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# A study of marsh foraminifera microhabitat in Harshad, Gujarat, India

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Foraminifera, abundant in the epipelagic and benthic realms, has an outstanding fossil record and is studied widely by micropalaeontologists. We document the systematics of benthic foraminifera from the marsh sub-environment of Harshad (N 21º50.53' - N 21º 50.06', E 69º 22.15' - E 69º 21.96'), Gujarat. We also report the vertical distribution pattern of the foraminiferal assemblages and comment on the region's ecological status. Two short cores of 15 cm each, were collected from the marsh sub-environment and investigated for benthic foraminifera. One of the core shows a high Total Foraminiferal Number (TFN) reaching more than 500 per one gram of dry sediment at deeper depths. A total of thirteen species were identified. This study depicts that *Ammonia tepida* is the dominant and most widely distributed species of the marsh region. The other species dominant in hyaline test forms include *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica,* and *Nonion* cf. *commune*, and porcelaneous form *Quinqueloculina* spp.

**Keywords**: Foraminifera, Benthic, Microhabitat, Harshad, Saurashtra.

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## INTRODUCTION

Foraminifera is unicellular marine protozoans abundant in the epipelagic and benthic realms. Their abundance in most marine environments, from near-shore to the deep sea, and the brackish habitats forms the basis of their micropalaeontological applications. As a group, they exhibit broad ecological tolerance to pH, salinity (Saraswat *et al.,* 2015; Murray, 2006), depths and temperature (Murray, 2006), dissolved oxygen concentration (Sengupta and Machain-Castillo, 1993; Gooday, 1994; Jorissen *et al*., 1995, 1998; De Rijk *et al.,* 2000) of the ambient waters. Their size, widespread distribution, and extreme diversity in the marine realm bring out their outstanding value in zonal stratigraphy, palaeoenvironmental, palaeobiological, palaeoceanographic, and palaeoclimatic interpretation, and analysis (Alve, 1995; Nigam *et al.,* 2006; Frontalini and Coccioni, 2008). Benthic foraminifera, being highly sensitive to the environment's changes, acts as the best parameter for monitoring these environmental changes preserved in the hard parts of their test. Slight environmental variations are mostly reflected in the vegetation pattern as well as in foraminiferal distribution. Therefore, there is a necessity of having adequate knowledge of their distribution pattern in marine environments, to utilize these organisms efficiently. India's western coastal regions house a range of marine ecosystems, varying from estuaries, cliffs, coral reefs, and marshes characterized by distinctive foraminiferal populations. The literature survey revealed that there are several studies on the taxonomic and ecological status of foraminifera from the west coast of India.

## PREVIOUS STUDIES

Bhalla and Nigam (1979) and Bhalla and Gaur (1987) worked on the foraminiferal diversity of Calangute and Colva beach sands. Bhalla and Raghav (1980) suggested that salinity is the prime governing factor while studying the ecology of foraminifera of the Malabar Coast. Desai and Pandya (1982) and Bhalla and Lal (1985) reported foraminifera of Saurashtra and Okha beach sand's coastal sediments, respectively. Bhalla and Nigam (1988) had worked on the cluster analysis of foraminifera from the six beaches of Saurashtra. Similar studies were done by Pandya (1985) and Rao and Srinath (2002) on beach sands along the Saurashtra coast. Talib and Farooqui (2007) studied the littoral sediments of Dwarka beach. Ghosh *et al.* (2009) examined the distribution of foraminifera in the Narmada and Tapti estuaries of the Gulf to use these as analogs for the study of palaeomacro-tidal estuarine environments and as a means of recording the extent of sea-level change in estuarine settings. Lakhmapurkar and Bhatt (2010) presented a survey on water chemistry, clay texture, and foraminiferal

