

Foraminiferal assemblages and their use as indicators of sediment movement : a study in the shelf region off Navapur, India

RAJIV NIGAM*

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Abstract—Factor analysis of 60 species of foraminifers from 13 stations off Navapur, reveals three major assemblages—*Ammonia annectens*, *Ammonia papillosus*–*Asterorotalia dentata* and *Ammonia baculites persicus* assemblages. These assemblages are governed by fresh water runoff and organic matter content in the sediments. A comparison of living and dead tests distribution of important assemblages indicates movement of sediment towards eastsoutheast and thus a current. The study is particularly important for predicting net sediment transport and planning and designing for offshore structures. The method adopted to decipher current–sediment transport may be useful in other areas where data on long-term movement of current or sediment transport are not available.

INTRODUCTION

THE National Institute of Oceanography, Goa, India had carried out extensive surveys for laying submarine pipe lines and the post-lay surveys for the development of Bombay high offshore oil field. During the surveys it was realised that for offshore structures not only the nature of the substrate but extensive current measurements are also very important.

The usual methods of determining the ocean currents are by using 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 microfaunal (e.g. foraminiferal) components are useful.

Benthonic foraminifera are excellent indicators of bottom conditions and in living stage possess pseudopodia. The pseudopodia help the organisms to collect the food and to anchor the foraminifera to the substrate and thus prevent its erosion by the currents (unless very strong). After death, the test is freed, behaves as sediment grains (ILLING, 1950) and thus is subjected to transport by the current (ERICSON *et al.*, 1951; SCHAFER and PRAKASH, 1968; WANG and MURRAY, 1983).

Introduction of Rose Bengal technique (WALTON, 1952) facilitated the identification of living foraminifera from the dead fauna and this can be used to establish the direction of sediment movement. The present study is an attempt in this direction.

This paper presents the results of factor analysis applied to foraminiferal data and compares the distribution of living and dead populations of these assemblages from the shelf region off Navapur. The fauna of this area has been described earlier by NIGAM and SETTY (1980, 1982), SETTY and NIGAM (1981) and NIGAM (1984).

* National Institute of Oceanography, Dona Paula, Goa-403 004, India.

ENVIRONMENT

Physical setting

The area receives a large input of fresh water from the Narmada, Mahi, Kim, Tapi, Purna, Ambica and Damanganga rivers. Of course, the Narmada and Tapi 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 a large quantity of terrigenous material. High concentrations of suspended matter, 4 mg l^{-1} in surface water, and 8 mg l^{-1} and even 13 mg l^{-1} in bottom water were reported by RAO and RAJAMANICKAM (1976).

Tidal ranges of the order of 5 m (at Daman) and 2.5 m (at Nawapur) have been reported (Indian Tide Table, 1978). The direction of currents in nearshore areas changes and even reverses from southwest to northeast and vice versa while surface currents speeds up to 2 to 5 kn were recorded (NAVAL HYDROGRAPHIC CHART, 1979). The surface water salinity ranges from 35.77 to 36.20‰ at a depth of 15 to 30 m and 35.7 to 36.1‰. Similarly, dissolved oxygen also varies from 4.82 to 5.14 for the surface water and 4.72 to 5.10 for water at a depth of 15 to 30 m (INITIAL REPORT *Darshak*, 1974).

Bathymetry

The area studied (Fig. 1) is off Navapur, west coast of India. The study area has smooth topography, whereas north of the study area is a deeper region bounded by a narrow, long, shallow sand bar (Eastern Bank) which rises abruptly from 40 to 43 m depth and is separated from the land by the Sutherland Channel (Fig. 1) which has a depth of 7 to 20 m.

Sediments

The study area is largely carpeted by clay except at Stas 3 and 4 (cobble-pebble shell fragment) and Sta. 21 (clay with admixture of sand). The sedimentological character of the sediments from this area has been discussed by SIDDIQUIE *et al.* (1981). The organic matter ranges from 0.08 to 2.06% in dry sediments, the values are generally low in the coarse substrate.

