



ADDRESSING ENVIRONMENTAL ISSUES THROUGH FORAMINIFERA – CASE STUDIES FROM THE ARABIAN SEA*

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ABSTRACT

The present global scenario poses multiple environmental problems such as the green house effect, ozone holes, global warming and consequential sea level rise, all being attributed to anthropogenic contributions. Obviously, there is an increased awareness about the past and the present environment, so as to be able to foresee the future variability in climate. However, climate prediction is a very delicate task and needs a thorough knowledge about the past. Past records have been maintained for not more than past 100-150 years, beyond which we would need proxies to give us information about the past climate.

During the past few decades, microfossils, especially foraminifera have become the prime source to address environmental issues. Extreme sensitivity of foraminifera to changing environmental conditions have led to development of techniques to understand the past sealevel fluctuations, monsoons, cyclones and storms, using their specific characteristics. The significant results thereby produced are also listed here. Besides being one of the most extensively used proxies for palaeoclimatic variations, foraminifera have also found applicability in marine -pollution and -archaeological studies.

There exists both need and scope for further development of foraminiferal techniques useful in environment impact assessment. So as to keep these techniques in sync with the changing modern trends, the traditional hard part studies of foraminifera need to be supplemented with a detailed foraminiferal-culture programme with a molecular biological approach.

Key words: Foraminifera, Environmental issues: Past environment (sea level rise, palaeomonsoon, etc), Modern environment (pollution, sediment transport)

INTRODUCTION

The importance of the word “Environment” is evident from the fact that many international programs like ‘International Geosphere Biosphere Program’ (IGBP) were conceived by the scientific community, many universities started special academic degree courses on ‘Environmental Sciences’ and a ‘Ministry of Environment’ was formulated by large constitutions such as the USA and India. The words ‘climate’ and ‘environment’ have been used frequently as interchangeable / synonyms. However, in the present context, we use the long-term changes in environment as climate. Modern environmental issues have gained attention ever since the adverse effects of pollution have become visible and demanded immediate action in designing monitoring-, preventive- and remedial-measures.

However, in recent years, awareness about climate, its variation, prediction and consequences therewith, has increased significantly, because of the potential impact of climatic variations on ecological, economic and political systems. Climatic changes due to global warming associated with the green house effect can cause rapid sea level rise, change the intensity and frequency of monsoons and cyclones, etc. (Nigam, 2003). However, warming and cooling of the earth and associated sea level rise has been known to occur even in the geological past. With the advent of man, the rates of these processes are likely to change. Therefore, the complex nature of human-climate interaction forms one of the most urgent matters of concern for the modern environment. In appreciating

the question of human impact on climate, records of past climatic fluctuation provides a context which informs present management decisions. The very future of humanity depends upon such decisions.

In view of the foregoing, it is apparent that issues related to present and past environment need to be addressed urgently. In recent years, a number of tools have developed and deployed to address such issues. Microfossils, especially foraminifera have been traditionally used for biostratigraphy with applications in oil industries. The main objective of this paper is to create more awareness about their use as powerful tools to address environmental issues of ancient and modern environments by giving examples from the Arabian Sea.

ISSUES OF THE PAST ENVIRONMENT

As discussed above, rise in sea level and changes in monsoonal rainfall pattern are the significant consequences of warming due to green house effect. For India it is more necessary to assess the impact of these changes as its economy depends on monsoonal rainfall. Similarly any accelerated rise in sea level will affect large population living along its nearly 7000 km long coastline.

Such effects of climatic variations can be faced with less hardship if the future climatic records and the related events can be predicted. Prediction is a delicate task and requires knowledge of the climatic variations in the geologic past with special reference to the Holocene. Since the written records of past climatic variations are available only for the last 100-150 years, indirect methods called proxies are used to generate

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long term past climatic variations. During the past few decades, microfossils, especially foraminifers have become the prime tool to generate palaeo-climatic records with better resolution. Besides being one of the most extensively used proxies for palaeoclimatic variations, foraminifers also find application in archaeological studies.

To assess the net impact of green house effect we need records of palaeo-sea level changes and palaeo-monsoonal fluctuations for the last few thousand years and on much finer temporal resolution. Such information is a prerequisite to understanding the climatic systems and the development/testing of reliable long-term predictive models.

Over the past nearly two decades, we have been studying marine sediments from the Arabian Sea to generate high resolution proxy climatic records and have objectively contributed to the field of deciphering changes in palaeosealevels, palaeomonsoons and palaeostorms/tsunamis.

A. Palaeosea levels

In order to assess accurately the magnitude of prospective rise in sea level due to global warming, an understanding of the sea level fluctuations in the past is necessary.

Development of Techniques: Changes in sea levels can be inferred either by shoreline movement or through depth fluctuations at particular locations. During the course of investigations, Nigam *et al.* (1993) discovered that barnacle fouling particularly species *Tetraclita squamosa* (Fig. 1) on

relict foraminiferal tests can be used as an additional tool for palaeoshore line changes. Nigam and Henriques (1992) have also developed a regional model for palaeo-depth determination, which is based on planktic percentage of foraminiferal fauna in surface sediment of the Arabian Sea. The relationship of planktic foraminifera with depth can be expressed by following equation:

$D = e^{(0.049 P + 3.036)}$, where D is depth in meters and P is percentage of planktonic foraminifera in fauna.

One of the main advantages of the proposed model is that it requires no detailed taxonomic study of the fauna. It is sufficient to separate the fauna into two groups, i.e. planktic and benthic. Preliminary sealevel fluctuation curves for the Arabian Sea region can be prepared by using palaeobathymetric information through the proposed model. Such information is of immense use to develop predictive models. The knowledge of relict foraminifera in certain environments also helps in deciphering palaeo-sea level conditions (Mazumder, 2004; Panchang *et al.*, communicated).

