

Foraminiferal Assemblages & Organic Carbon Relationship in Benthic Marine Ecosystem of Western Indian Continental Shelf

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Foraminiferal assemblages in the sediment and their relation to organic carbon have been studied in selected nearshore areas on the west coast, namely, Gulf of Kutch, Bombay-Daman sector, Vengurla-Dabhol sector, Cola Bay and Karwar. Study reveals that *Ammobaculites agglutinans* (d'Orbigny) and *Ammonia* spp have positive (direct) tendency towards organic carbon while miliolids (*Quinqueloculina* spp, *Spiroloculina* spp and *Triloculina* spp *Florilus-Nonion* and *Nonionella* spp have negative (inverse) tendency. The coefficient values become significant (at 0.1 level) only for *Ammobaculites* spp at Karwar, miliolids at Bombay-Daman, and for *Florilus-Nonion* at Karwar and Bombay-Daman areas. Total foraminifera and organic carbon are inversely correlated in the Cola Bay but in Gulf of Kutch, correlation is inconsistent due to very low values (0.138 to 0.529 %) of organic carbon. This relationship is further governed by a combination of other environmental factors.

Foraminifera are most ubiquitous and widely distributed in all marine ecosystems, yet, at times they become sporadic. Foraminiferal populations and organic matter content equally differ in various types of substrates. Therefore, their interrelationship in benthic marine ecosystem is of great significance.

Bordovskiy¹ and Setty² noted that a high biomass of bottom dwelling organisms (including foraminifera) usually have a low organic content, hence considered that the benthic biomass is inversely proportional to the organic content in the sediment. It is found that the foraminiferal populations were low when organic matter in the sediment is high³⁻⁶.

In order to evaluate further this relationship between organic matter and the foraminiferal assemblages of different substrates (and possibly environments) along the western Indian continental shelf, 5 regions (Gulf of Kutch; shallow neritic areas of Bombay-Daman and Dabhol-Vengurla; and inshore areas of Cola Bay, Goa and Karwar) are selected.

Materials and Methods

Snapper and Peterson grab samples collected during cruises 2 (1974), 17 (1976) and 28 (1978) of *R V Gaveshani* and of *M V Tarini* in Cola Bay, Goa and Karwar areas (1975, 1979), were studied.

Station locations along with depth, nature of substrate are given in Table 1.

Sampled material from each station is separated into 2 fractions (a) topmost 1 cm sediment and the overlying water, and (b) lower 2 cm sediment sample. Fraction (a) is treated with 20 ml rose bengal (1 g/l dist. water) and 20 ml of 5 % formaline to distinguish between the living and the dead foraminiferal specimens⁷.

Organic carbon content of fraction (a) of each sample was estimated by the El Wakeel and Riley's⁸

method. The value thus obtained is multiplied by a factor of 1.724 which represents the amount of organic matter present in the sample. The method has a coefficient of variation of about 7% with samples containing 1 % organic carbon. Values of both organic carbon and organic matter (percent dry weight) are shown in Table 1.

In order to study the magnitude of relationship, correlation coefficients between organic carbon/matter and foraminiferal species were computed using TDC-316 computer. This is in addition to a apparent visible relationship observed from the data. By assuming the Null hypothesis (H₀) that no relationship exists between the 2 sets of observations, the tabulated values of correlation by Fisher and Yates⁹ were used by testing this hypothesis at $P < 0.1$ level. For calculation of species diversity Shannon Wiener information function was used.

Results

Lithology and organic carbon content—Gulf of Kutch is a shallow regime with a restricted marine environment. A set of 5 samples, from 14-42 m depth, are from the outer part of the Gulf (seawards) whereas 10 with a depth range of 14-39 m depth are from the inner region, where there is only a thin veneer of sediment. At the mouth of the Gulf, the substrate is chiefly composed of silty clay to clayey silt with some sand and includes diatoms, (dead) miliolid and agglutinated foraminifera, ostracods, bivalves and a high degree of carbonaceous (organic) matter. The inner part of the Gulf consists of a very fine grained greenish gray clayey silt to silty sand. It includes 0.46 % of organic carbon with young foraminifera, bivalves and gastropods.

