

LIVING COCCOLITHOPHORIDS FROM THE ARABIAN SEA

M. V. S. GUPTHA, RAHUL MOHAN & A. S. MURALINATH

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Riassunto. Sono stati studiati i Coccolithophoridi raccolti nella zona eufotica del mare Arabico alla fine del monzone estivo (20 settembre-6 ottobre 1992). Sono state identificate 19 specie, le più abbondanti delle quali sono: *Emiliana huxleyi*, *Umbellosphaera irregularis*, *Umbilicosphaera sibogae* var. *foliosa* e *Gephyrocapsa oceanica*. Si è ritenuto che la bassa fertilità dell'acqua durante i mesi di Settembre e Ottobre abbia causato l'abbondanza di *E. huxleyi* e *U. irregularis*. Si è anche osservato che le malformazioni di *E. huxleyi* erano comuni durante il periodo di upwelling del monzone estivo, mentre la densità generale dei Coccolithophoridi decresceva da sud a nord. Altre considerazioni riguardano la densità dei Coccolithophoridi alle varie profondità dei sedimenti.

Abstract. Coccolithophorids collected from the euphotic zone in the Arabian Sea during the tail end of summer monsoon (Sept. 20 to Oct. 06, 1992) were studied. Nineteen species were recorded, most abundant among them were, *Emiliana huxleyi*, *Umbellosphaera irregularis*, *Umbilicosphaera sibogae* var. *foliosa* and *Gephyrocapsa oceanica*. Low fertility of water during September-October is believed to have caused the abundance of *E. huxleyi* and *U. irregularis*. It has also been observed that malformations of *E. huxleyi* are common during the summer monsoon upwelling period. It was also observed that the overall coccolithophorid density decreases from south to north. Higher coccolithophorid densities in the subsurface depths are attributed to suspected blooms and thermocline depth.

Introduction.

Coccolithophorids are unicellular marine phytoplankton belonging to biflagellate golden-brown algae which produce minute calcium carbonate plates called coccoliths. These coccolithophorids form a major constituent of the phytoplankton in the euphotic zone of the world oceans, which subsequently contribute to a large extent to the formation of pelagic sediment. Being very sensitive to environmental fluctuations they respond to and reflect the changing conditions in the euphotic zone. Coccolithophorids have been extensively studied for biostratigraphy and paleoceanography. Besides, these studies would be of great use in understanding the relationships between biocoenosis and thanatocoenosis of living floras in the water column and fossil floras

in the underlying bottom sediment. In view of the above we report here on the living coccolithophorids of the southern Arabian Sea waters.

Despite the fact that there has been considerable work carried out on coccolithophorids from the Arabian Sea, the research is largely confined to sediments (Martini & Muller, 1972; Cepek, 1973; Bukry, 1974; Boudreaux, 1974; Guptha, 1976, 1979, 1981, 1983, 1985, 1986; Houghton & Guptha, 1991).

Nevertheless, Norris (1971) for the first time studied the extant nannoplankton from the Indian Ocean (Arabian Sea). The study of living coccolithophorids was revived again after a lapse of more than a decade by Norris (1983, 1984, 1985), Woellner et al. (1988), Kleijne et al. (1989), and Kleijne (1991, 1992), who has documented the extant coccolithophorids in Arabian Sea samples collected in a traverse from the SE Indian Ocean to the Gulf of Aden and Red Sea. Yet, the number of studies on nannoplankton from the Indian Ocean are very scanty in comparison to Atlantic, Pacific and Mediterranean floras. Therefore, in order to add some useful information on living coccolithophorids in the Indian Ocean, the present study has been focussed on four stations in the southeastern Arabian Sea (Fig. 1; Tab. 1).

Hydrography.

The Arabian Sea is largely influenced by both the SW monsoon or summer monsoon (May-October) and the NE monsoon or winter monsoon (November-April)

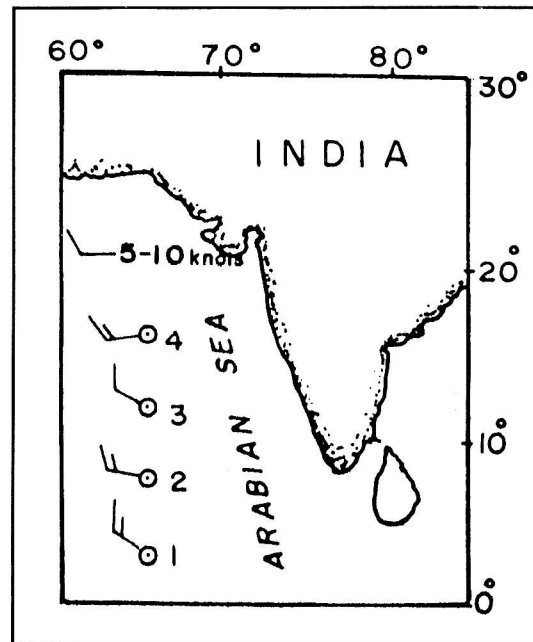


Fig. 1 - Location Map.