Significant Results: The relative rise and fall of sea level over the time has been studied with the help of foraminiferal evidences, both from the land (high sea level) as well as from the sea (low sea level). Foraminifers present in the shelly sediment layers in Goa (Nigam *et al.* 2005) and Lothal Dockyard (Cambay) (Nigam, 1988) are discussed as case studies of high sea stand. The results indicate the possibility of a high sea stand around 6,000 years BP. Nigam *et al.* (1992) have succeeded in demonstrating that as compared to the present,

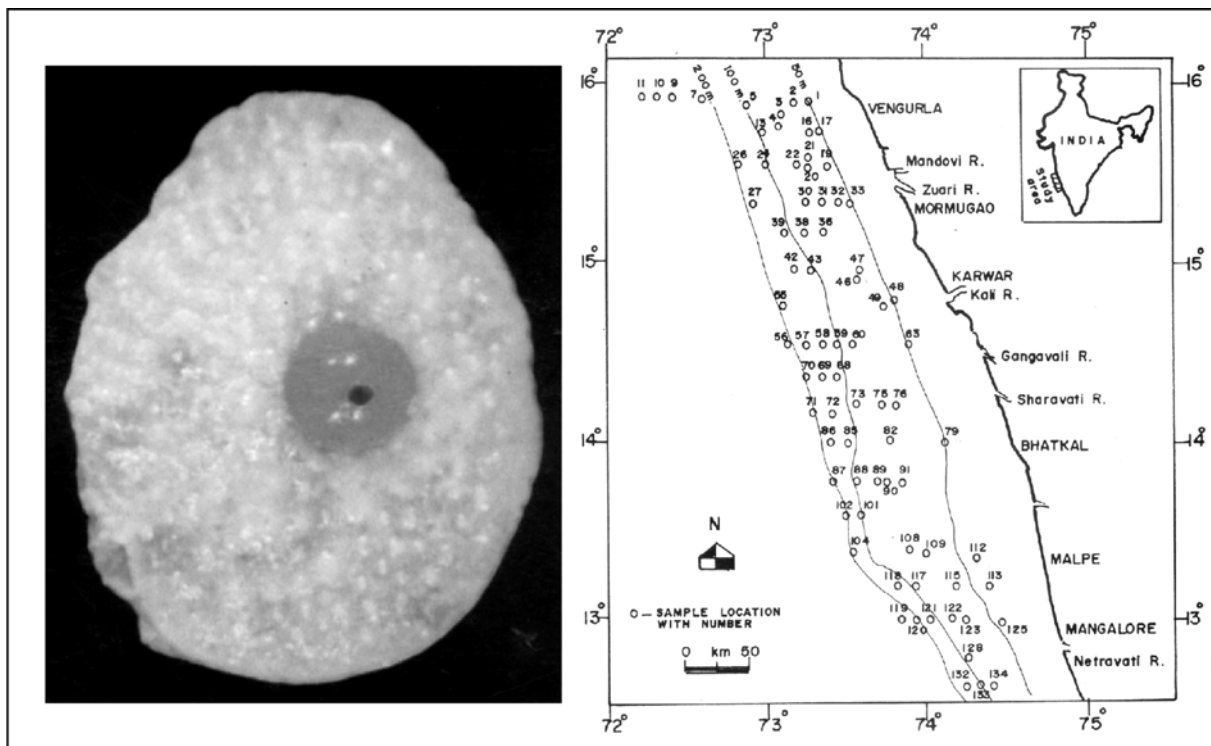


Fig. 1. Intertidal barnacle *Tetraclita squamosa* attached to relict foraminifera.

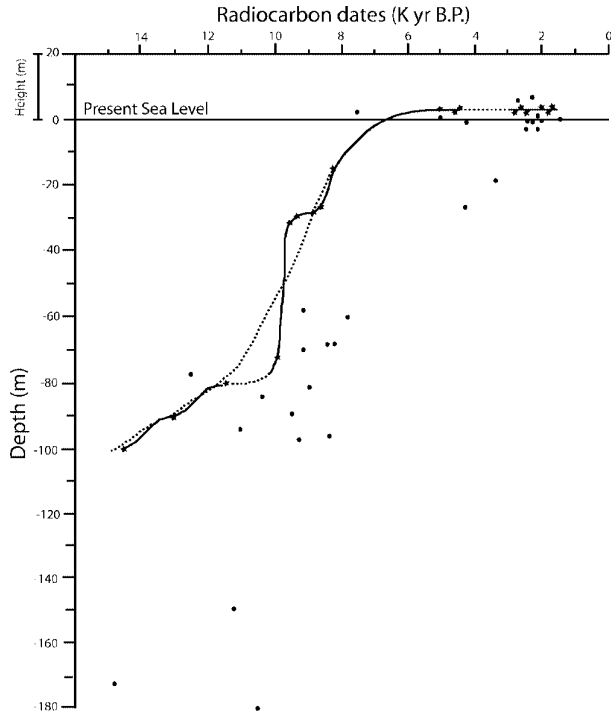


Fig. 2. Sea level curve for Central West Coast of India.

sealevel was lower by ~100 m about 14,500 years BP. and ~60 m about 10,000 years BP. During the last 10,000 years, three major episodes of sea level fluctuations were also reported (Nigam, 1990; 1995; 1996). Recent updating of the Holocene sea level curve (Fig. 2) for the central West Coast of India by Hashimi *et al.* (1995) will serve a long standing need of a standard sea level curve for the future workers. This curve later helped Nigam and Hashimi (2002) in justifying the finding of Neolithic human settlements at 30-40m water depth at ~9500 years BP.

Till the accurate assessments are obtained about magnitude of rise in sea level, under the Department of Environment sponsored research, using international figures, the socio-economic implications of anticipated sea level rise due to Greenhouse effect were assessed for Maharashtra, Goa and Karnataka states. Recognition of our expertise in this field came in the form of declaration by Govt. of India that NIO will be Coastal Regulation Zone (CRZ) authority to clear projects in coastal areas with reference to sea level rise associated with Greenhouse Effect.

A significant application of foraminiferal studies towards marine archaeological studies was recognized when during the excavation for Harappan settlement at Lothal, archaeologists came across a large rectangular structure and were unable to interpret as to whether it was a dockyard or an irrigation tank. This controversy was finally solved with the help of foraminiferal studies (Fig.3). The presence of foraminifers (which are almost exclusively marine), in the sediments from the tank, suggested that the rectangular tank was a dockyard connected to the open marine environment with high tidal range.

B. Palaeomonsoons

Recently, a few reviews on the past monsoons appeared in literature (Naidu, 1999). These reports mostly cover the work on planktic foraminifera from the deep-sea regions where rates of sedimentation are low and thus limiting the resolution. The high-resolution proxy records for palaeo-monsoonal precipitation are the need of the hour over which man’s impact can be more easily evaluated. This objective can be achieved by exploring coastal areas having high rates of sedimentation. First, we prepared a conceptual model (Fig. 4) and then developed techniques of using foraminifera as a proxy to determine the palaeo-monsoons.