Table 1—Station Coordinates, Depth, Nature of Substrate, Organic Carbon/Matter Content of Sediment from Different Locations

St. No.	Coordinates		Depth m	Substrate	Organic carbon (%) dry wt	Organic matter (%) dry wt
	Lat.	Long.				
Gulf of Kutch sector						
36	22°50'12"	69°08'12"	15	Silty clay	0.230	0.40
37	22°55'24"	68°57'54"	14	"	0.391	0.67
38	22°51'00"	68°58'36"	15	Clayey silt	0.460	0.79
39	22°45'18"	68°58'18"	26	Silty clay	0.368	0.63
40	22°39'42"	68°58'06"	42	Sand silt clay	0.345	0.59
49	22°31'06"	69°40'00"	36	"	0.299	0.51
50	22°34'21"	69°39'57"	38	Silty clay	0.414	0.71
51	22°38'48"	69°40'12"	41	Sand silt clay	0.276	0.47
53	22°45'12"	69°52'12"	30	Silty sand	0.138	0.24
54	22°41'42"	69°52'12"	39	Sandy clay	0.161	0.28
55	22°36'42"	69°52'06"	32	Clayey silt	0.529	0.91
56	22°39'24"	70°08'06"	22	Sand silt clay	0.299	0.51
57	22°44'24"	70°03'06"	21	"	0.368	0.63
58	22°49'30"	70°03'00"	21	"	0.322	0.55
59	22°47'00"	70°08'12"	14	Clayey silt	0.460	0.79
Bombay - Daman sector						
5	20°08'09"	72°32'49"	31	Clay	0.828	1.43
6	20°03'54"	72°30'01"	34.5	"	0.736	1.27
8	19°38'17"	72°27'01"	25	"	1.150	1.98
9	19°34'36"	72°22'04"	26.5	"	1.012	1.74
10	19°30'57"	72°16'57"	28	"	1.104	1.90
11	19°26'11"	72°10'50"	31	"	0.920	1.58
13	20°29'50"	72°29'56"	31	"	0.920	1.58
15	20°24'03"	72°27'37"	40	"	0.644	1.11
16	20°22'33"	72°26'57"	40.5	"	0.874	1.50
17	20°21'20"	72°26'25"	41.5	"	0.828	1.43
18	20°19'04"	72°25'29"	41	"	1.012	1.74
19	20°14'08"	72°23'31"	43	"	0.920	1.58
20	20°01'52"	72°18'30"	33.5	"	1.196	2.06
21	19°55'16"	72°15'51"	31	Clay	1.920	1.58
22	19°45'53"	72°12'32"	32	Clay	1.012	1.74
23	19°30'30"	72°05'48"	31	Clay	1.058	1.82
24	20°26'59"	72°27'31"	34	Sand	0.138	0.24
25	20°26'05"	72°27'13"	30	"	0.092	0.16
26	20°22'35"	72°25'46"	29	"	0.046	0.08
27	20°22'22"	72°25'42"	29	"	0.092	0.16
28	20°20'16"	72°24'57"	38	"	0.414	0.71
Dabhol - Vengurla sector						
1	17°35'00"	73°06'00"	15	Clay	1.771	3.05
2	17°35'00"	73°00'00"	25	"	1.978	3.41
3	17°35'00"	72°54'00"	34	Clayey sand	2.162	3.73
5	17°23'05"	73°02'00"	32	Clay	1.973	3.41
6	17°24'00"	73°07'04"	20	"	1.950	3.37
7	17°13'00"	73°10'05"	24	"	1.840	3.17
8	17°12'00"	73°05'06"	37	"	2.599	4.48
9	17°12'00"	73°00'00"	47	"	3.128	5.39
10	17°02'00"	73°01'05"	50	"	2.990	5.15
11	17°02'00"	73°07'00"	36	"	2.760	4.76
13	17°50'00"	73°14'00"	24	"	2.300	3.96
14	16°49'05"	73°09'05"	36	"	2.806	4.84
15	16°50'00"	73°04'00"	51	Sandy clay	1.932	3.33
16	16°38'00"	73°05'00"	48	Silty clay	2.852	4.92
17	16°38'00"	73°10'06"	37	Clay	2.944	5.07

Contd.

SETTY & NIGAM: FORAMINIFERAL ASSEMBLAGES & ORGANIC CARBON RELATIONSHIP

 Table 1—Station Coordinates, Depth, Nature of Substrate, Organic Carbon/Matter Content of Sediment from Different Locations —*Contd*

