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Foraminifera from beach sands along Saurashtra coast, north-west India

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Abstract

One hundred seven foraminiferal species have been identified and studied quantitatively in regard to their relative abundance in sand samples from 13 stations along the Saurashtra coast. This study has shown that *Ammonia beccarii* (Linné) variant is the dominant and most widely distributed species of the coast. *Ammonia tepida, Asterorotalia dentata, Hanzawaia asterizans* and *Pararotalia minuta* are the other abundant species of the fauna. The fauna is dominated by species of Rotaliina followed by Miliolina, Textulariina, Globigerinina, Lagenina and Robertinina. Furthermore, it shows affinity with that of Indo-Pacific faunal province. Also, the relationship between the abundance of Foraminifera and the median grain size of the sand is discussed.

Cluster analysis has been done for stations and species to enumerate or delineate thanatotopes and thanatofacies in the study area.

Introduction

The marine intertidal region is of great interest to biologists because it represents the height of adaptation shown by most forms of marine life living there to extreme environmental conditions such as wave action, exposure to desiccation and other related features caused by the tides of the sea. The senior author who collected sand samples from different locations of the Saurashtra coast, had an opportunity of studying one group of organisms, viz. Foraminifera in relation to faunal composition and distribution. Dr. Srinath is responsible for statistical treatment of the data.

Previous studies on Foraminifera from the Indian coasts include those of Cushman (1936) ; Cushman and Todd (1944) ; Chaudhury and Biswas (1954) ; Bhatia (1956) ; Rocha and Ubaldo, 1964 ; Bhalla, 1968, 1970 ; Bhalla and Nigam (1979) and Bhalla and Raghav (1980). The present work is a comprehensive report on Foraminifera and furthermore, so far as is known no detailed study on the fauna has been made of the Saurashtra coast.

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Material and methods

Sand samples were collected in March, 1980 from thirteen stations/ beaches along the Saurashtra coast (Fig. 1) at the swash

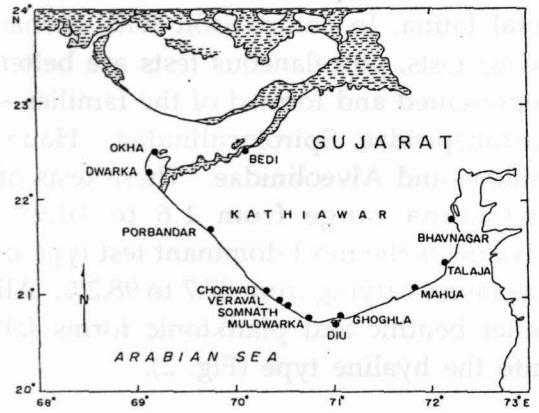

Fig. 1. *Map of the Saurashtra coast showing sampling locations.*

mark. The method of collecting the sand samples for the faunal analysis and grain size parameter - median diameter, is that of Reiter (1959). A portion of each sample was kept aside for the faunal studies; the samples were washed later over 105 µm sieve for separation of Foraminifera in the laboratory and calculation of percentage occurrence of foraminiferal species in total fauna was based on 300 specimens. The remaining portion of each sample was subjected to grain size analysis by the method of sieving. From the grain size data, cumulative frequency curves were drawn and grain size parameter, median diameter was computed for each sand sample.

Further, the faunal data were analysed using the clustering routine in STATISTICA. The clustering technique for both species and stations was made on the basis of unweighted pair-group method (Sokal and Sneath, 1963). The dendrograms were also obtained from STATISTICA.

Results and discussion

Sediments

Sediment samples collected from the shores of Bedi and Mahua consist of silt, while those of Bhavnagar are clay. In contrast, coarse sands occur at Dwarka. At Okha, Chorwad, Veraval and Talaja, the shore sediments are medium textured, medium grained and sandy. On the other hand, fine sands are predominant at the beaches of Porbandar, Somnath, Muldwarka, Diu and Ghoghla.

Abundance of Foraminifera

Foraminiferal abundance varies from 125 to 24950 specimens per gram of dry sand, with lowest concentration at Dwarka and highest at Ghoghla and there is a considerable station to station variability in abundance along the coast (Fig. 2).

The eastern side of Saurashtra coast (east of long. 70° 30′ E) includes 7 stations (Somnath, Muldwarka, Diu, Ghoghla, Mahua, Talaja and Bhavnagar) and the mean abundance of total populations of Foraminifera (live + dead) per gram at these stations is highest, with a mean concentration of 6887 specimens and lowest for 6 stations (Bedi, Okha, Dwarka, Porbandar, Chorwad and Veraval) covered along the coast on the west side of this longitude, with a density of 3555 specimens.

Further, there exists an inverse relationship between the size of the sand grains (median diameter) and the number of foraminiferal specimens in the sample. In this study, abundance is increasing with