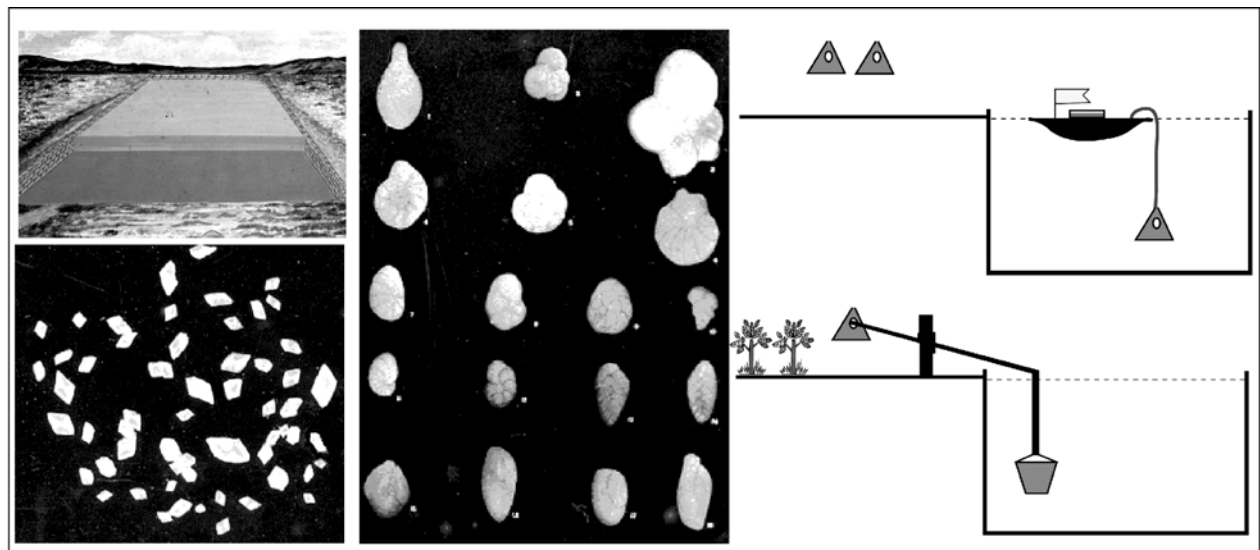


Fig. 3. Location of Lothal Dockyard, concept depicting controversy and foraminifera and Gypsum crystal encountered in sediments from the rectangular basin.

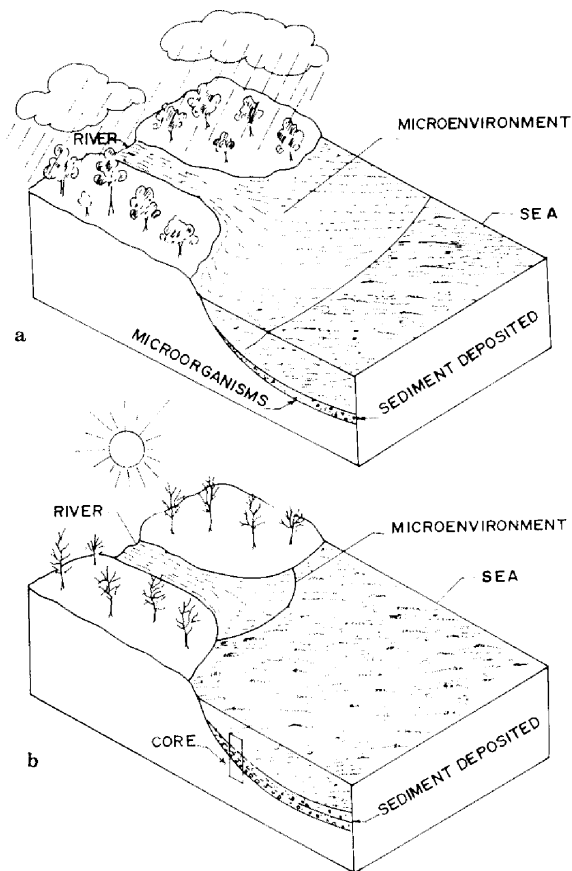


Fig. 4. Concept of microenvironment proposed to develop a technique to decipher paleomonsoons (a) Good monsoon conditions (b) Poor monsoon conditions.

Development of Techniques: Towards the beginning, we evaluated techniques using various parameters like coiling direction (Nigam and Rao, 1987; Nigam and Khare, 1992), and oxygen isotope ratios (Nigam and Sarkar, 1993) in foraminifera for this purpose. During this process, we developed new techniques for determining palaeo-monsoons.

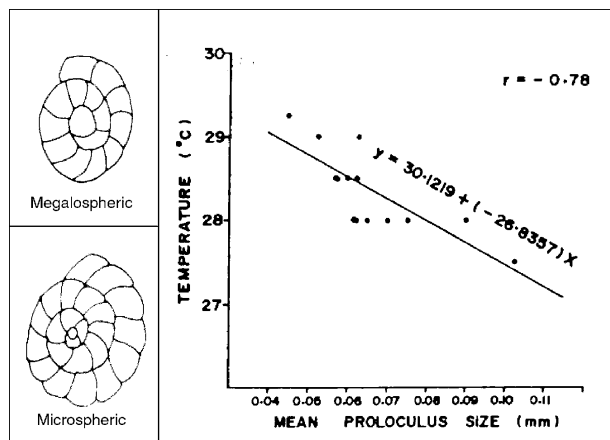


Fig. 5 Microspheric and megalospheric forms and Inverse relationship between mean proloculus size and salinity.

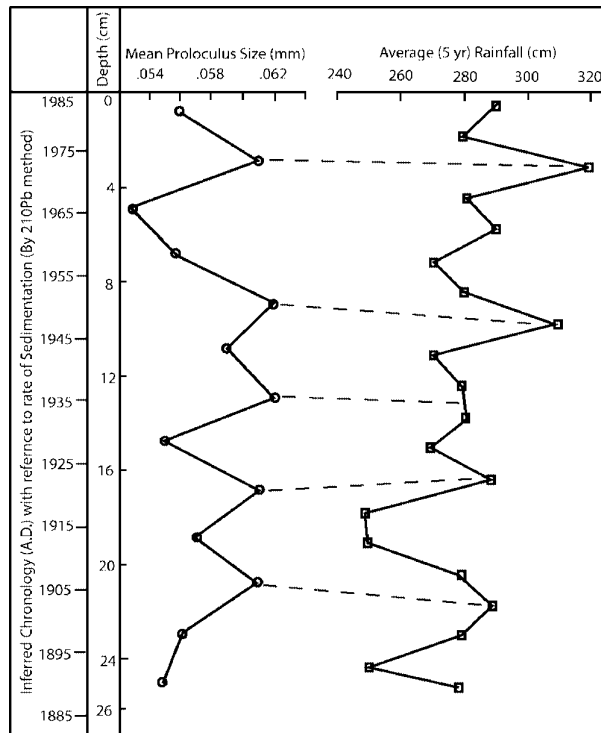


Fig. 6. Direct relationship between Mean Proloculus Size (MPS) and average rainfall in the 100 years over meteorological sub-division 31, which is the catchment area of the Kali River.

