

## Quantitative Radiolarian Assemblages in Surface Sediments from the Central Indian Basin and their Paleomonsoonal Significance

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**Abstract :** The percentage data of 47 radiolarian coarser taxonomic groups in the surface sediments from the central Indian Basin was subjected to cluster and factor analyses. The R-mode cluster analysis resulted in 3 dominant clusters which represent surface, subsurface and deep water dwelling radiolarian groups. The Q-mode factor analysis resulted into three dominant factors. The factor-1 is characterized by *Pyloniids* group dominating the southwestern part with higher salinity (>34.5/ppt), low sea surface temperature (<27°C) and high potential primary productivity (>0.2 mgC/m<sup>3</sup>/h) during the southwest monsoon. The factor-2 is characterized by *Spongodiscids* group dominating the northeastern part with lower salinity (<34.5/ppt), warmer SST (>28°C), and poor potential primary productivity (<0.2 mgC/m<sup>3</sup>/h) during the southwest monsoon. The factor-3 is characterized by *Euchtoniids* group dominating a transitional area between the two factors.

**Keywords :** Micropaleontology, Radiolaria, Statistical analyses, Physical Oceanography, Paleoclimate, Central Indian Basin

### INTRODUCTION

The International Geosphere-Biosphere Programme has stressed the need of quantitative data for the Multi-Proxy Mapping Programme (MMP) in order to understand the responses of ecosystem (assemblages) in the specific climatic regimes like Asian monsoon and El-Nino-Southern-Oscillation for deriving the transfer functions to estimate climatic changes in geological past (IGBP, 1990). Monsoon has a pronounced effect on the surface salinity due to enormous fresh water run off ( $90 \times 10^3 \text{ m}^3/\text{s}$ ) through the Ganges-Brahmaputra rivers in July-August, the peak of southwest monsoon, into the Bay of Bengal (Carroll *et al.* 1993). It causes lowering in surface salinity towards the Bay of Bengal, whereas water remains hypersaline towards the Arabian Sea (Wyrki, 1971). As majority of radiolaria inhabit the top 100 m of oceanic water (Anderson, 1983), they might record changes in surface salinity. Keeping the above in view, the present study was undertaken to map statistically sound, radiolarian assem-

blages characterizing the specific watermasses in the central Indian Basin which may help in paleomonsoonal studies.

Though, the radiolarian records in the Indian Ocean were scattered since 1872 (Ehrenberg, 1872), the first comprehensive study on distribution of radiolaria in surface sediments from the Indian Ocean was of Nigrini (1967). The literature review since Nigrini (1967) to Sharma and Mahapatra (1990) suggests that southern Indian Ocean (south of 20°S) has statistically sound percentage data based on extant radiolarian species or species groups resulting in radiolarian assemblages by Q-mode factor analysis from the surface sediments, which is well correlated not only to oceanographic watermasses of southern ocean, but also helpful in quantifying oceanographic changes by deriving the transfer functions (Lozano and Hays, 1976; Dow, 1978; Morley, 1989). Whereas, northern Indian Ocean (north of 20°S) has qualitative (presence or absence; Johnson and Nigrini, 1980, 1982) to semiquantitative (abundant,

common, rare; Sharma and Mahapatra, 1990) data on radiolaria from the surface sediments, which although indicates a trend in water masses, is not useful in quantifying the oceanographic changes in geological past. It also indicated the need of percentage data, a prerequisite for Q-mode factor analysis for statistically meaningful assemblages for the northern Indian Ocean.

Recently, because of the limitation of stratigraphic ranges in species level census data, the coarser taxonomic groups proposed by Riedel *et al.* (1985) and its later modifications have been widely used in the late Neogene paleoceanographic studies. Westberg-Smith and Riedel (1985), Westberg-Smith *et al.* (1986), Mullineaux and Westberg-Smith (1986), Sanfilippo (1988), and Gupta and Srinivasan (1992) found that the percentage data on coarser groups of late Neogene radiolaria can be successfully used for the paleoceanographic studies. However, no percentage data on modern radiolarian coarser taxonomic groups (hereafter morpho-groups) is available from any ocean basin. Therefore, the main objective of the paper was to generate such data, to perform R-mode cluster and Q-mode factor analyses in order to identify the chief water masses, and to correlate them with modern sea-surface temperature (SST), salinity, and potential primary productivity of the central Indian Ocean. As majority of radiolaria inhabit in the upper hundred meters of oceanic water column (Anderson, 1983), it is appropriate to summarize the surface water oceanographic characteristics of the central Indian Basin, in order to understand their influence on radiolarian distribution.

## OCEANOGRAPHIC SETTING

The tropical Indian Ocean exhibits seasonal changes in surface water characteristics during northeast monsoon (NEM, November-March) and southwest monsoon (SWM, June-September) seasons (Wyrtki, 1971). Sea-

surface temperature (SST), salinity and potential primary productivity (PPP) witness strong seasonality in the tropical Indian Ocean. The SST variation in December (SST-Dec.) is low (3°C, 26-29°C) and localized during NE monsoon, and high (6°C, 23-29°C) in August (SST-Aug.) during SW monsoon in areas north of 20°S (Figs.1a-b). Between 10°N to 4°S SST varies from 29-28°C, but between 4°S to 20°S SST gradient is higher (28-23°C) and isotherms are latitudinal during August in SW monsoon (Fig.1b). The surface water is 1-5°C cooler compared to the northern part during August between 4°S to 20°S. Due to extreme monsoonal atmospheric and oceanographic gradient, the surface water is characterized by hypersalinity (>34.5/ppt) caused by strong evaporation towards the Arabaian Sea side and hyposalinity (<34.5/ppt) towards the Bay of Bengal caused by high precipitation and large fresh-water run-off from the Indian subcontinent by the Ganges-Brahmaputra rivers during SW monsoon. Surface salinity exhibits seasonal fluctuation and a marked east west contrast, a peculiarity of the equatorial Indian Ocean, is evident (Wyrtki, 1971). Salinity varies from 32-34.5/ppt and 34.5-35.5/ppt in the east and west of 80°E respectively, during NE monsoon (Fig.1c). Salinity contrast is more pronounced that divides the basin obliquely along the 34.5/ppt isohaline into southwestern and northeastern parts during SW monsoon (Fig.1d). The surface water potential primary productivity (PPP) is lower (0.05-0.2 mgC/m<sup>3</sup>/h) during NE monsoon and higher (0.2-0.5 mgC/m<sup>3</sup>/h) during SW monsoon in the central part of the Basin (Figs.1e-f).