St. No.	Coordinates		Depth m	Substrate	Organic carbon (%) dry wt.	Organic matter (%) dry wt.
	Lat.	Lon.				
Dabhol-Vengurla Sector						
18	16°38'00"	73°16'06"	25	Clay	2.024	3.49
19	16°27'00"	73°18'00"	24	"	2.852	4.92
20	16°27'00"	73°12'05"	36	"	3.312	5.71
21	16°27'00"	73°07'00"	49	"	3.358	5.79
22	16°27'00"	73°10'00"	45	Silty clay	3.220	5.55
23	16°14'00"	73°17'06"	35	Clay	3.542	6.11
24	16°13'05"	73°12'07"	25	"	3.312	5.71
25	16°14'00"	73°23'02"	26	"	3.036	5.23
26	16°04'00"	73°19'00"	34	"	3.450	5.95
27	15°50'00"	73°23'00"	40	Clayey silt	3.588	6.18
28	15°50'00"	73°28'00"	30	Clay	3.174	5.47
29	15°50'00"	73°33'00"	20	Silty clay	2.806	4.84
Cola Bay, Goa sector						
1	15°54'07"	73°52'48"	3	Sand	0.092	0.16
2	15°53'52"	73°53'09"	3	"	0.161	0.28
3	15°52'18"	73°51'54"	7	Clay	3.588	6.18
4	15°50'30"	73°50'48"	9.5	Silty clay	2.484	4.28
5	15°51'04"	73°50'00"	9	Sand	3.128	5.39
6	15°52'54"	73°51'06"	6	Clay	3.979	6.86
7	15°53'51"	73°52'05"	3	Sand	0.207	0.36
8	15°53'42"	73°52'30"	4	"	0.172	0.30
9	15°53'24"	73°53'06"	5	"	0.805	1.39
10	15°51'48"	73°52'43"	8	Clay	3.128	5.39
11	15°51'04"	73°51'58"	10.5	"	1.196	2.06
Karwar sector						
1	14°46'49"	74°06'52"	8.3	Sand	0.506	0.872
3	14°46'39"	74°06'49"	9.6	Clay	3.450	5.948
4	14°46'34"	74°06'28"	10.2	"	3.496	6.027
5	14°46'29"	74°06'20"	10.6	"	3.636	6.265
7	14°46'21"	74°06'01"	11.7	"	2.484	4.282
9	14°46'11"	74°05'39"	12.8	"	3.128	5.392
11	14°46'04"	74°05'18"	13.8	"	2.898	4.996
13	14°46'01"	74°05'01"	14.5	"	2.576	4.441
15	14°46'15"	74°05'34"	12.6	"	2.438	4.203
17	14°46'31"	74°06'02"	11.4	Sandy clay	2.208	3.806
18	14°46'35"	74°06'10"	11.0	Clay	3.266	5.631
19	14°46'56"	74°06'35"	8.4	Sandy clay	3.312	5.709
21	14°46'24"	74°06'50"	9.6	Clay	3.312	5.709
22	14°46'21"	74°06'36"	10.6	"	3.542	6.106
23	14°46'17"	74°06'16"	11.4	"	3.082	5.313

Of the 21 samples analysed from the Bombay-Daman sector, 16 samples (sts 5-23) are of calcareous clays and 5 (sts 24-38) mostly sands¹⁰. The clayey sector is poor in foraminifera and ostracods, whereas the sandy sector includes somewhat large sized foraminifers and a few ostracods.

The lithology of the 25 samples analysed from Dabhol-Vengurla sector is mostly clayey with patches of sand and silty clay offshore with high organic content¹¹. Foraminifers in the same substrate often appear to be high to very high at some stations.

The substrate of Cola Bay, Goa from where 11 samples were collected, is an apron of sand along the shore, followed by clay predominantly and with a patch of silt at a depth of 9.5 m. Foraminifera are common in littoral and offshore areas but large sized ones are found nearer shore. The carbonaceous matter is higher in the clays, less in silt and least in sands.

The Karwar sector, from where 12 samples are collected, consists chiefly of greenish gray clays with a few patches of sandy clay. Very high organic carbon (3.636% and average 2.882%) with small and

embryonic foraminifera is noted.

In this study various species of miliolids are treated as one unit, though individually different species do not represent the same ecology or distribution. This is necessitated as the populations of each was not large enough to make an impact on their own in the given environment.

Foraminiferal assemblages relative to substrate and organic carbon content—Gulf of Kutch: Organic carbon content of sediments is very low compared to other areas (Table 1). Low values are attributed to low sedimentation rate, low input of organic matter and rapid decay, arid conditions, sparse vegetation and lack of inflow through streams from the surrounding terrain¹². The organic matter is therefore authigenic in nature, chiefly contributed by algae, corals and molluscs. The fluctuations of organic carbon content is negatively correlated with depth (Fig.1). But the total foraminiferal number and species diversity remain constant but tend to modify consequent on the change in the sediment character^{5,13,14}. Thus the foraminiferal population and diversity are highest in very fine grained sediments, (where organic carbon content is higher, 0.391 to 0.529 %) while they decrease in coarser grained sediment. Living neonic, thin-shelled, miliolids (*Quinqueloculina seminulum*, *Triloculina trigonula*, *T. tricarinata*, *Spiroloculina eximia*) are dominant in the silts and clayey silts but they are porcellaneous in adult form in the sandy substrate having low organic matter. The agglutinated genera and species (*Ammobaculites*, *Sigmoilopsis*, *Milliammina fusca*, *Siphonoperta*, *Haplophragmoides* and *Textularia*) are dominant in medium grained zones where the organic carbon content varies from (0.23 to 0.391 %). *Ammonia beccarii* and its variants, *Elphidium* and *Pararotalia* are found throughout the Gulf in juvenile forms in finer substrate and large to very large-sized ones in the coarser substrate. Though essentially foraminiferal dominance is high where the substrate is clayey or silty clay, with high organic carbon content the pattern gets disturbed at certain stations, with sharp changes, hence delineation into clearcut zones becomes difficult.