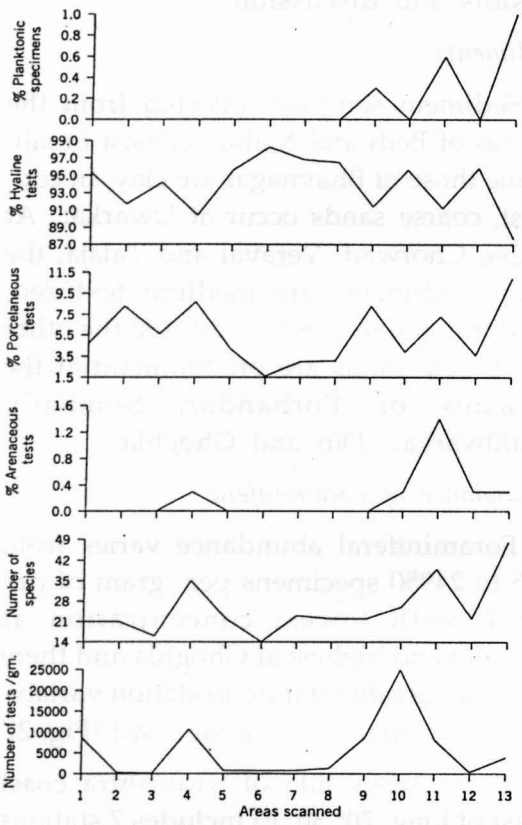

Fig. 2. *Distribution analyses of foraminiferal fauna (Legend for areas/ stations scanned : 1, Bedi ; 2, Okha ; 3, Dwarka ; 4, Porbandar ; 5, Chorwad ; 6, Veraval ; 7, Somnath ; 8, Muldwarka ; 9, Diu ; 10, Ghoghla ; 11, Mahua ; 12, Talaja ; 13, Bhavnagar).*

median diameter in phi units in the curvilinear form as a log-log function (Fig. 3).

Foraminiferal test types

The foraminiferal fauna consists of arenaceous, porcelaneous and hyaline tests. Arenaceous forms are very rare and represented by families – Trochamminidae, Eggerellidae and Textulariidae ; their percentage varies from 0.3 to 1.4% in the total fauna. In comparison with arenaceous tests, porcelaneous tests are better represented and formed of the families – Cornuspiridae, Spiroloculinidae, Hauerinidae and Alveolinidae. These tests of the fauna range from 1.6 to 10.9%. Hyaline is the most dominant test type in the fauna varying from 87.7 to 98.2%. All other benthic and planktonic forms fall into the hyaline type (Fig. 2).

Distribution and abundance of foraminiferal species

One hundred seven species belonging to 6 suborders, 20 superfamilies and 47 genera have been identified and listed under 30 families in accordance with the classification of Loeblich and Tappan (1988) and the percentage occurrence of each foraminiferal species at different stations covered along the coast is given in Table 1, showing that *Ammonia*

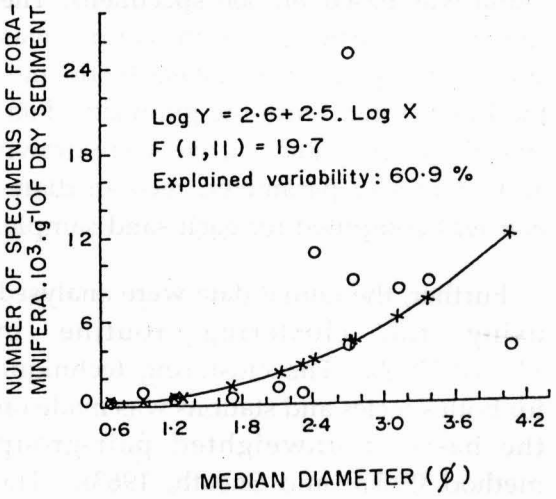

Fig. 3. *Relationship between abundance of Foraminifera and median diameter of sand.*

Table 1. *Percentage occurrence of foraminiferal species in total population*

	Areas scanned												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Foraminiferal species													
Family Trochamminidae													
Trochammina globigeriniformis var. *pygmaea* Höglund	—	—	—	—	—	—	—	—	—	0.3	—	—	—
Trochammina japonica Ishiwada	—	—	—	—	—	—	—	—	—	—	—	0.3	—
Family Eggerellidae													
Eggerelloides scaber Haynes	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Family Textulariidae													
Textularia conica d' Orbigny	—	—	—	0.3	—	—	—	—	—	—	0.7	—	—
Textularia cuneiformis d' Orbigny	—	—	—	—	—	—	—	—	—	—	0.7	—	—
Family Cornuspiridae													
Cornuspira involvens (Reuss)	0.7	—	—	—	—	—	—	—	—	—	—	—	—
Family Spiroloculinidae													
Spiroloculina aequa Cushman	—	—	—	—	—	—	—	—	—	—	1.0	—	0.3
Spiroloculina angulata Cushman	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Spiroloculina laevigata Cushman and Todd	—	—	—	—	—	—	—	—	—	—	0.7	—	—
Family Hauerinidae													
Massilina annectens Schlumberger	—	—	—	0.3	—	—	—	—	—	—	—	—	—
Quinqueloculina agglutinans d' Orbigny	—	0.3	—	—	—	—	—	—	—	—	—	—	—
Quinqueloculina crassa var. *subcuneata* Cushman	—	—	—	—	0.3	—	—	—	0.3	—	—	0.3	—
Quinqueloculina dimidiata Terquem	0.7	—	—	—	—	—	—	—	0.7	—	—	—	7.0
Quinqueloculina echinata d' Orbigny	—	—	—	—	—	—	—	0.3	—	0.7	—	—	—
Quinqueloculina elongata Natland	—	—	—	—	—	—	—	—	—	—	0.3	—	—
Quinqueloculina lamarckiana d' Orbigny	—	1.0	0.3	1.3	0.3	—	—	—	1.7	0.3	0.7	—	0.3
Quinqueloculina lata Terquem	—	—	—	—	—	—	—	—	—	—	—	—	1.7
Quinqueloculina moynensis Collins	—	—	—	0.3	—	—	—	—	—	—	—	—	—
Quinqueloculina oblonga (Montagu)	—	0.3	—	—	—	—	—	—	—	—	1.0	—	—
Quinqueloculina parkeri (Brady)	—	0.7	0.3	—	—	—	—	0.3	—	—	—	—	—
Quinqueloculina polygona d' Orbigny	—	—	—	0.3	0.3	—	—	—	—	0.3	—	—	—
Quinqueloculina pseudoreticulata Parr	—	0.7	—	—	—	—	—	—	—	0.3	—	—	—
Quinqueloculina reticulata d' Orbigny	—	—	—	—	—	—	—	—	0.3	—	—	—	—
Quinqueloculina seminula (Linnaeus)	2.0	1.7	2.3	3.3	1.7	—	1.3	1.3	4.7	1.7	2.0	3.3	0.3
Quinqueloculina tenagos Parker	1.3	—	—	—	—	—	—	—	—	—	—	—	—