## MATERIAL AND METHODS

The surface sediment samples were collected from 42 locations (Table I) using Pettersson grab, spade core-tops, and boomerang grabs (with a small plastic tube attached to

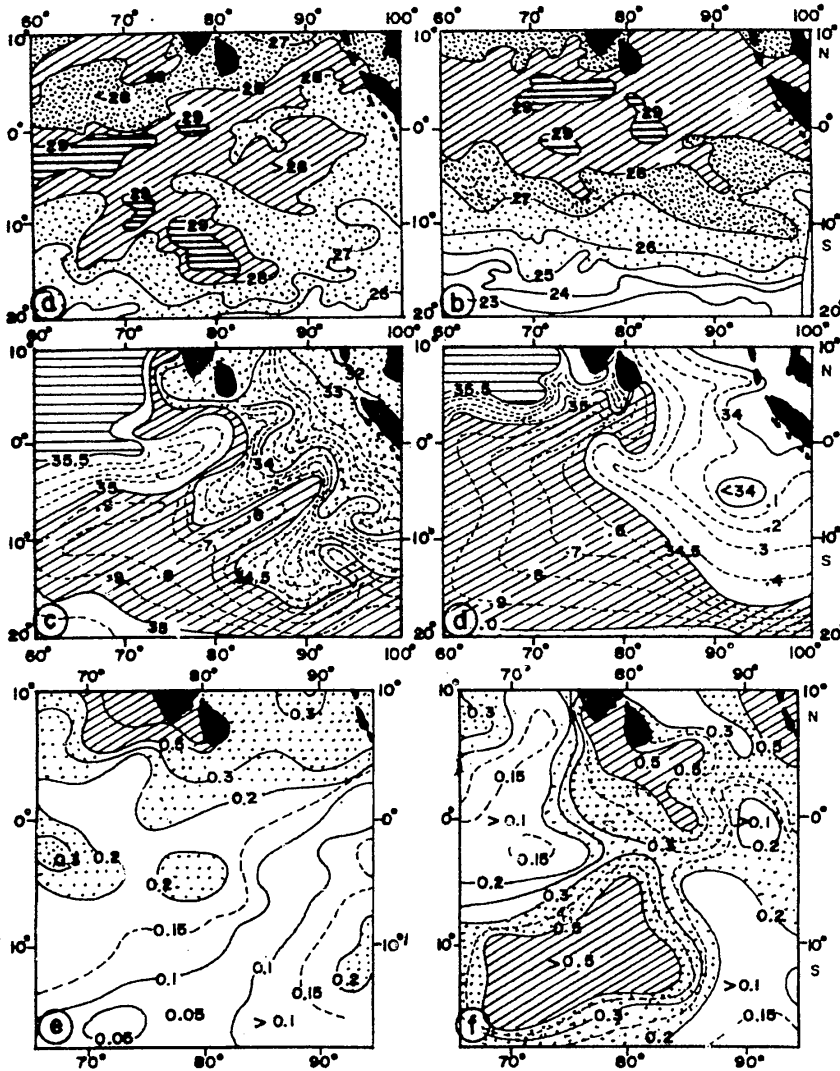


Fig.1. Seasonal variation of sea surface temperature (SST), salinity and potential primary productivity in the central tropical Indian Ocean. Sea surface temperature (a) SST-Dec., (b) SST-Aug., and salinity (c) November-December (d) July-August are after Wyrtki (1971). Potential Primary productivity during NE monsoon (e) and SW monsoon (f) is after Krey and Babenard (1976).

the grab-jaw) during various cruises of *RV GAVESHANI*, *MV FARNELLA*, *MV SKANDYSURVEYOR* for the survey of the polymetallic nodules in central Indian Basin (Fig.2). Sediment samples were oven dried for overnight at controlled temperature of 40°C and cooled at

room temperature before weighing. Weighed sediments were soaked in distilled water and 10% sodium hexametaphosphate was added. Samples were stirred and left overnight. Later, hydrogen peroxide (30%) was added (50 ml) for disaggregation and dispersal. For removal

of calcium carbonate, about 30 ml of glacial acetic acid was added. After carbonate removal, the material was sieved over 62.5  $\mu$ m mesh under mild water jet. To remove the clay infilling within the radiolarian tests an ultrasonic vibration treatment was given for half a

minute. Later, randomly settled radiolarian slides (Moore, 1973) were made to quantify radiolarian count data. Though, 250 radiolarian species were identified in the present samples (Gupta, 1991) using radiolarian literature (1835-1980) in microfiches and a guide to

Table I. Latitude, Longitude, water depth, sediment type and sampling device used in the Central Indian Basin.

S.N.	Sample No.	Latitude +=N, -=S	Longitude E	Depth (m)	Sampler used	Nature of Sediment
1.	RVG 2483	-02.050	82.079	4590	PG	Calc.
2.	RVG 2486	-05.000	82.090	4990	PG	Calc.
3.	RVG 2494	-04.000	83.190	3750	PG	Calc.
4.	RVG 2501	-04.000	84.000	4860	PG	Calc.
5.	RVG 2513	-01.080	85.000	4600	PG	Calc.
6.	RVG 2520	-01.125	87.020	4600	PG	Calc.
7.	RVG 2528	-08.070	86.109	5200	PG	Silic.
8.	RVG 2531	-07.012	88.155	5080	PG	Silic.
9.	RVG 2532	-06.001	88.090	5150	PG	Silic.
10.	RVG 2533	-05.075	88.180	5030	PG	Calc/Silic.
11.	RVG 2535	-03.062	88.065	4820	PG	Calc.
12.	RVG 2537	-01.059	88.095	4620	PG	Calc.
13.	F 47	-13.500	73.999	5150	PG	Silic.
14.	F 56	-14.002	73.001	4389	PG	Calc.
15.	F 81	-12.490	77.001	5486	Spd C	Silic.
16.	F 99	-05.000	75.992	4492	PG	Calc.
17.	F 101	-07.027	76.002	5290	PG	Silic.
18.	F 150	-07.444	78.954	NA*	PG	Silic.
19.	F 151	-07.550	78.467	NA*	PG	Silic/Calc.
20.	F 152	-07.489	78.014	NA*	PG	Silic/Calc.
21.	F 153	-08.024	76.967	NA*	PG	Silic/Calc.
22.	F 154	-07.021	76.980	NA*	PG	Silic/Calc.
23.	F 155	-07.004	78.495	NA*	PG	Silic/Calc.
24.	F 156	-07.067	79.500	NA*	PG	Silic/Calc.
25.	F 157	-06.468	77.439	NA*	PG	Silic/Calc.
26.	F 158	-06.500	78.945	NA*	PG	Calc.
27.	F 199	-12.007	76.477	5450	BG t	Silic.
28.	F 379	+01.089	74.670	2475	PG	Calc.
29.	S 105	-11.010	74.985	5022	BG t	Silic.
30.	S 120	-13.006	72.984	4300	BG t	Silic.
31.	S 121	-12.007	73.003	5075	PG	Silic.
32.	S 124	-12.017	73.003	5000	PG	Silic.
33.	S 126	-14.017	72.016	5000	BG t	Silic.
34.	S 127	-11.999	70.990	4750	PG	Calc/Silic.
35.	S 128	-11.969	75.465	3007	BG t	Calc.
36.	S 129	-12.006	76.452	5100	PG	Silic.
37.	S 139	-11.514	81.490	NA*PG	Silic.	
38.	S 183	-13.510	78.979	5388	BG t	Silic.
39.	S 206	-15.090	83.560	NA*	PG	Silic.
40.	S 210	-15.487	82.950	5040	PG	Silic.
41.	S 231	-14.890	73.530	4900	PG	Silic/Calc.
42.	S 241	-15.500	72.991	4650	PG	Calc.