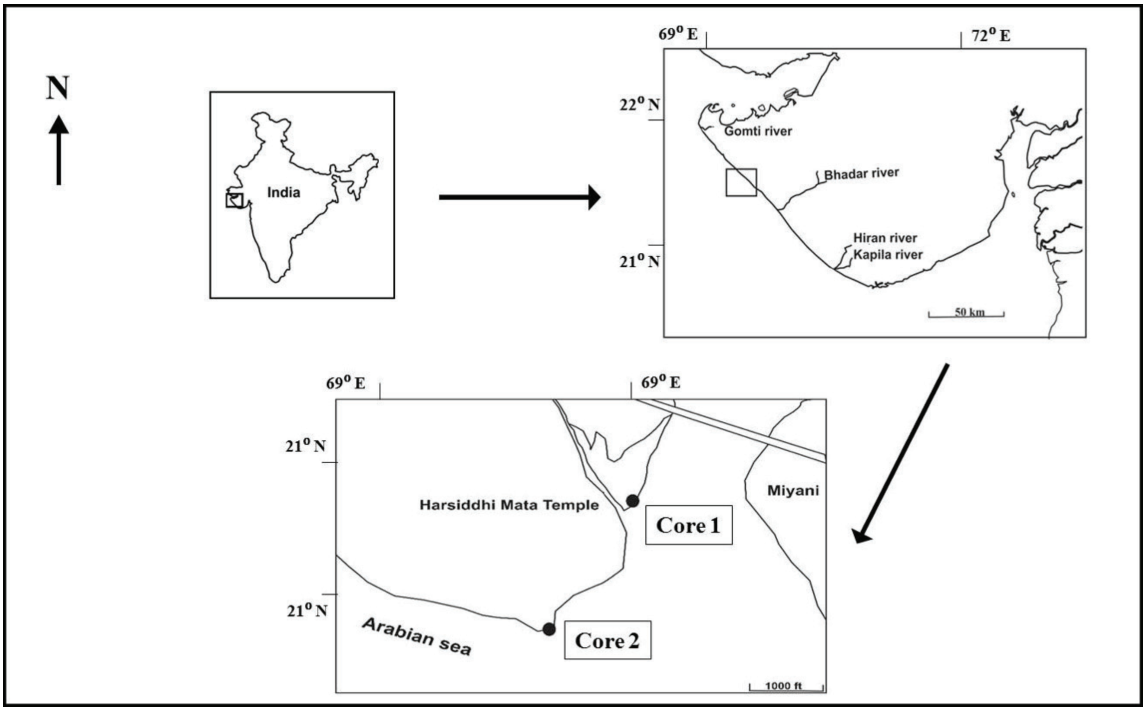


Fig. 1. Core sampling stations in Harshad, Gujarat.

content of the Meda Creek to evaluate geo-environmental status in post-barrage conditions. An analysis of the seasonal distribution trends from the Saurashtra coast has been carried out by Buragohain and Ghosh (2021). However, foraminiferal studies in the Harshad estuarine area are relatively scanty, as evident from the literature survey. The present investigation records foraminiferal assemblages in the marsh sub-environments of Harshad. The study will better understand their microhabitat and record the change of environment due to barrage construction and compare with assemblages in the same environmental settings along the west coast.

## STUDY AREA

The central part of the Saurashtra peninsula comprises undulating plains and is dissected by rivers like Machchu, Brahnani, Ojhat, Kamb, Surekh, Somal, flowing out in all directions. It is represented by several estuaries, islands, mudflats, sand flats, and cliffs. Harshad, famous for Harsiddhi Mata Temple is a marsh area in Gandhvi village of Jamnagar district of Gujarat along the western coastline of India, which has been selected as the study area (Fig. 1). The elevation of this town is about 49 feet. A barrage was constructed in 1973 A.D. on the estuarine part of Meda Creek, Harshad (Sinha *et al.,* 1996; Lakhmapurkar and Bhatt, 2010). The study area stretches along the coastal plain of Harshad towards the south, comprising of a complex network of estuarine environments like creeks, tidal channels, beach, tidal flats, coastal cliffs, spit, and coastal plains and marshes. The Total Suspended Solids (TSS) in the creek water varies from nearly 300 mg/l to 490 mg/l; pH ranges from 8.19 to 8.89 (Lakhmapurkar and Bhatt, 2010). The water samples' salinity varies from 35 to 44‰ and Dissolved Oxygen (D.O.) availability varies in the range of 3.30 mg/l to 4.45 mg/l (Lakhmapurkar and Bhatt, 2010). However, our study is based on the downcore variation of foraminifera in the wetlands. Currently, the marsh area is restricted only to the creek's right bank and is characterized by *Avicennia sp.* (Singh, 2000; Ghosh *et al.,* 2012). Organic black laminations were observed in the compact mud of the marsh area during core collection. Extensive mangrove vegetation dominated by *Avicennia* sp. with pneumatophores were characterized with low diversity of marine gastropods *Telescopium* sp. and *Cerethium* sp.

## MATERIALS AND METHODS

The core samples were collected in October 2016 and April 2017. Two short core samples of 15 cm each were recovered with the help of a 20 cm short corer, from the Harshad marsh area for the study of benthic foraminifera (Table-1). The core had a diameter of 5cm. The cores were sub-sampled at 1centimetre. The sediment samples of both the cores were kept in fifteen different wide, tight-mouthed plastic containers for each core, corresponding to the layers of both the cores obtained. Rose Bengal solution (2 grams Rose Bengal powder mixed uniformly in 1-liter ethanol)was added immediately to the collected samples, to preserve the living foraminifera and differentiate it from the dead foraminifera, as it stains pink the living cytoplasm. The collected stained sediment was washed with a stream of water on top of a brass sieve of 63 μm. The 63 μm sieve helped eliminate all the silt and clay particles, leaving the fine sand and a larger

Fig. 2. Typical marsh sub-environment in Harshad right bank, dominated by *Avicennia* sp.

fraction (*i.e.,* the fraction including the size range of most foraminifera). The residual coarse fraction was then dried in an oven and examined under a stereo zoom microscope (Nikon SMZ 1000). Further observation for precise examination and illustration was done using a Scanning Electron Microscope (ZEISS EVO 18) in the Department of Geological Sciences, Jadavpur University. The sorted foraminifera was stored in the Foraminiferal Applications Laboratory, Department of Geology, University of Calcutta, Kolkata.