MATERIAL AND METHODS

Thirteen samples used in the present study were collected (January 1978) from the inner shelf within a depth range of 24 to 43 m off Navapur during the 28th cruise of R.V. *Gaveshani*.

The sediment samples were collected by a modified Peterson Grab (area 900 cm^2). The top 1 cm layer was separated from each sample and fauna was preserved in a 10% buffered formaline solution and stained with Rose Bengal for recognition of living individuals. Samples were sieved on $63 \mu\text{m}$ mesh and the $+63 \mu\text{m}$ fraction was dried. Keeping 300 to 500 specimens as target, total foraminiferal tests were picked from a weighed sample (depending on the richness of the fauna).

The total foraminiferal number were then standardised to 1 g to study the relative abundance. All the species of foraminifera were identified and quantitative distribution charts of the living and dead fauna were prepared.

Among the various multivariate statistical techniques, factor analysis was found useful to obtain a few meaningful assemblages out of a large number of species. These assemblages can be plotted on a map to study the geographical distribution and the

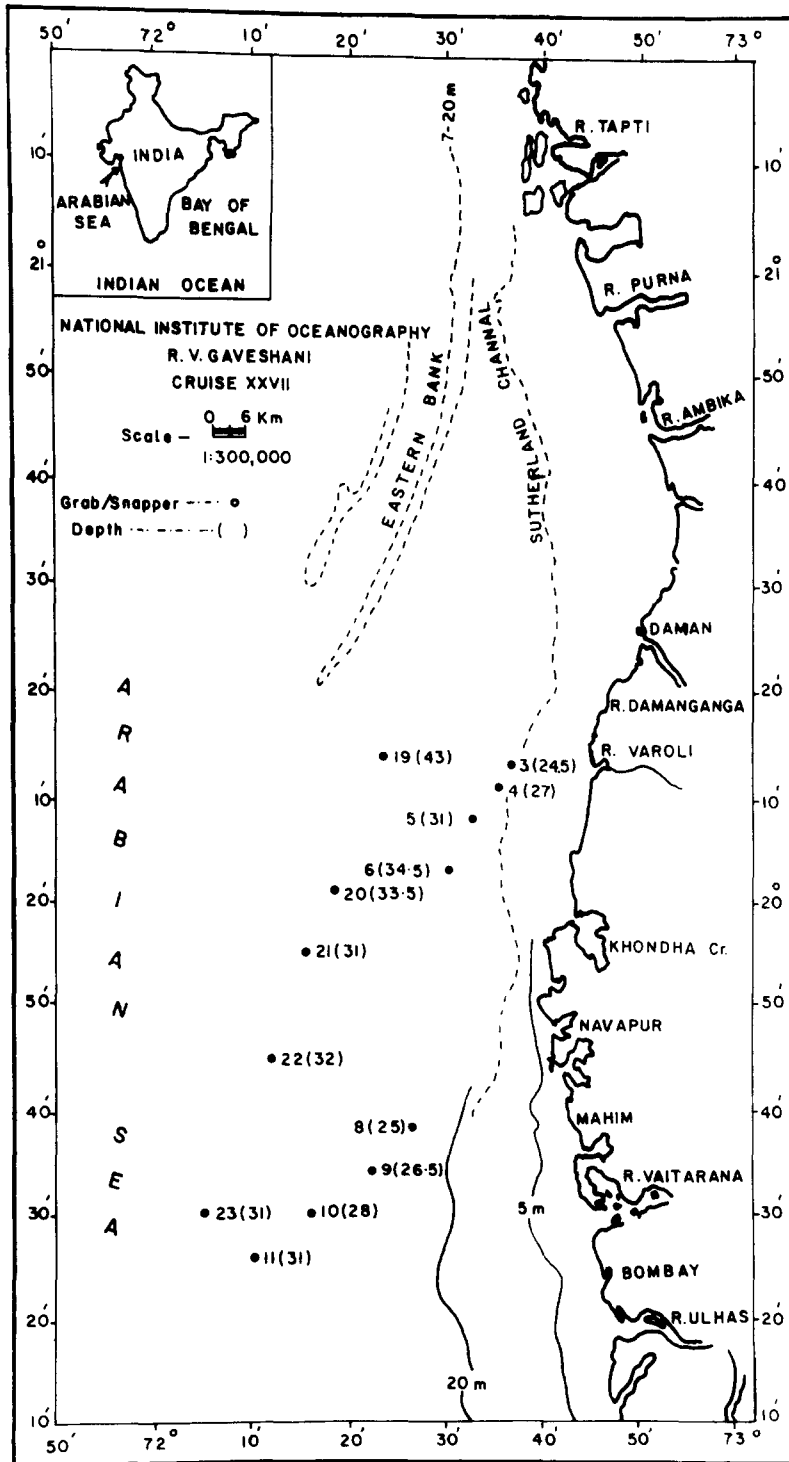


Fig. 1. Station location map.

resulting pattern can be compared to any environmental parameter or group of parameters for which informations are available. Factor analysis is being applied to different fields of micropaleontology including foraminiferal studies (HOWARTH and MURRAY, 1969; IMBRIE and KIPPS, 1971; STREETER, 1972; THIEDE, 1975). Only a few efforts have been made to apply this technique to voluminous foraminiferal data from the Indian region (NIGAM and THIEDE, 1983). In the present study, foraminiferal data from the shelf region off Nawapur was subjected to a Q-mode factor analysis using Fortran IV CABFAC program (KLOVAN and IMBRIE, 1971). The computer analysis was carried out at the computer centre of the University of Oslo, Norway.

