

Distribution of planktonic Foraminifera in waters of the submarine coral banks in southeast Arabian Sea during winter

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Twentyfive species of planktonic Foraminifera are recorded from 36 plankton tows collected from waters of the submerged coral banks—Bassas de Pedro, Sesostris and Cora Divh—located at northern end of the Laccadive group of islands in southeastern Arabian Sea. High standing stocks of these organisms are found in plankton tows north of 13°N where upwelling indicator species namely *Globigerina bulloides* and *Neogloboquadrina dutertrei* are observed. Most of the spinose species show higher concentrations in 0-10 m than in 0-200 m tows. Although they form a major component of the fauna, non-spinose species show an increase in relative abundance in December as compared with studies of other winter months in the Arabian Sea and are represented chiefly by those of *Globorotalia* and *Globigerinita*. Distribution of species in plankton tows reveals that *Globigerinoides ruber*, *G. sacculifer* and *Globigerinita glutinata* are the most dominant forms, while less dominant species being *Globigerinella aequilateralis* and *Globorotalia tumida*. Foraminiferal fauna in general depicts closer affinity with that of equatorial waters of the world and is typical of a tropical reef region under peak winter conditions.

Knowledge of seasonal patterns of planktonic Foraminifera is essential in understanding their developmental stages, ecology and distributional trends. In addition, utility of such studies in paleoenvironmental interpretation has been stressed earlier by Tolderlund and Bé¹, Deuser², Deuser *et al.*³, and Williams *et al.*⁴ have also shown the importance of some seasonal index foraminiferal species in registering seasonal contrast in paleoclimatic and paleoceanographic reconstructions. It is a logical corollary to state from investigations^{1,5-9} of planktonic Foraminifera that they reflect distinct distributional patterns and abundance in different seasons.

Although notable strides have been made on distributional and ecologic patterns of Recent planktonic Foraminifera in Indian Ocean during the last three decades, it is still poorly understood with respect to their seasonal fluctuations as reviewed previously¹⁰. In this period, however, some seasonal aspects of them in the Arabian Sea have been recorded¹¹⁻¹⁶. As more information has to be gleaned from such studies in northern Indian Ocean which lies mostly within the tropics and is subjected to a large scale monsoonal changes, planktonic Foraminifera present in waters of the submerged coral banks in southeastern Arabian Sea are described in this work to interpret their nature and distribution during winter season.

Study area

Topography—The submarine banks—Bassas de Pedro, Sesostris and Cora Divh—situated north of coral reefs of the Laccadives are widely spaced and isolated from one another (Fig. 1). They are submerged below waters ranging in depth from 20 to 77 m and are characterized by high topography and hard substratum which generally favour growth of corals. Coral growth might have started during glacial times of lower sea level (Pleistocene) and continued in the Holocene. Last Cenozoic marine transgression is responsible for the rise of sea level from 130 m below the present level to about 20 m below the present sea level over a period of 8000 years¹⁷. This is the actual reason why the banks north of Laccadives are submerged over the said period of time as the rate of sea level rise exceeds the rate of coral growth.

Hydrography—During winter (November-February) in the open waters, the general set up is westerly and off the west coast of India, dominant direction of the current to about 20°N is north-north-westerly. A detailed study of hydrography of southeastern Arabian Sea during winter season has been reported earlier¹⁸⁻²⁰. Winter conditions start setting in the Arabian Sea during November, reaching peak in December¹⁸ and prevail till February. The cool air in winter lowers the temperature of sea

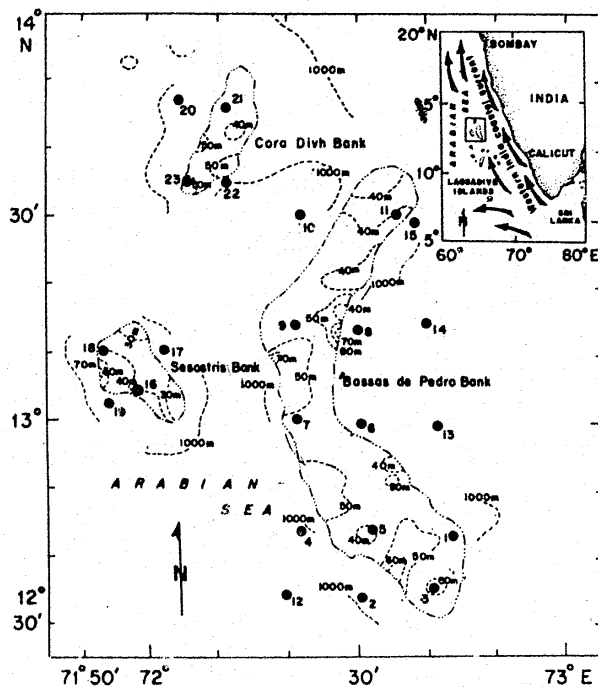


Fig. 1—Map of eastern Arabian Sea (insert) and submarine coral banks showing surface coastal circulation of waters off the west coast of India, study area and plankton sampling locations

surface²¹ at the head of Arabian Sea and Bay of Bengal by as much as 3°C. In December, surface temperature of the Laccadive offshore waters¹⁹ plummets down markedly ranging between 28°–29°C in comparison with summer²² temperature of these waters varying from 30° to 30.6°C. Because of winter cooling at the surface, thermal inversions are frequent in topmost layers. With the deepening of thermocline and vertical mixing followed by surface cooling, the temperature in the mixed layer which extends to average depth of 60–80 m is very low. Also, with greater uniformity of temperature in the layer depth, temperature frequency curves are very peaked and unimodal. It is noted that surface salinities in summer are rather low varying between 34.4 and 35.5×10^{-3} , but in winter, they show higher values with a wide range between 34.2 and 36.2×10^{-3} . Different manifestations of salinity at the surface in southeastern Arabian Sea during winter are due to differential evaporations which in turn can be related to the geographical relation of land and sea¹⁸. Different water masses in this sea in winter have been analyzed¹⁹ based on *T-S* diagrams. Besides, sinking as well as high surface salinities are noted in the upper layers of the Laccadive offshore waters. Also, during this period, upwelling has been noted²⁰ in the vicinity of Minicoy due to divergence. The upwelling in the southeastern Arabian Sea is as

well associated with the presence of submarine ridge—the Laccadives—Chagos Ridge, which is known to cause enrichment of surface waters²³ and by the 'island mass effect' also due to northward flowing current²⁴ which is in the path of Laccadive islands and submerged coral banks.

Materials and Methods

Twentythree surface hauls (0–10 m) and 13 vertical hauls (0–200 m) were collected aboard *R. V. Gaveshani* during cruise 206 (December 1988) with Heron-Tranter net of mesh size 150 μm , fitted with a Rigosha flow meter. Surface hauls were made at all the sites, while vertical hauls only at the sites located outside the banks where water depth is > 200 m (Fig. 1). Treatment of plankton samples, processing of faunal data and statistical study are same as adopted earlier¹⁶ in this work.

Results and Discussion

Ecology—In the present study, hydrographic observations pertain to surface-water temperature and salinity (Fig. 2 A, B). Surface temperature varies between 28.5° and 29.5°C. Surface temperatures above 29.3°C are found in the southern region while in the northern part, it ranges from 28.5° to 29°C. With temperatures which are low at the surface, high surface salinities are noted in December. In this study, high saline waters $> 36 \times 10^{-3}$ are found in the middle area of western side, whereas in the southern region salinities as low as 32.9×10^{-3} are observed, which may be due to the effect of Bay of Bengal water carried by the branch of Northeast Monsoon Current along the west coast of India²⁵. This low salinity water condition in the waters off southwest India is indicated²⁶ by depletion of ^{18}O in the shells of surface-dwelling planktonic Foraminifera in sediments off the coast during this period (salinity and ^{18}O are linearly correlated). Banse²⁴ also observed this water or Equatorial Surface Water off Cochin during December and January in the northward flowing coastal current.

