

# Micropaleontology and Mineral magnetic evidences of the Holocene mudflats of Navlakhi, Gulf of Kachchh

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## ABSTRACT

A combination of foraminiferal and mineral magnetic analyses has been used to reconstruct the depositional environment of the clays from a 3.5 m shallow core of the mudflats of Gulf of Kachchh. The overall foraminiferal assemblage is related to the Early Holocene high sea level. The quantitative analyses of the two most common families viz., *Nonionidae* and *Elphidiidae* of the clays established definite relations between the counts of *Elphidiidae* and the values of magnetic parameters. The relatively lower values of ARM/SRIM, S-ratio and  $\chi$  correspond to the lower counts of *Elphidiidae* inferring low discharge periods during drier climates of weaker monsoons. Similarly, high values of magnetic parameters correspond to the higher counts of *Elphidiidae* inferring high discharge periods of wetter climates of stronger monsoons. During wet periods of monsoonal reinforcements occurring at the early and middle (?) Holocene, it is postulated that there is an overall reduction in magnetic grain size as reflected in higher values of ARM/SIRM, low haematite content from high S-ratio values and increase in percentage abundance of the micro-fauna of *Elphidiidae* and vice versa.

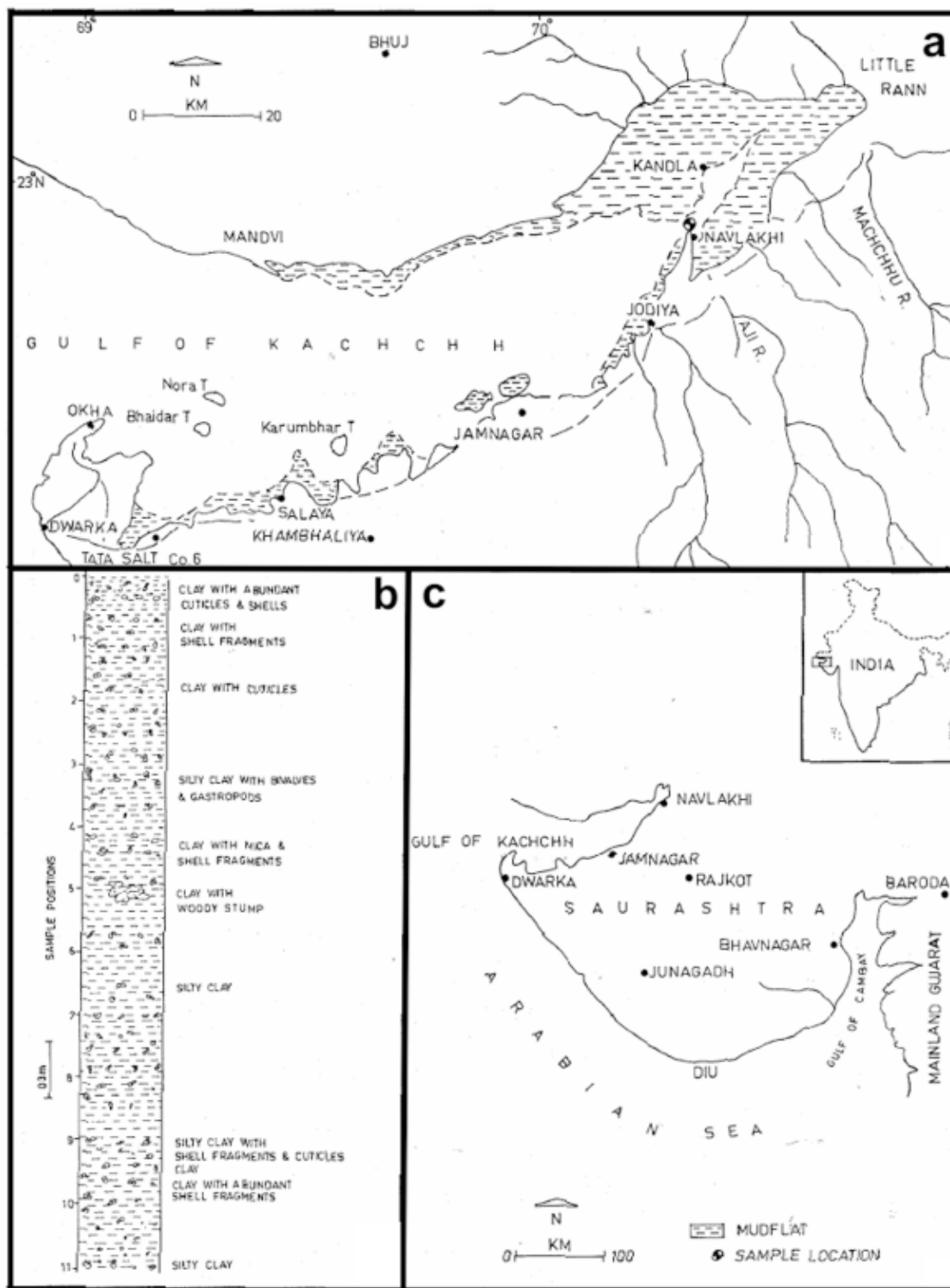
## INTRODUCTION

Coastal zones that form the interface between the land and marine processes are the repositories of palaeo environmental phenomena and hence studies of coastal sediments assume greater significance. Several studies are carried out the world over to understand the coastal environment and its management (Pirazzoli 1991). The studies on the coastal environment are also important in light of the sea level changes. In this context, the study of Holocene coastal sediment archives has acquired special status as they provide invaluable sources for understanding climate-sea level interactions.