Note : NA\* = Depth data not available as the Echosounder did not worked. Sampling devices i.e. PG= Petterson grab, BG t= boomerang grab with 10 cm plastic tube attached, Spd C= Spade core top.

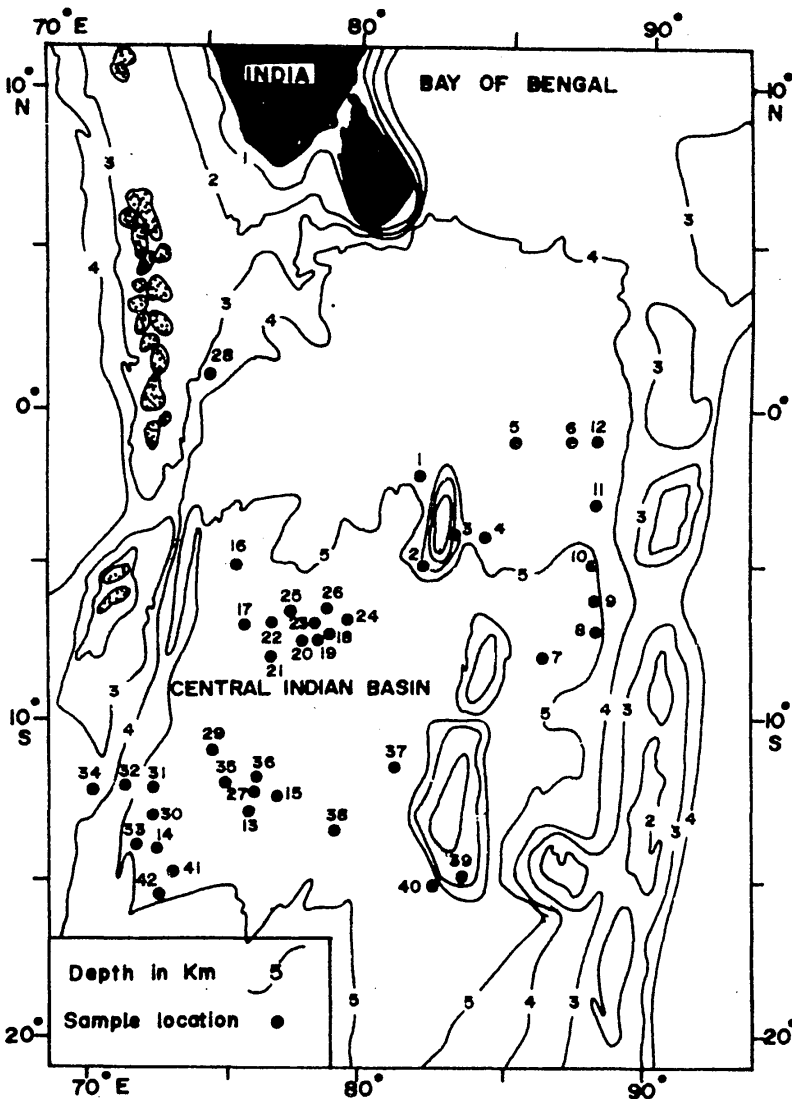


Fig.2. Location of the surficial sediment samples in the central Indian Basin. Bathymetric contours are in km (Udnitsev, 1976).

modern radiolaria (Nigrini and Moore, 1979); the census data was generated on coarser taxonomic groups (Riedel *et al.* 1985; Mullineaux and Westberg-Smith, 1986) to provide a base for long ranging (Holocene to late Neogene) transfer function. These groups are defined and illustrated in Gupta (1991), Gupta and Srinivasan (1992). Percentage data

of 47 morpho-groups from 42 samples (Data is available on request) was used for cluster and factor analyses (Davis, 1973).

**RESULTS AND DISCUSSION**

**R-mode cluster analysis**

The percentage data of 47 radiolarian

morphogroups in 42 samples was subjected to computation using Spearman rank correlations using formula of Tate and Clelland (1957) and weighted pair-group average clustering method (Davis, 1973) was applied and the result is presented in the form of two dimensional hierarchy dendrogram in which morphogroups are presented along X-axis while similarity level on y-axis (Fig.3) There are three main clusters, i.e. cluster A, B and C, at 0.03 level of similarity.

**Cluster A.** Cluster A is characterized by *Pyloniids*, *Artiscins*, *Larcospira* and *Litheliids* groups. Members of these morphogroups (*Tetrapyle octacantha*, *Octopyle stenozona*, *Didymocyrtils tetrathalmus*, *Larcospira*

*quadrangula*) are found in abundance in the upper surface water (abundance maxima at 25-50 m) of the Pacific and Atlantic Ocean (Renz, 1976; McMillen and Casey, 1978; Kling, 1979).

**Cluster B.** It is characterized by 13 morphogroups. The morphogroups *Collosphaera*, *Acrosphaera*, and *Disolenia-Siphonosphaera* represent colonial radiolarians having preference to the 0-50 m of surface water (McMillen and Casey, 1978; Kling, 1979). The morphogroups like *Heliodiscus*, *Spongodiscids*, *Spongaster-Spongocore*, *Stylosphaera* and *Hexaccontium* are represented by *Heliodiscus echinischus*, *Spongotrochus longispinus*, *Spongotrochus*