Foraminiferal abundance—Very high concentrations of total planktonic Foraminifera are found in plankton tows north of 13°N with maximum densities of 305600 (0–10 m) and 77778 (0–200 m) specimens in 1000 m^3 at sts. 21 and 14 respectively in the northern area where upwelling indicator species are predominant. Lower abundances varying from 13120 to 103428 (0–10 m) and from 4508 to 21078 (0–200 m) in 1000 m^3 occur in the southern area (Fig. 2 C, D). Total planktonic foraminiferal abundance is more in 0–10 m than in 0–200 m tows. Comparison of foraminiferal abundance in pairs of

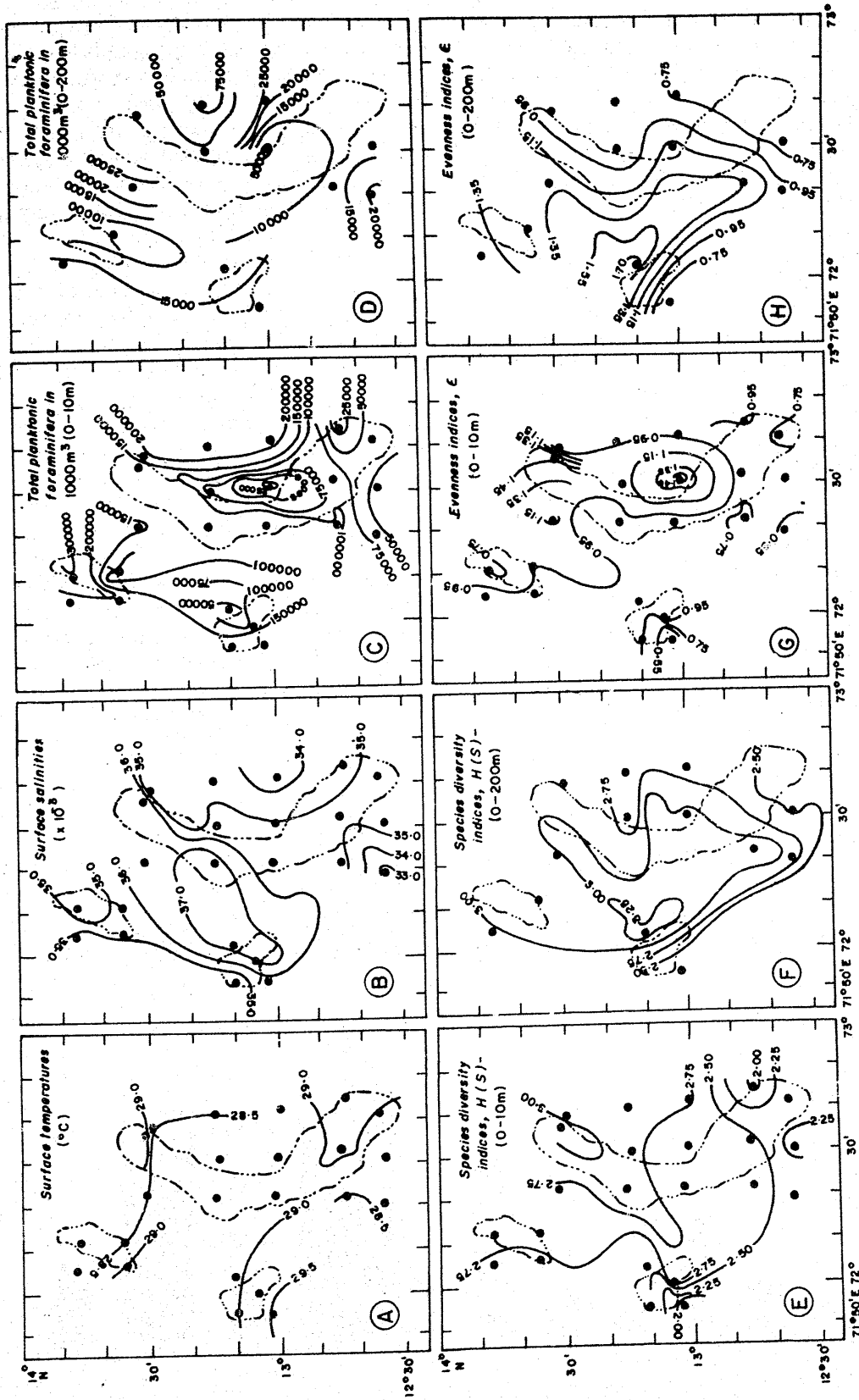


Fig. 2—Surface temperatures (A), surface salinities (B), total number of specimens in 1000 m³ of water in 0-10 m (C) and 0-200 m (D) tows, species diversity indices, $H(S)$ of 0-10 m (E) and 0-200 m (F) tows and evenness indices, ϵ of 0-10 m (G) and 0-200 m (H) tows.

adjacent stations—(2,3), (6,7), (8,9), (17,18), (20,21) and (22,23) shows that higher concentrations occur at 0-10 m of shallow sites inside the banks than at 0-10 m of deep sites located outside (Fig. 3 A, B). This is possibly due to two factors: 1) Perturbations produced by the banks leading to nutrient enrichment of the overlying water through barrier effects. 2) Ascending motion of waters caused by the banks by which nutrient-laden water is brought to the surface by the northward drift of the western India coastal current²⁴ during winter (December/January). Similar type of local upwelling has been observed owing to bottom topography in the Galapagos area of Pacific Ocean where west-east flowing Equatorial Undercurrent is in the path of an obstacle²⁷. Student's *t* test also indicates that concentrations in 0-10 m tows of shallow sites (sts. 3, 7, 9, 18, 21, 23) are not similar to those of deep sts. 2, 6, 8, 17; 20, 22 ($t=2.0680$ ($P<0.1$)). By contrast, in other pairs of stations, (16, 19), (11, 15) and (4, 5), 0-10 m tows of deep sites show higher densities than those of shallow sites and it can be explained for the first two pairs of sites because of different days of collections of representative samples. But in the other pair of sts. (4,5), reason for the observed faunal trend remains unknown, even though respective samples were collected on the same day as in the first case mentioned before. Further, the study of

surface-water temperature and salinity correlated with total planktonic Foraminifera suggests that these are not the only factors controlling their abundance as shown by multiple regression model fitted for the fauna ($P>0.05$), other ones like nutrients and food supply also have influence on it. The average of five years' data of phosphate content in surface waters of Laccadive Sea shows²⁸ variation between $0.47-1.044 \mu\text{g-at.l}^{-1}$. Also, Jayaraman and Seshappa²⁹ reported high values of total phosphorus off the west coast of India both during SW and NE monsoon periods. In general, high concentrations of planktonic Foraminifera are recorded in regions rich in nutrients^{8,30}. The above observations of faunal data are in conformity with this finding.