In India, the Holocene coastal sediments that occur as extensive clay-rich mudflats are the dominant coastal features, especially in the intertidal regions of the Gulf of Kachchh in the northern part of the west coast. These mudflats have not been studied in detail despite their importance as excellent sediment proxies toward understanding the coastal evolution and related events. The aim of this study is to fill this lacuna in our knowledge through a combined micro-paleontological and mineral magnetic study on the Holocene mudflats of the Gulf of Kachchh in order to understand the palaeo climatic conditions.

## AREA OF STUDY

Navlakhi forms the major mudflat of the Gulf of Kachchh (22°15' N to 23°40' N and 68°20' E to 70°40' E), and is located along the fringes of major Hansthal creek in the State of Gujarat. The Gulf stretches over 170 km across from Okha in the west to Little Rann on the landward end in the east (Fig. 1). Jamnagar and Rajkot districts of Saurashtra form the southern boundary while Kachchh district constitutes the northern limit of the Gulf (Fig. 1). The average rainfall in this region ranges from 400 to 600 mm resulting mostly from the southwest monsoon. Air temperature varies from 7.8°C in January to 44.8°C in May and the water temperature ranges from 15° to 35°C. At present, there is no perennial river in Saurashtra and Kachchh and discharge of rainwater through seasonal monsoon is reduced due to the construction of dams. Tide amplitude as recorded in the Gulf varies from 3.0 m to 7.0 m (Chauhan 1994). Water salinity, especially in the creek, normally varies from 37 per milli to 44 per mill and still higher salinity is recorded in summer in water bodies of the hyper saline zone. According to Gupta (1977), the average rate of sedimentation during the Holocene in the Little Rann was about 2.0 mm per year ranging



**Figure 1.** Map showing Saurashtra coast, Gulf of Kachchh, sample location and reconstructed lithocolumn of the Navlakhi mudflat section

from 1.5 to 3.0 mm per year at different locations. The distribution of organic carbon in the Gulf of Kachchh is also not uniform (Setty et al. 1982).