The original idea of using dimorphic variations (mean proloculus size) in palaeoclimatic reconstruction was first published by Nigam (1986) by using samples from the Skagerrak, North Sea. The concept was further followed in subsequent publications (Nigam, 1988; Nigam and Rao, 1987) with little modifications wherein, dimorphism in *Cavartalia annectens* from the west coast of India was used as signifying the relationship between salinity (as factor of monsoon) and mean proloculus size (Fig. 5). Pursuing this idea further, Nigam and Khare (1995) established the significance of correspondence between river (Kali in Karwar) discharge and mean proloculus size of benthic foraminifera (Fig. 6) in palaeo-monsoonal studies. While studying surface and subsurface sediments off central west coast of India, Nigam *et al.* (1992 and 1994) also found that morphological (coarser morphogroups) variation in benthic foraminifera as response to changing salinity can be used as an additional tool in palaeo-monsoonal studies. These techniques are simple, less expensive, need less sorting time, which can also be supported by computerised image processing. Development of these techniques helped us to generate high-resolution records of palaeo-monsoons. Since reliability of any new technique can be best strengthened through culture experiments, a foraminiferal culture program has been established and preliminary results have already been published by Nigam *et al.* (*Proc. XV ICMS*, 1996 and *Jour. Pal. Soc. India.*, 1996) and Nigam and Caron (2000). However,

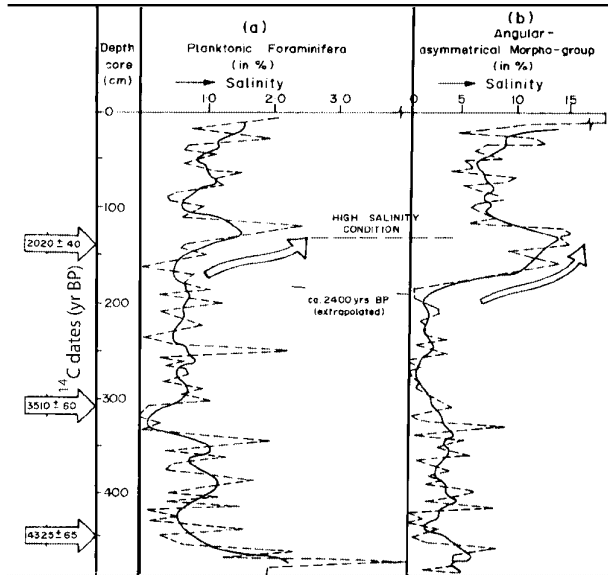


Fig. 7. Down core profiles of the frequency variations of planktonic foraminifera and angular-symmetrical morpho-group of benthic foraminifera (Thick arrow indicates change in the monsoonal precipitation towards dry phase after a good spell).

development of a full-fledged laboratory, capable of handling comprehensive programs related to development of proxies for palaeoclimate, pollution and gas hydrate program is in progress.

Significant Results: Studies on core samples off Karwar

(Fig. 7), west coast of India showed the clear signals of marked high rainfall around 4000 and 3500 years BP (Nigam and Khare, 1992; 1999; Nigam, 1993) and reversal of rainfall condition since 3500 B.P. with a marked low at 2000 years BP (Nigam and Khare, 1994). These findings gathered support from palynological investigations of the same core (Caratini *et al.*, 1994) and foraminiferal studies off Oman, western Arabian Sea by Naidu (1996). Nigam (1993) has inferred that monsoonal precipitations were rather high at 280, 840, 1610 & 2030 years before present. Nigam *et al.* (1995) also deciphered a cyclicality of approximately 77 years in concentration of drought years (Fig.8) and pointed out the possibility of correlation between the inferred cycle and the Gleissberg cycle caused because of variation in the radius of the sun (Fig. 9). This pilot study when viewed in background of the last century rainfall data, gave an indication in 1989 that the forthcoming decades may have a good average rainfall (Nigam and Nair, 1989; Nigam, 2000). We are now working to provide a regional scenario for rainfall pattern.

A better understanding about future changes in monsoonal rainfall is definitely useful for long-term planning. If calamities such as floods or droughts can be anticipated well in time, the resources could be managed and shared or distributed, contributing to balance the economy of the country during the time of crisis. Sufficient or excess rainfall conditions will even improve relationship between the states as well as bordering countries sharing water resources.

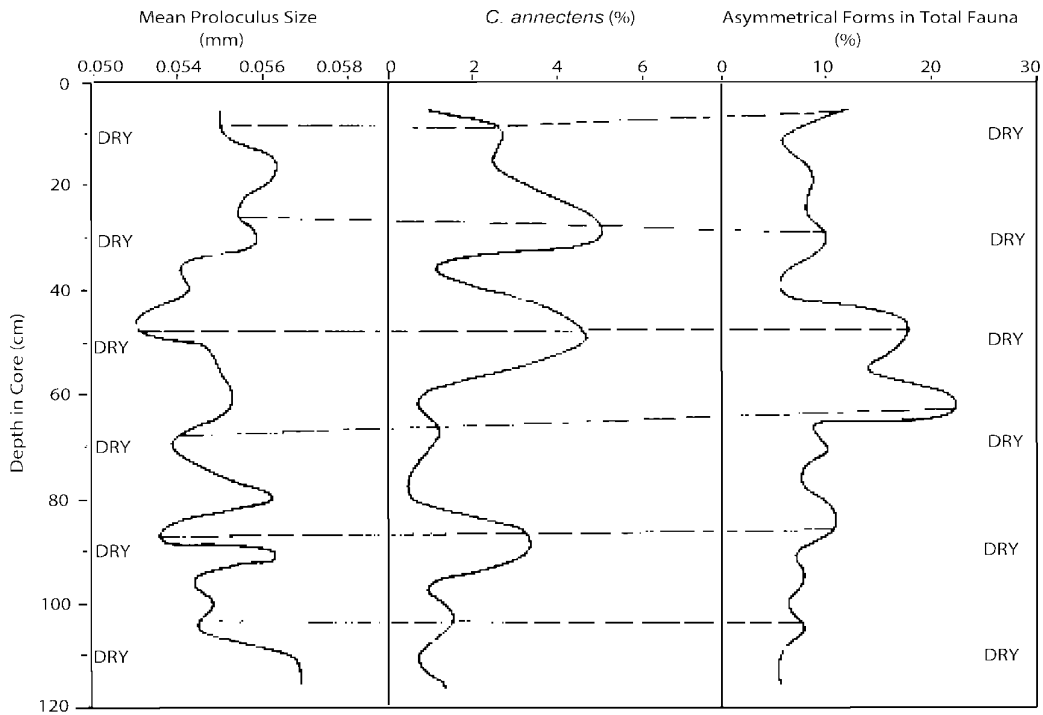


Fig. 8. 77-year cyclicality as deciphered from down-core variation in abundance, percentage of angular asymmetrical form and mean proolocus size of *Cavarotalia annectens* off Karwar.