Southeastern Arabian Sea is known to be most fertile by supply of nutrients followed by peak of phytoplankton productivity only during southwest monsoon season due to strong upwelling that occurs along the southwest coast of India³¹. However, nutrient enrichment of these waters including Laccadive Sea is known to take place even in winter by weak upwelling^{32,33}. Thus, productivity of the waters in southern Arabian Sea is directly related to intensity of upwelling. Further, one divergence zone lying between $70^{\circ}-72^{\circ}\text{E}$ and $8^{\circ}-11^{\circ}\text{N}$ and a convergence zone along axis around 74°E have been observed during winter³⁴. Undoubtedly, higher concentra-

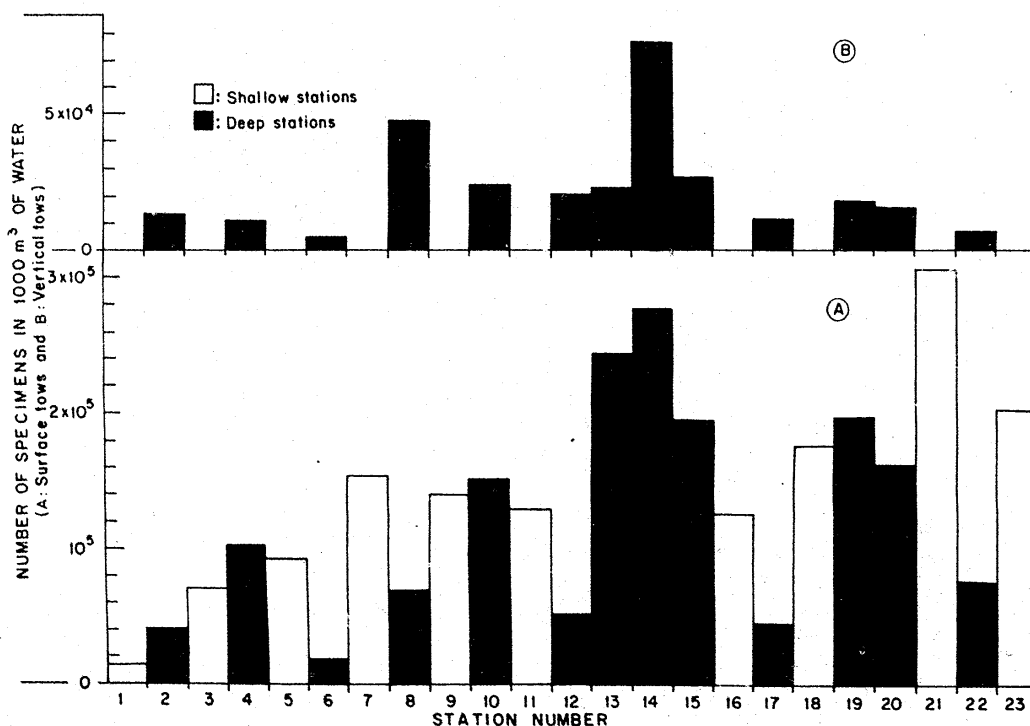


Fig. 3—Absolute abundance of total planktonic Foraminifera in surface (A) and vertical (B) tows at shallow and deep sites

ations of total planktonic Foraminifera in the present study are linked to pulses of phytoplankton development that occurs in December or January³¹.

Faunal diversity and equitability—Shannon-Wiener diversity index, $H(S)$ measures diversity in terms of information gathered taking into consideration not only the number of species, but also their frequencies without making any assumption about the distribution of species. It is given³⁵ as:

$$H(S) = \sum_{i=1}^S pi \cdot \ln(pi)$$

where pi is the proportion of the i th species and S is the number of species observed. This index also reflects productive nature of the waters based on species richness. Furthermore, $H(S)$ is not as variable as S , since it is not subjected to fluctuations due to presence or absence of a rare species.

For equally distributed species, $e^{H(S)} = S$ [because maximum value of $H(S)$ is obtained when all the species have equal frequencies in which case $H(S) = \ln S$ according to MacArthur³⁶] which in turn can be used as a measure of equitability. Heip³⁷ has defined it as:

$$\epsilon = e^{H(S)-1}/(S-1)$$

where $e^{H(S)}$ is the equivalent number of equally distributed species. The above relation is found to have a better statistical behaviour because it is not at all altered when all the species are increased or decreased by a constant number of individuals. Equitability measures the evenness or probability of occurrence of species. If equitability is higher, it means all the species have more or less the same probability of occurrence. In other words, their distribution is almost random. If equitability is low, it will show dominance of a few species.

In the present study, species diversity index, $H(S)$ in 0-10 m increases in the northeast area with maximum value of 3.19 at site 11. Minimum index of 1.95 is found at sts. 1 and 19 (Fig. 2E). In the case of 0-200 m tows, relatively high diversity indices ranging from 2.09 to 3.29 are observed (Fig. 2F).

Species equitability, ϵ of 0-10 m tows shows increasing trend in the northeast area similar to diversity. In waters of Sesostris and in the region south of 12°45' N, it varies from 0.43 to 1.04. But in 0-200 m tows relatively high evenness indices varying between 0.5 and 1.72 are recorded (Fig. 2G,H).

In both 0-10 m and 0-200 m tows, $H(S)$ and ϵ are found to be linearly related, i.e. diversity changes lead to alterations in equitability ($r=0.5457$, $P<0.05$, for 0-10 m tows and $r=0.8887$, $P<0.05$, for 0-200 m tows).

Cluster analysis for coexistence of species—This study defines that in 0-10 m tows of shallow sites 5 clusters of species are formed [$r>0.63$, ($P<0.05$)] (Fig. 4A), they being (a): 10, 17, 19, 1, 132, 5, 8, 14, 23), (b): (7, 24, 3), (c): (20, 21), (d): (9, 12, 22), and (e): (16, 25, 15, 2, 6). In contrast, at 0-10 m of deeper sites, only 4 clusters (Fig. 4B) formed are (a): (2, 7, 5, 24, 1, 12, 19, 6, 10, 13, 22, 3), (b): (17, 21, 4, 23), (c): (18, 20, 8), and (d): (9, 14). Thus, dendrograms (Fig. 4A, B) for grouping of species at 0-10 m for both shallow and deep sites indicate that the number of clusters formed is more at shallower than at deep sites. The largest cluster for deep sites has more number of species than those of the largest cluster for shallower sites. This implies that more number of species present at 0-10 m level of deep sites require the same environmental conditions than those of 0-10 m for shallow sites. It means as well that when all the species coexist in the area they are all exposed to the same ecological characteristics³⁸ thereby indicating stability of the environment.

Considering all the sites (deep + shallow) of the study area, coexistence of species shows that in 0-10 m tows (Fig. 4C), there are 4 significant clusters [$r=0.41$, $P<0.05$]- (a): (12, 9, 4, 5, 6, 24, 1, 2, 23, 11, 22), (b): (8, 20, 17, 7, 19, 3, 16, 21), (c): (13, 15), (d): (14, 25). All the species in the cluster 'a' contribute major part to the foraminiferal density, since they are dominant in the fauna under this cluster. On the contrary, in 0-200 m tows (Fig. 4D) only one major cluster is formed [$r>0.55$, ($P<0.05$)] (a): (2, 16, 15, 3, 18, 19, 5, 21, 6, 23, 4, 10, 14, 17, 7). All the abundant species with the exception of *G. glutinata* come under this cluster.

Presence of more number of clusters in 0-10 m hauls suggests that species at this level require different environmental conditions for their existence.

Distribution of foraminiferal species—Twentyfive species of planktonic Foraminifera have been identified from 36 plankton-tow samples and most of spinose species show greater abundance at 0-10 m than at 0-200 m level of tows (Table 1). These species can be confined to the groups—warm-water species (*Globigerina calida*, *G. falconensis*, *G. rubescens*, *Globigerinella aequilateralis*, *G. adamsi*, *Hastigerina pelagica*, *Globigerinoides tenellus*, *G. conglobatus*, *G. ruber*, *G. sacculifer*, *Orbulina universa*, *Pulleniatina obliquiloculata*, *Globorotalia anfracta*, *G. flexuosa*, *G. menardii*, *G. tumida*, *G. unguata*, *Globorotaloides hexagona*, *Globoquadrina conglomerata*, *Neogloboquadrina dutertrei* and *Turborotalita humilis*), warm-temperate water species (*Globorotalia scitula*), cosmopolitan species (*Globigerinita glutinata*) and cold-temperate water species (*Globigerina bulloides* and *G. quinqueloba*).