Bombay-Daman Sector: Organic carbon content is low in sands but high in clays (Table 1). The dominating foraminiferids are: *Ammonia* (90% at st 28) followed by *Ammobaculites* sp. (82% at st 9), miliolids (40% at st 24), *Nonion-Florilus* (42.5% at st 27) and *Elphidium* sp. (28.5% at sts 13,15,16 and 20). Relationship between these species and organic carbon is shown (Fig.2). *Ammobaculites* and *Ammonia* have a direct relationship while miliolids (*Quinqueloculina*, *Spiroloculina* and *Triloculina*) show an inverse relationship. But, this relationship becomes significant at 0.1 level for *Florilus-Nonion* suite only (Fig.2D).

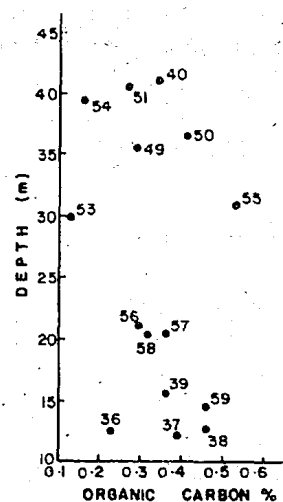


Fig. 1— Distribution of organic carbon in terms of depth from open sea conditions to shallow restricted marine environment in the Gulf of Kutch

Dabhol-Vengurla sector: The species diversity in relation to organic carbon are recorded in Fig.3E.

At st 18 (Table 1) the miliolids are abundant with *Quinqueloculina seminulum* dominating; but when the organic carbon value rises (st 8, Table 1) *Spiroloculina depressa* alone is present and with a further increase of organic carbon (st 17, Table 1), the foraminiferal number of miliolids decreases. But at st 24 *Triloculina tricarinata* becomes the lone species. This shows that the interspecific relationship that caused a sensitive increased/decreased incidence in miliolids is primarily due to organic carbon content variation in the sediment. But for *Ammonia beccarii*, *Nonion elongatum*, *Florilus boueanum*, *Nonionella auricula*, *N. turgida*, *N. auris* and *N. basispinata* this rise or fall of organic carbon content appears to be well within their range of tolerance, hence may be interpreted as suitable and conducive for their normal growth and development (Fig. 3A-D). *Florilus* sp. is reported to be dominant in regions where there is low runoff and high organic matter¹⁵.

Ammonia beccarii is present both in the living and the dead assemblages as the most dominant species along with *Trochammina inflata* and *T. pacifica* at st 13 with high organic carbon (Table 1). Thus it presupposes that organic matter is the chief influencing factor for the high population of this species. The microisolation (niche) of *T. inflata* and *T. pacifica* at st 1 and *A. beccarii* at st 12 caused a microenvironment due to low salinity (31.3 to 32.1‰), estuarine condition and high organic matter content in the sediment. Similarly, *Ammobaculites agglutinans* is the single species living at 34 m depth on clayey substrate (st 26) with an organic carbon content of 3.45% while the dead assemblage includes *Trochammina pacifica*, *Florilus boueanum* and *Nonion elongatum*.