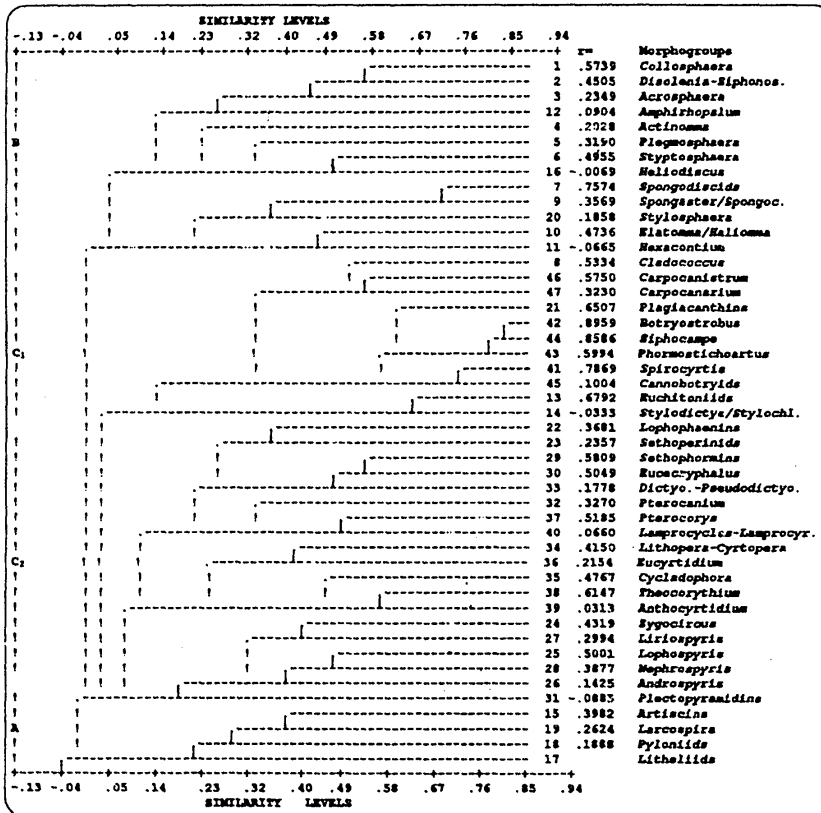


Fig.3. Weighted-pair group average dendrogram (R-mode cluster) of 47 radiolarian morphogroups counted in present study.

*multispinus*, *Spongaster tetras*, *Dupptractus pyriformis*, *Hexastyle phaenaxionius* in 50-100 m of surface water (McMillen and Casey, 1978). Other morphogroups like *Actinomma*, *Elatomma-Haliomma*, *Plegmosphaera*, *Styptosphaera*, and *Amphirhopalum* are also associated with cluster B. Hence, cluster B may be interpreted as surface water fauna (0-100 m) in the present study.

Cluster C can be divided into subcluster C<sub>1</sub> and C<sub>2</sub> at 0.03 level of similarity. Subcluster C<sub>1</sub> is comprised of 11 morphogroups i.e. *Euchitoniids*, *Stylocdictya-Stylochlamydidium*, *Cladococcus*, *Carpocanistrum*, *Carpocanarium*, *Plagiocanthins*, *Botryostrobus*, *Siphocampe*, *Phormostichoartus*, *Spirocyrtis*, and *Cannobotryids* etc. Kling (1979) reported upper subsurface maxima of *Botryostrobus auritus/australis*, *Phormostichoartus carbula*, *Hymeniastrum euclidis*, and *Stylocdictya validispina* at 100 m watermass in north-east Pacific. McMillen and Casey (1978) reported association of *Spirocyrtis scalaris*, *Stylocdictya multispina*, *Euchitonia furcata* in 50-100 m watermass in Gulf of Mexico. Therefore, subcluster C<sub>1</sub> represents 50-100 m watermass.

Subcluster C<sub>2</sub> is comprised of 19 morphogroups and is chiefly characterized by *Eucecryphalus*, *Dictyo-Pseudodictyophimus*, *Pterocrys*, *Lamprocyclas-Lamprocrytis*, *Cycladophora*, *Anthocytidium*, *Lophospyris-Phormospyris* and *Plectopyramidins* morphogroups. Kling (1979) reported *Eucecryphalus sestrodiscus*, *Dictyophimus crisae*, *Pseudodictyophimus gracilipse*, *Pterocorys zancleus*, *Lamprocyclas maritialis*, *Cycladophora davisiana*, *Anthocyrtdium zanguebaricum*, and *Phormospyris sp.* with abundance maxima at 100-200 m constituting subsurface watermass of northeast Pacific. *Lophophaenaenins*, *Sethoperinids*, *Sethophormins*, *Pterocanium*, *Lithopeera-Cyrtopera*, *Eucyrtidium*, *Zygocircus*, *Nephrospyris*, *Androsphyris* are other morphogroups associated with subcluster C<sub>2</sub>.

*Plectopyramidins* morphogroup (represented by *Cornutella profunda*, *Plectopyramis*, *Bathropyramis* etc.) is the representative of deeper dwellers (>700-2000 m) in this cluster (McMillen and Casey, 1978; Kling, 1979). As majority of the morphogroups in subclusters C<sub>1</sub> and C<sub>2</sub> are representing upper (50-100 m) and lower (>100 m) subsurface dwelling taxa, cluster C may be correlated to the subsurface watermass (depth >100 m) in present study. As no data on vertical distribution of living radiolarians within the water column of the Indian Ocean is available, one may depend on the information from the other two oceans. Apparently, the faunal depth stratification of the water column in the Indian Ocean may not be drastically different to that of Atlantic and Pacific Oceans.

#### Q-mode factor analysis

The percentage data was subjected to Q-mode factor analysis (Kolvan and Imbrie, 1971) to achieve statistically meaningful assemblages or factors on ND 520 Computer using factor analysis program (Fernandes and Mahadevan, 1982). Weighted species composition in each factor (factor scores) and partitioned assemblage composition in each sample (factor loading) were achieved. Out of 5 factors initially searched for, only 3 factors were considered to be significant, which explain 91.56% of the original variance. Digital data on variance, cumulative variance and factor loading matrix of each factor is available from the author on request, whereas, varimax factor score matrix of each morphogroup is presented in Table II. All the three factors are named after the most dominant morphogroup. High communalities (>0.9) with a high total variance explained indicates that the three factors successfully describe major features of the radiolarian morphogroup distribution in the basin. Radiolarian factors and their dominant morphogroups are plotted as factor values and percentage of morphogroup contour maps and factors are viewed in three dimensional plots

at 45°/45° and 225°/45° of rotation of the axis (Golden Software, 1989). In three dimensional of perspective by using SURFER program plots, X and Y axis are the latitudes and

Table II. Factor score matrix after varimax rotation.