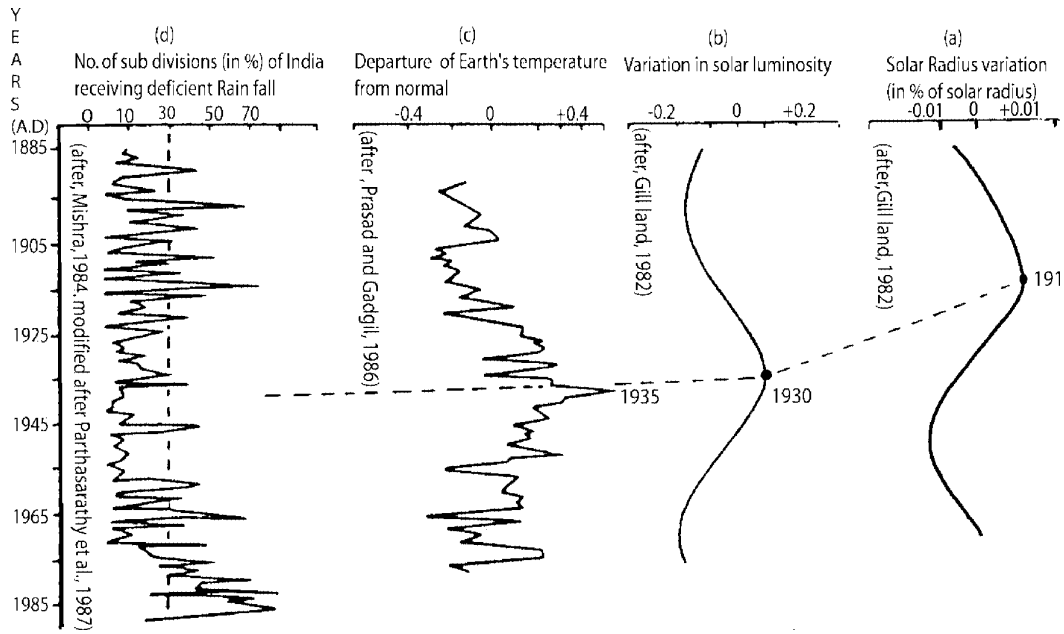


Fig. 9. The 77 year cyclicality of monsoons corresponding to the Gleissberg Solar Cycle.

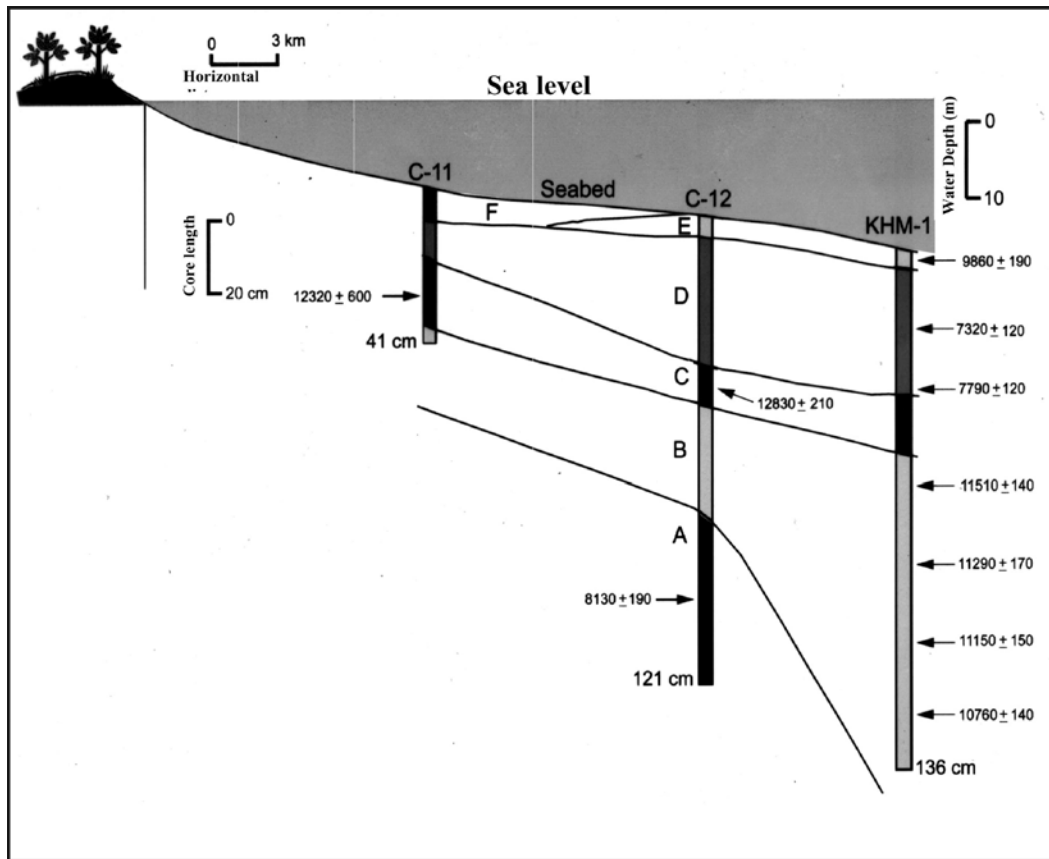


Fig. 10. Generalised zoning in the cores with reference to the faunal clusters and radiocarbon dating. Inverted sediment sequence in zone B and C deposited under the influence of storm/tsunami.

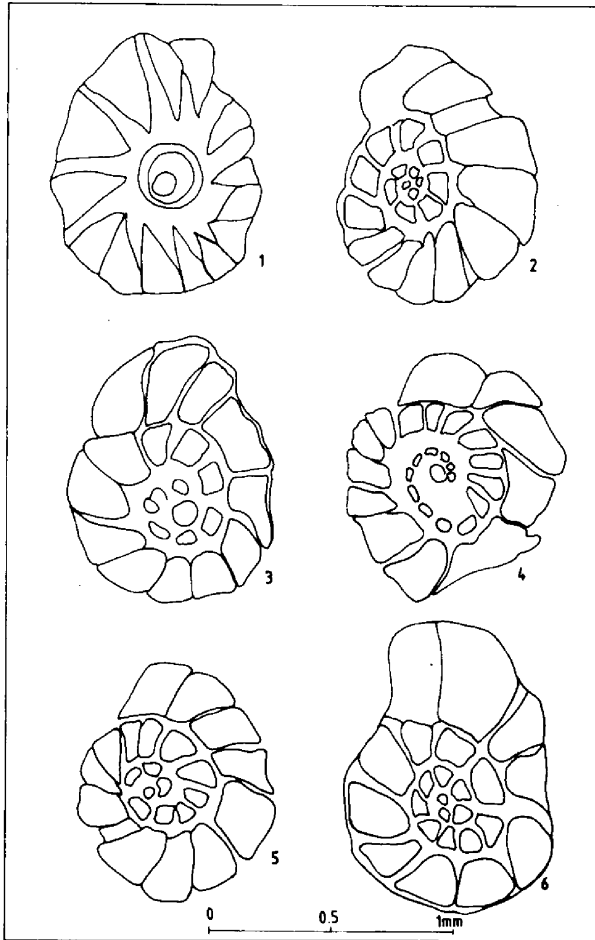


Fig. 11. *Ammonia annectens* showing abnormalities in the growth of the tests indicating pollution.