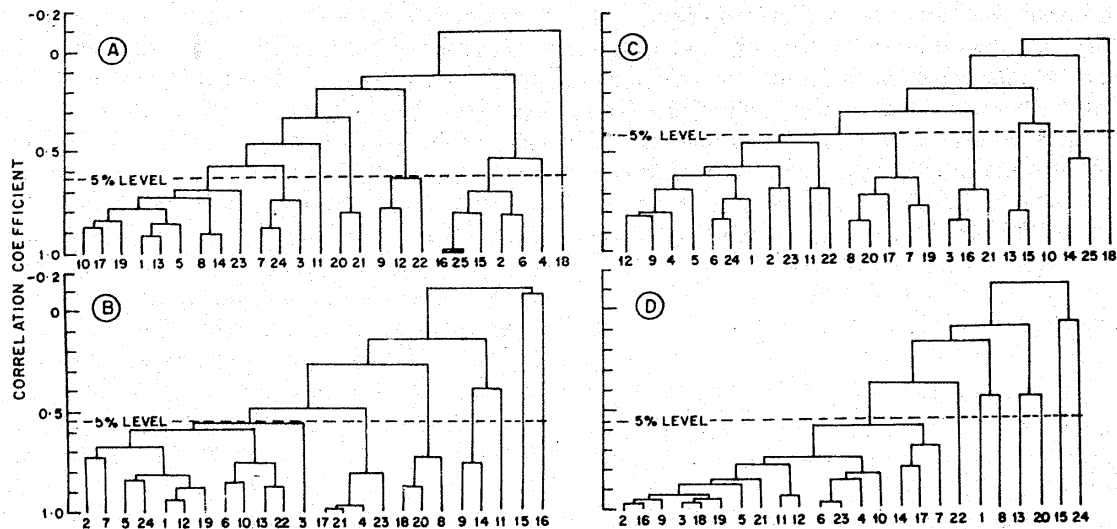


Fig. 4—Dendrograms showing coexistence of various foraminiferal species in 0-10 m tows of shallow (A) and deep (B) sites, in 0-10 m tows of all the sites (C) and in 0-200 m tows (D) [(1) *Globigerina bulloides*; (2) *G. calida*, (3) *G. falconensis*, (4) *G. quinqueloba*, (5) *G. rubescens*, (6) *Globigerinella aequilateralis*, (7) *G. adamsi*, (8) *Hastigerina pelagica*, (9) *Globigerinoides tenellus*, (10) *G. conglobatus*, (11) *G. ruber*, (12) *G. sacculifer*, (13) *Orbulina universa*, (14) *Pulleniatina obliquiloculata*, (15) *Globorotalia anfracta*, (16) *G. flexuosa*, (17) *G. menardii*, (18) *G. scitula*, (19) *G. tumida*, (20) *G. unguata*, (21) *Globorotaloides hexagona*, (22) *Globoquadrina conglomerata*, (23) *Neogloboquadrina dutertrei*, (24) *Globigerinita glutinata*, and (25) *Turborotalita humilis*]

Species of interest related to winter season and their absolute abundance (no. of specimens in 1000 m³) and distribution patterns in the reef waters are as follows:

(1) *Globigerinella aequilateralis* (Brady)—It shows an increase in abundance off eastern side of the middle area of Bassas de Pedro, peak abundance being 23000 and 4444 specimens in 0-10 m and 0-200 m tows respectively at st. 14 (Fig. 5A, B).

(2) *Globigerinoides ruber* d'Orbigny—Like *G. aequilateralis*, higher concentrations of this species at 0-10 m tows occur off eastern Bassas de Pedro with highest abundance of 33000 specimens at site 13, while in 0-200 m tows it is 9200 at site 14. Lower densities of this species are present south of 13°N (Fig. 5C, D).

(3) *Globigerinoides sacculifer* (Brady)—This is the most abundant species of the fauna studied showing an increase in abundance at 0-10 m tows in the northeast area with density > 75000 specimens occurs at sts. 13, 18, 19 and 21, maximum value being 140400 at site 24 and lower concentrations < 10000 are found around southeastern part of Bassas de Pedro. But at 0-200 m tows, its density is low (> 10000) in the northeast region (Fig. 5E, F).

(4) *Globorotalia menardii* (d'Orbigny)—As in north Atlantic, it is scarce in this part of the Arabian Sea during winter and shows low concentration ranges of 286-1000 (0-10 m) and 13-178 (0-200 m) in plankton tows.

(5) *Globorotalia tumida* (Brady)—This tropical species shows higher concentrations in waters off the northeastern part of Bassas de Pedro. Highest abundance of this species occurs in 0-10 m (67222) and 0-200 m (161333) tows at st. 14 (Fig. 5G, H).

(6) *Pulleniatina obliquiloculata* (Parker and Jones)—Though it is a winter species occurring in higher concentrations in subtropical waters of north Atlantic, it is sparsely distributed in this tropical region. At 0-10 m level, it occurs only at 5 sites mostly inside the banks ranging in density from 200 to 800 specimens and it is still very much lower in concentration in 0-200 m tows varying between 12 and 44 (Fig. 6A, B).

(7) *Globigerina bulloides* d'Orbigny—It manifests higher density in plankton tows in the northeast area with abundance variations of 160-5760 (0-10 m) and 40-712 (0-200 m) specimens (Fig. 6C, D).

(8) *Neogloboquadrina dutertrei* (d'Orbigny)—In both 0-10 m and 0-200 m tows, it increases in concentration off eastern Bassas de Pedro. In the southern area, its increase is in the southeast direction for 0-10 m hauls, whereas it is southwest for 0-200 m tows (Fig. 6E, F).

(9) *Globigerinita glutinata* (Egger)—It is another abundant species showing higher densities in the northern area from 12°50'N with maximum concentration of 52444 specimens at 0-10 m, while it is 11067 at 0-200 m level at site 14 (Fig. 6G, H).

Table 1—Absolute abundance (no. of specimens in 1000 m³ of water) and species percentages (within parentheses) of planktonic Foraminifera at different sites in plankton tows