## RESULTS AND DISCUSSION

*Ammonia tepida* is the most dominant foraminifera in the study area. Based on their abundance, all other species include *Rotalidium annectens*, *Elphidium*

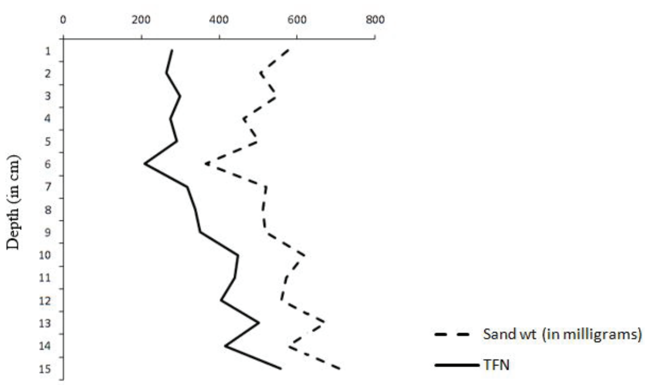


Fig. 3. Variation of total foraminiferal number with the grain size of sediments in Core 1

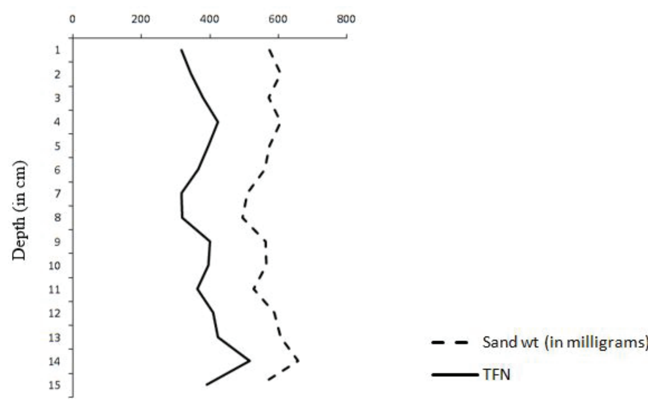


Fig. 4. Variation of total foraminiferal number with the grain size of sediments in Core 2.

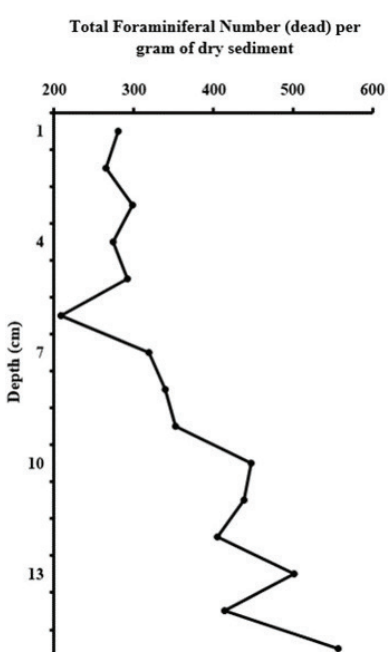


Fig. 5a. Downcore variation of foraminifera (dead) in Core 1.

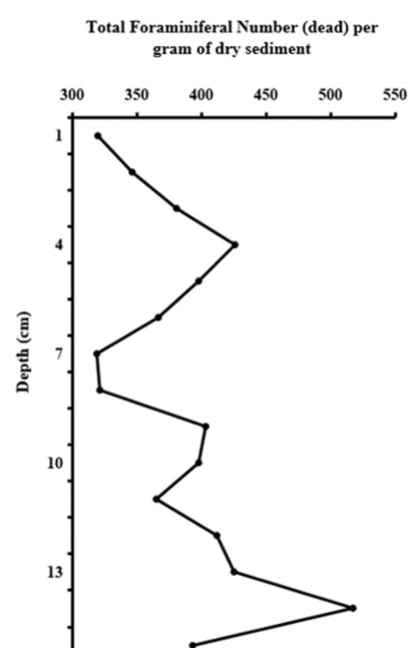


Fig. 5b. Downcore variation of foraminifera (dead) in Core 2.

Table 1. Sampling location details in marsh sub-environments of Harshad, Gujarat.

| Core Number | SMI | Envronment | Core recovery |
|---|---|---|---|
| Core 1 | 21º50.53'N 69º22.15'E | Marsh area | 15 cm |
| Core 2 | 21º50.06'N 69º21.96'E | Marsh area towards the open | 15 cm |

*crispum*, *Pararotalianipponica, Nonion* cf. *commune, Quinqueloculina seminulum, Quinqueloculina sulcata, Quinqueloculina pseudoreticulata, Cibicides refulgens, Cibicides* sp.*, Eponides repandus, Elphidium craticulatum, Elphidium advenum* and *Triloculina trigonula.* Two larger benthic foraminifera, *Nummulites venosus,* and *Amphistegina radiata* have been observed but are transported in the marsh and not in-situ species of the marsh region.