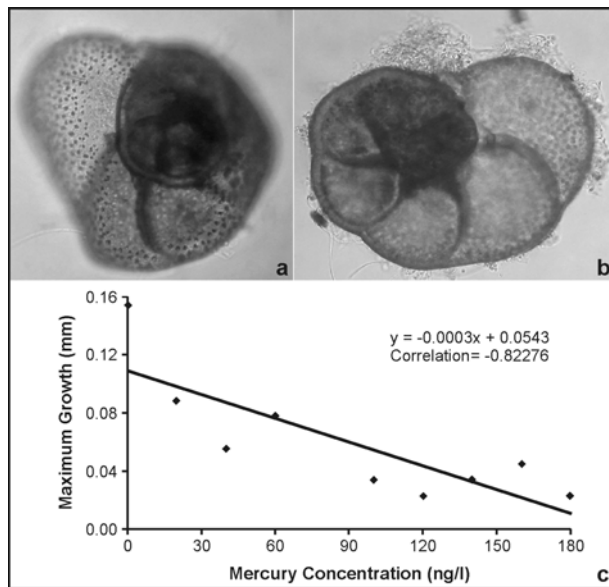


Fig. 12. (a) Normal specimen of live *Rosalina leei* maintained in normal seawater. (b) Unusual orientation of the newly added chambers as well as a comparatively larger last chamber in laboratory culture due to Mercury in the media. (c) Growth shows negative correlation with Hg concentration.

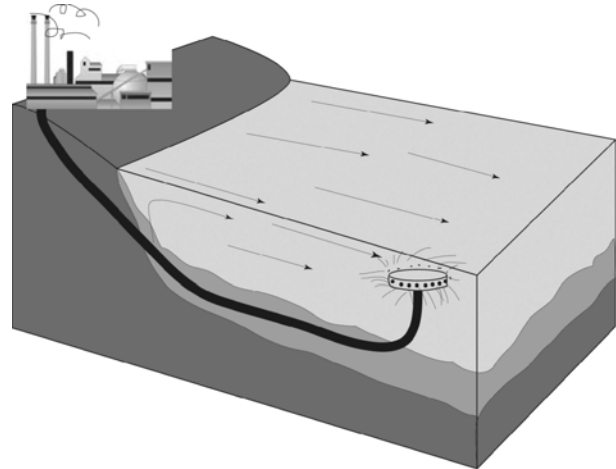


Fig. 13. Schematic diagram showing the concept of laying pipe line along with water Diffuser.

C. Palaeostorm / tsunami

Out of many consequences of global warming, increase in magnitudes and frequencies of storms is of utmost importance. The bad memories of the recent Orissa super-cyclone and tsunami are still haunting the common man, planners and scientists. Is there any evidence of synchronization of warming and storm in the past? Is there any cyclicity in the occurrence of storms in the past? Not yet investigated. There is a pressing need to pursue such research in the coming days.

The entire East Coast and part of West Coast (particularly Saurashtra) of India often face the furies of storms. At least one such finding (Nigam and Chaturvedi, 2005) based on foraminiferal evidences show that during early Holocene, rapid sea level rise along with warming, left the signatures of powerful storms/tsunamis off Kachchh, Gujarat, India. This study, exhibited a sequence wherein older sediments are sandwiched between younger sediments in a core (Fig. 10). Based on these results, a schematic model is proposed to explain the presence of inverted sediment sequences with fine-grained sediments and small sized foraminifera. It was hypothesized that the erosion of sediments from the deeper region, transportation of fine-grained sediments against gravity and deposition in shallower regions is possible only under the influence of storms/tsunamis. This is a first report of such a situation along the west coast of India. The study also suggests the need for detailed integrated geological and geophysical investigations not only for Kachchh but also for some other storm / tsunami prone areas (particularly the east coast) along the Indian coasts.

Tsunami is not a climatic phenomenon and is associated with intense earthquakes having epicenters in marine realm. However, it is expected that such past events must have left their signatures in the form of erosion, slumping and

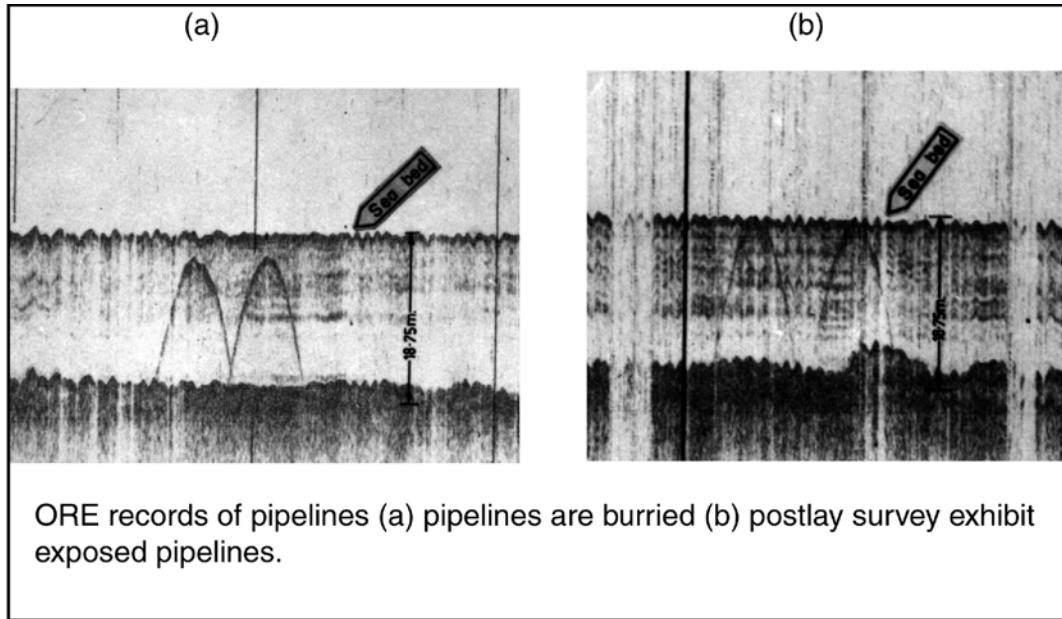


Fig. 14. Sub-bottom profiler records showing (a) buried pipe line and (b) exposed pipe lines.

depositional features. Though enough evidences are not there, possibility of cyclicity is pointed out (Tad Murty, 2005). Thus, the working hypothesis developed to understand the cyclicity of cyclones could be used to understand the cyclicity in tsunamis (if any). However, it is not always easy to differentiate between storm and tsunami deposits in coastal areas.