Station No.	Date (1988)	<i>G. bulloides</i>	<i>G. calida</i>	<i>G. falconensis</i>	<i>G. quinqueloba</i>	<i>G. rubescens</i>	<i>G. adamsi</i>	<i>G. aequiliteralis</i>	<i>H. pelagica</i>	<i>G. tenellus</i>	<i>G. conglobatus</i>	<i>G. ruber</i>	<i>G. sacculifer</i>	<i>G. universa</i>	<i>P. obliquiloculata</i>	<i>G. flexuosa</i>	<i>G. menardi</i>	<i>G. scitula</i>	<i>G. tumida</i>	<i>G. unguilata</i>	<i>G. conglomerata</i>	<i>G. hexagona</i>	<i>N. duterrei</i>	<i>G. glutinata</i>	<i>T. humilis</i>
1	7/12	160 (1.2)	-	-	-	480 (3.7)	-	160 (1.2)	960 (7.3)	-	-	3680 (28.0)	6400 (48.9)	-	-	-	-	-	-	-	-	-	-	1230 (9.8)	-
2	8/12	-	266 (0.6)	-	-	-	-	2400 (5.8)	4000 (9.7)	266 (0.6)	1067 (2.6)	5067 (12.3)	23200 (56.1)	-	-	-	-	267 (0.6)	-	-	-	800 (1.9)	4000 (9.7)	-	
3	8/12	870 (1.2)	1884 (2.6)	-	1014 (1.4)	1159 (1.6)	-	5217 (7.3)	1159 (1.6)	580 (0.8)	1594 (2.2)	10144 (14.2)	36957 (51.8)	435 (0.6)	-	-	-	290 (0.4)	145 (0.2)	145 (0.2)	145 (0.2)	2999 (4.1)	6312 (9.6)	-	
4	9/12	857 (0.8)	571 (0.6)	-	1714 (1.7)	2000 (1.9)	-	13714 (13.3)	1143 (1.1)	357 (0.3)	-	13143 (12.7)	51429 (49.7)	-	-	-	286 (0.3)	571 (0.6)	571 (0.6)	857 (0.8)	857 (0.8)	2000 (3.9)	14286 (13.8)	-	
5	9/12	1455 (1.6)	364 (0.4)	-	1455 (1.6)	2182 (2.3)	-	12363 (13.2)	364 (0.4)	1091 (1.1)	2909 (3.1)	12727 (13.6)	42545 (45.5)	364 (0.4)	364 (0.4)	-	-	727 (0.8)	727 (0.8)	-	-	-	3636 (3.9)	10909 (11.7)	-
6	10/12	228 (1.3)	-	-	457 (2.6)	913 (5.1)	-	2968 (16.7)	-	-	1370 (7.7)	1598 (9.0)	6849 (38.4)	-	-	-	-	-	-	-	-	-	457 (2.6)	2963 (16.6)	-
7	10/12	2000 (1.3)	1428 (0.9)	286 (0.2)	2000 (1.3)	3429 (2.2)	-	16857 (11.0)	4571 (2.9)	857 (0.6)	2571 (1.7)	27143 (17.7)	60286 (39.4)	571 (0.4)	-	-	-	2286 (1.5)	2286 (1.5)	-	857 (0.6)	-	1714 (1.1)	26286 (17.2)	-
8	11/12	1032 (1.5)	1806 (2.6)	-	1548 (2.2)	387 (0.6)	-	3227 (4.6)	4903 (7.0)	516 (0.7)	3742 (5.3)	10710 (15.3)	24258 (34.7)	645 (0.9)	-	-	-	516 (0.7)	516 (0.7)	516 (0.7)	-	645 (0.9)	15434 (22.1)	-	
9	11/12	1559 (1.1)	3704 (2.6)	390 (0.3)	1170 (0.8)	1170 (0.8)	-	21053 (15.0)	390 (0.3)	390 (0.3)	3314 (2.4)	13255 (9.5)	30409 (21.7)	585 (0.4)	195 (0.1)	-	-	9942 (7.1)	9942 (7.1)	2339 (1.7)	195 (0.1)	390 (0.3)	1559 (1.1)	46978 (33.6)	-
10	12/12	2333 (1.5)	1000 (0.7)	-	1667 (1.1)	1333 (0.9)	-	28000 (18.5)	1333 (0.9)	-	1333 (0.9)	12667 (8.3)	33333 (22.0)	-	-	-	-	20333 (13.4)	20333 (13.4)	2000 (1.3)	-	2667 (1.8)	45667 (29.7)	-	
11	12/12	727 (0.6)	4000 (3.1)	-	2545 (2.0)	3273 (2.5)	-	17818 (13.8)	1455 (1.1)	1455 (1.1)	2545 (2.0)	15636 (12.1)	22545 (17.4)	727 (0.6)	-	-	-	25818 (19.9)	25818 (19.9)	3273 (2.5)	364 (0.3)	3273 (2.5)	25273 (17.9)	-	
12	17/12	738 (1.4)	738 (1.4)	-	369 (0.7)	984 (1.9)	-	2829 (5.5)	1599 (3.1)	369 (0.7)	615 (1.2)	7257 (14.0)	20787 (40.0)	-	-	-	-	5289 (10.2)	5289 (10.2)	861 (0.2)	123 (0.2)	123 (0.2)	8610 (16.6)	-	
13	20/12	2400 (1.0)	3600 (1.5)	800 (0.3)	1600 (0.7)	2600 (1.1)	-	14000 (5.7)	3000 (1.2)	1200 (0.5)	2200 (0.9)	33000 (13.5)	82800 (34.0)	-	-	200 (0.1)	-	1000 (0.4)	1000 (0.4)	4000 (20.9)	600 (0.2)	800 (0.3)	6200 (2.5)	33500 (13.9)	-
14	20/12	2556 (0.9)	2444 (0.8)	-	3000 (1.1)	2222 (0.8)	-	333 (0.1)	2667 (0.9)	1778 (0.6)	2444 (0.8)	26778 (9.6)	73667 (26.5)	111 (0.04)	-	-	-	6722 (24.2)	6722 (24.2)	13389 (5.0)	667 (0.2)	111 (0.2)	1333 (0.5)	52444 (13.8)	-
15	20/12	800 (0.4)	5760 (3.0)	160 (0.1)	2880 (1.5)	2720 (1.4)	-	320 (0.2)	12480 (5.4)	160 (0.1)	1440 (0.7)	19680 (10.1)	53600 (27.4)	-	-	-	-	55840 (28.9)	55840 (28.9)	3680 (1.9)	480 (0.2)	2720 (1.4)	30720 (15.7)	-	
16	14/12	667 (0.5)	1667 (1.3)	-	1000 (0.8)	1333 (1.1)	-	15667 (12.4)	667 (0.5)	667 (0.5)	2000 (1.6)	16667 (13.2)	40333 (32.0)	-	-	-	-	333 (0.3)	333 (0.3)	1666 (1.3)	667 (0.5)	2667 (2.1)	17333 (13.8)	-	
17	15/12	111 (0.003)	444 (1.0)	-	444 (1.0)	333 (0.8)	-	3778 (8.5)	1111 (2.5)	222 (0.5)	1000 (2.3)	6889 (15.6)	17890 (40.5)	111 (0.003)	-	-	-	5000 (11.0)	5000 (11.0)	222 (0.5)	-	111 (0.003)	6556 (14.9)	-	
18	15/12	1412 (0.8)	706 (0.4)	-	2824 (1.6)	2824 (1.6)	-	13176 (7.5)	3765 (2.1)	1176 (0.7)	1412 (0.8)	20000 (11.4)	85647 (48.7)	-	-	-	-	17176 (9.8)	17176 (9.8)	1412 (0.8)	235 (0.1)	24000 (13.6)	-		

(contd.)

Table 1—Absolute abundance (no. of specimens in 1000 m³ of water) and species percentages (within parentheses) of planktonic Foraminifera at different sites in plankton tows—Contd.

Station No.	Date (1988)	<i>G. bulloides</i>	<i>G. calida</i>	<i>G. falconensis</i>	<i>G. quinqueloba</i>	<i>G. rubescens</i>	<i>G. adamsi</i>	<i>G. aequilata</i>	<i>H. pelagica</i>	<i>G. tenellus</i>	<i>G. conglobatus</i>	<i>G. ruber</i>	<i>G. succulifer</i>	<i>G. univertsa</i>	<i>P. obliquiloculata</i>	<i>G. inflexa</i>	<i>G. flexuosa</i>	<i>G. menardii</i>	<i>G. scintilla</i>	<i>G. univida</i>	<i>G. unguilata</i>	<i>G. conglomera</i>	<i>G. hexagona</i>	<i>N. duerrei</i>	<i>C. glutinosa</i>	<i>T. humilis</i>
19	15/12	-	800 (0.4)	-	2000 (1.0)	2400 (1.2)	17600 (8.9)	2800 (1.4)	1200 (0.6)	800 (0.4)	19600 (98.7)	98000 (49.7)	800 (0.4)	-	800 (0.4)	-	-	-	-	18400 (9.3)	2000 (1.0)	800 (0.4)	400 (0.2)	29600 (15.0)	-	-
20	16/12	1714 (1.1)	2667 (1.6)	1333 (0.8)	3619 (2.2)	23619 (14.5)	5524 (3.4)	1905 (1.2)	952 (0.6)	952 (0.6)	14286 (8.8)	59810 (36.7)	952 (0.6)	-	-	24762 (15.2)	380 (0.2)	-	-	3429 (2.1)	17524 (10.8)	-	-	-	-	-
21	16/12	1800 (0.6)	5000 (1.6)	4200 (1.4)	24800 (8.1)	3200 (1.0)	24800 (8.1)	3200 (1.0)	3000 (1.0)	2800 (0.9)	19200 (10.4)	140400 (45.9)	2200 (0.7)	200 (0.001)	-	55000 (8.0)	800 (0.3)	600 (0.2)	-	5800 (2.2)	31400 (10.3)	-	-	-	-	-
22	17/12	258 (0.3)	-	1031 (1.3)	1289 (1.7)	5928 (7.7)	1289 (7.7)	258 (0.3)	773 (0.5)	773 (0.5)	10309 (39.1)	29897 (39.1)	-	258 (0.3)	-	11855 (15.5)	773 (1.0)	-	-	773 (1.0)	11855 (15.5)	-	-	-	-	-
23	17/12	3355 (1.6)	3484 (1.6)	387 (0.2)	1935 (1.0)	5161 (2.6)	24258 (12.1)	1935 (1.0)	1935 (1.0)	1161 (0.6)	14968 (7.4)	72906 (36.2)	-	645 (0.3)	645 (0.3)	129 (0.1)	387 (0.2)	129 (0.1)	387 (0.2)	25935 (12.9)	1290 (0.6)	258 (0.1)	4645 (2.3)	36387 (18.1)	129 (0.1)	

