiferal number (TFN) varies considerably within the study area (Fig.3). The samples adjacent to the sand bar are barren of foraminiferal tests and those in Sutherland Channel are very low in foraminifera, whereas the samples from the open shelf (stations 3-11 and 19-23) are quite rich in TFN except at station 21 where the substrate is silt.

The total species number (TSN) also varies; at some stations the assemblage is monospecific whereas a maximum of 9 species is recorded at station 9. Among the 16 species recorded, only 5 species, namely *Ammobaculites percicus*, *Ammonia annectens*, *A. papillosus*, *Asterorotalia dentata* and *Pararotalia nipponica* constitute 71.42 to 100% of the total assemblage.

Some comparisons

Rao (1974) had reported 14 species from the Mandovi-Zuari estuaries from the central western shelf of India, of these only *Ammonia tepida* is present in the assemblage of the Gulf of Khambhat. Setty (1976) studied the benthonic foraminifera from the polluted marine environment of Cola Bay, Goa. Out of the 12 species of foraminifera living there *Ammonia tepida*, *Asterorotalia* (= *Ammonia*) *dentata* and *Bolivina striatula* are common in the present study. The assemblages of the Cola Bay were different from the other regions affected by marine pollution. Setty and Nigam (1980) recorded 32 species of living foraminifera from the neritic regime off the Dabhol–Vengurla sector of the western shelf; the following are present in the Daman–Bombay sector; *Bolivina striatula*, *Ammonia annectens*,

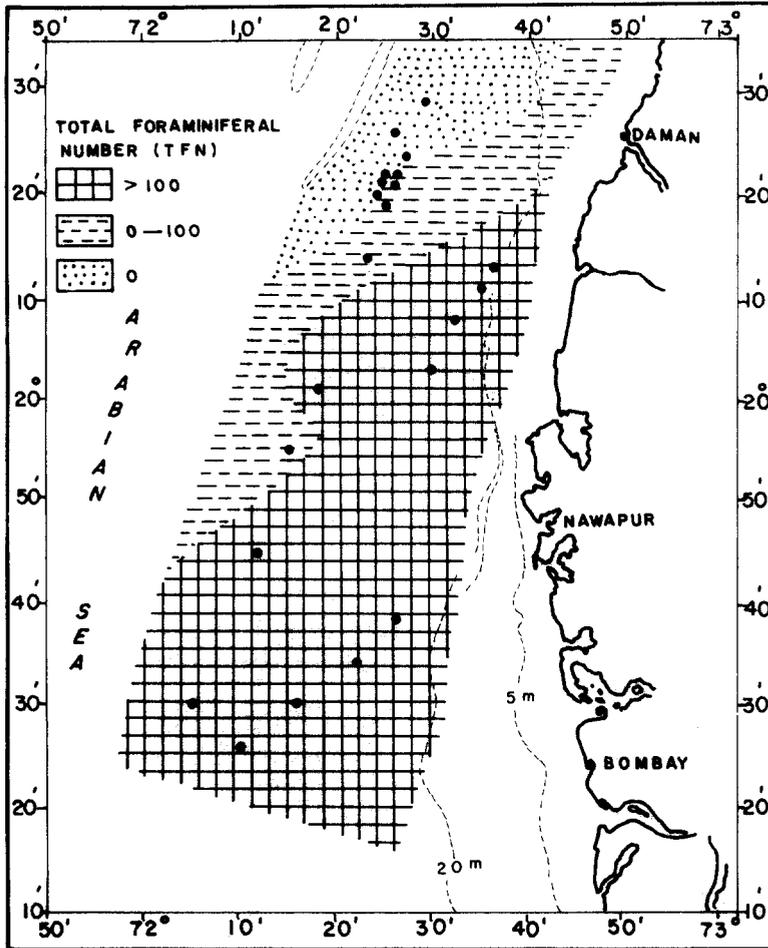


Fig.3. Map showing distribution of total foraminiferal number (TFN) in the study area.