Quinqueloculina vulgaris d' Orbigny	—	1.3	1.7	0.3	1.0	—	0.7	—	0.3	—	—	—	—
Miliolinella circularis (Bornemann)	—	—	—	—	0.3	—	—	0.3	—	—	—	—	—
Triloculina brevidentata Cushman	—	—	—	—	—	—	—	—	—	—	—	—	0.7
Triloculina cuneata Karrer	—	—	—	0.3	0.3	—	—	—	—	—	—	—	—
' Biloculine variety '													
Triloculina fichtelliana d' Orbigny	—	—	—	—	—	—	—	—	0.3	—	0.3	—	—
Triloculina oblonga (Montagu)	—	—	—	—	—	—	—	—	—	—	0.7	—	—
Triloculina rotunda d' Orbigny	—	1.3	0.3	—	—	0.3	—	0.3	—	—	0.3	—	0.3
Triloculina subrotunda (Montagu)	—	—	—	—	—	—	0.7	—	—	—	—	—	—
Triloculina tricarinata d' Orbigny	—	0.3	—	0.3	—	—	—	—	—	0.3	—	—	—
Triloculina trigonula (Lamarck)	—	0.7	—	—	—	0.3	0.3	—	—	0.3	—	—	—
Spirosigmoilina parri Collins	—	—	—	2.3	—	0.3	—	0.3	—	—	0.3	—	—
Family Alveolinidae													
Borelis pulchra d' Orbigny	—	—	—	—	—	—	—	0.3	—	—	—	—	—
Borelis (Neoalveolina) pygmaea var.	—	—	0.7	—	—	0.7	—	—	—	—	—	—	—
schlumbergeri Reichel													
Family Vaginulinidae													
Lenticulina (Robulus) limbosus (Reuss)	—	—	—	—	—	—	0.3	—	—	—	—	—	—
Family Lagenidae													
Lagena marginata (Walker and Boys)	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Family Epistominidae													
Epistomina bradyi Galloway and Wissler	—	—	—	—	0.7	—	—	—	—	—	—	—	—
Family Conorboididae													
Conorboides advena (Cushman)	—	—	—	—	—	—	—	—	—	—	—	0.3	—
Family Globigerinidae													
Globigerina quinqueloba Natland	—	—	—	—	—	—	—	—	—	—	—	—	0.7
Globigerinella aequilateralis (Brady)	—	—	—	—	—	—	—	—	—	—	0.3	—	—
Globigerinoides ruber d' Orbigny	—	—	—	—	—	—	—	—	0.3	—	0.3	—	0.3
Family Bolivinidae													
Bolivina lanceolata Parker	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Bolivina pseudoplicata Heron-Allen	0.7	—	—	—	—	—	—	—	—	—	0.3	—	0.3
and Earland													
Bolivina striatula Cushman	0.3	—	—	—	—	—	—	—	—	—	—	—	2.3
Bolivina vaughani Natland	—	—	—	—	—	—	—	—	—	—	—	—	1.3
Brizalina variabilis (Williamson)	—	—	—	—	—	—	—	—	—	—	—	—	2.3
Family Loxostomatidae													
Loxostomum limbatum (Brady)	—	—	—	—	—	—	—	—	—	—	0.3	—	—
Family Cassidulinidae													
Cassidulina algida Cushman	—	—	—	—	—	—	—	—	—	—	—	—	1.3
Cassidulina californica Cushman	—	—	—	—	—	—	—	—	—	—	—	—	0.3
and Hughes													