Table 1. Varimax factor scores matrix

Species	Factor 1	Factor 2	Factor 3
* <i>Ammobaculites persicus</i>	-0.070	0.974	-0.043
* <i>Ammonia annectens</i>	0.025	0.043	0.983
* <i>A. papillosus</i>	0.960	0.066	-0.032
<i>A. sobrina</i>	0.014	0.006	0.006
* <i>A. tepida</i>	0.011	0.001	0.008
* <i>Asterorotalia dentata</i>	0.052	-0.031	0.001
<i>A. inflata</i>	0.025	0.146	0.040
<i>Bolivina goesii</i>	0.000	0.008	0.004
* <i>B. striatula</i>	0.052	0.071	-0.008
<i>Bulimina laevigata</i>	-0.008	0.028	0.005
<i>B. marginata</i>	0.005	0.010	-0.000
<i>Cibicides</i> sp.	0.001	-0.003	0.017
<i>Elphidium advena</i>	0.001	0.007	-0.002
* <i>E. discoidale</i>	0.043	0.030	-0.006
<i>E. falunicam</i>	0.006	0.029	0.009
<i>E. minutum</i>	0.029	0.105	0.025
* <i>Eponides repandus</i>	0.007	-0.032	0.091
<i>Fissurina lucida</i>	-0.001	0.008	0.002
<i>Florilus scaphum</i>	0.004	0.004	-0.003
<i>Luxostonium limbstam</i>	-0.000	0.004	0.003
<i>Miliammina fusca</i>	0.009	-0.002	-0.003
<i>Nonion boueanum</i>	0.009	0.002	-0.002
<i>N. elongatum</i>	-0.000	-0.001	0.011
* <i>Pararotalia nipponica</i>	0.028	-0.012	0.011
* <i>Poroeponides cribrorepandus</i>	0.016	-0.011	0.019
<i>Protelphidium granosum</i>	-0.001	-0.011	0.111
<i>Pseudoeponides nakazotoensis</i>	0.001	0.025	0.005
<i>Quinqueloculina lamarkiana</i>	0.007	-0.001	-0.002
<i>Q. longituda costata</i>	0.001	-0.022	0.067
<i>Q. longirostra</i>	0.004	-0.002	0.004
<i>Q. pseudoreticulata</i>	0.004	-0.013	0.037
<i>Q. seminulum</i>	-0.000	0.005	0.016
* <i>Siphogenerina rephanus</i>	0.009	-0.006	0.012
<i>Spiroloculina eximia</i>	0.006	-0.004	0.008
<i>S. planissima</i>	0.018	-0.012	0.020
* <i>Triloculina oblonga</i>	0.014	-0.009	0.015
<i>T. rupertiana</i>	0.003	-0.008	0.020
<i>T. tricerinata</i>	0.003	-0.002	0.004
Other species	0.029	0.029	-0.004