## GEOLOGY AND GEOMORPHOLOGY

The Gulf of Kachchh region exhibits a variety of geological formations such as the Late Tertiary sandstone, conglomerates and grits, and the Quaternary formations of miliolitic limestone, alluvium, beach sands and mudflats including the sediments of Little Rann (Shrivastava 1968; Biswas 1971; Merh 1993; Chamyal & Merh 1995). Lithological variations have been observed from Okha in the west to Navlakhi in the east. The sediments in and around Navlakhi and Kandla are fine-grained clay to silty clays as evident from the vast mudflats whereas coarse sediments represented by moderately hard shelly limestone and conglomerates dominate in the western part toward Okha. The Holocene marine sequence rests unconformably over older rocks and is distinguished by well-defined lithological and environmental diversities. At Navlakhi, the clays are directly resting over the basalt. The marine Holocene rocks can be practically traced all along the coastal areas right from the Great Rann of Kachchh in the north (Fig. 1) to as far as south Gujarat and beyond, along the west coast. Not much work has been carried out on the Quaternaries of Kachchh and northern Saurashtra coast and practically no systematic documentation is available on the lithological, stratigraphic as well as paleontological aspects. However, Merh (1993) indicated that the fluvio-marine sediments of Little Rann show evidences of sea level fluctuations influenced by glacio-eustasy and neotectonism while Sharma (1990) observed that the raised beach sands mudflats in the area represent the high Holocene strandline.

## METHODOLOGY

Core sampling up to a depth of 3.5 m was done by driving a PVC pipe into the mudflat zone at a location about 200 m west of Navlakhi Port, where about 10 m thick clay horizon directly rests over the basaltic basement. The retrieved core was subsampled at 10 cm intervals in the laboratory. In all, 35 samples were used for micropaleontological studies. In the present study, we have included the analysis of only 20 samples. The clay samples were processed using conventional H<sub>2</sub>O<sub>2</sub> method to recover foraminifera, Ostracods and other microfossils. The microfossils were recovered through 140 mesh-sized fractions of the sediments. The average size of the microfossils

is 180 microns. The coarser fraction of the sediment is practically devoid of microfossils indicating absence of adult forms. The mineral magnetic analyses were carried out on 44 samples at 8 cm interval and the curves for various magnetic parameters such as ARM/SIRM, S-ratio and  $\chi$  were plotted on a graph. Similarly the quantitative analysis of four most common foraminiferal families viz., *Miliolidae*, *Rotaliidae*, *Elphidiidae* and *Nonionidae* were carried out. The clay samples at two levels were dated at BSIP, Lucknow. An attempt is made here to analyse the results obtained from all these laboratory studies synergistically in order to interpret past climate (monsoon) and environment in the Gulf region.

## MUDFLAT SECTION OF NAVLAKHI

The mudflats exhibiting wavy mounds, depressions and channels of varying thickness (3m to 10m) are well exposed during the intervals of low tides across Sui creek near the Custom Office at Navlakhi. A 3.5 m core sample collected by driving a PVC pipe into the clay layer during the low tide level and the sediment sequence is logged. As shown Fig. 1, the upper part of the core is mainly represented by greenish gray silty clay with occasional clay bands. At this level, the mangrove cuticles and shell fragments are common. Megascopic analyses reveal minor variation in sediment grain sizes from the top of the core, closer to the low tide level. On the other hand, the lower part of the core between 2.61 and 3.5 m depth comprises semi consolidated green clay with abundant mica flakes giving a typical luster to the clay. The deposition of clay may be the result of both coastal erosion and inputs from several rivers located in the vicinity with a major share of load coming from the slopes drained by the Machchhu and Aji rivers.

## MICROFOSSIL ASSEMBLAGE

A variety of microfossil groups such as foraminifers, ostracods, bryozoans, holothurian sclerites and sieve-plates are commonly found in the clay samples. These microfossils are very well preserved and unusually smaller than their normal size as most of them could be recovered from the 140 mesh-sized fraction of the sediment. In the present assemblage, the benthic as well as planktic foraminifera are being reported from the finer clay sediments of Navlakhi. The occurrence of fifteen families viz., *Spiroloculinidae*, *Hauerinidae*, *Miliolidae*, *Nodosariidae*, *Cancriidae*, *Bagginidae*, *Planorbulinidae*, *Boliviniidae*, *Rosalinidae*, *Trimosinidae*, *Lagenidae*, *Nonionidae*, *Elphidiidae* and *Rotaliidae* are noted. The foraminiferal assemblages