ISSUES OF THE MODERN ENVIRONMENT

A. Pollution monitoring

Pollution is a phenomenon, which is always associated with increasing industrialization to attain fast economic growth. Sea is the ultimate resting ground for wastes

generated from most industries in general and coastal areas in particular. The massive pollution causes the fall in live products of the sea (like fishes) and thus negatively compensates some of the benefits of industrialization. Therefore, there is a worldwide awareness to control pollution for which detection / monitoring is the first step. Being very sensitive to environmental changes and due to their good preservation potential, foraminifera (marine micro-organisms) have been used to monitor marine pollution in coastal areas as foraminifers incorporate such minute changes of the marine environment, in their tests. In India too, a number of researchers have published their results (Rao and Rao, 1979; Setty, 1982; Setty and Nigam, 1984; Naidu *et al.*, 1985; Bhalla and Nigam, 1986; Rao, 1996; Jayaraju and Reddi, 1996, etc.) in this field. A full review on status of these studies at the national and international level can be seen in Nigam *et al.* (2005).

The pollution monitoring through foraminifers started with attribution of peculiar foraminiferal features at any location to the circumstantial presence of pollutants at that site. These peculiar features of the foraminifers in polluted areas included, variation in the abundance of total, calcareous and agglutinated foraminifers, species diversity, abnormal tests (Fig. 11) etc. The abnormalities of tests included stunted growth, abraded margins, dissolved ornamentations, etc. (Setty and Nigam, 1984). Most of these studies were aimed to discuss the changes in foraminiferal fauna through the spatial distribution with reference to proximity and distal zones from effluent discharge point of a factory (Nigam *et al.*, 2005). This approach is found useful to deduct pollution restricted to small areas, i.e. to a particular factory with particular effluent (Bhalla and Nigam, 1986).

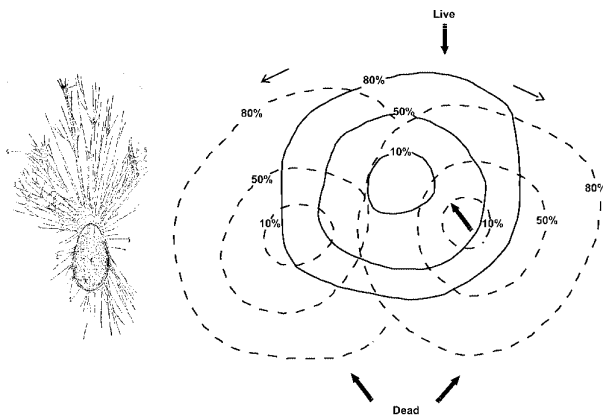


Fig. 15. Live foraminifera with pseudopodia and concept showing use of foraminifera in deciphering sediment transport direction (arrow) through comparison of contours of living and dead foraminifera.

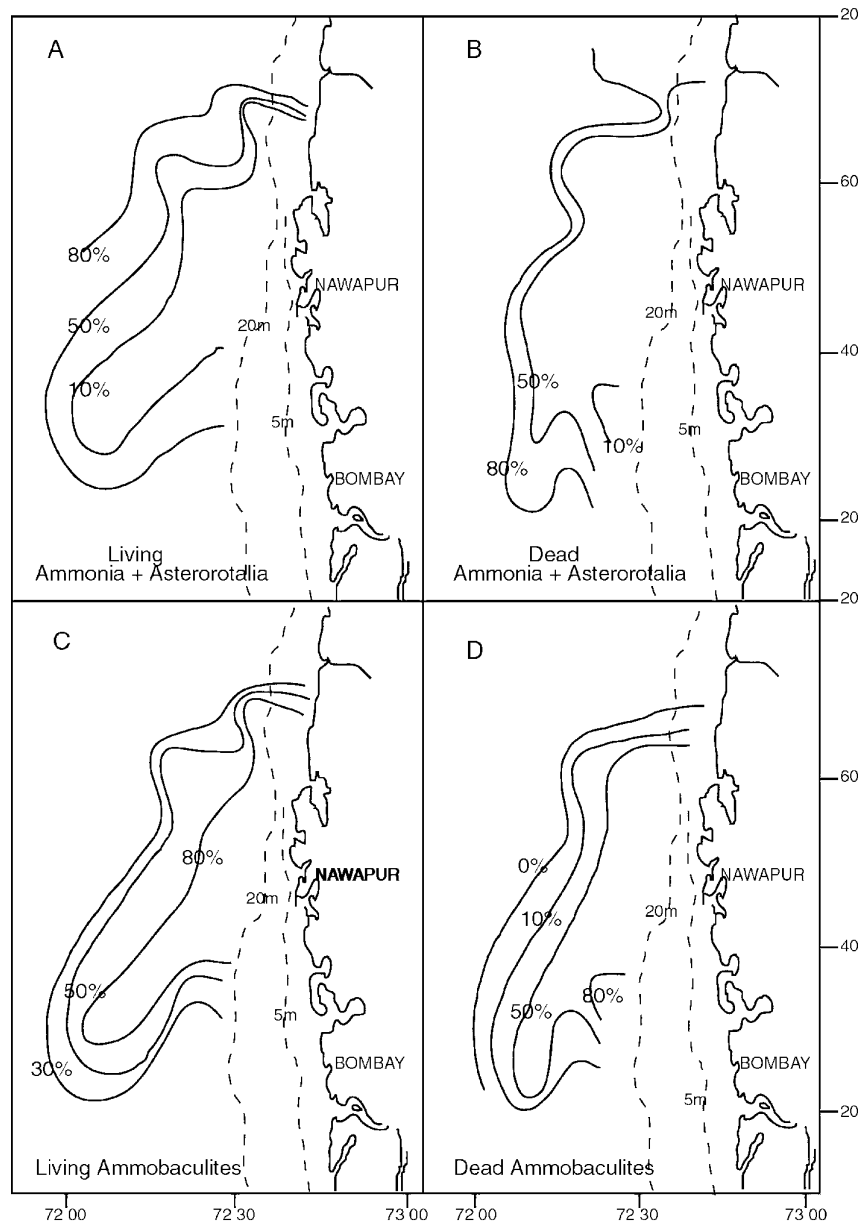


Fig. 16. Comparison of Live (A and C) and dead (B and D) foraminifera in sediments off Navapur indicating net sediment transport direction towards southeast.