The foraminiferal assemblage includes six families of Rotalids, four families of Miliolids, and three families of Elphidids. Eleven genera of hyaline calcareous foraminifera and four genera of porcelaneous calcareous foraminifera have been identified. No agglutinated foraminifera have been found. The marsh assemblages of the Gulf of Cambay (Ghosh *et al.,* 2009) are significantly different in foraminiferal populations than marshes of the Harshad region. The absence of agglutinated forms and some typical calcareous forms such as *Haynesina* spp., *Rosalina* sp., *Murrayinella* sp., and *Cribrononion* sp. are noteworthy differences in comparing both marshes of the west coast.

The total foraminiferal number (TFN) is plotted downcore (Figs. 5a, 5b), to understand the variation in abundance for both the cores. Foraminiferal population varies from 319 to 557 specimens per gram of dry sediments in both the cores, with the lowest concentration in Core 2 and highest in Core 1. The TFN increases after 6 cm of core depth. It indicates that ambient conditions such as salinity, temperature, and nutrients were favourable for the high foraminiferal population at deeper depths. Research studies state that foraminiferal populations exhibit a non-linear response to salinity-induced pH change (Saraswat *et al.,* 2005; Nigam *et al.,* 2008) and even temperature (Saraswat *et al.,* 2011) based on culture experiments.

Epifaunal foraminifera is usually found in the top few centimeters of the sediment-water interface, whereas infaunal forms are located at deeper levels (Ghosh *et al.,* 2009; Singh *et al.,* 2017; Kaithwar *et al.,* 2020). The infaunal-epifaunal ratio was plotted with core depth (Figs. 6a, 6b), revealing that infaunal species dominate both the core. It indicates less energy and adequate dissolved oxygen condition in the study region (Singh *et al.,* 2017; Kaithwar *et al.,* 2020). Interestingly, after 6 cm, there is a drop in infaunal-epifaunal ratio. The trend matches with the TFN. This suggests the abundance of epifaunal morphogroups beyond 6 cm depth and can be related to the turbulent environment when a river drains into the sea (Nigam *et al.,* 1992; Nigam *et al.,* 2009, Manasa *et al.,* 2016). Nigam *et al.* (2007) reported distribution of recent benthic foraminifera in surface sediments along the western coastal continental margin of India suggesting a relative abundance of infaunal morphogroups. Seasonal change in dissolved oxygen and food availability (Vander Zwaan *et al.,* 1999) are the factors that control the dominance of foraminiferal species. The shift in microhabitat maybe because of barrage reconstruction, adversely affecting the estuarine ecosystem (Sinha *et al.,* 1996; Mirza and Sarkar, 2004).

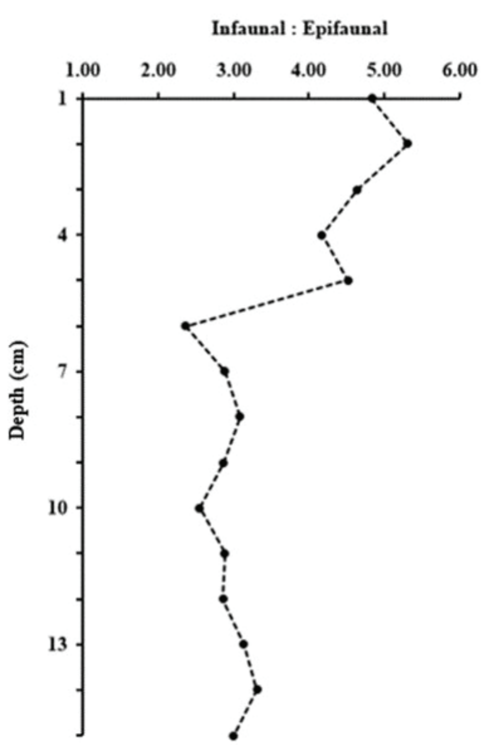


Fig. 6a. Infaunal-epifaunal ratio with respect to depth (Core 1).

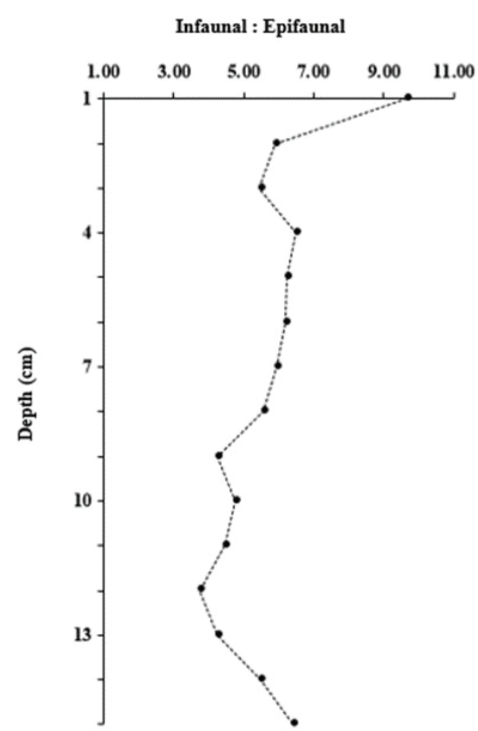


Fig. 6b. Infaunal-epifaunal ratio with respect to depth (Core 2).