Family Buliminidae													
Bulimina marginata d' Orbigny	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Bulimina pupoides d' Orbigny	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Family Buliminellidae													
Reussella spinulosa (Reuss)	—	—	—	—	—	—	—	—	—	—	0.3	—	—
Family Bagginidae													
Cancris auriculus (Fichtel and Moll)	—	—	—	0.7	—	—	—	—	—	—	—	—	0.7
Family Eponididae													
Eponides broeckhianus (Karrer)	—	—	—	0.7	—	—	—	—	—	—	—	—	—
Eponides repandus (Fichtel and Moll)	—	0.3	—	1.0	0.7	0.7	0.7	—	—	0.7	0.3	—	—
"Eponides repandus (Fichtel and Moll)" var. *concamerata* (Williamson)	—	—	—	0.3	—	—	—	—	—	—	—	—	0.3
Poroeponides cribrorepandus Asano and Uchio	—	4.7	1.3	0.7	0.3	0.7	1.0	1.3	—	1.0	—	—	—
Family Discorbidae													
"Discorbis" aguayoi Bermudez	—	—	—	—	—	—	—	—	—	—	—	0.3	—
Discorbis nitida (Williamson)	—	—	—	—	—	—	—	0.3	—	—	—	—	0.3
Family Glabratellidae													
Glabratella patelliformis (Brady)	—	0.3	0.3	0.3	—	—	—	—	—	—	—	—	—
Family Rosalinidae													
Gavelinopsis praegeri (Heron-Allen and Earland)	—	—	—	—	—	—	—	—	—	—	0.7	—	—
Neoconorbina orbicularis (Terquem)	—	—	—	0.3	—	—	—	—	—	—	—	—	—
Rosalina bertheloti (d' Orbigny)	—	—	—	—	—	—	—	—	—	0.7	—	—	—
Rosalina floridana (Cushman)	—	—	—	—	—	—	—	—	—	—	—	—	1.3
Rosalina globularis d' Orbigny	—	—	—	0.3	—	—	—	—	—	—	—	—	—
Rosalina vilardeboana d' Orbigny	—	—	—	—	—	—	—	—	—	—	—	—	3.0
Family Planulinidae													
Hyalinea balthica (Schröter)	—	—	0.3	—	—	—	—	—	—	—	—	—	—
Family Cibicididae													
Cibicides pseudoungerianus (Cushman)	—	0.7	—	2.3	—	—	0.3	—	0.7	1.3	0.7	0.3	—
Cibicides refulgens Montfort	—	2.7	—	2.3	—	—	3.7	4.3	5.7	0.3	1.0	7.0	2.7
Family Amphisteginidae													
Amphistegina radiata (Fichtel and Moll)	—	3.6	3.7	—	0.3	0.3	0.3	1.0	—	—	—	—	—
Family Nonionidae													
Haynesina germanica (Ehrenberg)	3.0	—	—	—	—	—	—	—	—	—	0.3	4.0	2.3
Nonion depressulum (Walker and Jacob)	1.7	—	—	0.3	—	—	—	—	—	—	0.3	0.3	—
Nonion pacificum (Cushman)	—	—	—	—	—	—	—	—	—	—	—	—	7.0
Nonion scaphum (Fichtel and Moll)	—	—	—	—	—	—	—	—	—	—	1.0	—	3.0

Nonionella auricula Heron-Allen and Earland	0.3	—	—	—	—	—	—	—	—	—	—	—	—
Protelphidium tisburyense (Butcher)	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Melonis pompilioides (Fichtel and Moll)	—	—	—	—	—	—	—	—	—	—	—	—	0.7
Pullenia elegans Cushman and Todd	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Family Gavelinellidae													
Hanzawaia asterizans (Fichtel and Moll)	—	—	—	2.0	—	—	1.0	2.7	3.3	6.0	13.7	1.0	4.3
Hanzawaia concentrica (Cushman)	—	—	—	—	0.3	—	—	0.3	—	—	0.7	0.7	—
Hanzawaia nitidula (Brady)	0.7	—	—	3.3	1.3	0.3	2.3	1.3	4.0	0.3	3.0	1.0	1.7
Family Rotaliidae													
Pararotalia globosa (Millet)	1.0	—	—	—	—	—	—	—	—	—	—	—	0.3
Pararotalia minuta (Takayanagi)	—	—	—	9.7	—	—	—	—	2.3	0.7	6.7	2.7	21.7
Ammonia beccarii (Linné) variant	280	273	680	190	707	833	507	550	303	333	190	407	93
Ammonia advena (Cushman)	1.3	—	—	1.3	—	—	—	—	—	—	1.0	1.0	1.3
Ammonia parkinsoniana (d' Orbigny)	—	—	—	0.3	0.7	—	1.3	1.0	—	—	0.3	—	—
Ammonia sobrina (Shupack)	1.3	—	—	0.3	1.0	—	0.3	—	—	1.7	0.3	—	—
Ammonia tepida (Cushman)	43.0	—	0.3	7.7	0.3	—	0.3	1.7	4.0	2.7	5.7	10.3	13.0
Asterorotalia dentata Parker and Jones	3.3	37.7	4.7	29.0	11.3	8.0	25.7	19.0	32.3	41.0	18.0	13.3	1.3
Asterorotalia inflata (Millet)	0.3	—	—	1.3	—	—	—	0.3	2.7	0.3	7.7	6.3	0.3
Family Ephidiidae													
Elphidium advenum (Cushman)	—	—	—	0.7	—	—	0.3	—	1.3	1.0	1.0	—	—
Elphidium craticulatum (Fichtel and Moll)	—	—	—	0.3	1.0	1.3	1.3	—	—	—	—	—	—
Elphidium crispum (Linnaeus)	—	9.0	6.3	2.0	4.3	1.3	3.0	6.3	2.7	3.0	3.0	—	0.3
Elphidium discoidale (d' Orbigny)	1.3	—	—	4.3	1.7	—	3.3	1.7	1.3	0.7	5.0	5.0	0.3
Elphidium excavatum (Terquem)	4.7	—	—	—	—	—	—	—	—	—	0.3	0.3	—
Elphidium gunteri Cole	—	—	—	—	—	—	0.7	—	—	—	—	—	0.3
Elphidium hispidulum Cushman	—	—	0.3	—	—	—	—	—	0.3	—	—	—	—
Elphidium incertum (Williamson)	3.7	—	—	—	—	—	—	0.3	0.3	1.0	—	1.0	0.7
Elphidium magellanicum Heron-Allen and Earland	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Elphidium mexicanum Kornfeld	—	—	—	—	—	—	0.3	—	—	—	—	—	—
Elphidium poeyanum (d' Orbigny)	0.7	—	—	—	—	—	—	—	—	—	—	0.3	0.7
Family Nummulitidae													
Nummulites (Operculinella) venosus (Fichtel and Moll)	—	4.7	9.0	—	1.0	2.0	—	—	—	—	—	—	—
Operculina gaimardi d' Orbigny	—	0.7	—	—	—	0.3	—	—	—	—	—	—	—