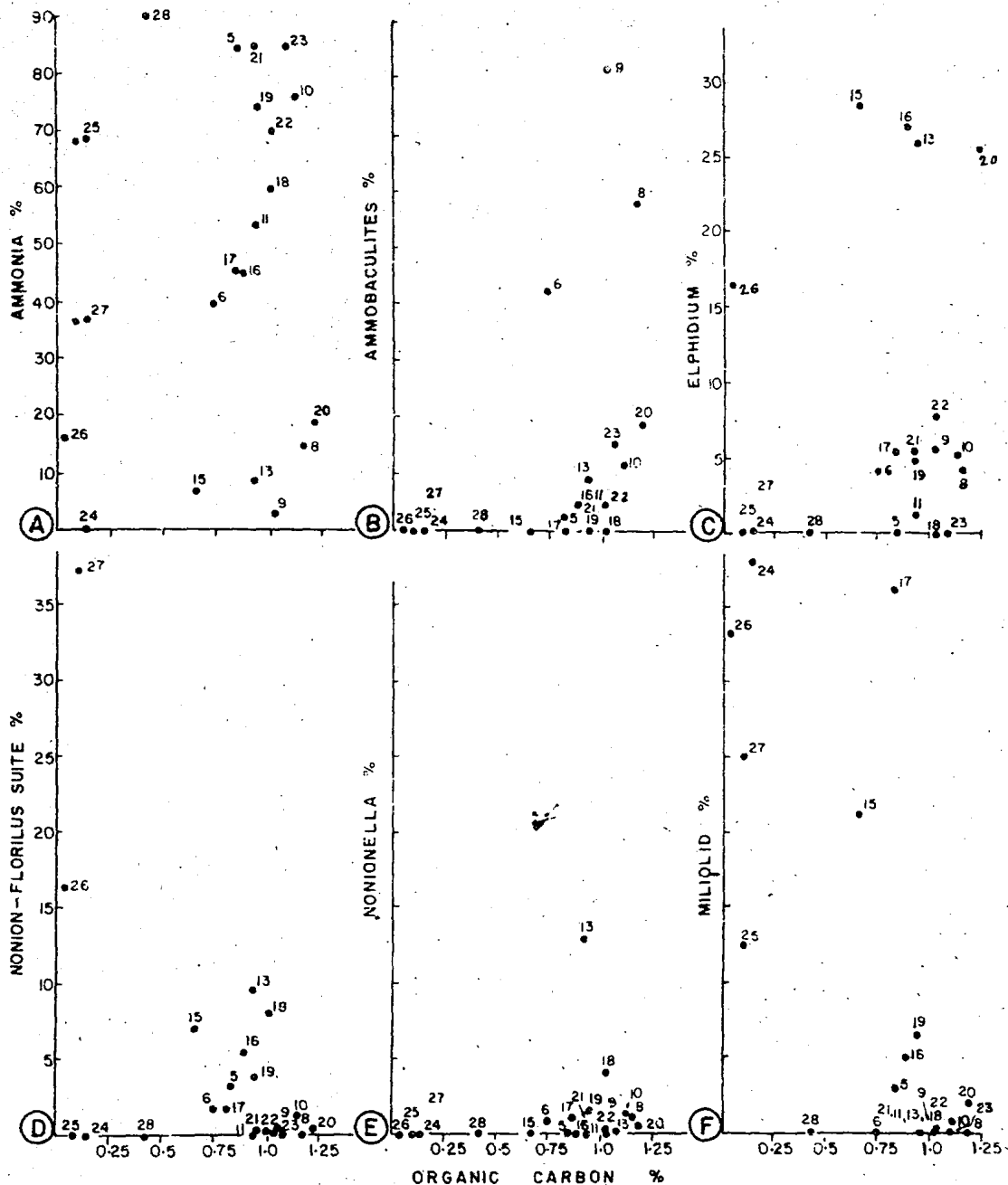


Fig. 2.—Foraminiferal assemblage (dead) and organic carbon relationship in Bombay-Daman area with reference to (A) *Ammonia* and (B) *Ammobaculites* showing positive tendency and (C) *Elphidium*, (E) *Nonionella* and (F) Miliolids showing negative tendency. This relationship becomes significant to (D) *Nonion-Florilus* suite

Trochammina, *Florilus* and *Nonion* which have depth, salinity and other environmental ranges suitable have no living representatives while *Ammobaculites agglutinans* continues to survive. This may be attributed to high organic carbon content (being a critical factor) favouring one (*A. agglutinans*) but lethal to others (Fig. 3A-D).

Cola Bay, Goa: Out of 68 species identified (25 from the topmost surface of the substrate whose living ones

are represented by 12 species only) 2 are planktic types (dead) but 10% of the total benthics are agglutinated forms. In the intertidal and very shallow nearshore environment *Ammonia-Florilus-Elphidium* suite is predominant where organic carbon content in the sediment is low (0.034%). *Ammonia beccarii* and its variants, *Florilus scaphus*, *F. boueanum*, *Elphidium crispum* and *Pararotalia* sp. are robust and large in size, but most of the ammonias are megalospheric. *Brizalina*