S.N.	Morphogroups	Factor 1	Factor 2	Factor 3
1.	<i>Collosphaera</i>	-.11938	.06622	-.18115
2.	<i>Desolenia/Siphonosphaera</i>	-.08504	-.01688	-.17025
3.	<i>Acrosphaera</i>	-.07907	.04339	-.02394
4.	<i>Actinomma</i>	-.01605	.05010	-.01930
5.	<i>Plegmosphaera</i>	-.04295	-.00856	-.03119
6.	<i>Styptosphaera</i>	-.01732	.01810	.01034
7.	<i>Spongodiscids</i>	.06957	.91690**	.13188
8.	<i>Cladococcus</i>	.00454	.03725	.00450
9.	<i>Spongaster/Spongocore</i>	.00102	.19101	-.01688
10.	<i>Elatomma/Haliomma</i>	-.07312	.12595	.03420
11.	<i>Hexacantium</i>	-.14444	.12885	.11469
12.	<i>Amphirhopalum</i>	-.00128	.00108	-.00208
13.	<i>Euchitoniids</i>	-.04020	.02870	-.80286**
14.	<i>Stylodictya/clamydium</i>	-.01822	.20066	-.46019*
15.	<i>Artiscins (Didymocytis)</i>	-.50850*	-.02526	.07491
16.	<i>Helioidiscus</i>	-.02620	.04724	-.01078
17.	<i>Litheliids</i>	-.08554	.02957	-.05589
18.	<i>Pyloniids (Tetra, Hexa, Octapyle)</i>	-.78207**	.00731	-.05595
19.	<i>Larcospira quadrangula</i>	-.14655	.03881	.09429
20.	<i>Stylosphaera/Axoprimum</i>	-.00432	.10106	.01014
21.	<i>Plagiocanthins</i>	-.00444	-.00006	-.02681
22.	<i>Lophophaenins</i>	-.02949	.01374	-.03829
23.	<i>Sethoperinids</i>	-.00753	.01408	-.00800
24.	<i>Zygocircus</i>	-.06454	.04548	-.06482
25.	<i>Lophospyris/Phormospyris</i>	-.12661	.11068	-.08112
26.	<i>Androspyris</i>	-.00070	.00547	-.00377
27.	<i>Liriospyris</i>	-.03072	.03071	.00118
28.	<i>Nephrospyris</i>	-.00682	.00232	-.00863
29.	<i>Sethophormins</i>	-.03303	.02166	.01137
30.	<i>Eucecryphalus</i>	-.00781	.00579	.00282
31.	<i>Plectopyramidins</i>	-.00901	-.00899	-.02884
32.	<i>Pterocanium</i>	-.04948	.04989	-.04073
33.	<i>Dictyoph./Pseudodictyophimus</i>	-.00707	.00405	-.00571
34.	<i>Lithopera/Cyrtopera</i>	-.00519	.00910	-.00197
35.	<i>Cycladophora</i>	-.00036	.01508	.00700
36.	<i>Eucyrtidium</i>	-.01137	.00493	-.04518
37.	<i>Pterocorythids</i>	-.05549	.02994	-.00407
38.	<i>Theocorythium</i>	-.02214	.02187	.00097
39.	<i>Anthocyrtdium</i>	-.08229	.04109	.03168
40.	<i>Lamprocyclas/Lamprocyrtis</i>	-.02187	.01582	.02844
41.	<i>Spirocyrtis</i>	-.00061	-.00570	-.01632
42.	<i>Botryostrobis</i>	.00626	-.00784	-.04019
43.	<i>Phormostichoartus</i>	.00861	.00051	-.04200
44.	<i>Siphocampe</i>	.00687	-.01588	-.04779
45.	<i>Cannobotryids</i>	.00666	-.00857	-.03060
46.	<i>Carpocanistrum</i>	-.00896	-.00445	-.01566
47.	<i>Carpocanarium</i>	.00305	.00536	.00107

\*\* Values considered to be most significant contributor (morphogroup) in the factor.

\* Values considered to be secondary contributor (morphogroup) in the Factor



longitudes and Z axis is the value of the factor. Three dimensional plots have been earlier used for the best presentation in biogeographic and paleoceanographic studies (Floden and Haq 1980).

#### FACTOR 1 : PYLONIIDS ASSEMBLAGES

The factor 1 accounted for 45.3% of variance and is characterized by *Pyloniids* group (Fig.4). Percentage of *Pyloniids* group

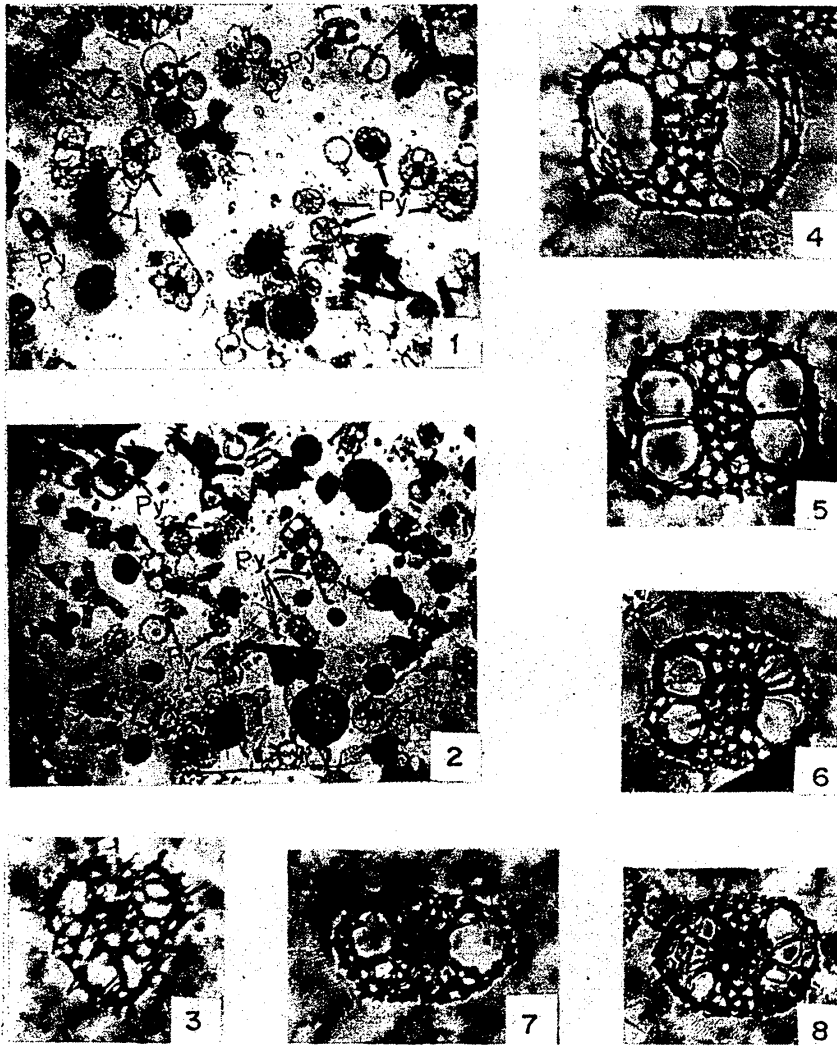


Fig.4. Member species of Pyloniids assemblage (depicted with arrows). The magnifications and co-ordinates of the slides are also mentioned. (1) A typical view field of the Pyloniids assemblage showing dominance of Pyloniids (arrows). Slide S-124A, view field L/19X106, X36. (2) Another view field showing dominance of Pyloniids (arrows). Slide S-105A, view field 10X110, X36. (3) *Hexapyle dodecantha* Haeckel, Slide S-126A, view field L/12X/192, X160. (4) *Tetrapyle octacantha* Muller, slide S-124A, view field L/14X111, X160. (5) *Octapyle stenoazona* Haeckel, slide S-125A, view field L/21X102, X160. (6-8) *Phorticium pylonium* Haeckel. (6) Slide S-124A, view field L/9X119, X160. (7) Slide S-124A, view field L/17X120, X160. (8) Slide S-105A, view field L/11X110, X160.

and values of factor-1 are contoured (Figs.5a-b) and both of them show highest loading in the area shown by hatches. Dominance of the factor one is also presented three dimensionally (Figs.5c-d). It is primarily characterized by *Pyloniids* (*Tetrapyle octacantha*, *Octopyle stenozona*, and *Hexapyle dodecantha*) morphogroup, whereas *Artiscins* (*Didymocyrtis tetrathalmus*) morphogroup is the secondary contributor (Table II). The factor assemblage is named after the primary contributor *Pyloniids*. The southwestern area of dominance exhibits high salinity (>34.5/ppt), low

SST (>27°C), and high potential primary productivity (>0.2 mgC/m<sup>3</sup>/h) of the surface water during southwest monsoon (Figs.1b,d,f) than during northeast monsoon (Fig.1a,c,e). Therefore, the factor may be correlated with high salinity (>34.5/ppt), low SST (<27°C), and high ppp (>0.2 mgC/m<sup>3</sup>/h) during southwest monsoon.