Areas : 1, Bedi ; 2, Okha ; 3, Dwarka ; 4, Porbandar ; 5, Chorwad ; 6, Veraval ; 7, Somnath; 8, Muldwarka ; 9, Diu ; 10, Ghoghla ; 11, Mahua ; 12, Talaja ; 13, Bhavnagar

beccarii variant is the abundant and most widely distributed species. It is followed by *Ammonia tepida* and *Asterorotalia dentata* in order of occurrence and abundance. Two foraminiferal species found at all the stations are *A. beccarii* (Linné) variant and *Asterorotalia dentata*. Species present at 10 or >10 locations are *Quinqueloculina seminula, Hanzawaia nitidula, Ammonia tepida, Elphidium crispum* and *E. discoidale*. Species occurring at > 5 but < 10 stations are *Quinqueloculina lamarckiana, Q. vulgaris, Triloculina rotunda, Eponides repandus, Poroeponides cribrorepandus, Cibicides pseudoungerianus, C. refulgens, Amphistegina radiata, Hanzawaia asterizans, Pararotalia minuta, Ammonia advena, A. parkinsoniana, A. sobrina, Asterorotalia inflata, Elphidium advenum* and *E. incertum*. Fortynine species have been observed at a location from a single sample itself. All other remaining species are found to occur in the range between > 1 and < 5 sites. The relationship between the number of species and the foraminiferal abundance is not highly significant for the samples ($r = 0.275$, $p < 0.05$).

Of the species listed under classification of Foraminifera, 14 species have been recorded for the first time from Indian waters, they being *Quinqueloculina echinata, Q. elongata, Q. moynensis, Spirosigmoilina parri, Borelis (Neoalveolina) pygmaea* var. *schlumbergeri, Epistomina bradyi, Bolivina lanceolata, B. vaughani, Brizalina variabilis, Cassidulina algida, C. californica, "Discorbis" aguayoi, Pullenia elegans* and *Elphidium magellanicum*. These species are illustrated on Plate 1, Figs. 1-30.

The fauna is dominated by species characteristic of the Indo-Pacific region although some of them such as *Quinqueloculina seminula, Triloculina oblonga, T. tricarinata* and *Cornuspira involvens* are cosmopolitan in distribution. This feature of the fauna along the west coast of India and offshore region of Arabian Sea corroborates the earlier reports (Bhatia, 1956 ; Rocha and Ubaldo, 1964 ; Rao, 1970-71 ; Seibold, 1975 and Bhatia and Kumar, 1976).

Cluster analysis for stations and species

It is well known that a multivariate technique called cluster analysis has been extensively used in investigations on foraminiferal fauna to delineate biotopes or biofacies (Kaesler, 1966; Mello and Buzas, 1968; Howarth and Murray, 1969 ; Gevirtz *et al.*, 1971; Parker and Berger, 1971 ; Ujiie and Nagase, 1971; Johnson and Albani, 1973 and Ujiie, 1973). It is mainly used to identify patterns in the data. In this study, clustering technique has been applied to the data on Foraminifera from the Saurashtra coast for the aforementioned purpose. While utilizing cluster analysis, the study has made use of Unweighted Pair-Group Method (Sokal and Sneath, 1963).

In the present study, cluster analysis has been applied to the total number of Foraminifera (live + dead). Thus the assemblages are considered to be thanatofacies (death assemblages) and areas of uniform environmental conditions are thanatotopes (areas in which similar organisms coexist).