do not exhibit any significant diversity, as these comprise very few genera. These include *Spiroloculina*, *Quinqueloculina*, *Dentalina*, *Lagena*, *Bolivina*, *Trimosina*, *Cancris*, *Rosalina*, *Cibicides*, *Caribbeanella*, *Nonion*, *Pararotalia*, *Criboelphidium*, *Elphidium*, and *Ammonia*. In addition, juvenile forms of *Globigerina bulloides* and *Globigerinoides* are also found in the sediments.

#### SEDIMENT MINERAL MAGNETIC PROPERTIES

The core samples were subjected to measurements of magnetic susceptibility ( $\chi$ ), Anhysteretic Remanent Magnetization, ARM (peak field = 100 mT, bias field = 0.05mT) together with SIRM (Saturation Isothermal Remanent Magnetization at 1.5 T). Their interparametric ratios like S-ratio (simplified here as  $IRM_{0.3T}/SIRM$ ) and ARM/SIRM have been computed. Thermomagnetic and X-ray diffraction analyses (XRD) of magnetic extracts indicate the presence of (titano) magnetite.  $\chi$ , ARM and SIRM are concentration dependent; to eliminate this dependence, ratios between individual magnetic parameters of S-ratio and ARM/SIRM can be used to assess the magnetic assemblage grain size in sediments. The S-ratio is an indicator of the proportion of high coercivity (particularly antiferromagnetic minerals such as haematite and goethite), to the lower coercivity ferrimagnetic (magnetite and maghaemite), but it is really discriminant only when the proportion of

antiferromagnetic material is greater than 80% of the magnetic assemblage (Bloemendal et al. 1992). ARM/SIRM decreases with increasing grain size.

#### RESULTS

As mentioned above, the foraminiferal assemblage is characterized by low diversity. Out of fourteen foraminiferal families viz., *Hauerinidae*, *Rotaliidae*, *Elphidiidae* and *Nonionidae* are the most common, and are dominantly represented by *Quinqueloculina*, *Ammonia*, *Elphidium* and *Nonion*, respectively. Statistical curve obtained for each family indicated that there is a definite pattern for *Nonionidae* and *Elphidiidae* (Fig. 2) which can be matched with the magnetic curves. There is a decrease in *Rotaliidae* from the bottom of the studied core up to 100 cm level followed by fluctuations in the percentage from 30% in the topmost sample to almost 80% at 80 cm level (Fig. 2a). A reversal of this trend is noticed, however, in the case of *Miliolids* (Fig. 2b). There is a general fluctuation in the value of *Nonion* from 20 % in the bottommost sample to almost 60% in the samples analysed from the top portion of the core (Fig. 2c). Higher percentages of *Elphidium* both at the upper and lower portions of the core are interrupted by one peak of lower percentage of *Elphidium* in the middle (Fig. 2d). Interestingly, a comparison of the curve of *Elphidium* with other magnetic parameters highlights the history of high and low discharges in and around Navlakhi in the Gulf.