* Also found in living fauna.

RESULTS

A total of 60 species of benthonic foraminifera were recorded from 13 stations. Among these 16 species (marked within the tables) were living (Tables 1 and 2). Distribution of living and dead foraminifera has been discussed in detail in earlier publications (NIGAM, 1984; SETTY and NIGAM, 1981). Percentage distribution data of 60 species from 13 stations formed the basis for Q-mode factor analysis. Out of 60 species, 24 species were eliminated (Table 2) from the original data matrix and percentages of all such species summed for each sample. These species were included under 'other species'. A final matrix of 39 variables (38 species + 'other species') was then submitted to Q-mode factor analysis. Three factors were finally obtained, explaining 93.5% of the information given in the original data matrix. Variance and cumulative variance for these factors are given in Table 3. Figure 2 (A to C) shows the contours corresponding to factor loading at different stations for three important factors/assemblages. Varimax factor score matrix (Table 1) shows contribution of each species to all factors. The factors are further described as assemblages and named for one or more few common species in each factor as determined from Table 1. Factor 1 (36.08%): *Ammonia papillosus*-*Asterorotalia dentata* assemblage. Factor 2 (29.09%): *Ammonia annectens* assemblage. Factor 3 (28.36%): *Ammobaculites persicus* assemblage.

Table 2. List of species included in factor analysis under 'other species'

<i>Ammobaculites agglutinans</i>
<i>Angulogerina angulosa</i>
<i>Bolivina subspine</i>
<i>B. variabilis</i>
<i>Eggerella advena</i>
<i>Fursenkoina pontoni</i>
<i>Henzewia concentrica</i>
<i>Legena striatula</i>
<i>Nonion depresulum</i>
<i>N. granosum</i>
<i>N. jaksonensis</i>
* <i>Nanionella basispinatum</i>
* <i>N. turgide</i>
* <i>N. sp.</i>
<i>Quinqueloculine laevigata</i>
<i>Q. venusta</i>
* <i>Q. vulgaris</i>
<i>Textularia agglutinane</i>
<i>Triloculina trigonula</i>
<i>Trochammina globigeriniformis</i>
<i>T. inflata</i>
<i>Virgulinea sp.</i>

* Also found in living fauna.

Table 3. Variance and cumulative variance for each factor

Factor No.	Variance (%)	Cumulative variance
1	36.08	36.08
2	29.09	65.17
3	28.36	93.53