#### FACTOR 2 : SPONGODISCIDS ASSEMBLAGES

The second factor accounted for 25.99% of variance and is characterized by *Spongodiscids*

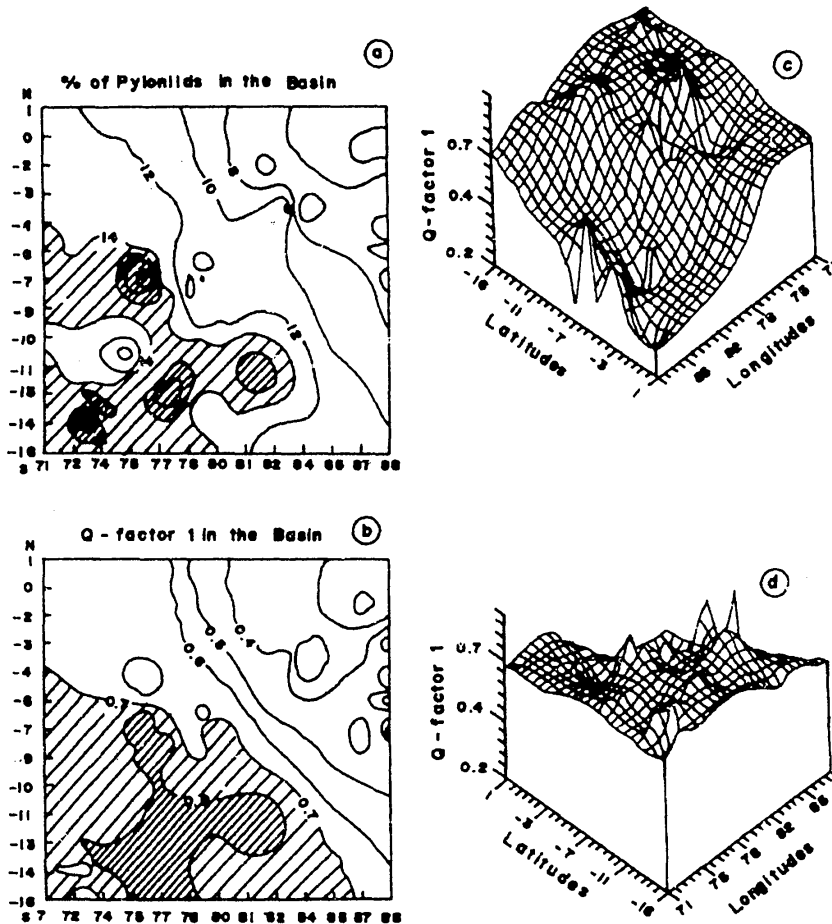


Fig.5. Computer generated contour maps [(a) % distribution of *Pyloniids* group; (b) loading of factor 1, higher loading shown with hatches] and three dimensional views [(c) at 45°/45° and (d) at 225°/45° rotation of perspective axis] of factor 1 in the basin.

group (Table II, Fig.6). Percentage of *Spongodiscids* group and values of factor 2 are contoured (Figs.7a-b) and both of them show

highest loading in the area shown by hatches. Dominance of the factor-2 is also presented three dimensionally (Figs.7c-d) for the better

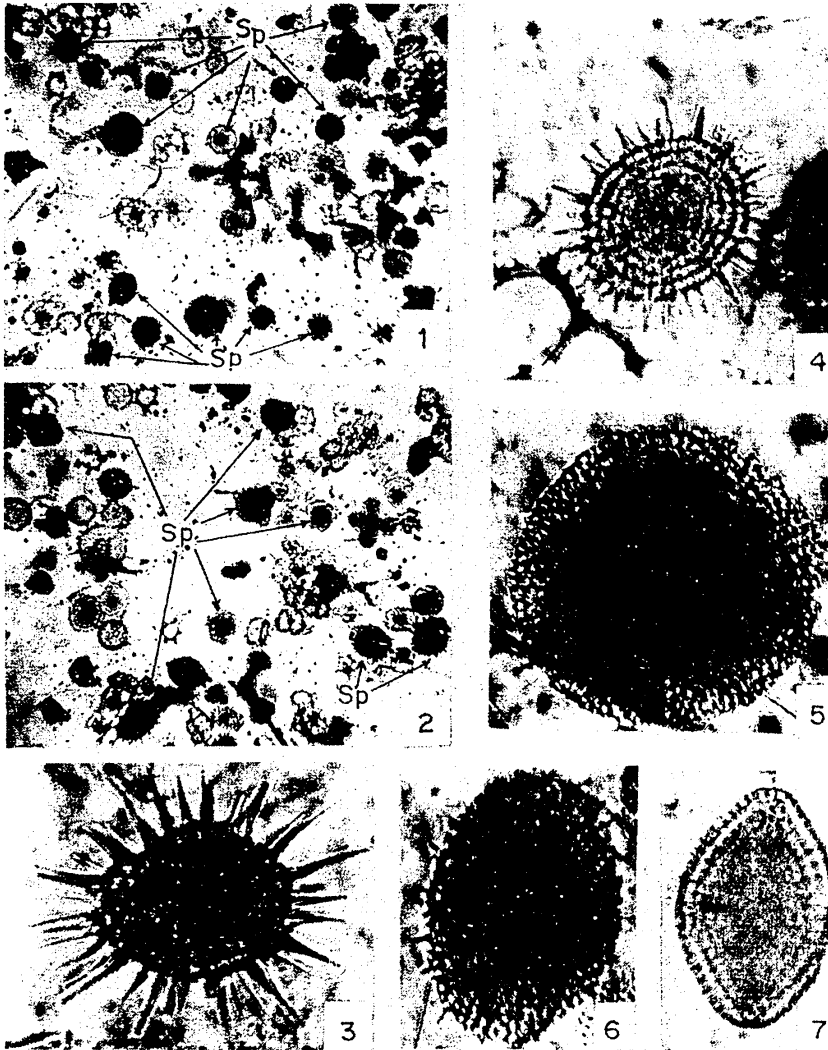


Fig.6. Member species of *Spongodiscids* assemblage (depicted with arrows). The magnifications and co-ordinates of the slides also are mentioned. (1) A typical view field of the *Spongodiscids* assemblages showing dominance of *Spongodiscids* (arrow pointing Sp.). Slide RVG-2537B, view field L/5X105, X36. (2) A typical view field of the *Spongodiscids* assemblage showing dominance of *Spongodiscids* (arrow pointing at Sp.). Slide RVG-2537B, view field L/13X108, X36. (3) *Spongotrochus glacialis* Popofsky, slide S-124A, view field L/8X99, X160. (4) *Spongurus cf. elliptica* (Ehrenberg), slide S-125A, view field L/20X102, X160. (5) *Spongopyle osculosa* Dreyer, slide S-124A, view field L/18121, X160. (6) *Spongotrochus (?) venustum* (Bailey), slide S-124, view field L/5X133, X160. (7) *Spongurus cf. elliptica* (Ehrenberg), slide S-124A, view field L/20X102, X160.

