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## 29. Benthic Foraminifers as Indices of Diversity and Hyposalinity in a Modern Clastic Shelf Regime, off Bombay, India

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A tidally energized clastic shelf regime at 25–45 m depth off Bombay-Daman composed of silty sand, silty clay, and clay fractions is located between a sand bar and the coast. The sand bar, running parallel to the coast, has a variable height of 7–20 m at submerged depth. Sub-Recent foraminiferal populations and their diversity are noticeably low at stations near the sand bar while relatively high in the clay substrate. Miliolids are abundant in the sandy and silty sand substrates. *Ammonia*, *Ammobaculites*, and miliolids are the dominant species followed by *Nonion* in silty, *Nonionella* in clay, and *Florilus* and *Elphidium* in silty clay substrates. In the living populations *Ammonia* and *Ammobaculites* are also abundant but *Elphidium*, *Nonionella*, and miliolids are rare, while *Nonion* is totally absent. The similarity index between the two populations is considerable. The  $\alpha$  index and triangular plot representations of Murray (1973) indicate hyposalinity. This may be attributed to freshwater influx from the rivers. Nonionidae and Miliolidae are found to be negatively affected (inversely proportional) by the organic carbon content in the sediment. Reworked Paleogene fauna from the nearby Surat-Broach area are also observed in this region.

### INTRODUCTION

The Bombay-Daman near-shore shelf area is a turbulent zone subject to movements from storms, tides, and surges. The turbulence is caused by strong currents, high tidal effects, and exceptionally long waves. This highly agitated, high energy region lies shorewards to the oil and gas bearing region of the Bombay High. As part of an oceanographic survey of the Bombay High region and an institutional project on the distribution and ecology of foraminifera, several surface samples and cores were collected during the 28th cruise of the *R.V. Gaveshani* in 1981. The study revealed the diversity of rich benthic fauna, mixing of older fauna with the Recent, and ecological conditions governing their distribution. The

interference composite caused by erosion interaction of Paleogene sediments in the nearby depositional environment was reported earlier (Nigam and Setty 1980).

### OCEANOGRAPHIC SETTING

The northern area is bound in the east by the mainland and in the west by a thin, long, shallow sand bar, which rises suddenly from a 40–43 m depth and terminates at a submerged 7–20 depth. The southern part—a smooth, even topography presumably formed by clay cover—is exposed to the open ocean.

The study area is largely carpeted by clay but interspersed by silty clay, silty sand, and cobble-pebble-shell highs. The organic carbon ranges from a low of 0.04 percent in sand to a high of 1.92 percent in clays. Estimation of organic carbon in sediments was made following the method of El Wakeel and Reley (1957).

### RESULTS AND DISCUSSION

#### Foraminiferal composition

Total foraminiferal number in a standard sample size (1 gm weight dry sediment) is indicative of the productivity of a region. A quantitative analysis of standard samples of all stations of the area for living and dead foraminifera was made. It revealed that the total faunal density (living and the dead) was highest in the southern part (in clayey substrate), considerably reduced in the northern area, and very low near the sand bar. Living foraminifera were totally absent near the sand bar but some of the dead ones were preserved in the sediment.

The diversity or total species number in the living populations is very low while among the dead it is very high; however, it complements the total foraminiferal number. Thus, the faunal population (high or low), distribution, and diversity pattern are influenced by tidal effect (5–10 m), high energy agitation of the waters, and inflow from coastal rivers.

This suggests a higher sedimentation rate in the northern region, which decreases southwards into the open ocean. The total absence of living benthic foraminifera near the sand bar, reduced population density in the adjoining area, and consequent repetition of a low diversity profile are most probably the result of unfavorable conditions such as high suspended matter in the water, poor visibility, high energy waves, tides, and currents. These factors would prevent their attachment to the substratum, and proliferation. The higher values seen in the deep populations indicate postmortem transport of the tests through tides and currents. These would differentially deposit them elsewhere upon dissipation of the high

energy, causing the suspended loads to drop and allowing the foraminifera and others to be deposited in the sediments. Further, Illing (1950) demonstrated that current transport of empty (dead) tests causes dissimilarities between the living and dead benthic fauna and also directly affects the distribution of living species (Murray 1965, Kureshy 1969, Brooks 1973). Similarly, daily high energy tidal movement affects benthic foraminiferal distribution (Haynes and Dobson 1969).

### Hyposalinity index

According to Murray (1973), it is possible to differentiate environments through ranges of diversity. The ratio between the number of individuals and the number of species in the living or the dead (fossil) foraminifera in each sample gives the range in diversity ( $\alpha$ -index). On plotting, for the living population the  $\alpha$ -index value is less than 2, while for the dead populations it is less than 4. This, when compared with the range chart (Murray 1973, figure 101, p. 240) indicates a hyposaline lagoon or a near-shore shelf sea condition. This corresponds with the study area.

Similarly, when the ratios of the three main suborders of foraminifera (Miliolina, Textulariina, and Rotaliina) were plotted on a triangular plot and compared with the summary diagram of Murray (1973), a maximum concentration was shown of fossil foraminifera stations falling close to the Rotaliina-Textulariina side. Thus, indicating again a hyposaline lagoonal condition.

This analysis further proved that hyposaline conditions prevail in the region, attributable largely to the mixing of freshwater inflow from the coastal rivers with the normal marine tidally influenced waters of the protected southern channel.

### Faunal distribution

A total of 62 species of benthic foraminifera, including 16 living, were found in the study area. Planktonic foraminifera were rare and, hence, are not discussed. *Ammonia*, *Ammobaculites*, and miliolids are predominant in the dead populations but their representatives in the living are rare.