PLATE 1

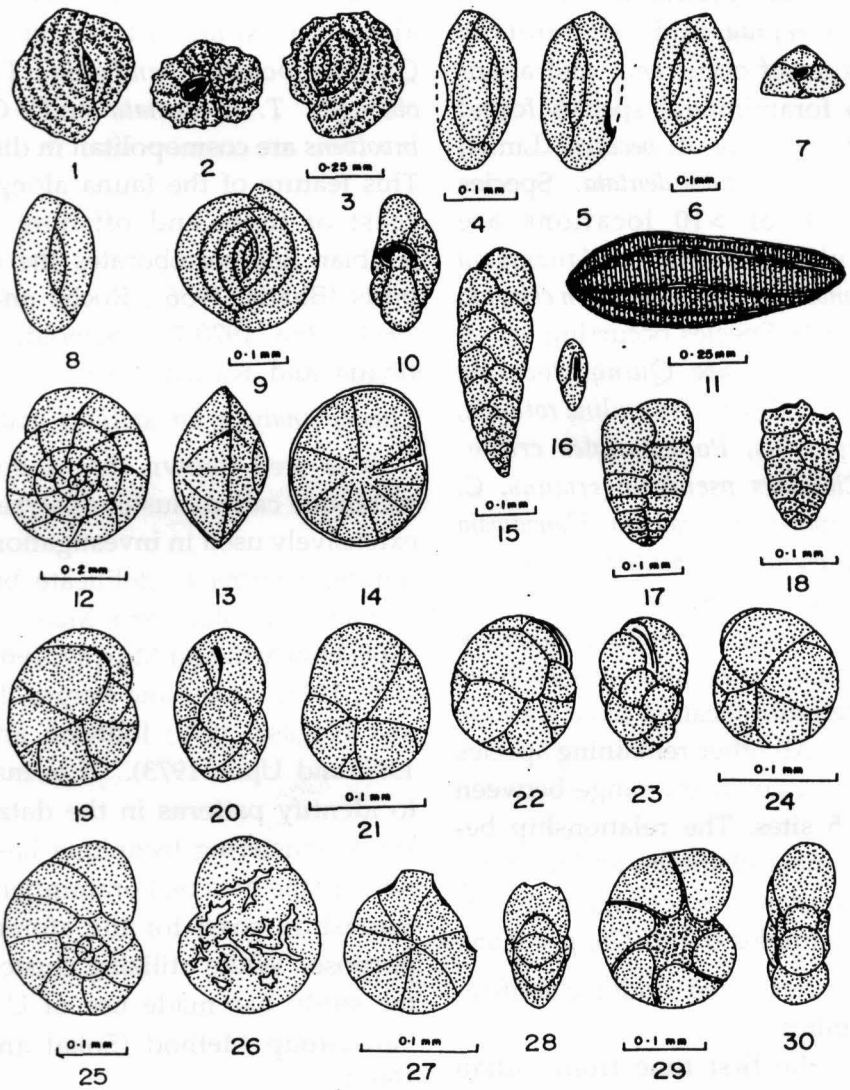

Plate 1. Foraminiferal species [*Quinqueloculina echinata* (d' Orbigny) : 1, 3, opposite sides ; 2, apertural view. *Q. elongata* Natland : 4, 5, opposite sides. *Q. moynensis :* 6, 8, opposite sides; 7, apertural view. *Spirosigmoilina parri* Collins : 9, side view ; 10, apertural view. *Borelis (Neoalveolina) pygmaea* var. *schlumbergeri* (Reuss) : 11, side view. *Epistomina bradyi* Galloway and Wissler : 12, dorsal view ; 13, peripheral view ; 14, ventral view. *Bolivina lanceolata* : 15, side view ; 16, apertural view. *Bolivina vaughani* Natland : 17, side view. *Brizalina variabilis* (Williamson) : 18, side view. *Cassidulina algida* Cushman : 19, 21, opposite sides ; 20, peripheral view. *C. californica* Cushman and Hughes : 22, 24, opposite sides ; 23, peripheral view. *"Discorbis" aguayoi* Bermudez : 25, dorsal view ; 26, ventral view. *Pullenia elegans* Cushman and Todd : 27, side view ; 28, peripheral view. *Elphidium magellanicum* Heron -Allen and Earland : 29, side view ; 30, peripheral view.]

A total of 13 stations have been clustered on the basis of similarity in abundance of species measured by euclidean distance through unweighted pair-group average method and four thanatotopes are established (Fig. 4).

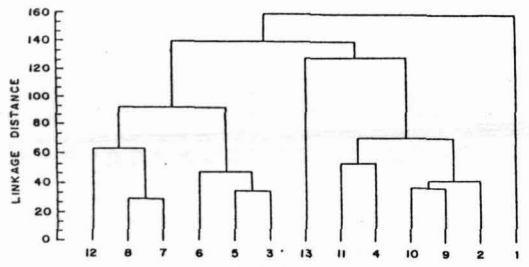

Fig. 4 *Dendrogram showing clustering of 13 stations/ areas based on similarity in abundance of species measured by euclidean distance through Unweighted Pair-Group Average Method.*

Thanatotope I comprises sts 7, 8 and 12. The dominant species occurring at these locations are : *Ammonia beccarii* variant and *Asterorotalia dentata*. But *A. tepida* (10.3%) is common at st 12 and very rare (0.3-3.0%) at other locations.

Thanatotope II consists of sts 3, 5 and 6. The most dominant species at these locations is *A. beccarii* variant. *A. dentata* (11.3%) occurs only at Chorwad (st 5) and is rare (4-9%) at other sites.

Thanatotope III includes sts 4 and 11. *A. dentata* is the abundant species (> 25%) at st 4. All other species such as *A. beccarii*, *A. dentata* and *Pararotalia minuta* are common (10-25%) at these stations.

Thanatotope IV is represented in sts 2, 9 and 10. The abundant species at these locations, in the order of abundance are : *A. dentata* and *A. beccarii* variant.

It is seen from the dendrogram that sts 1 and 13 are distinct and they are not coming under any cluster. The major species at st 1 where sediment is silty, are *A. tepida* and *A. beccarii* variant. On the other hand, the sediment at st 13 is clayey and the fauna is characterized by two common species – *Pararotalia minuta* and *A. tepida.*

Of the total of 107 species, only 43 species have been used in the cluster technique. The remaining 64 species represented < 1% in the samples have been omitted, since the ecological conditions are best reflected by the distribution of the abundant species. The results of this cluster analysis are shown in the dendrogram in Fig. 5. Eleven thanatofacies clusters are recognized. The foraminiferal assemblages that constitute these facies are given below. The number prefixing a name of species is its identification in the dendrogram (Fig. 5).

Thanatofacies A

This shallow-water and the largest facies includes very rare species (1-3%) such as 1 *Spiroloculina aequa*, 3 *Quinqueloculina lamarckiana*, 5 *Q. oblonga*, 7 *Q. tenagos*, 8 *Q. vulgaris*, 9 *Triloculina rotunda*, 10 *Spirosigmoilina parri*,15 *Eponides repandus*, 19 *Cibicides pseudoungerianus*, 23 *Nonion*