STATION NO.	LATITUDE	LONGITUDE
1.	3° 00' 00" N	65° 00' 00" E
2.	7° 00' 00" N	65° 00' 00" E
3.	11° 00' 00" N	65° 00' 00" E
4.	15° 00' 00" N	65° 00' 00" E

Tab. 1 - Geographic location of sampling stations.

(Wyrтки, 1973). During the summer monsoon, the Arabian Sea surface water circulation is dominated by a strong, wind-driven cyclonic gyre which is characterised by the westward flowing South Equatorial Current, the eastward flowing Monsoon Current and the strong Western Boundary Current or Somali Current. Circulation during the winter monsoon is comparatively weak and is characterised by a North Equatorial Current, an eastward flowing Equatorial Counter Current to the south and a moderately developed anticyclonic gyre in the Bay of Bengal (Defant, 1961).

Along the western Arabian Sea, intense upwelling develops during the summer monsoon (Currie et al., 1973; Bruce, 1974; Colborn, 1975). Conditions of weak and sporadic upwelling have also been observed in the Laccadive Sea, during the summer monsoon (Colborn, 1975). Owing to excess evaporation, high salinity water is formed in the Arabian Sea.

Temperature and salinity profiles derived from CTD measurements made during September-October, 1992 show that the thickness of the warm mixed layer increases from about 60 m at the southern station (#1) to 90 m at the northern station (#4). Sea surface temperature (SST) ranges from 27.54° to 28.6°C and salinity from 36.02 ‰ to 36.47 ‰ (Fig. 2). During this period, the wind speed ranges from 5 to 18 knots (1 Nautical Mile /hour) in the west/northwesterly direction (Fig. 1).

Material and methods.

As part of the Indian programme of the Joint Global Ocean Flux Study (JGOFS) in the Arabian Sea, which was planned to focus on the processes related to climatic change, a pre-JGOFS cruise was organised onboard *ORV Sagar Kanya* in the Arabian Sea between September 20 and October 6, 1992 (Fig. 1 and Tab. 1). This enabled us to collect water samples for the present investigation. Five litres of water were collected at four stations with Niskin water bottles in the euphotic zone (0-200 m). At two stations (#2 and 4) samples were also collected both during day (D) and night (N). These water samples were immediately filtered using a millipore filter system connected to a vacuum pump through a preweighed millipore filter of 47 mm diameter and a pore size of 0.45 µm; filters were subsequently dried in an oven. Later, these dried filters were weighed on a Mettler single pan digital balance to estimate the total particulate standing stock. In addition, continuous temperature and salinity profiles were taken at all stations. The millipore filters were scanned under JOEL 840 A Scanning Electron Microscope (SEM) to identify the coccolithophorids. For SEM observation a part of the filter was mounted on a specimen stub with conducting silver paste and coated with Gold-Palladium alloy (100 Å) in a sputter coater.

Identification of coccolithophorids was done with reference to Okada & McIntyre (1977), Okada & Honjo (1973), Winter et al. (1979), Nishida (1979), Samtleben & Bickert (1990), Kleijne (1990, 1991, 1992, 1993), Samtleben & Schroeder (1992).