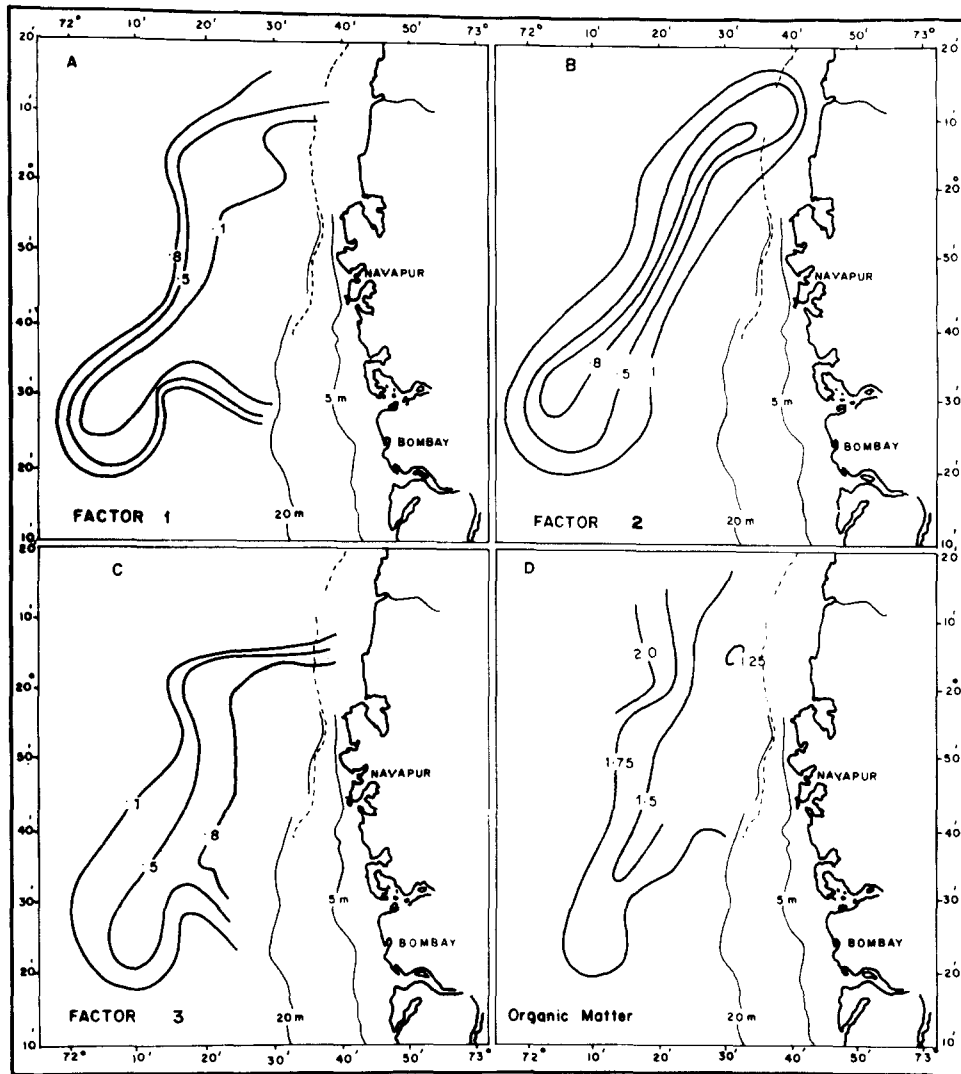


Fig. 2. Contours showing distribution of (A) factor 1: *Ammonia papillosus*-*Asterorotalia dentata* assemblage, (B) factor 2: *Ammonia annectens* assemblage, (C) factor 3: *Ammobaculites persicus* assemblage and (D) organic matter (%) in dry sediments.

DISCUSSION

Assemblages

A. papillosus-*A. dentata* assemblage has the maximum concentrations at the stations away from the coast and gradually decreases towards the coast (Fig. 2A), whereas *A. annectens* assemblage has a greater concentration at intermediate stations and decreases towards the outer stations and towards the coast (Fig. 2B). The above species are large in size and are abundant on the beaches (BHATIA, 1956; BHALLA and NIGAM, 1979) and shelf

waters (SETTY and NIGAM, 1980) of the west coast and can withstand abrasion during transport (BHALLA, 1968, 1970).

A. persicus assemblage has the maximum concentration in the nearshore areas and decreases towards the outer stations (Fig. 2C). *Ammobaculites* is a tropical genus characteristic of a hyposaline environment (MURRAY, 1973; SEIBOLD, 1975) assemblage is indicative of fresh water influence.

The distribution of organic matter (Fig. 2D) shows a gradual decrease towards the coast and may be another factor besides salinity, which is effecting the distributions of assemblages.