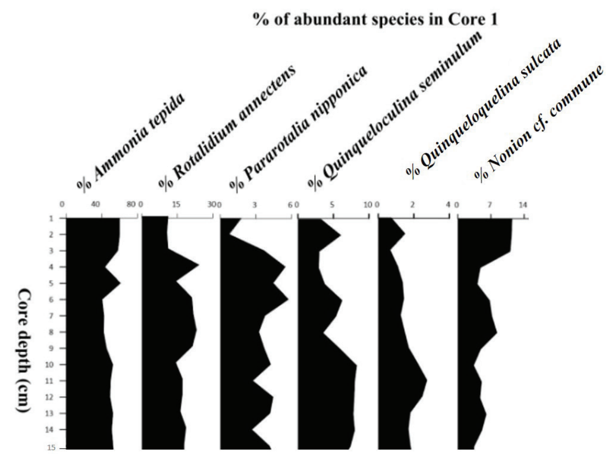


Fig. 7. Variation of dominant species along with the depth of Core 1.

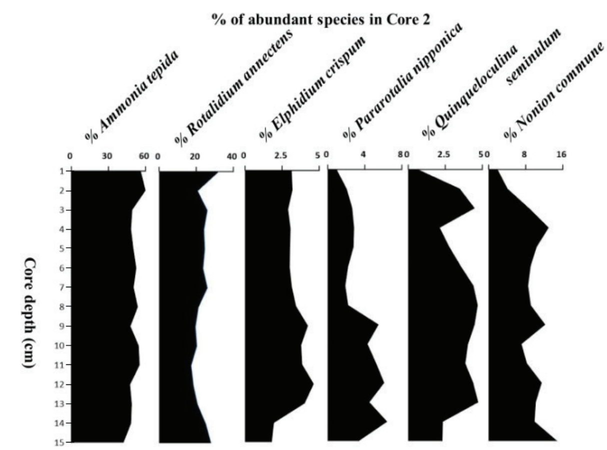


Fig. 8. Variation of dominant species along with the depth of Core 2.

The dominant species variation graph has been plotted (Figs. 7, 8). *Ammonia tepida* (~60%) is the most dominant species contributing 60% of the total foraminiferal population. This is followed by *Rotalidium annectens* (~32%), *Nonion* cf. *Commune* (~11%), *Quinqueloculina seminulum* (<9%), and *Pararotalia nipponica* (<7%) indicate that the low energy environment conditions are favourable to both, Rotaliida and Miliolida order. The abundance of *Ammonia* sp. can be related to its adaptability to large variations of salinity, fine sediments, and shallow depth (Goldstein and Moodley, 1993).

Murray's ternary plot shows the cluster of points near the calcareous hyaline wall type, for both the cores (Fig. 9). The abundance of hyaline tests in the study area can be attributed to high salinity conditions. A low population of porcelaneous foraminifera has been observed in both the cores. However, higher counts in Core 1 indicate a low energy condition regime than Core 2 (nearer to open sea).

Another statistical analysis was performed using Fisher's alpha index, which plots the total number of species versus the total number of individuals for each centimeter of the core (Fig. 10). This analysis aims to find the diversity type of the foraminiferal population. Fisher's index of foraminiferal assemblages varies from 2 to 4, in both the cores, which indicates that this area's overall diversity is low to moderate, typical of marsh environments (Ghosh *et al*., 2009, Ghosh *et al*., 2014).

A good correlation between microhabitat preference and morphological parameters of an individual taxon has been suggested in Corliss and Fois (1990) studies. Benthic foraminifera from different habitats shows distinct morphological features (*e.g.* Corliss, 1985; Corliss and

Table A. Details of total foraminiferal number (all dead) and coarse fraction of sediments for Core 1.

| Core Interval | Total for a miniferal number (All dead) | Weight of the coarse fraction (in gms) |
|---|---|---|
| 1 cm | 280 | 0.298 |
| 2 cm | 265 | 0.241 |
| 3 cm | 299 | 0.252 |
| 4 cm | 274 | 0.189 |
| 5 cm | 292 | 0.210 |
| 6 cm | 209 | 0.156 |
| 7 cm | 319 | 0.202 |
| 8 cm | 399 | 0.173 |
| 9 cm | 352 | 0.166 |
| 10 cm | 448 | 0.171 |
| 11 cm | 439 | 0.134 |
| 12 cm | 405 | 0.155 |
| 13 cm | 501 | 0.171 |
| 14 cm | 414 | 0.164 |
| 15 cm | 557 | 0.151 |

Table B. Details of total foraminiferal number (all dead) and coarse fraction of sediments for Core 2.