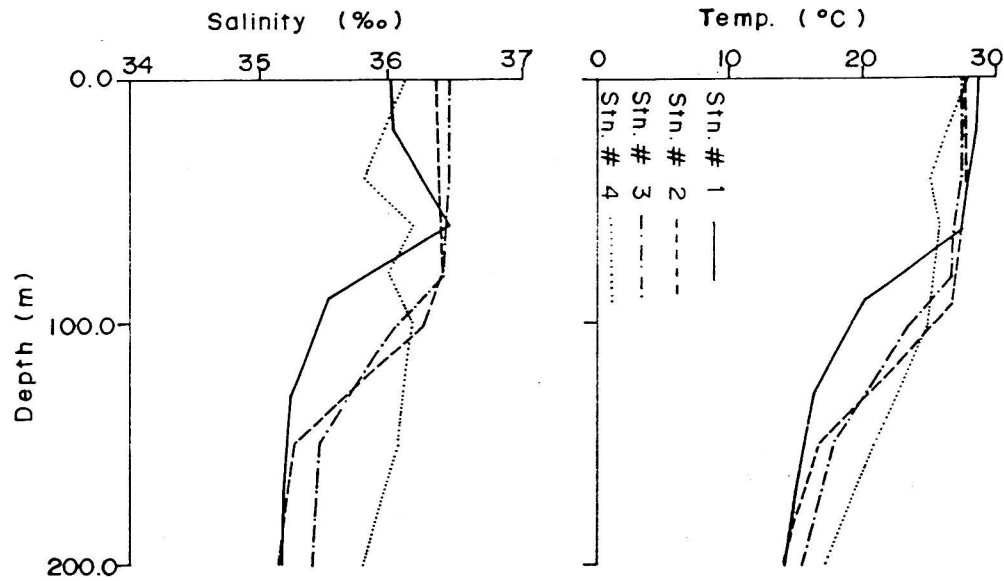


Fig. 2 - Salinity and Temperature profiles.

Standing crop.

In order to estimate the coccolithophorid standing crop, 15 random fields of view of varying magnifications were scanned under SEM. Standing crop was estimated as follows:

$$\frac{\text{No. of specimens counted} \times \text{Diameter of filter}}{\text{Total area of photograph taken} \times \text{Volume of water filtered}} = \text{specimens per unit volume}$$

Summing up the standing crop of all the 15 fields of view yielded, after computation, the total standing crop (Tab. 2).

Results.

Total particulate standing stock $>0.45 \mu\text{m}$ is largely constituted by coccolithophorids, diatoms and dinoflagellates.

Tab. 2 & 3 and Fig. 4, reveal that the total coccolith cell densities range from 213 to 21862 cells/litre at various depth intervals in the euphotic zone upto a depth of 130 m (observed depth limit), in the Arabian Sea. These cell densities tend to decrease progressively from the equatorial region at the southern station (#1) (24524 cells/litre) to northern station #4 (3627 cells/litre), except at station #2, wherein the anomalously highest cell density (33475) was recorded. The distribution pattern of coccolithophorids in the surface of the ocean shows that it ranges from 1992 cells/litre to 13128

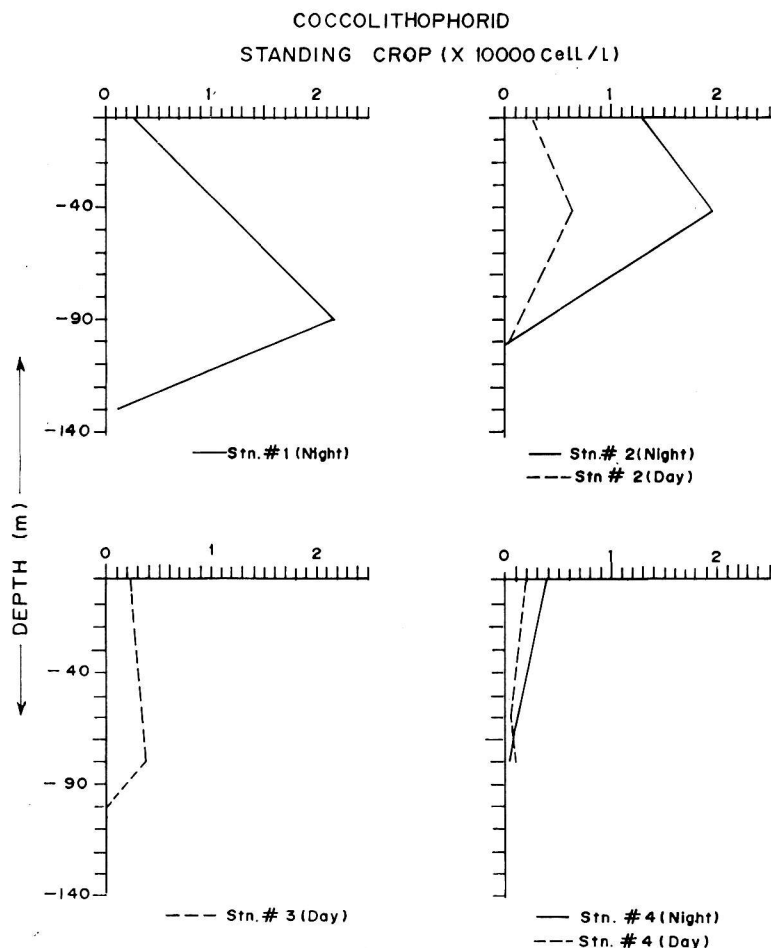


Fig. 3 - Standing Crop (10,000/l).

cells/litre, except for Stn.# 2N which shows the highest cell density, the remaining stations show moderate densities. It was also noted that the higher cell densities which are largely comprising of *E. huxleyi* are mostly confined to subsurface depths. The second dominant species *U. irregularis* is mostly restricted to the surface of the water in the euphotic zone at stations # 1N, 2N, 3D and 4N. On the contrary, further northward at station #4, cell densities were comparatively greater both during day and night in the surface of the water, which is mostly constituted by *E. huxleyi* along with a less abundant species *G. oceanica*.