Prolonged pollution in rather large areas can also be attempted through quantitative comparison of faunal data in surface sediments collected with sufficient time gap. Mandovi estuary, Goa provided an opportunity to test this conceptual framework. This area was selected for two reasons. The catchment area of this estuary is known for its open cast mining for iron ore, and its pre-monsoon foraminiferal distribution data for 1972 was available (Rao, 1974). Nigam *et al.* (2002, 2005), based on samples collected in 1990, generated the data on foraminiferal distribution in Mandovi estuary and compared the results. The study revealed that during 18 years, total foraminiferal number (TFN) had come down considerably (2

to 42 specimens/g in 1990 as compared to 10 to 139 specimens/g in 1972). Similarly, total species number (TSN) also declined from 18 (in 1972) to 14 (in 1990). It was postulated that decline in fauna was due to continuously increasing suspended load (2-4 mg/l in 1972, 4.5 - 8 mg/l in 1982 and 6.69 - 114.49 mg/l in 1990) in the estuary. The increased suspended load could be attributed to mining activities in the catchment area of Mandovi River along with its tributaries. Extraction of one tonne of iron ore generates about 1.5 to 4 tonnes of mining reject, and over the years more than 1 billion metric tonnes of mining reject is estimated to have accumulated in mining belt of Goa. The loose mining reject gets eroded due to flood-

ing during monsoon and transported downstream, thus increasing suspended load in river. In view of the foregoing it was summarised that decrease in foraminiferal population in Mandovi estuarine sediments during 1972-1990 indicated the influence of mining pollution. However, when the same methodology was followed with an objective to estimate the health of the near by Zuari Estuary through foraminiferal distribution in its surface sediments, the opposite situation was revealed (Panchang *et al.*, 2005). The foraminiferal data generated was compared with the three-decade-old foraminiferal data collected in 1972 and Total Suspended Matter (TSM) data over the years. It was interesting to note that there had been a substantial increase in the maximum Total Foraminiferal Number (TFN), from 1143 specimens in 1972 to 3057 specimens per gram sand in 2003. Even the Total Species Number (TSN) had increased from 24 in 1972 to 50 in 2003. This was in compliance with the TSM data collected over the years, which had considerably decreased. The foraminiferal data, TSM data and reduction in mining activities in the catchment area of the Zuari Estuary suggested an improvement in the environmental health of the estuary. The changes are due to shift in Iron ore mining focus from South Goa (catchment area of Zuari estuary) to North Goa (catchment of Mandovi estuary). Therefore both the studies strengthen the view that foraminifera can be used as a tool to monitor marine pollution.

The advantage of application of foraminifers, over other chemical and biological techniques, for pollution monitoring lies in their potentiality to decipher temporal variation in type and concentration of pollutants at any site even in the absence of pre-pollution studies, based on the recovery of foraminifers from the sediment core samples. Realizing the potential application of characteristic foraminiferal features from the polluted areas to decipher the variation in introduction and concentration of pollutants at any given location with time, efforts were made to characterize the specific types of foraminiferal features to the specific pollutants. It was at this point that the need of culture studies was widely felt which resulted in numerous lab and field culture studies where foraminifers were subjected to specific pollutants in order to document their response to these pollutants (Fig. 12) and to develop effective foraminiferal proxies for pollution monitoring through time (Saraswat *et al.*, 2004). Such studies are still going on and it is felt that culture studies need to be supplemented with advanced crystallographic and molecular studies (Saraswat *et al.*, 2003) in order to find the mechanism through which foraminifers respond to pollutants.

However, applying the understanding of foraminifera does not stop at detecting and monitoring marine pollution in coastal areas. As industrial development is a necessity for economic growth, pollution cannot be stopped completely. Therefore steps have to be taken to minimize the adverse effects of pollution. This objective is largely achieved through

disposal of effluent in deeper areas (Fig. 13) where, through diffuser, under the influence of current pattern, effluents disperse towards the open ocean and thus effect is neutralised in coastal areas- a zone of high fishing activities. In order to carry the effluents to diffuser point, we need to lay a pipeline. As an exposed pipeline at the bottom is likely to get damage particularly during trawling, the same has to be buried under sediments. Appropriate pipeline routes are selected through seabed surveys. Soft sediment substrates are preferred so that pipelines sink into the sediments due to their own weights. When such conditions are not available, trenching followed by filling is the only alternative. However, in some cases post-lay surveys indicated that the pipelines are subsequently exposed and damaged as the protective sediment layer is eroded (Fig. 14.) This established a need to know the long-term sediment transport history regions where pipelines need to be laid. This requirement gave us an opportunity to develop a technique where knowledge of foraminifera was used to decipher sediment transport direction.

B. Sediment transport

The usual methods of determining the currents are by using current meters or fluorescent, radioactive, mineral tracers, etc. These methods only give the results for a particular time. But if net sediment movement under the influence of currents on a long-term basis is required, these techniques can be supplemented with other methods. In such cases, for example, the study of microfossils, e.g. foraminiferal component is useful.

Development of Techniques: The concept is based on the fact that benthic foraminifera are excellent indicators of bottom conditions and in the living stage possess pseudopodia. The pseudopodia help the organisms to collect food and to anchor to the substrate and thus prevent their displacement by currents (unless very strong). After death, the freed tests behave as sediment grains and thus get subjected to transport by currents. The Rose Bengal staining technique facilitates the differentiation of live foraminifera from the dead. If there is no major sediment transport, then contouring of major assemblages of living and dead fauna should be more or less identical in any area (Figure 15). If not, sediment transport direction can be inferred by directional contour patterns.

Significant Results: The concept was tested (Fig. 16) through comparison of distribution of living and dead population of important foraminiferal assemblages (derived through factor analysis) from the shelf area off Navapur, west coast of India (Nigam, 1986). The study indicated the existence of a current, which is responsible for sediment transport in the southeast direction. It is proposed that this approach can be very useful where the direct measurements of current are difficult due to rough oceanographic conditions.

Equipped with the understanding of the nature of marine

sediments and their foraminiferal contents along with their scope of applications, geologists/palaeontologists are better placed to offer the services to various industries for development of harbours / minor ports and route selection for effluent discharge pipelines to protect coastal environment from marine pollution.

RECOMMENDATIONS

Foraminifera have acquired the position of a very important and a very essential tool for many studies aimed to tackle environmental issues of the past and the present. But there still exists a need and scope for further development of foraminiferal techniques to addresses successfully the new type of problems cropping up with development without sustainability.

Supplementary to the traditional hard part studies, a detailed foraminiferal-culture programme with molecular biological approach is the need of the hour as through such programs, existing techniques (based on circumstantial field correlations) can be validated and new techniques can be developed. These studies may also lead to development of new molecules - a first step in application of foraminifera in drug development and thus in medical industry.

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