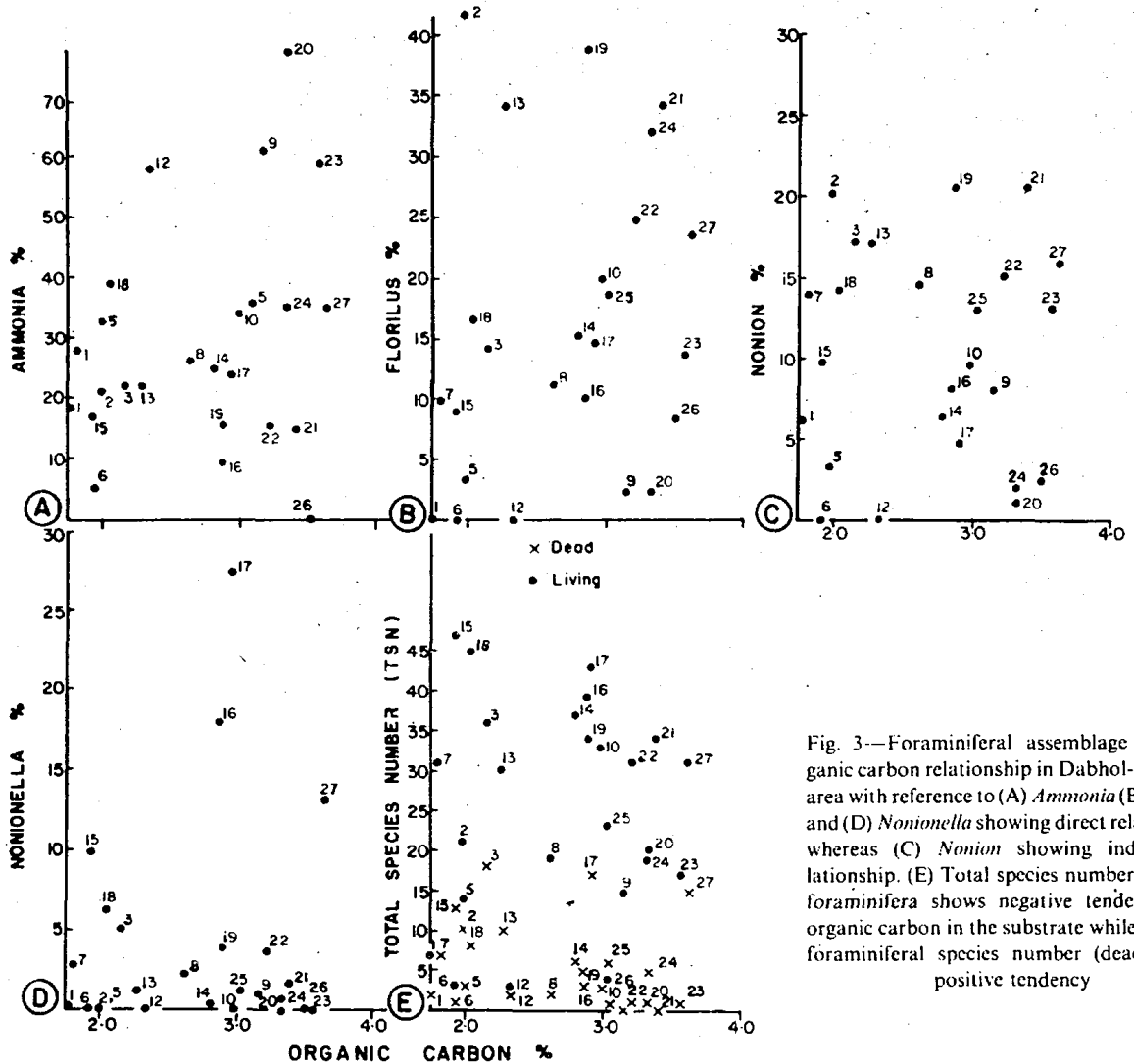


Fig. 3—Foraminiferal assemblage and organic carbon relationship in Dabhol-Vengurla area with reference to (A) *Ammonia* (B) *Florilus* and (D) *Nonionella* showing direct relationship whereas (C) *Nonion* showing indirect relationship. (E) Total species number of living foraminifera shows negative tendency with organic carbon in the substrate while the total foraminiferal species number (dead) shows positive tendency

striatula, *Gavelinopsis complanata* and *Gyroidinoides* sp. are rare at stations where organic carbon ratio is high (3.128 to 3.979%).

The total foraminiferal number (TFN) of the agglutinated forms decreases on silty-clay and clayey substrates.

The Shannon-Wiener diversity index (H)¹⁶ is within a range of 1.8-2.9 and indicates the inverse relationship with organic carbon (Fig.4B). But the relationship between foraminiferal abundance and organic carbon is also inversely proportional as the coefficient value is 0.574 (Fig.4A). Therefore this relationship becomes significant here (at $P < 0.1$). Setty² has noted that the organic carbon in a sediment is inversely proportional to the diversity and abundance of the foraminiferal populations.

Among miliolids, *Quinqueloculina seminulum* and *Q. venusta* predominate at a range of 0.092-2.484% organic carbon in the sediment while *Q. bicostata*

decreases in its population size if the organic carbon content increases beyond 0.207%. Interestingly, *Spiroloculina communis* increases when the carbon content ranges upward from 1.196%, *S. excavata* becoming common when organic carbon is 0.092% but decreases with increased organic carbon content (1.196%).