| Core Interval | Total for a miniferal number (All dead) | Weight of the coarse fraction (in gms) |
|---|---|---|
| 1 cm | 320 | 0.256 |
| 2 cm | 346 | 0.262 |
| 3 cm | 381 | 0.193 |
| 4 cm | 426 | 0.181 |
| 5 cm | 398 | 0.177 |
| 6 cm | 367 | 0.195 |
| 7 cm | 319 | 0.191 |
| 8 cm | 321 | 0.175 |
| 9 cm | 403 | 0.161 |
| 10 cm | 398 | 0.169 |
| 11 cm | 365 | 0.164 |
| 12 cm | 412 | 0.177 |
| 13 cm | 425 | 0.183 |
| 14 cm | 517 | 0.142 |
| 15 cm | 393 | 0.156 |

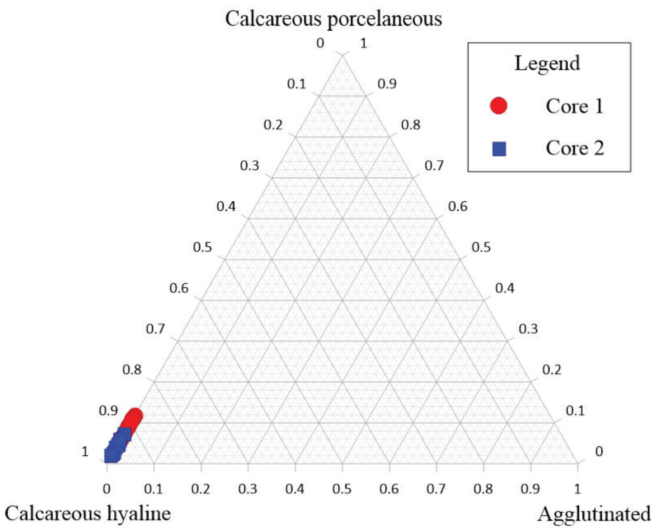


Fig. 9. Murray's ternary plot shows foraminiferal wall types.

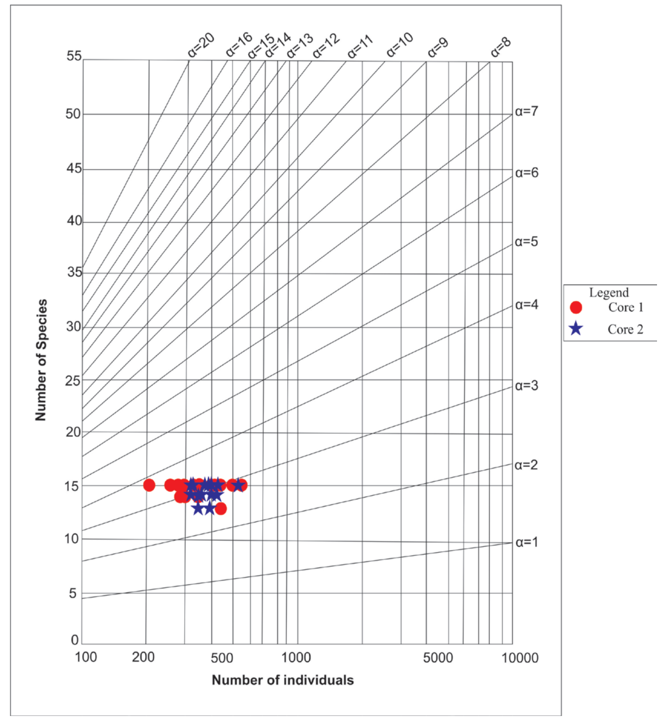


Fig. 10. Fisher's alpha diversity index plot.

Emerson, 1990). Epifaunal taxa live on top of the sediment, shallow infauna in the top 2 cm and deep infauna below 2 cm within the sediment (Murray, 1991; Barmawidjaja *et al.,* 1992; Buzas *et al.,* 1993; Ghosh *et al.,* 2009; Singh *et al.,* 2017; Kaithwar *et al.,* 2020). The abundance pattern of epifaunal species reflects the bottom water condition of sediment/water interface, whereas, increased abundance of infaunal taxa is indicative of the low energy environment and dominance of clay sediments. Infaunal taxa are considered to prefer relatively lower-oxygen habitat because of a decrease in dissolved-oxygen content downward in sediment (Sengupta and Machain-Castillo 1993; Goodday 1994; Kaiho, 1994; Jorissen *et al.,* 1995, Manasa *et al.,* 2016; Das *et al.,* 2019). The black laminations within the core sediments are indicative of low oxygen conditions in down core.

## CONCLUSIONS

1. Thirteen foraminiferal species have been identified, belonging to families Rotalids, Miliolids, and Elphidids.
2. The distribution of species shows that *Ammonia tepida* is the most abundant species amongst all the other identified species, in both the cores. It indicates a low energy environment and high clay content.
3. Mostly the species are calcareous hyaline in nature, with moderate populations of porcelaneous tests.
4. An abundance of infaunal species in both the cores indicates a low energy regime and poor oxygen conditions.