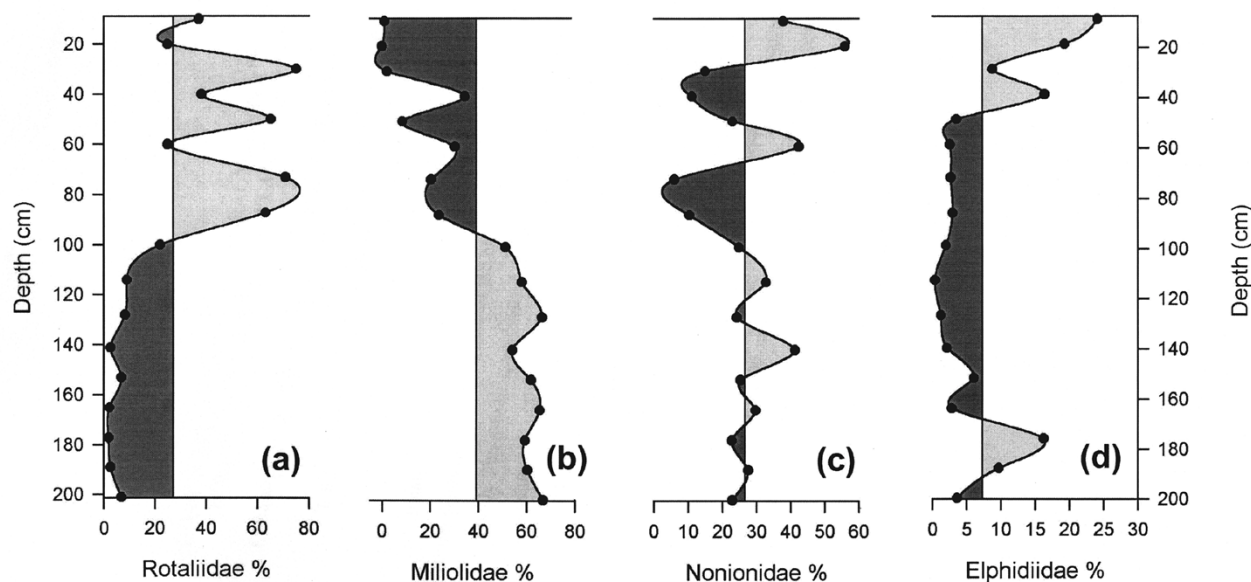


Figure 2a-d. Foraminiferal analysis of Navlakhi mudflat core

The clay samples yielded shells and other mega fossils. However, the required quantity of the shells for  $^{14}\text{C}$  dating could not be separated and hence the whole sediment sample was sent for  $^{14}\text{C}$  dating to BSIP, Lucknow. Samples of two levels viz., 1.3 m to 2.0 m were estimated to  $9390 \pm 140$  yr BP (calibrated 11040 – 10430 yrs BP, BS No. 1990) and  $8720 \pm 200$  yrs BP (calibrated 10150 – 9530 yrs BP, BS No.1987) respectively. The average  $^{14}\text{C}$  dates indicate early Holocene age to the clay sediments of Navlakhi.