Vertical tows (0 - 200m)																												
2	9/12	160 (1.2)	356 (2.7)	89 (0.7)	267 (2.0)	53 (0.4)	1493 (11.2)	782 (5.9)	160 (1.2)	569 (4.3)	1761 (13.2)	5013 (37.5)	249 (1.9)	-	-	53 (0.4)	-	-	-	53 (0.4)	-	18 (0.1)	195 (1.5)	284 (2.1)	1921 (13.7)	-	-	
4	9/12	56 (0.5)	243 (2.2)	93 (0.8)	262 (2.4)	37 (0.3)	2000 (17.9)	822 (7.4)	206 (1.8)	636 (5.7)	1570 (14.0)	2729 (24.5)	299 (2.7)	-	-	19 (0.2)	-	-	-	19 (0.2)	-	75 (0.7)	75 (0.7)	318 (2.9)	1644 (14.8)	-	-	
6	10/12	40 (0.9)	40 (0.9)	40 (0.9)	67 (1.4)	215 (4.8)	498 (11.0)	418 (0.9)	418 (0.9)	135 (3.0)	660 (14.6)	1441 (31.9)	67 (1.5)	13 (0.3)	13 (0.3)	-	-	-	-	13 (0.3)	-	54 (1.2)	121 (2.7)	620 (13.7)	13 (0.3)	-	-	
8	11/12	712 (1.5)	193 (0.4)	18 (0.04)	548 (1.1)	438 (0.9)	5809 (12.0)	1644 (3.4)	438 (0.9)	785 (1.6)	4913 (10.2)	17151 (35.7)	201 (0.4)	37 (0.1)	37 (0.1)	1388 (11.6)	511 (0.2)	73 (0.2)	-	1388 (11.6)	511 (0.2)	39 (0.2)	193 (0.8)	636 (2.6)	5686 (22.9)	-	-	
10	12/12	174 (0.7)	328 (1.3)	58 (0.2)	405 (1.6)	289 (1.2)	2621 (10.5)	1195 (4.8)	308 (1.2)	540 (2.2)	3373 (13.6)	5243 (21.2)	443 (1.8)	-	-	2872 (5.6)	366 (1.7)	50 (0.5)	-	50 (0.5)	300 (1.7)	50 (0.5)	300 (1.7)	1450 (12.4)	-	-	-	
17	15/12	300 (2.6)	200 (1.7)	50 (0.4)	700 (6.0)	370 (3.1)	899 (5.0)	106 (0.6)	53 (0.3)	212 (1.2)	2274 (12.6)	11054 (61.3)	212 (1.2)	53 (0.3)	53 (0.3)	476 (2.6)	-	-	-	476 (2.6)	-	-	-	582 (3.2)	1480 (9.2)	-	-	
19	15/12	53 (0.3)	158 (0.9)	53 (0.3)	370 (2.1)	324 (2.0)	1382 (8.7)	1088 (6.9)	235 (1.5)	382 (2.4)	1029 (6.5)	5868 (3.2)	515 (3.2)	-	-	1912 (12.0)	103 (0.6)	-	-	1912 (12.0)	103 (0.6)	-	-	324 (2.0)	1926 (12.0)	-	-	
20	16/12	132 (0.8)	441 (2.8)	221 (1.4)	324 (2.0)	123 (0.8)	61 (0.9)	599 (5.8)	92 (1.4)	123 (1.7)	814 (15.5)	2242 (33.6)	15 (0.2)	-	-	461 (6.9)	31 (0.5)	31 (0.5)	-	461 (6.9)	31 (0.5)	-	-	322 (4.8)	998 (15.0)	-	-	
22	17/12	77 (1.2)	261 (3.9)	15 (0.2)	15 (0.2)	292 (1.4)	39 (0.2)	1285 (6.0)	272 (1.2)	350 (1.7)	3270 (33.6)	7085 (2.5)	525 (0.1)	-	-	2725 (12.9)	156 (0.7)	-	-	2725 (12.9)	156 (0.7)	-	-	117 (0.6)	740 (3.5)	3250 (15.4)	-	-
12	17/12	370 (1.8)	253 (1.2)	19 (0.1)	58 (0.3)	255 (1.0)	93 (0.4)	1308 (5.3)	208 (0.5)	313 (1.3)	3114 (13.1)	10465 (43.9)	-	-	-	3230 (13.5)	394 (1.7)	-	-	3230 (13.5)	394 (1.7)	-	-	324 (4.8)	3137 (15.4)	-	-	
13	20/12	174 (0.7)	463 (1.9)	12 (0.1)	69 (0.3)	1422 (1.8)	444 (5.7)	578 (0.7)	2133 (2.7)	1022 (1.3)	9200 (32.3)	25157 (82.3)	44 (0.1)	12 (0.1)	12 (0.1)	127 (0.5)	-	-	-	127 (0.5)	-	-	-	324 (4.8)	3137 (15.4)	-	-	
14	20/12	267 (0.3)	1956 (2.5)	178 (0.2)	756 (1.0)	267 (1.0)	235 (0.9)	1422 (5.7)	578 (0.7)	492 (1.8)	4406 (16.1)	17396 (43.0)	21 (0.1)	11 (0.04)	11 (0.04)	2684 (9.7)	160 (0.6)	21 (0.1)	-	2684 (9.7)	160 (0.6)	-	-	391 (1.2)	2717 (9.9)	-	-	
15	20/12	471 (1.7)	888 (3.2)	32 (0.1)	439 (1.6)	267 (1.0)	235 (0.9)	1422 (5.7)	578 (0.7)	492 (1.8)	4406 (16.1)	17396 (43.0)	21 (0.1)	11 (0.04)	11 (0.04)	2684 (9.7)	160 (0.6)	21 (0.1)	-	2684 (9.7)	160 (0.6)	-	-	391 (1.2)	2717 (9.9)	-	-	