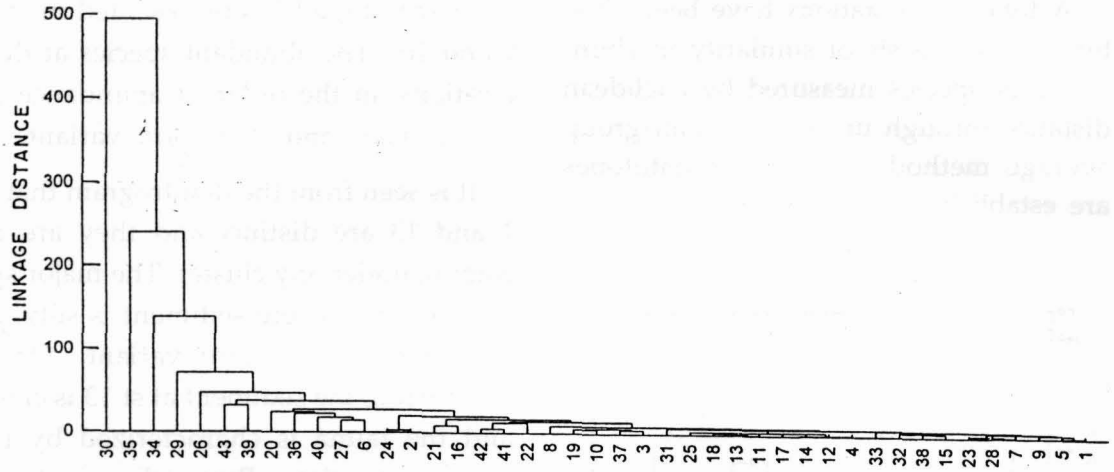

Fig. 5. Dendrogram showing co-existence of 43 foraminiferal species based on presence or absence at 13 stations measured by euclidean distance through Unweighted Pair-Group Average Method. Legend : 1. *Spiroloculina aequa*, 2. *Quinqueloculina dimidiata*, 3. *Q. lamarckiana*, 4. *Q. lata*, 5. *Q. oblonga*, 6. *Q. seminula*, 7. *Q. tenagos*, 8. *Q. vulgaris*, 9. *Triloculina rotunda*, 10. *Spirosigmoilina parri*, 11. *Bolivina striatula*, 12. *B. vaughani*, 13. *Brizalina variabilis*, 14. *Cassidulina algida*, 15. *Eponides repandus*, 16. *Poroeponides cribrorepandus*, 17. *Rosalina floridana*, 18. *R. vilardeboana*, 19. *Cibicides pseudoungerianus*, 20. *C. refulgens*, 21. *Amphistegina radiata*, 22. *Haynesina germanica*, 23. *Noion depressulum*, 24. *N. pacificum*, 25. *N. scaphum*, 26. *Hanzawaia asterizans*, 27. *H. nitidula*, 28. *Pararotalia globosa*, 29. *P. minuta*, 30. *Ammonia beccarii* (Linné) variant, 31. *A. advena*, 32. *A. parkinsoniana*, 33. *A. sobrina*, 34. *A. tepida*, 35. *Asterorotalia dentata*, 36. *A. inflata*, 37. *Elphidium advenum*, 38. *E. craticulatum*, 39. *E. crispum*, 40. *E. discoidale*, 41. *E. excavatum*, 42. *E. incertum*, 43. *Nummulites (Operculinella) venosus.*

depressulum, 28 *Pararotalia globosa*, 31 *Ammonia advena*, 32 *A. parkinsoniana*, 33 *A. sobrina*, 37 *Elphidium advenum* and 38 *E. craticulatum*. Most of these species are representatives of nearshore turbulent zone (0-40 m depth), with the exception of a few forms such as *Spiroloculina aequa*, *Cibicides pseudoungerianus* and *Spirosigmoilina parri* belonging to off-shore fauna (> 40-200 m). In this faunal ensemble, *Elphidium craticulatum* is typically an Indo-Pacific species.

Thanatofacies B

This is the second largest thanatofacies consisting of 8 very rare species (1-3%) like 4 *Quinqueloculina lata*, 11 *Bolivina striatula*, 12 *B. vaughani*, 13 *Brizalina variabilis*, 14 *Cassidulina algida*, 17 *Rosalina floridana*, 18 *R. vilardeboana* and 25 *Nonion scaphum*. Of these, *Bolivina striatula* and *Cassidulina algida* are off-shore forms of continental shelf, while the remaining species occur both at the littoral zone and continental shelf areas.

Thanatofacies C

This facies is represented by a lone species like 30 *Ammonia beccarii* variant and is widely distributed in the Atlantic, Indian and Pacific oceans. It occurs commonly in shallow-water areas and seems

to be mostly limited to brackish water. In this study, its distribution covers Thanatotopes I, II, III, IV and also sts 1 and 13 which are distinct.

Thanatofacies D

The member of Thanatofacies D, 35 *Asterorotalia dentata* is restricted to Indo-Pacific region.

Thanatofacies E

The member, 34 *Ammonia tepida* of this facies which is characteristic of shallow-brackish water shows highest abundance at st 1 (43%) and is common at st 12 (thanatotope I), (10.3%) and st 13 (13%).

Thanatofacies F

A lone member, 29 *Pararotalia minuta* of this facies which occurs in nearshore turbulent zone (0-40m depth) is rare (4-9%) at sts 4 (9.7%) and 11 (6.7%) of Thanatotope III but common (10-25%) at st 13 (21.7%).

Thanatofacies G

The member of Thanatofacies G, 39 *Elphidium crispum* is the most abundant in shallow, turbulent waters and cosmopolitan in distribution. It can tolerate a wide range of environmental change (Myers,1943). In this study, it is widespread or even ubiquitous.

Thanatofacies H

The members of Thanatofacies H, 6 *Quinqueloculina seminula,* 20 *Cibicides refulgens,* 26 *Hanzawaia asterizans,* 27 *H. nitidula,* 36 *Asterorotalia inflata* and 40 *Elphidium discoidale* are inner shelf species.

Thanatofacies I

The first species of this facies, 2 *Quinqueloculina dimidiata,* occurs at nearshore and also at the lower part of the intertidal zone and the second member, 24 *Nonion pacificum* is the inner shelf species.