A. papillosus, *Asterorotalia dentata*, *Nonionella basispinata* and *N. turgida*. The difference in fauna of the Damam—Bombay sector might be due to the high-energy environment.

Foraminifera and environment off Damam—Bombay sector

In the study area, samples off Bombay represent a low-energy environment, whereas samples off Damam (near Eastern Bank) come from a high-energy environment with intermediate samples representing the transitional environment.

Large foraminiferal populations are associated with the low-energy area (TFN > 100). These become reduced towards the north and living foraminifera are almost absent in samples near the sand bar, i.e. areas of high-energy environment (Fig.3).

In the marine environment, clay generally represents low-energy conditions, whereas sand is a product of high energy. Relationship of foraminifera to the substrate show that large assemblages of foraminifera were found associated with the clayey substrate, moderate to rare assemblages in clay with admixture of sand, and foraminifera are rare to absent in the sandy substrate.

The *Ammonia-Elphidium* assemblage is typical of many nearshore areas (Sengupta, 1977), but in the present study area it is represented by an *Ammonia-Ammobaculites-Pararotalia* assemblage. *Ammonia* is a hyposaline to hypersaline, sediment, 15–30°C, 0–50 m, inner shelf genus whereas *Ammobaculites* is hyposaline, sediment, inner shelf genus (Murray, 1973). Based on these ecological data this assemblage indicates hyposalinal conditions in the Daman–Bombay sector.

The diversity index α is less than 3, which indicates hyposalinal and near-shelf seas, whereas the comparison of the triangular plot (Fig.4) with the summary diagram of Murray (1973) indicates hyposaline, lagoonal or shelf conditions. These analyses reveal a hyposaline environment in this sector which is also suggested by the large fresh-water discharge of the Narmada and Tapti rivers (Unesco Report, 1971).

Some of the abundant species, such as *Ammonia annectens* (= *Streblus annectens*), *A. papillosus* (= *S. papillosus*), *Asterorotalia dentata* (= *S. dentata*) and *Pararotalia nipponica* have been frequently reported from the sandy beaches of India (Bhatia, 1956; Bhalla, 1968, 1970; Bhalla and Nigam, 1979). These species are considered to withstand the rigor of abrasion and high energy on the beaches.

No living foraminiferal fauna was observed in the samples near the sand bar (stations 24–28), whereas very small assemblages were found at stations 13–18. Vora et al. (1979) reported sand waves from this area and concluded “the presence of sand waves supported by high-energy hydrodynamic considerations prevailing in the Gulf and high suspended load confirm that the

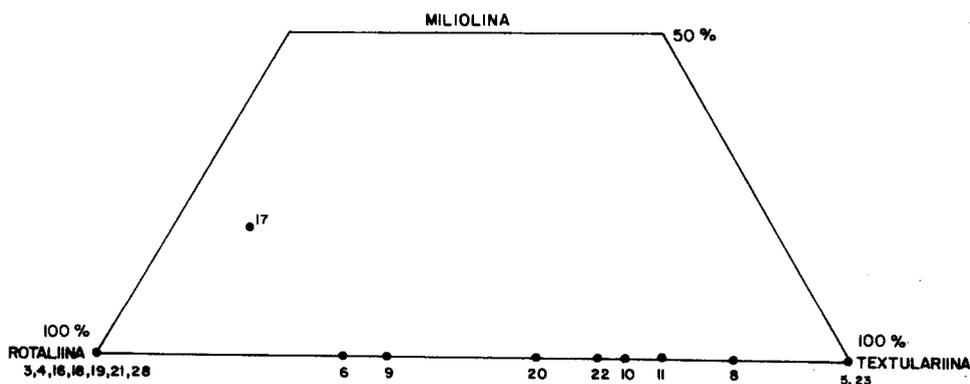


Fig.4. Triangular diagram to show the proportions of the three wall types in the living assemblages in study area.