Karwar Region: *Ammonia annectens*, *A. dentata*, *A. tepida* are present in the entire area and apparently are not related to substrate or organic carbon content variation. *Florilus scaphum*, and *Nonion* sp. suit is dominant in clays with low organic carbon content. *Trochammmina inflata* and *Ammobaculites agglutinans* predominate in sandy clays with low organic carbon and inversely proportional (Fig.5E) with it.

This clearly indicates that few species tolerate high organic carbon content in the sediment while a majority of the species are inversely proportional to it.

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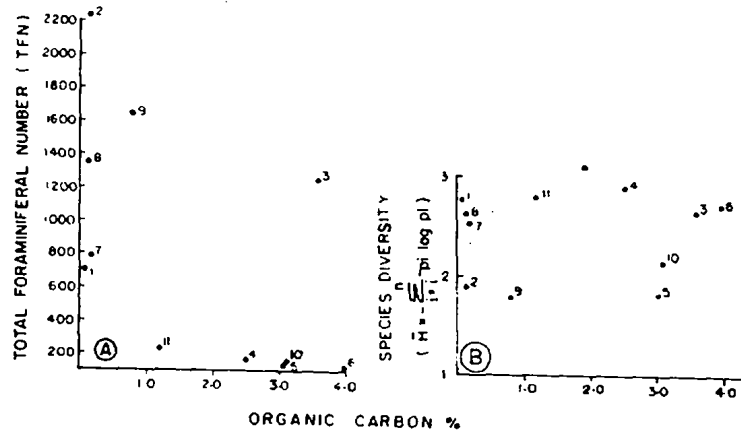


Fig. 4—(A) Total foraminiferal number (TFN) and (B) species diversity (H) and their relations to organic carbon in Cola Bay, Goa area where they show negative tendency