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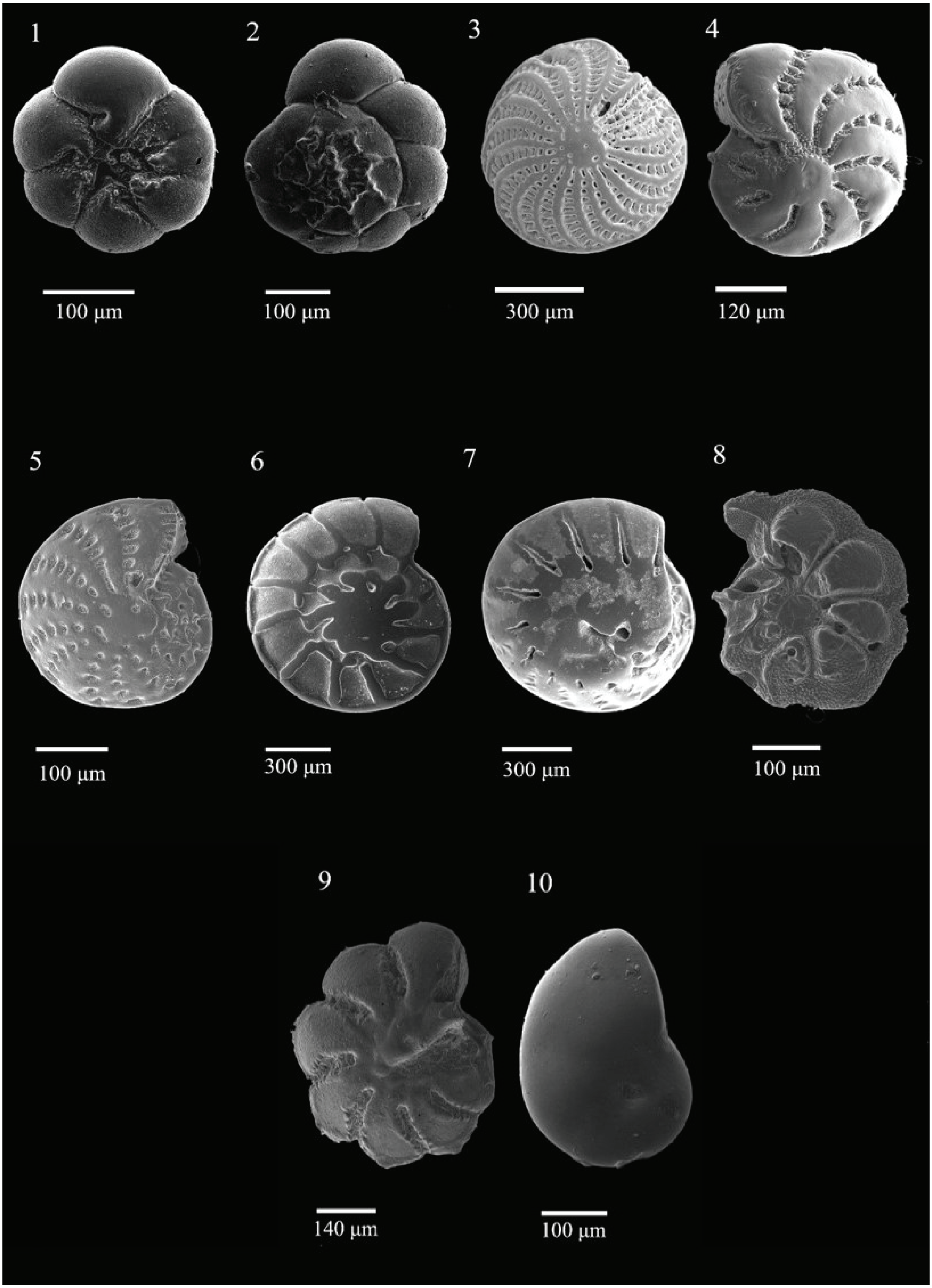
## APPENDIX