Living/dead fauna as indicators of sediment transport

HJULSTROM (1939) observed that lowest fluid velocities required for initiation of particle movement occur for those particles which fall in the 0.1 to 1.0 mm diameter range. As the foraminiferal test comes within the above limit it is the most susceptible to erosion and transport by low velocity current.

BOLTOVSKOY and WRIGHT (1976) concluded that when studying Recent foraminifera the distinction between living and dead tests aids greatly in the recognition of displaced fauna. Hence, percentage distributions of living and dead fauna of the important genera constituting the above three factors/assemblages were compared. As there is little difference in the morphology and ecology of *Ammonia* and *Asterorotalia* their combined distribution of living and dead populations are presented in Fig. 3A and B. Similarly, living and dead populations of *A. persicus* are presented in Fig. 3C and D.

Figure 3A and B shows remarkable difference between the distribution of living and dead fauna. For example, Stas 3, 4 and 19 have more than 80% of living assemblage, whereas at Sta. 5 this assemblage is absent. However, in the dead assemblage at Stas 3, 4 and 19 percentage occurrences were reduced to 48 to 78% and at Sta. 5 increased to 85%. This difference is clearly seen in Fig. 3. A comparison of the contours for 80, 50 and 10% for both living and dead fauna show a shift towards eastsoutheast.

Similarly, Fig. 3C and D also shows a shift to contours towards eastsoutheast. The contour of 80%, which was covering a large area in living fauna (Fig. 3C), was observed only at one station (No. 9) in dead fauna (Fig. 3D). The contour of 0%, which was far northwest in living fauna, came closer to nearshore for the dead fauna. At Sta. 5 *A. persicus* is 100% in living fauna whereas in dead fauna it is only 3.03%.

In view of the above, it is concluded that foraminiferal tests after their death, are transported towards eastsoutheast in conformity with the predominant current direction in this area.

This observation is further supported by the general absence of smaller foraminiferal assemblages like *Ammonia baccarii* assemblage which is quite common in many nearshore areas of the world (SENGUPTA, 1977), including one in the south of the study area (NIGAM and SARUPRIA, 1981). This is probably because smaller tests may have been carried away by turbulent transport into the upper layer of water.

NIGAM (1982) studied Recent foraminifera from beaches (Bombay to Kaniyakumari) of the west coast of India. In this study it was found that species belonging to *Lagena*, *Fissurina*, *Bolivina*, *Bulimina*, *Uvigerina*, *Hopkinsina* and *Glabratelia* were present in Juhu beach, Bombay and absent in sediments from other beaches. These species are mostly found in mud and occur in shelf to slope regions (MURRAY, 1973). The occurrence of such species in beach sands in Bombay confirms the above conclusion that these species