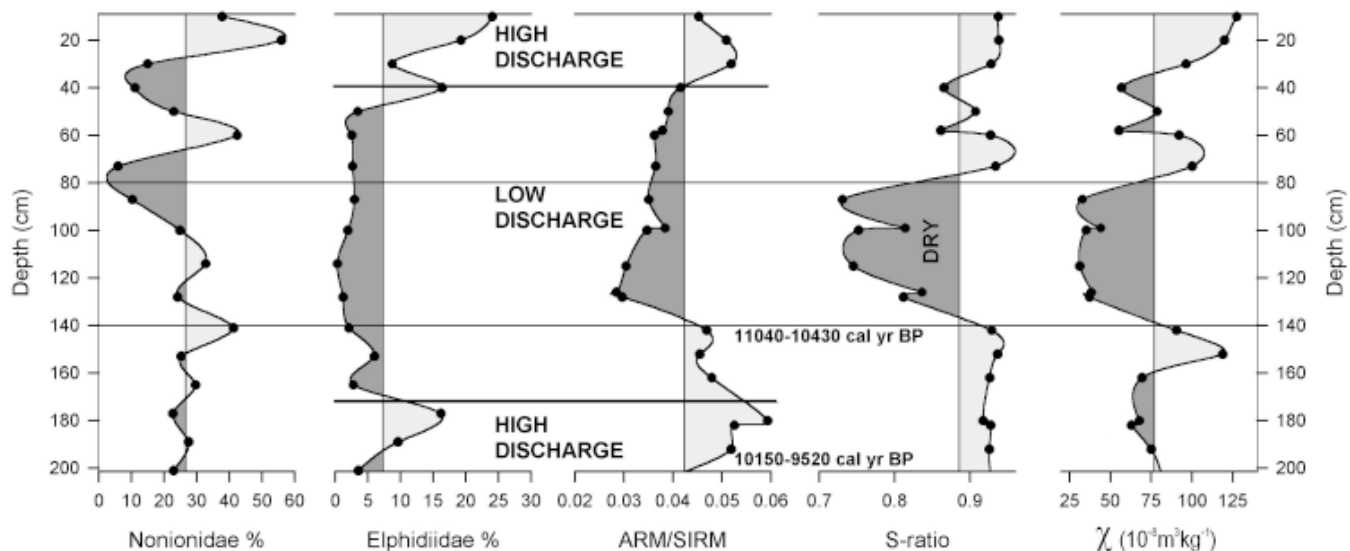
Magnetic mineral records reveal similar trends of foraminiferal assemblages (Fig. 3). Magneto-mineralogical S-ratio ranges between 0.9 and 0.95 at two depth intervals of 200 cm-140 cm and again at 80 cm – 0 cm, indicated the presence of low coercivity titanomagnetite component. The magnetic susceptibility ( $\chi$ ) and ARM/SIRM display higher values in the same depth levels, though  $\chi$  shows an alternating high and low phases. On the other hand, ARM/SIRM follows higher trends of S-ratio. At intervals of middle depths between 140 cm and 80 cm, lower values are observed in all three magnetic records. The low S-ratio values represent the presence of high coercivity haematite supported by lower  $\chi$  values and low ARM/SIRM reflect larger magnetic grains though its increasing trend is observed from 140 cm to 80 cm depth.

### DISCUSSION

The clays in and around Navlakhi form the vast mudflats in this region. Lithologically, the clays vary

from very soft, greenish gray, silty clay to plastic light green clay and are rich in chlorite (Nair et al. 1982). The clays at places have micaceous luster due to abundant micro grains predominantly of fluvial origin. The average of the estimated  $^{14}\text{C}$  dates indicates early Holocene age to these clays at Navlakhi. Thus the shallow benthic foraminifera viz., *Spiroloculina*, *Quinqueloculina*, *Dentalina*, *Lagena*, *Bolivina*, *Trimosina*, *Cancris*, *Rosalina*, *Cibicides*, *Caribbeanella*, *Nonion*, *Pararotalia*, *Criboelphidium*, *Elphidium*, and *Ammonia* in the clays belong to the conditions of the higher sea level in this region.

In addition, the assemblage also consists of species of *Globigerinoides* and *Globigerina bulloides*. Generally the planktic foraminifera are oceanic and they do not thrive in the very shallow tidal regions. Setty et al. (1982) have reported *Globigerina bulloides* from the mouth of the Gulf. The occurrence of these species in the clays at Navlakhi might be attributed to prevailing west-east tidal currents during flooding in the Gulf. The reported foraminiferal assemblage is characterized by very small and thin tests. Interestingly, Setty et al. (1982) made similar observations for the foraminiferal fauna of the offshore region of the Gulf. Thus, it is seen that there is no major difference in the foraminiferal composition between the offshore sediments and the modern clay sediments of the Gulf region. And the distribution of foraminifera across the Gulf remained the same at least since the early Holocene. Another significant feature of the assemblage is its morphogroups.