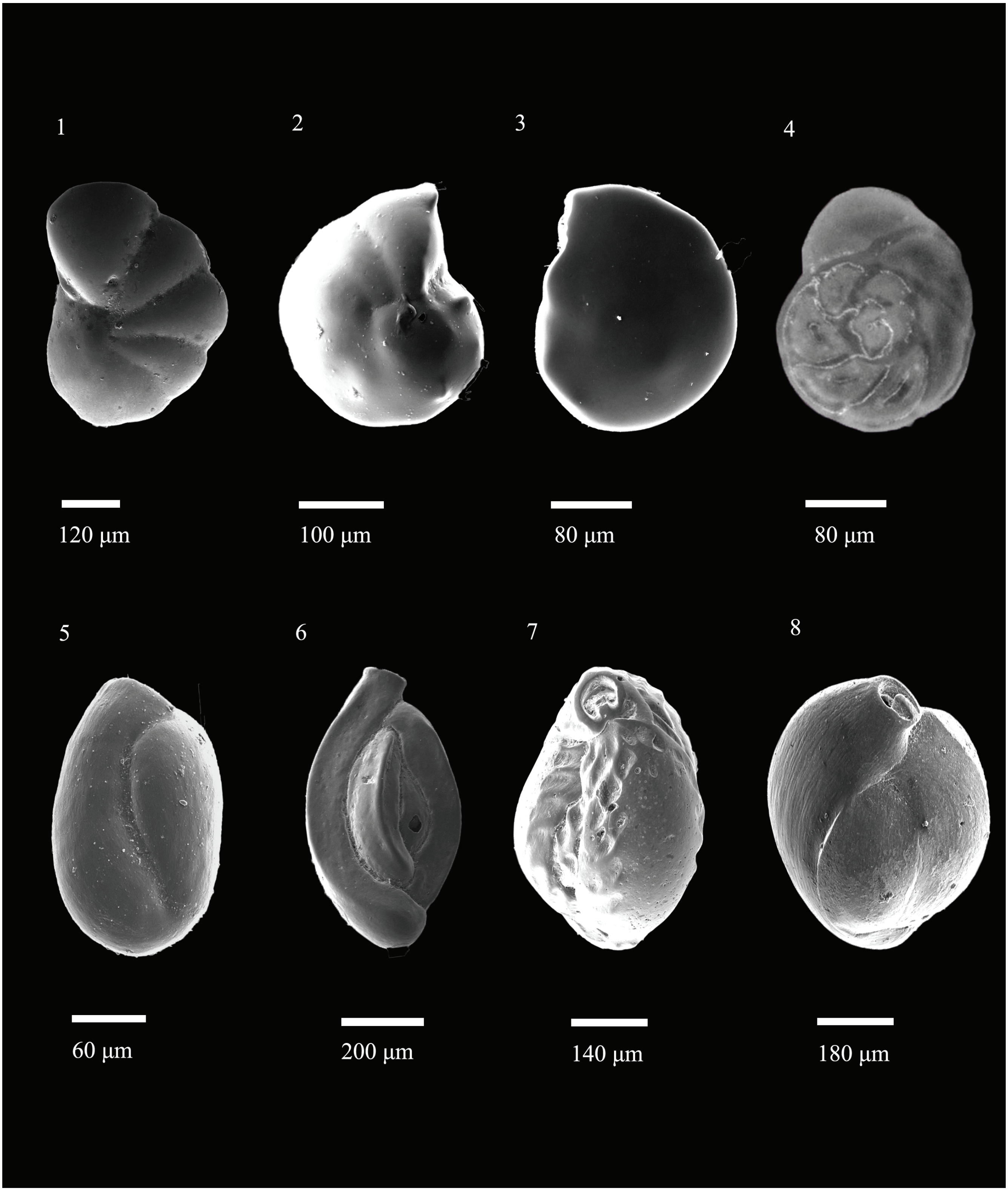
List of foraminiferal species

1. *Ammonia tepida* (Pl. 1, Figs. 1, 2);
2. *Elphidium crispum* (Pl. 1, Fig. 3)
3. *Elphidium craticulatum* (Pl. 1, Fig. 4)
4. *Elphidium advenum* (Pl. 1, Fig. 5)
5. *Rotalidiu mannectens* (Pl. 1, Figs. 6, 7)
6. *Pararotalia nipponica* (Pl. 1, Figs. 8,9)
7. *Nonion* cf. *commune* (Pl. 1, Fig. 10)
8. *Cibicides* sp.(Pl. 2, Figs. 1, 2)
9. *Cibicides refulgens* (Pl. 2, Fig. 3)
10. *Eponides repandus* (Pl. 2, Fig. 4 )
11. *Quinqueloculina seminulum* (Pl. 2, Fig. 5)
12. *Quinqueloculina sulcata* (Pl. 2, Fig. 6)
13. *Quinqueloculina pseudoreticulata* (Pl. 2, Fig. 7)
14. *Triloculina trigonula* (Pl. 2, Fig. 8)




## EXPLANATION OF PLATE I

1. *Ammonia tepida* (U); 2. *Ammonia tepida* (Si); 3. *Elphidium crispum* (Si); 4. *Elphidium craticulatum* (Si); 5. *Elphidium advenum* (Si); 6. *Rotalidium annectens* (S); 7. *Rotalidium annectens* (U); 8. *Pararotalia nipponica* (U); 9. *Pararotalia nipponica* (S); 10. *Nonion* cf. *Commune* (U). Legends: S = Spiral view, U = Umbilical view, Si = Side view.




**EXPLANTION OF PLATE-II**

1. *Cibicides sp.* (U); 2. *Cibicides sp.* (U); 3. *Cibicides refulgens* (S); 4. *Eponides repandus* (S); 5. *Quinqueloculina seminulum* (Si); 6. *Quinqueloculina sulcata* (Si); 7. *Quinqueloculina pseudoreticulata* (Si); 8. *Triloculina trigonula* (Si) Legends: S = Spiral view, U = Umbilical view, Si = Side view.