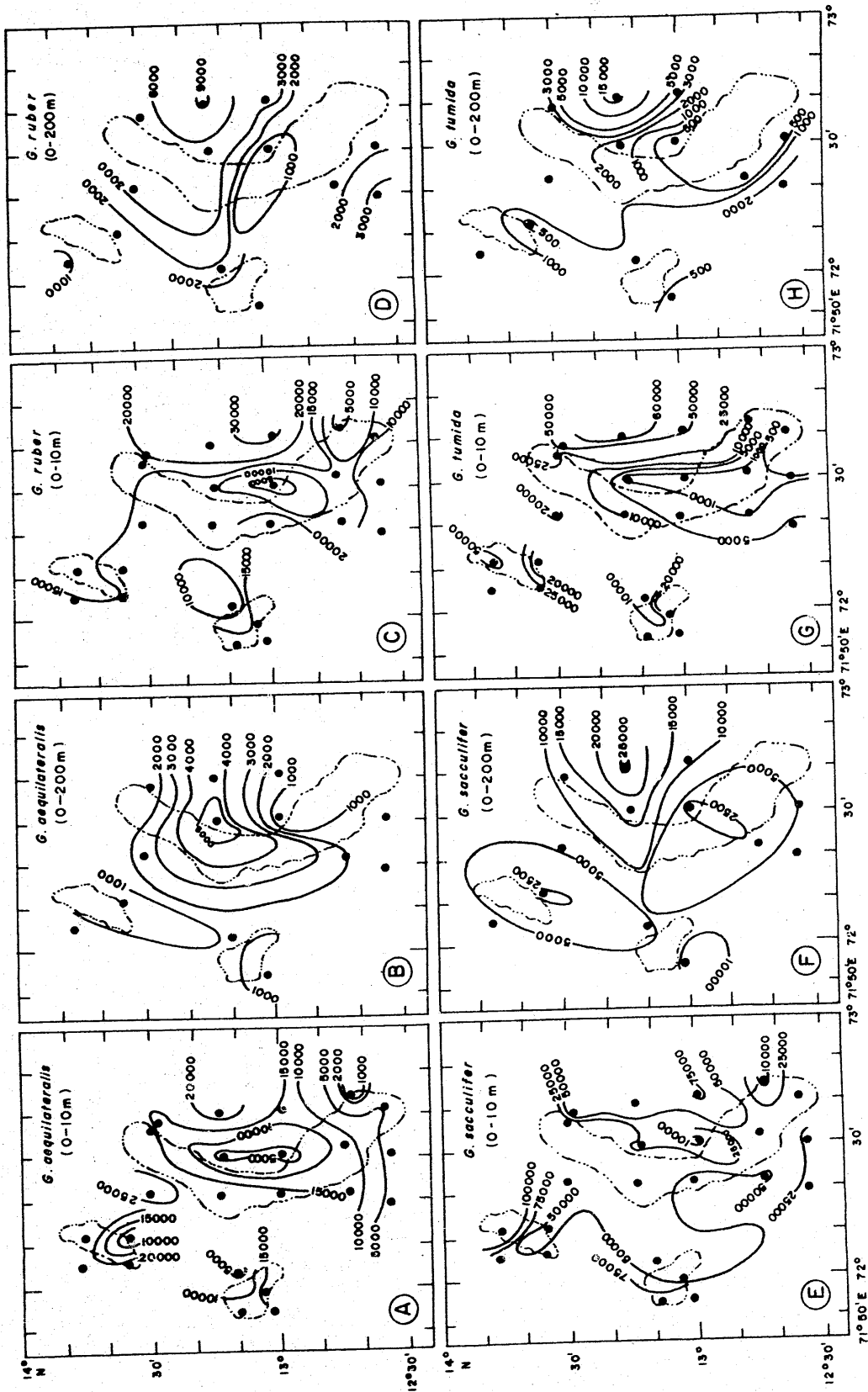


Fig. 5—Absolute abundance (number of specimens in 1000 m³) of foraminiferal species [*G. aequilateralis* in 0-10 m (A) and 0-200 m (B) tows, *G. ruber* in 0-10 m (C) and 0-200 m (D) tows, *G. sacculifer* in 0-10 m (E) and 0-200 m (F) tows and *G. tumida* in 0-10 m (G) and 0-200 m (H) tows]

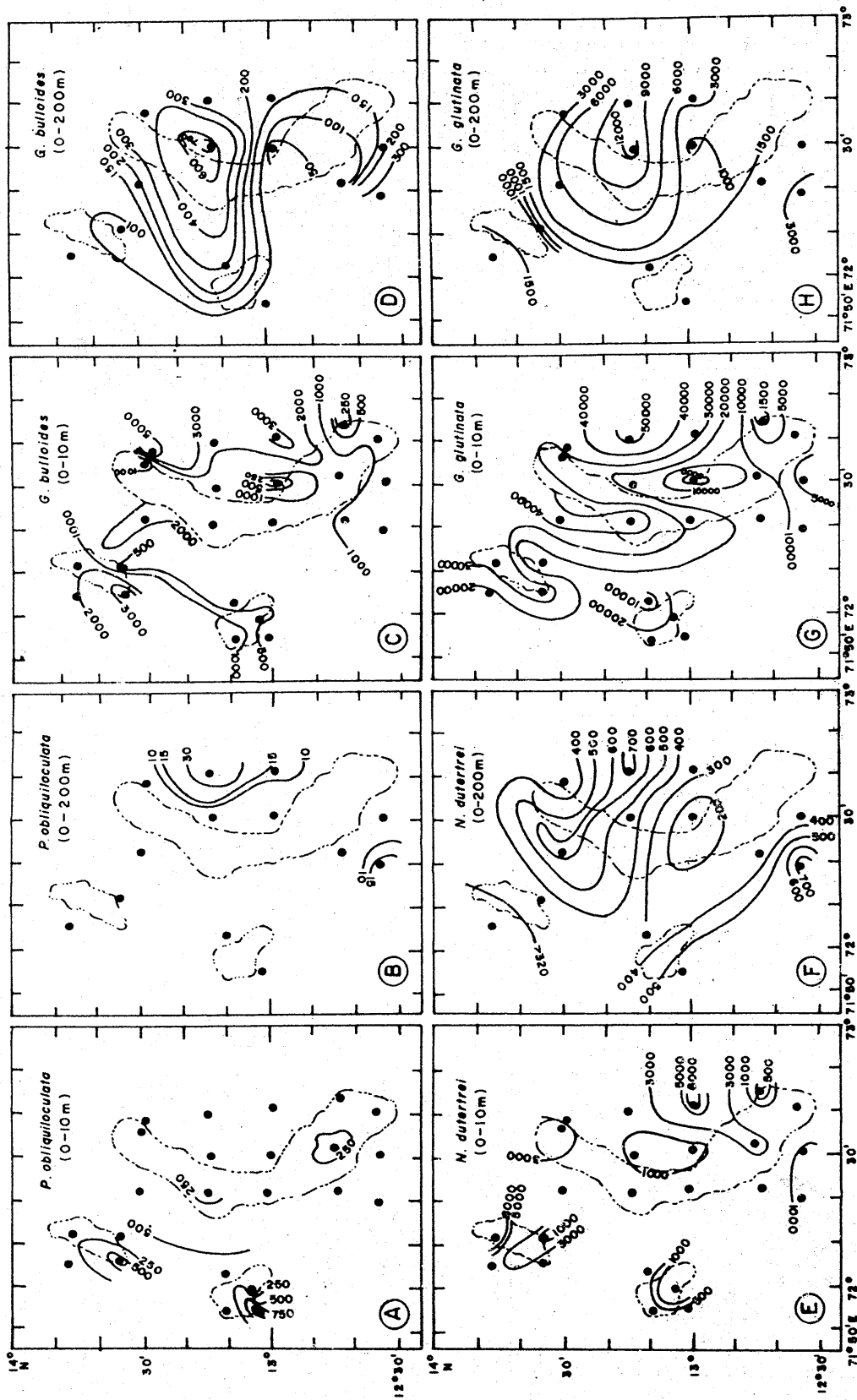


Fig. 6—Absolute abundance (number of specimens in 1000 m³) of foraminiferal species [*P. obliquiloculata* in 0-10 m (A) and 0-200 m (B) tows, *G. bullioides* in 0-10 m (C) and 0-200 m (D) tows, *N. duterrei* in 0-10 m (E) and 0-200 m (F) tows and *G. glutinata* in 0-10 m (G) and 0-200 m (H) tows]

As seen from Table 1 and Figs. 5 and 6, foraminiferal species—*G. sacculifer*, *G. glutinata*, *G. tumida*, *G. ruber* and *G. aequilateralis* are abundant and *G. anfracta*, *G. flexuosa*, *G. scitula* and *T. humilis* are rare.