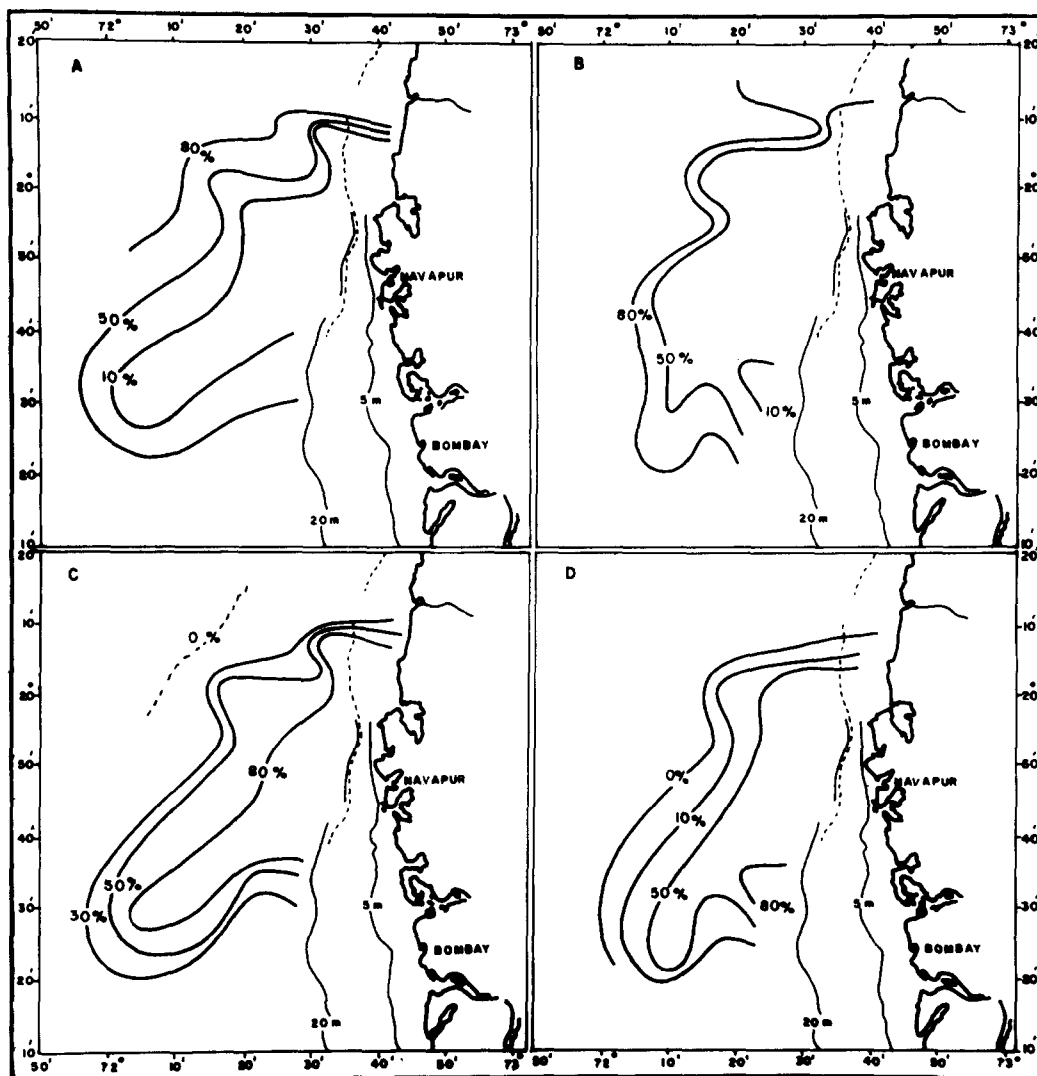


Fig. 3. Distribution (%) of (A) living *Ammonia* + *Asterorotalia*, (B) dead *Ammonia* + *Asterorotalia*, (C) living *Ammobaculites* and (D) dead *Ammobaculites*.

were carried by from deeper parts in the form of suspension and finally deposited on the beach.

CONCLUSIONS

A total of 60 species of foraminifera were recorded and out of these 16 were found living.

Factor analysis of the fauna reveals three major foraminiferal assemblages, i.e. *A. papillosus*-*A. dentata*, *A. persicus* and *A. annectens* assemblages. These assemblages were influenced by fresh water and organic matter content in the sediment.

Comparison of living and dead tests distribution of *Ammonia*, *Asterorotalia* and *Ammobaculites* indicates existence of an underwater current which is responsible for sediment transport in the east-southeast direction.

In view of the importance of the area due to increasing offshore structures in connection to development of Bombay offshore oil field, the deduced currents may be confirmed by a detailed study.

The present study is limited to a small area but may indicate a large-scale transport, part of which is covered in the study area.

Finding of the underwater sediment movement, based on foraminiferal studies as discussed in the present paper, can be used as a model for preliminary finding of such currents in other areas where the direct measurements of currents is difficult due to rough oceanographic conditions (as in the case of the present study).

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