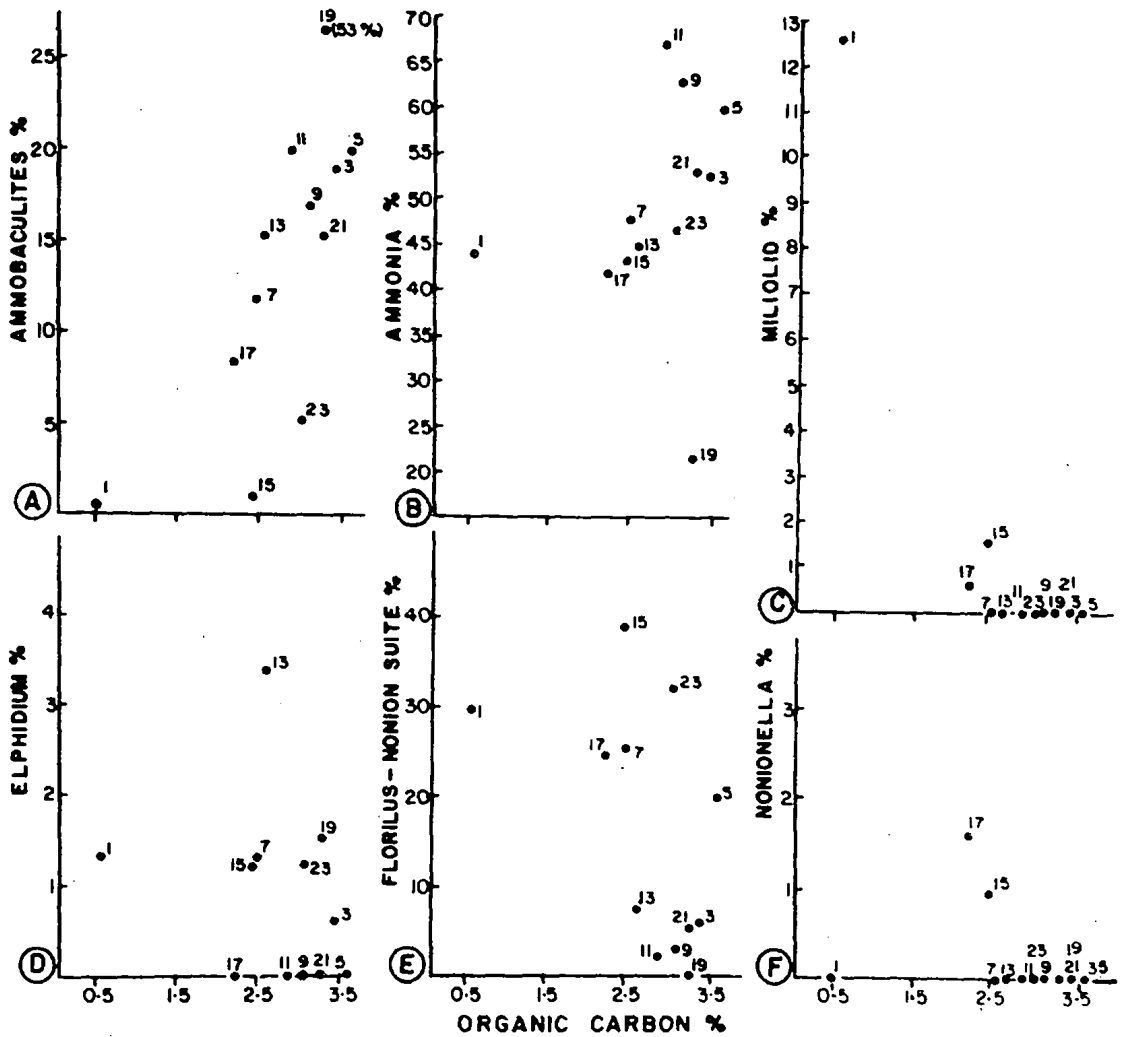


Fig. 5—Foraminiferal assemblage and organic carbon relation in Karwar area with reference to (A) *Ammobaculites* and (B) *Ammonia* showing positive tendency and (C) Miliolids (D) *Elphidium* (E) *Florilus-Nonion* suite and (F) *Nonionella* suite showing negative tendency

Discussion

The organic carbon content in sediment is variable within each area and from area to area investigated (Table 1). The foraminiferal assemblages of the study area indicate that they are closely related with the nature of the substrate and the presence and retention capacity of organic carbon in it. Figs 2,3 and 5 show that 3 suites of foraminifera, viz. miliolids, *Ammonia-Elphidium* and *Nonion-Florilus* are directly, (but together with the agglutinated species) and other minor groups are inversely proportional with the fluctuations of organic carbon in the sediment.

Among the miliolids, *Quinqueloculina seminulum* dominates in substrates with organic carbon ranging up to 2.024% (at Dabhol-Vengurla region) and 2.484% (Cola Bay, Goa area), but it disappears when it is 2.944% (Dabhol-Vengurla region). *Spiroloculina excavata* and *S. communis* are dominant with 0.920% organic carbon in Bombay-Daman area while it gets reduced with 1.196% at Cola Bay, and Karwar inshore areas. Juvenile, thinshelled, hyaline type miliolids are dominant in silts and clays (as in Gulf of Kutch) but they are typically procollanous in sandy substrates as in Gulf of Kutch, and Cola Bay, but they tend to be more agglutinated types in sands (Cola Bay, and Karwar areas).

Nonionella opima is known to increase with the increase in organic carbon (5-8.8 to 9.8%) in Gulf of Cariaco¹⁷ and low salinity from 1 to 31‰¹⁶. *Florilus grateloupi* and *Fursenkoina pontoni* are also known to become smaller and thicker in high organic carbon regions as in Eastern Venezuela and greater Antilles regions¹⁸. Similar populations of *Florilus grateloupi* together with some abnormal specimens were found in Cariaco Gulf and Uraba Gulf under conditions of environmental stress caused by pollution¹⁹, in Jabos Bay, southern Puerto Rico under conditions of oxygen depletion and high organic matter²⁰. The miliolids (*Quinqueloculina*, *Spiroloculina* and *Triloculina*), *Florilus-Nonion*, and *Nonionella* show a negative (inverse) tendency at 3 regions (Bombay-Daman, Dabhol-Vengurla and Karwar sectors). The correlation values become significant to miliolids at Bombay-Daman area, for *Ammobaculites* at Karwar sector only, but to *Florilus-Nonion* at Bombay-Daman and Karwar.

Similarly quantitative analysis of organic carbon against foraminiferal assemblages like *Ammobaculites* ($r=0.058$; 0.540) at Bombay-Daman and Karwar and

Ammonia ($r=0.027$; 0.0257; and 0.208) at Bombay-Daman, Dabhol-Vengurla and Karwar respectively indicates a positive correlation. The correlation value becomes significant ($P<0.1$) for *Ammobaculites* at Karwar only. When analysed quantitatively, the relationship at Cola Bay, Goa shows that the total foraminiferal number (TFN) is inversely proportional to organic carbon but at Gulf of Kutch it is inconsistent due to very low values. Such inconsistencies and fluctuations, it is observed, have a direct bearing on a combination of factors like the nature of substrate (for the retention of organic matter), salinity (relating to inflow), water depth (pertaining to sedimentation rate) and input (terrigenous and pollution due to industrial discharges) through various pathways influencing the marine ecosystem in these regimes.

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