Comparison with other areas—Comparative study of seasonal successions of planktonic Foraminifera off Bermuda^{1,5}, with that of present study during winter months reveals wide differences between these 2 faunal zones—the fauna in northern Sargasso Sea or mid-latitudes of western north Atlantic is characterized by winter species such as *Globorotalia truncatulinoides*, *G. hirsuta*, *G. inflata*, *P. obliquiloculata* and *G. bulloides* which occur in higher frequencies between January and March. But in the tropical region of this study, the fauna consists of dominant tropical indigenous species showing average percentages in decreasing order of relative abundance in the water column are *G. sacculifer* (37.3%), *G. tumida* (9.4%), *G. rubescens* (1.8%) and *N. dutertrei* (1.6%) and the tropical co-occurring species being *G. glutinata* (15.5%), *G. ruber* (12.7%), *G. aequilateralis* (9.5%), *H. pelagica* (2.9%), *G. conglobatus* (2%) and *G. bulloides* (1%). Further, during winter, unlike the fauna from 30°N in north Atlantic⁷, which is dominated by non-spinose species of *Globorotalia*, in the present study, these species are of *Globigerinita* besides *Globorotalia*. In both these studies, species common in current systems near the continental margins like *G. aequilateralis*, *H. pelagica* and *N. dutertrei* occur in higher concentrations. As in the southeastern Arabian Sea, *G. sacculifer* is the most abundant species in southern Sargasso Sea⁷ during winter. Other species common in these two areas are: *G. rubescens*, *H. pelagica*, *G. conglobatus*, *G. menardii* and *G. tumida*. *T. humilis* observed only in northern Sargasso Sea is rare in this tropical region. On the whole, the fauna of this part of Arabian Sea is similar to that of southern Sargasso Sea³⁹ south of 30°N or south of “oceanic front” in north Atlantic⁷ during winter.

In accordance with the suggestions^{5,40} which have been amply substantiated by later studies^{3,41-43} in waters off Bermuda in the Sargasso Sea, surface temperature as low as 19.4°C is observed during winter and high value of 27.6°C in summer. This temperature range is considerably larger when compared with that of southeastern Arabian Sea waters where minimum temperature, 28°C in winter (December) and maximum of 30.6°C in summer (April) are noted. In general, lower surface temperatures prevail in this study area and Sargasso Sea during winter.

It is shown further in the Sargasso Sea off Bermuda^{1,2,5} that *G. ruber* occurs in surface waters throughout the year, but in the case of *G. truncatu-*

linoides, it is abundant in surface waters only during winter and in summer, it descends to greater depths. In this context, it is necessary to mention that faunal study in regard to depth habitats of species in different seasons is still in its infancy so far as Indian Ocean is concerned.

The present study has a closer affinity with that of Red Sea⁴⁴ in the sense it is observed that spinose species constitute a larger component of the fauna in both southwest and northeast monsoon seasons. In summer, the non-spinose species like *G. menardii* and *N. dutertrei* are known to be abundant in upwelling areas of western Arabian Sea, but sparse in the Gulf of Aden and southern Red Sea. However, these species show higher concentrations in surface waters of Red Sea only during inflow of nutrient-rich waters of the Arabian Sea along the Red Sea in northward direction in winter with a nutrient gradient boundary at 18°-20°N. North of 20°N Red Sea is therefore depleted in phytoplankton. It is indicated earlier^{44,45} that *G. ruber* depends more on phytoplankton for food than *G. sacculifer*. As a result, the former is abundant in the southern Red Sea and the latter in the northern Red Sea. The northward current of the western Arabian Sea waters along the Red Sea as observed^{44,46} at certain times caused by prevailing hydrographic conditions in the area even during southwest monsoon season is rather unusual. Under this situation, distribution patterns of *G. sacculifer* and *G. ruber* are same as observed during winter in Red Sea. *G. aequilateralis* increases northwards and *G. glutinata* shows no definite distribution pattern. The non-spinose species—*G. menardii*, *P. obliquiloculata*, *N. dutertrei* and *G. glutinata* occur in higher concentrations in the Red Sea during winter inflow. Thus, the fauna of Red Sea in comparison with that of Arabian Sea indicates that it is not only influenced by monsoons, but also by the changes in hydrography at any time in any season.

Faunal studies of Zhang¹⁴ and Zobel¹¹ made earlier during early and late winter respectively in eastern Arabian Sea are described here to bring out some of their differences as compared with that of present study. Zhang¹⁴ recorded two distinct foraminiferal assemblages from the east central Arabian Sea in November, they being winter tropical assemblage and winter tropical upwelling assemblage. The former includes species such as *G. ruber*, *G. sacculifer* and *G. aequilateralis* in the order of abundance and the latter comprises *G. bulloides* and *N. dutertrei*. He also reported very low concentrations of *G. glutinata*, while *G. tumida* is absent. In plankton tows of eastern Arabian Sea, Rao *et al.*¹⁶ also noted low density of *G. glutinata* (7.4%) and abs-

ence of *G. tumida* during early winter. In some ways, the fauna of these studies^{14,16} is similar to the one recorded by Zobel¹¹ in the eastern Arabian Sea off India between 8° and 23°N where although *G. glutinata* is encountered, *G. tumida* is not there; *G. sacculifer* and *G. aequilateralis* show dominance by late winter. The difference in winter tropical assemblage as given above and that of the present study is that in addition to aforementioned species of this ensemble, other forms like *G. tumida* and *G. glutinata* not only occur in higher frequencies but also have shown dominance. This can be ascribed to prevalence of complete winter conditions in southeastern Arabian Sea in December¹⁸. It is of some interest to mention here that in contrast with the present study based on faunal data from plankton tows, Cullen and Prell³³ have shown that *G. glutinata* occurs in higher concentrations than *G. sacculifer* in Arabian Sea sediments. In the absence of sufficient faunal data on seasonal occurrences and depth habitats of the planktonic species for the Arabian Sea, it is not possible at the moment to ferret out the cause of this difference between these two species in waters and sediments.

Furthermore, the fauna of southeastern Arabian Sea is in consonance with that of equatorial waters of the oceans by the presence of species such as *G. aequilateralis*, *G. ruber*, *G. sacculifer*, *G. tumida* and *G. glutinata* in fair abundance. Other species in the fauna which are characteristic of equatorial waters are *G. adamsi*, *P. obliquiloculata*, species of *Globorotalia*, *Globoquadrina conglomerata*, *G. hexagona*, *N. dutertrei* and *T. humilis*. The cold-temperate water species, *G. bulloides*, which occurs in less abundance in southeast Arabian Sea, is known to be ubiquitous in equatorial waters of the world oceans^{30,39,47,48}. Like waters of the submerged coral banks in the Arabian Sea which are productive based on the abundances of the fauna, other oceanic areas such as equatorial regions of the world are also known to be fertile as manifested by very high concentrations of planktonic Foraminifera^{8,30,48-51}.

In conclusion, this study gives 3 indications—first is in regard to the types of foraminiferal species which show dominance in the reef areas of the tropics during peak winter season. Among spinose species, which form bulk of the fauna, *G. sacculifer* is the most abundant species in the winter faunal assemblage as in southern Sargasso Sea, Red Sea and Arabian Sea and others in relatively less abundance being *G. ruber* and *G. aequilateralis*. The non-spinose species belonging to genera, *Globorotalia* and *Globigerinita* show an increase corresponding to winter peak. The second clue pertains to highly productive nature of the reef areas which is

due to local upwelling caused by dynamic hydrographic conditions prevailing in the region as evidenced by the indicator species such as *G. bulloides* and *N. dutertrei*. This in turn suggests how all oceanic areas within tropical regions are not barren as has been commonly believed. Finally, it has to be stated that in the assessment of the investigations of ecology and distribution of living planktonic Foraminifera, insofar as seasonal study is concerned, it is not only periods and intervals but also intervals indicating peaks of seasons of their observations, should separately be given due consideration.

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