#### MILIOLINA

Species belonging to this Superfamily are not very common, represented only in the dead populations. The miliolids (*Quinqueloculina*, *Triloculina*, and *Spiroloculina*) are grouped together. The *Quinqueloculina* included seven species: *Q. laevigata*, *Q. longiducta* *tostata*, *Q. longirostra*, *Q. venusta*, *Q. seminulum*, *Q. vulgaris*, and *Q. pseudoreticulata*. There were four species of *Triloculina*: *T. oblonga*, *T. rupertiana*, *T. tricarinata*, and *T. trigonula*; and two species of *Spiroloculina*: *S. eximia* and *S. planissima*. These organisms are common in sandy and silty sands

but are almost absent in clays. They are mainly temperate to tropical forms mostly restricted to the 0–40 m inner shelf, normal marine, hyposaline to hypersaline lagoonal conditions. Living populations of some of the species encountered are rare to very rare.

#### TEXTULARIINA

*Ammobaculites* is the most important genus represented in the living and dead populations. The species are: *A. agglutinans* and *A. persicus*. At some stations living forms are found but they mostly occur in the southern area with some patches of them in the northern region. *Ammobaculites* is typically hyposaline, tropical, and restricted to lagoons, marshes, and inner-shelf areas.

#### ROTALIINA

The important genera represented are *Ammonia*, *Elphidium*, *Nonion*, *Bolivina*, and *Bulimina*.

*Ammonia* fauna. Several species of *Ammonia* and a few transitional forms of *Ammonia*/*Asterorotalia* occur, constituting nearly 80 percent of the total populations. The species are: *Ammonia annectans*, *A. tepida*, *A. sobrina*, *A. papillosus*, and *Asterorotalia dentata*. Living forms are observed in most of the stations. *Ammonia* is typically a hyposaline form favoring sandy or silty sand substrate, a temperature of 15–30°C, and is restricted to 0–50 m depth of smooth, lagoonal or inner shelf, hyposaline to hypersaline conditions. It is the transitional fauna between marine and open marine faunal groups (Walton 1964). Faunal dominance is reduced beyond 50 m (Setty and Nigam 1980).

*Elphidium* fauna. This species is more commonly associated with *Ammonia*, hence it has a similar range in distribution. *Elphidium* includes: *E. advena*, *E. discoideale*, *E. falunicum*, and *E. minutum*. Some rare specimens were found to be living. The organisms are abundant in silty clay, reduced in clays but almost absent in sandy substrate. While *Elphidium*'s faunal affinity is with *Ammonia*, its density is very low. It is less abundant off river mouths but sometimes tends to be low or absent when river inflow and terrigenous material deposition become high. It does increase gradually towards the open ocean.

*Nonion* fauna. The five species are: *N. boeuanum*, *N. depressulus*, *N. elongatum*, *N. granosum*, and *N. jacksonensis*. No living specimens were found; the fossil representatives were concentrated in silty sands. It is an open-shelf fauna having a depth range of 0–180 m, characteristically absent off river mouths but found in silty sands. It is also a hyposaline to normal marine shelf fauna, ranging from cold to tropical oceanic regions. Only one species of *Florilus* (*F. scaphus*) was observed in some silty clay stations.

*Bolivina* fauna. *Bolivina* is typically common in an outer neritic-bathyal zone (150–1,000 m) preferring clayey substrate at temperatures ranging from 1–30°C, but it is also observed near shore. It is absent off river mouths as are *Elphidium*, *Bulimina*, *Nonion*, *Nonionella*, and *Florilus*. *Bolivina* is very poorly represented in the entire area, and almost absent in the sandy substrate. The four species are: *B. goesii*, *B. striatula*, *B. variabilis*, and *B. acutula*. No living specimens were encountered.

*Nonionella* fauna. Living species of *Nonionella*, which are rare, are confined to clays along with the dead population. *Nonionella* has a depth range of 10–1,000 m and is common in deeper waters. The fauna are represented by *N. basispinata*, *N. turgida*, and *N. auris*.

The dominant genera thus far discussed are common, regional, and characteristic of the ecosystem, hence they can be correlated to those occurring under similar conditions (Setty et al. 1974). Although many species were observed in the region, as a general rule, only two or three species showed generic dominance over others. The other species recorded were rare, often restricted only to certain stations, and found in specific microenvironments (Setty and Nigam 1980).

The percent distribution and faunal dominance observed demonstrate that *Ammonia*, being dominant, shows high tolerance in the overlapping environment. *Nonion* and *Elphidium*, absent or rare in regions where there is a high influx of freshwater, are intolerant to hyposaline conditions. The increased populations of *Bolivina* and *Bulimina* at the outer stations indicate their preference for normal marine conditions and intolerance to fluctuating nearer shore environments.

### Reworked fauna

Nigam and Setty (1980) reported the occurrence of some characteristic Paleogene foraminifera, which were encountered as earthy colored highly polished, rounded grains (in a well-preserved state) filled with secondary material and mixed with Recent and near-Recent in situ fauna in the northern region. The material was found to be reworked from out-crops of the Surat and Broach areas and derived from the eroding Narmada-Tapti-Kim rivers.

### Interrelationship of foraminifera with organic carbon

Foraminiferal assemblages in the sediment and their relationship to organic carbon were studied in selected near-shore areas of the western Indian coast (Setty and Nigam 1982). Organic carbon is low in sands but high in clays (0.04 to 1.92 percent dry weight). The dominating foraminifera are: *Ammonia* (90 percent), *Ammobaculites* (82 percent), miliolids (40 percent), *Nonion-Florilus* assemblage (42.5 percent), and *Elphidium* (28.5 percent). This interrelationship shows that *Ammobaculites* and *Ammo-*

*nia* have a direct relationship while the miliolids show an inverse one. Statistically, the *Nonion-Florilus* assemblage shows significantly negative correlation.

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