perspective. Factor 2 has highest loading on northeastern part of the basin. *Spongodiscids* group includes *Spongotrochus glacialis*, *Spongodiscus resurgense*, *Spongodiscus biconcavus*, *Spongurus spp.* and *Spongopyle osculosa* in its counts. The northeastern area of dominance is marked by low salinity (<34.5/ ppt) due to influence of the fresh water run-off from the Ganges-Brahmaputra into the Bay of Bengal during July-August, higher SST (>28°C), and low PPP (Fig.1). Therefore, the factor is correlated with low salinity (<34.5/ ppt), high SST (>28°C) and low PPP during southwest monsoon.

### FACTOR 3 : EUCHITONIIDS ASSEMBLAGE

The third factor is a transitional one accounted for 17.77% of variance and is characterized by *Euchitoniids* group (Table II, Fig.8). Percentage of *Euchitoniids* group and values of factor 3 are contoured (Figs.9a-b) and both of them show highest loading in the transitional area shown by hatches. Dominance of the factor 3 is also presented three dimensionally (Figs.9c-d). *Euchitonia elegans*, *E. furcata*, *Euchitonia sp.*, *Dictyocoryne truncata*, *Dictyocoryne profunda* and *Hymeniastrum euclidis*.

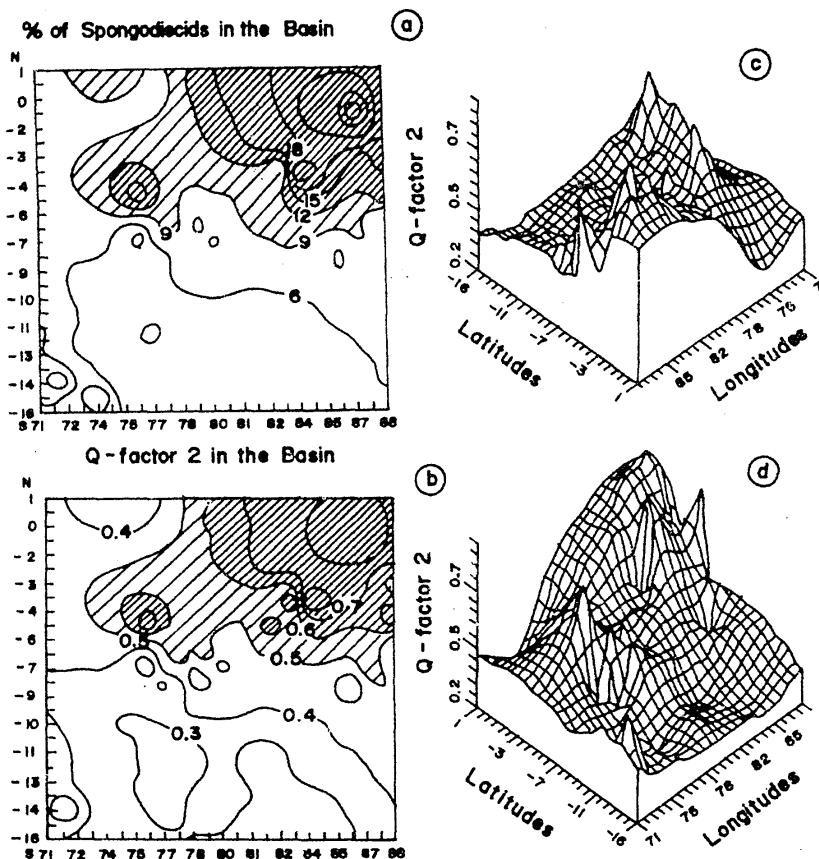


Fig.7. Computer generated contour maps [(a) % distribution of *Spongodiscids* group; (b) loading of factor 2, higher loading shown with hatches] and three dimensional views [(c) at 45°/45° and (d) at 225°/45° rotation of perspective axis] of factor 2 in the basin.

### RELATIONSHIP WITH OCEANOGRAPHIC VARIABLES

In order to verify the relationship of various factors with SST, salinity and PPP, the International Indian Ocean Expedition (IIOE) oceanographic data/charts (Fig.1) of southwest and northeast monsoon periods were digitized and their values were retrieved at respective geographical co-ordinates at the each sampling locations. The values of SST-Dec., SST-Aug., surface salinity of July-August and November-December, and PPP of SW and NE monsoon were related with the three factors. The correlation matrix is presented in Table III. High correlation coefficients ( $N=42$ ,  $r=>0.490$  significant at 0.001 level, 99.9%) of factor 1 and 2 with SST, salinity and PPP during southwest monsoon are noteworthy, and suggest that these assemblages are significant to derive the long range transfer functions for quantifying oceanographic changes in geological past.

### PALEOCEANOGRAPHIC SIGNIFICANCE

Surface distribution of the radiolarian factors in present study clearly indicates three well defined watermasses overlying the central Indian Basin i.e., (i) high salinity, cooler, highly productive watermass in southwestern part, (ii) low saline, warmer, low productive watermass in northeastern part and (iii) a transitional one. As the region is equatorial and monsoon dominated, the oceanographic variations in geological past may not be strong in terms of glacial and interglacial, as in the variation of monsoonal intensities. This view is supported with the paleomonsoonal studies of Prell (1984), Prell and Van Campo (1986) and Prell and Kutzbach (1987) that during the glacial periods the monsoon was weaker and climate was drier than the interglacial one in the Indian Ocean. The monsoonal variations may be studied by counting *Pyloniids* and *Euchitoniids* morphogroups in subsamples of