sediments at the sea bed in the region are probably mobile". Sand waves have been reported from many areas but little work on the benthonic foraminifera associated with them has been carried out. Jones et al. (1965), while describing the sand waves of Warts Bank, Isle of Man reported "owing, perhaps, to the coarse and presumably unstable nature of the sediments the larger infauna is poor in number of species and individuals". They also noted that rate of sand wave travel averages 5–10 cm per day. Owen et al. (1967) have taken 465 underwater photographs of sea floor of Vineyard Sound. These photographs exhibit changing patterns of sand ripples and sand waves but no living benthonic organisms. The knowledge of the distribution and ecology of living foraminifera from the sand waves is scanty. Murray (1969) recorded 14 species of foraminifera from station no.1232 of Vineyard Sound where large sand waves were reported. The living assemblage was dominated by *Eggrella advena*, *Rosalina* spp. and *Trochammina ochracea*. Small assemblages of living foraminifera have also been observed from other high-energy areas of the world, but as mentioned above, the present assemblage is totally devoid of living individuals though dead tests were present.

Nigam and Setty (1980) reported 42 species and a high concentration of reworked foraminifera (>80% of reworked/total) from the region where living foraminifera are absent. These reworked specimens are "characteristically earthy coloured, highly polished, badly abraded, affecting the nature, periphery and shape". These reworked/older specimens must have been brought by the Narmada–Kim–Tapti rivers from the Surat–Broach outcrops. As the source rock is not far from the site of deposition, it is believed that these specimens were highly abraded and polished by the continuously shifting/unstable substrate.

The tidal currents disrupt the sediments, which destroys the feeding net of foraminifera (Richter, 1964) and can adversely affect the quantity of living specimens in the areas of rapid movement (tidal zone; Boltovskoy and Wright, 1976). High-energy conditions (tidal range 5–10 m) prevail in the northern half of the study area, probably contributing to the paucity of the living foraminifera.

The high tidal currents, high concentration of suspended matter and thus low penetration of light, and the high fresh-water influx are the factors responsible for the poor assemblages of the living foraminiferal fauna. The shifting substrate near the sand bar keeps benthonic foraminifera in suspension, not allowing them to attach to the substrate and to flourish. The instability is too severe for any species to survive.

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APPENDIX I

Living foraminiferal fauna encountered within the study area

1. *Ammobaculites persicus* Lutze, 1974, Arten, "Meteor" Forschungsergeb., Reihe, C, 17, pl.2, figs.27-35.

Remarks: This species was reported by Lutze (1974) from the Persian Gulf. Specimens of the present study have a short uncoiled part as compared to Gulf samples.

This is a widely occurring species in the material and is the only species at stations 9 and 23. Its abundance varies from 10 to 66.67% at stations 6-11, 17, 20, 22, and 23.

2. *Ammonia annectens* (Parker and Jones).

Rotalia beccarii (Linné) var. *annectens* Parker and Jones, 1865, Philos. Trans. R. Soc. London, Vol.15: 187-422, pl.19, figs.11a-c.

Remarks: This species is widely reported from sandy beaches and nearshore areas of the East and West Coasts of India. In our material it constituted 8-40% of the total living assemblages at stations 3-4, 6-11, 16-18, and 20-22.

3. *Ammonia papillosus* (Brady).

Rotalia papillosus Brady, 1884, Challenger Report, Zool. Vol.9, p.708, pl.106, fig.9.

Remarks: This papillate species commonly occurs in Indian waters. In the present material it varies from 5.0 to 60.6% and at station No.28 is the sole living species where only 5 living specimens were reported in 1 g of dry sediment. It is present at stations 3, 4, 6-11, 16-22, and 28.

4. *Ammonia tepida* (Cushman).