**Figure 3.** Foraminiferal and mineral magnetic records from the Navlakhi mudflat core. Interpreted levels of low and high discharges are marked across the plots (see text)

Following Severin's (1983) classification of external test morphology and the recent modified version by Nigam & Khare (1999) the benthic foraminiferal genera mentioned in the text dominantly belong to relatively symmetric rounded, planispiral morphogroup. The dominance of this morphogroup in the assemblage studies coincides with the modern general trend of the occurrence of the morphogroup in the living and total populations in all the modern shallow marine areas. The occurrence of morphogroup such as planoconvex, elongate flattened, biconvex keeled and tapered one also noticed in the present assemblage. Nevertheless, the foraminiferal composition and the dominance of only one (rounded planispiral) type of morphogroup indicate the low diversity in this marginal marine set up of the region. Walton (1964) and Boltovskoy et al. (1991) have observed that such type of environment is comparatively more variable, resulting in number of species. In this context, the studied region also shows variable conditions. Erosional activity resulting due to turbidity conditions along the margins of the Hanstal creek are the common phenomena in this region. This must be the principal cause of the low speciation and small thin tests among the microfossils in general and foraminifera in particular. Besides other factors such as influx of fresh water have also affected the foraminiferal composition.

The quantitative analyses of four common families viz., *Miliolidae*, *Rotaliidae*, *Elphidiidae* and *Nonionidae* are compared with S-ratio and it is found that there is a similarity between the trend of *Elphidiidae* and S-ratio (Fig. 3). The higher values of S-ratio coincide with comparatively higher number of *Elphidiidae* at two levels viz., 1.4 m to 2 m and 1.0 m to 0.6 m while the lower values of S-ratio coincide with the low numbers at level 0.6 m to 1.4 m. The curve of *Nonionidae* shows general fluctuations in the frequency; however, the lower values of S-ratio coincide with lower number of *Nonionidae* at level 0.4 m to 1.3 m.

The relation of magnetic parameters (Fig. 3) to climate change is through discharge variations across time. For example, the low variations in the reverse field S-ratio, which relates directly to the presence of haematite (also confirmed by thermomagnetic experiments), indicate fresh water influx in this environmental setup. As this magnetic mineral is derived from erosion of oxidized soils of the catchment during drier periods, low values in S-ratio can directly be related to low discharge conditions (weaker monsoons). On the other hand, high S-ratio values reflecting more titanomagnetite in the sediments

reveal increased fresh water influx during wet periods of monsoon reinforcement. It is further argued that during wet periods, the formation of single domain (titano-) magnetite grains is promoted probably due to break down of multi-domain grains in the sediment provenance of the mudflat. This hypothesis is further confirmed by high ARM/SIRM (Fig. 3) during increased discharge periods. Such conditions presumably gave rise to fluctuation in salinity, at least locally. It is observed that out of four families, the foraminiferal forms of *Elphidiidae* have responded to these fluctuations resulting in variations in its relative abundance. Interestingly, Polyak et al. (2002) have presented extensive studies on the benthic foraminiferal assemblages from the Arctic shelf and have discussed the effect of freshwater discharge and related variations in the *Elphidiidae* population. Our results warrant more detailed work on the seasonal fluctuations in the salinity, temperature and oxygen content of the modern environment with special reference to the modern *Elphidiidae* population in the Gulf of Kachchh. These studies certainly demonstrate that even at the family level, foraminifera may provide useful insights into climate related salinity changes in partially enclosed seas/gulfs especially when combined with magnetic information.

## CONCLUSIONS

1. The low foraminiferal diversity is attributed to the turbidity conditions that prevailed in this marginal marine environment of deposition. Test morphology shows the dominance of rounded planispiral morphogroups
2. The occurrence of planktic foraminifera is due to the influence of west-east tidal stream and currents
3. S-ratio together with ARM/SIRM suggests the influence of fresh water resulting in salinity variations
4. The foraminiferal forms belonging to *Elphidiidae* have responded to these fluctuations

## ACKNOWLEDGEMENTS

CR and PPR are thankful to Dr. V.S.P. Rao, Director, ARI, for encouragement and necessary facilities. The financial support by DST (ESS/72/011/95) and ARI to carry out this work is gratefully acknowledged. PPR acknowledges CSIR for financial assistance. We thank Prof. S.N. Rajaguru for his valuable advice; Dr. G. Rajagopalan, BSIP, Lucknow for providing <sup>14</sup>C-dates and Dr. A.S. Khadkikar for many useful discussions.

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