Thanatofacies J

The members of this facies, 16 *Poroeponides cribrorepandus,* 21 *Amphistegina radiata* and 43 *Nummulites (Operculinella) venosus* are inner shelf species.

Thanatofacies K

This is the shallow-brackish water facies, which includes three species : 22 *Haynesina germanica,* 41 *Elphidium excavatum* and 42 *Elphidium incertum.*

Biofacies

A foraminiferal faunal division is seen when the Saurashtra coast is arbitrarily divided along 70° 30′ 00″ E between the western and eastern coast areas. The western coast facies is characterized by certain major species in every population, they being *Ammonia beccarii* variant, *A. tepida* and *Asterorotalia dentata.* The eastern coast facies on the other hand, is dominated by species such as *Ammonia beccarii* variant, *Asterorotalia dentata, Para-rotalia minuta, Hanzawaia asterizans* and *Ammonia tepida* in order of abundance.

Comparison with other studies along the Indian coasts

Bhatia (1956) reported 45 species of Foraminifera from shore sands of Bhogat (Saurashtra) and Bombay. Of them, 17 species are identical with those reported in this paper, they being *Textularia conica, Quinqueloculina crassa* var. *subcuneata, Q. lamarckiana, Q. seminula, Triloculina rotunda, T. tricarinata, Nonion scaphum, Elphidium advenum, E. craticulatum, E. crispum, Bulimina marginata, Bolivina pseudoplicata, B. striatula, Brizalina variabilis, Loxostomum limbatum, Asterorotalia dentata* and *Cancris auriculus*. He observed no arenaceous forms at the Bombay localities. But the assemblage of Bhogat beach (21° 58′ 00″ N, 69° 12′ 30″ E) is characterized by the presence of two arenaceous forms – *Textularia conica* and *T. foliacea*. Rocha and Ubaldo (1964) listed 52 species from sands of Diu, Gogolá and Simbor and out of them 35 are unknown in the present study area. Bhalla and Nigam (1979) recorded 36 species from the Calangute beach sands, Goa. Among them, 16 species are common to the Saurashtra coast. Further, the assemblage of Calangute beach is characterized by two abundant species – *Ammonia annectens* (= *Asterorotalia dentata*) and *Pararotalia nipponica* (Asano). The frequently occurring species are *Elphidium indicum, Eponides repandus* and *Poroeponides cribrorepandus*. Out of 25 species reported from the shore sands of Malabar coast (Bhalla and Raghav, 1980), 11 of them are not known to occur in the present area of study. Rao *et al.*, (1989) recorded 82 species of Foraminifera from the Late Quaternary aeolian sands of the Thar Desert out of which 32 are common to the beaches of Saurashtra. The Thar Foraminifera were derived from a number of sources, one of the sources being from beaches along the Indian coast of the Arabian Sea. The most abundant and widely distributed species in the Thar assemblage is *Ammonia beccarii* (Linné) variant similar to the present study.

The miliolite rocks are mostly of eolian, blown from the beaches. All 10 species of Foraminifera reported earlier from Late Pleistocene miliolite at Porbandar are found in the beaches of the present coast.

The Foraminifera derived from near beaches of the coast and probably most of those derived from inland sources, did not move into the dunes of Thar by saltation. They were transported in suspension possibly by buoyant convection (Rao *et al.*, 1989).

On the east coast of India, Bhalla (1968) recorded 16 species from Visakhapatnam beach material. Among them, only 6 species were found in the present study. Also, he (1970) gave an account of 15 species of Foraminifera from Marina beach sands, Madras. Of the species reported, 5 species are observed along the coast of Saurashtra.

It is patent from the above faunal studies that one species – *Asterorotalia pulchella* = *trispinosa* – is recorded only from the east coast of India. So far as is known, this species is neither recorded from the Arabian Sea nor from the estuaries on the

west Indian coast. It is possible that this species is endemic to the Bay of Bengal.

Conclusions

1. One hundred seven foraminiferal species have been identified and studied quantitatively in regard to their percentage occurrence from sand samples collected from 13 stations along the Saurashtra coast.
2 An inverse relationship exists between the size of the sand grains (median diameter) and the number of foraminiferal specimens in the sample. Along the coast, abundance increases curvilinearly with median diameter in phi units.
3. The distribution of species shows that *Ammonia beccarii* (Linné) variant is the dominant and most widely distributed species as in the dune sands of Thar Desert thereby confirming the observation that one of the sources of Thar Foraminifera being the beaches of Arabian Sea.
4. The fauna is dominated by species of Rotaliina followed by Miliolina, Textulariina, Globigerinina, Lagenina and Robertinina.
5. Arenaceous Foraminifera are rare and represented by genera *Trochammina, Eggerelloides* and *Textularia*. Porcelaneous Foraminifera are represented by *Cornuspira, Spiroloculina, Massilina, Quinqueloculina, Miliolinella, Triloculina* and *Spirosigmoilina*. Hyaline test types dominate the fauna.
6. Most of the species reported in the study, are also known from Indo-Pacific region.
7. Four thanatotopes are observed. Of them, Thanatotope I of the Eastern coast facies and Thanatotope II of the Western coast facies are similar in abundance of species in the respective clusters of the stations. Further, sts 1 and 13 are distinct in showing dominance of certain species.
8. Eleven thanatofacies are established. The species clustered do confirm the existence of two biofacies namely Western coast facies and Eastern coast facies. Further, they almost correspond with the assemblages that characterize the thanatotopes.
9. The beach fauna of Saurashtra coast is a mixed assemblage of species from shoal environment (0-10 fathoms) and continental shelf. The presence of offshore species in this study could be ascribed to the action of bottom water currents and wave action.

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