Rotalia beccarii (Linné) var. *tepida* Cushman, 1926, Carnegie Inst. Washington, Publ.344 (Dept. Mar. Biol. Pap.23) p.79, pl.1.

Remarks: *A. tepida* is present at station No.20 only where it forms 6.25% of the total living assemblage.

5. *Asterorotalia dentata* (Parker and Jones).

Rotalia beccarii (Linné) var. *dentata* Parker and Jones, 1865, Philos. Trans. R. Soc. London, 155, pp.387, 422, pl.19, fig.6, 139c.

Remarks: This is one of the species which can withstand a high-energy environment. In the present material it occurs at stations No.3, 6, 9, 10, 16, 18, 19 and 21. Its abundance varies from 6.67 to 40%.

6. *Bolivina striatula* Cushman, 1922, Carnegie Inst., Washington, vol.17, p.27, pl.3, fig.10.

Remarks: It occurs at station No.19 (20.0%) and 9 (1.79%) only.

7. *Elphidium discoidale multiloculatum* Cushman and Ellisore, *Elphidium discoidale* (D'orbigny) *multiloculatum* Cushman and Ellisore, 1945, J. Paleontol, vol.19, No.6, p.561, pl.75, fig.92.

Remarks: In the present assemblage it is a rare species found at stations No.9 (1.79%) and 20 (4.61%) only.

8. *Eponides repandus* (Fichtel and Moll)

Nautilus repandus Fichtel and Moll, 1798, Testacea Microscopica, p.35, pl.3, figs.a-d.

Remarks: 5.88 and 14.28% occurrences of *E. repandus* were noted at station No.3 and 4.

9. *Nonionella basispinata* (Cushman and Moyer)
Nonion pizarrense (Berry) var. *basispinata* Cushman and Moyer, 1930, Cushman Found. Foraminifer. Res. Contrib., Vol.6, No.3, p.54, pl.7, fig.18.
 Remarks: *N. basispinata* was found living at stations No.8 and 9 forming 1.89 and 3.57%, respectively.
10. *Nonionella turgida* (Williamson)
Rotalia turgida Williamson, 1858, Trans. R. Soc. London, pp.50—51, pl.4, figs.95—97.
 Remarks: 4.45% occurrence was noted at station 9 only.
11. *Nonionella* sp.
 Remarks: A few specimens of *Nonionella* were recorded at station No.9 which cannot be referred to any known species. They constitute 4.45% of the total assemblage. Because of paucity of material and restriction to one station, a new name has not been assigned.
12. *Pararotalia nipponica* (Asano)
Rotalia nipponica Asano, 1936, Geol. Soc. Jpn. J., vol.43, no.515, p.614, pl.31, figs.2a—c.
 Remarks: *P. nipponica* was confined to only two stations (3 and 4) where it constitutes 1.76 and 35.71%, respectively.
13. *Poroepionides cribrorependus* Asano and Uchio, 1951, Illust. Cat. Japan Tert. Small. Foram., pt.14, p.18. figs.132—133.
 Remarks: A species very rarely observed from Indian water. In our material it was found at stations No.3 and 4 where it constitutes 5.88 and 14.28% of the total living assemblage.
14. *Quinqueloculina vulgaris* D'Orbigny, 1826, Ann. Sci. Nat., vol.7, p.302, no.33.
 Remarks: Only 10.0% occurrence was noted at station no.17.
15. *Siphogenerina rephanus* (Parker and Jones)
Uvigerina (Sagrina) rephanus Parker and Jones, 1865, Philos. Trans. R. Soc. London, p.364, pl.18, figs.16—17.
 Remarks: Observed at station No.3 (5.58%) only.
16. *Triloculina oblonga* (Montagu)
Vermiculam oblongum Montagu, 1803, Test. Britanica, p.522, pl.14, fig.9.
 Remarks: Miliolids are very rare in study area. Triloculina was represented only by this species at station No.17 (10.0%).

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