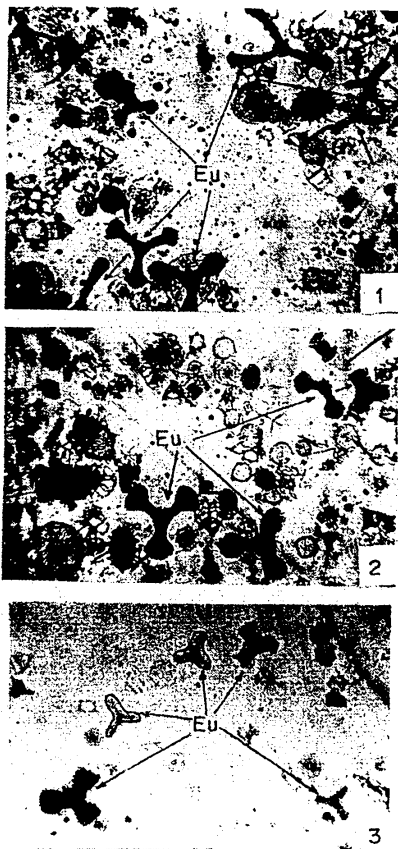


Fig.8. Euchitoniids assemblage (Member species are depicted with arrows. The magnifications and co-ordinates of the slides are also mentioned). (1) A typical view field of the Euchitoniids assemblage showing dominance of Euchitoniids (arrows pointing Eu). Slide S-124A, view field L/19X92, X36. *Dictyocoryne truncatum* (Ehrenberg) at top left corner; *Euchitonia furcata* Ehrenberg at top right edge; *Hymeniastrum euclidis* Haeckel, at lower left edge; *Dictyocoryne profunda* Ehrenberg, at lower right edge. (2) A typical view field of the Euchitoniids assemblage showing dominance of Euchitoniids (arrows pointing Eu). Slide S-124A, view field L/8X122, X36. *Dictyocoryne truncata* (Ehrenberg) at top right corner. (3) A typical view field of the Euchitoniids assemblage showing dominance of Euchitoniids (arrows pointing at Eu). Slide RVG-2498B, view field L/22X122, X36. *Dictyocoryne truncatum* (Ehrenberg) and *Euchitonia* spp.

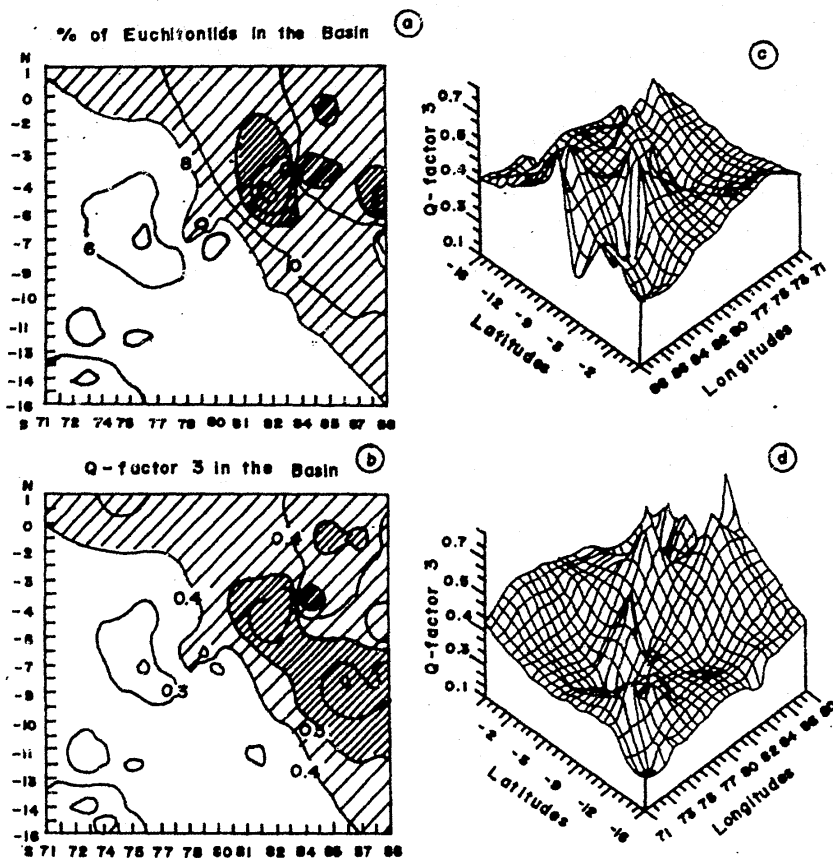


Fig.9. Computer generated contour maps [(a) % distribution of Eulichtoniids group; (b) loading of factor 3, higher loading shown with hatches] and three dimensional views [(c) at 45°/45° and (d) at 225°/45° rotation of perspective axis] of factor 3 in the basin:

Table III. Correlation (Spearman rank correlation) matrix of various variables with the three radiolarian factors.

	Fact-1	Fact-2	Fact-3	Sal-NE	Sal-SW	PPP-NE	PPP-SW	SST-Dec.	SST-Aug.
Factor-1	1.000								
Factor-2	-0.879	1.000							
Factor-3	-0.239	0.039	1.000						
Sal-NE	0.578	-0.685	0.249	1.000					
Sal-SW	0.675	-0.656	0.153	0.830	1.000				
PPP-NE	-0.154	0.097	-0.108	-0.112	0.127	1.000			
PPP-SW	0.666	-0.499	-0.161	0.413	0.665	0.133	1.000		
SST-Dec.	0.028	-0.159	-0.135	-0.194	0.033	0.011	1.000		
SST-Aug.	-0.667	0.571	-0.120	-0.689	-0.772	0.476	-0.544	0.149	1.00

Note : The r value >0.49 and >0.39 are significant at 0.001 and 0.01 level respectively for the degree of freedom (N) 42 surface samples.

the core. To test the hypothesis, the ratio of *Pyloniids* (Factor-1, high saline) and *Euchitoniids* (Factor-2, low saline) are worked out in a sediment core (SS-667, Lat.9°S, Long.77°E and water depth 5325 m) from the same basin. The results indicate that *Pyloniids*/*Spongodiscids* ratio (a salinity index) has changes in down core and reflect the monsoonal changes, which will be published elsewhere.

### CONCLUSIONS

The coarser morphogroup based radiolarian data from the surface sediments is generated to study the statistically meaningful radiolarian assemblages in the central Indian Basin. R-mode clusters suggest that majority of faunal groups represent the surface watermass (0-100 m). Q-mode factor results indicate three radiolarian factors (assemblages) explaining 91.56% of the environmental information in the original data matrix. The first factor (*Pyloniids* assemblage) dominated the southwestern part of the basin and is characterized by higher salinity (>34.5/ppt), cooler temperature (<27°C) and high potential primary productivity (>0.2 mgC/m<sup>3</sup>/h) during southwest monsoon. The second factor (*Spongodiscids* assemblage) dominated north-eastern part of the basin characterized by lower salinity (<34.5/ppt), higher SST (>28°C), and low potential primary productivity (<0.2 mgC/

m<sup>3</sup>/h) during southwest monsoon. The third factor (*Euchitoniids* assemblage) is the transitional between factor 1 and 2. It indicates that the quantitative radiolarian distribution is chiefly governed by the southwest monsoonal oceanographic characteristics (SST, salinity and PPP). Higher correlation coefficients of SST, salinity and PPP with these factors suggest that they are potential for the long range transfer functions for southwest monsoon. Moreover, the down core fluctuation of the ratio of *Pyloniids* versus *Spongodiscids* (P/S) may represent the monsoonal fluctuation in geological past.

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