The present study revealed the occurrence of nineteen species of modern coccolithophorid taxa, which are moderate in abundance. As seen from Fig. 5-9 and Tab. 2 & 3, the dominant species are *Emiliana huxleyi*, *Umbellosphaera irregularis*, *Calciosolenia murrayi*, *Gephyrocapsa oceanica*, *Syracosphaera variabilis*, *Sy. variabilis* type D and

Species	STN.#1 (Night)			STN.#2 (Night)			STN.#2 (Day)			STN.#3 (Day)			STN.#4 (Night)			STN.#4 (Day)		
	0m	90m	130m	0m	40m	100m	0m	40m	100m	0m	80m	100m	0m	60m	80m	0m	60m	80m
<i>C. murrayi</i>	x	1773	x	2304	4896	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>C. leptoporus</i>	x	x	x	x	x	35	x	23	x	198	197	99	x	99	99	x	32	x
<i>E. huxleyi</i>	493	789	197	2133	2892	177	546	1800	x	691	99	x	2226	494	99	423	x	887
<i>G. oceanica</i>	x	1872	99	85	601	x	99	415	x	99	x	x	318	296	296	704	x	99
<i>H. triarcha</i>	x	x	x	x	x	x	x	151	x	x	x	x	x	x	x	x	x	x
<i>O. antillarum</i>	x	65	x	x	x	x	x	96	96	x	x	x	x	x	x	x	x	x
<i>O. fragilis</i>	x	70	x	x	x	x	x	107	101	x	x	x	x	x	x	x	x	x
<i>R. clavigera</i>	99	x	x	x	x	x	x	4	x	x	x	x	x	x	x	x	x	x
<i>A. brasiliensis</i>	x	99	x	85	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Scyphosphaera</i> sp.	x	x	x	x	111	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>M. adriaticus</i>	x	x	x	x	4451	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>G. corolla</i>	x	x	x	x	x	x	x	297	x	x	x	x	x	x	x	x	x	x
<i>Sy. pulchra</i>	x	x	x	x	x	x	18	3	x	x	x	x	x	x	x	x	x	x
<i>Sy. prolongata</i>	x	x	x	x	445	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Sy. variabilis</i>	x	x	x	x	x	x	x	1013	x	x	3548	x	x	x	x	x	x	x
<i>Sy. variabilis</i> type D	x	x	x	2048	1944	x	x	298	x	99	x	x	x	x	x	x	71	x
<i>U. irregularis</i>	986	x	x	3402	2438	108	1792	2206	x	1379	x	x	1431	197	x	x	x	x
<i>U. tenuis</i>	1084	x	x	85	x	x	x	105	x	x	x	x	x	x	x	x	x	x
<i>U. sib. var. foliosa</i>	x	x	591	x	326	285	x	6	394	x	x	114	x	x	x	865	546	x
indetermined	x	17194	296	2986	1638	x	x	x	x	x	x	x	x	x	x	x	x	x
total	2662	21862	1183	13128	19742	605	2455	6523	591	2466	3844	213	3975	1086	494	1992	649	986

Tab. 2 - Distribution of coccolithophorids (Cells/litre).

Species	STN.#1 (Night)			STN.#2 (Night)			STN.#2 (Day)			STN.#3 (Day)			STN.#4 (Night)			STN.#4 (Day)		
	0m	90m	130m	0m	40m	100m	0m	40m	100m	0m	80m	100m	0m	60m	80m	0m	60m	80m
<i>C. murrayi</i>	x	8.0	x	17.6	24.8	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>C. leptoporus</i>	x	x	x	x	x	5.8	x	0.3	x	8.0	5.0	46.0	x	9.0	20.0	x	5.0	x
<i>E. huxleyi</i>	19.0	4.0	17.0	16.2	14.6	29.3	20.0	27.6	x	28.0	3.0	x	56.0	45.0	20.0	21.0	x	90.0
<i>G. oceanica</i>	x	9.0	8.0	0.6	3.0	x	4.1	6.3	x	4.0	x	x	8.0	27.0	60.0	35.0	x	10.0
<i>H. triarcha</i>	x	x	x	x	x	x	x	2.3	x	x	x	x	x	x	x	x	x	x
<i>O. antillarum</i>	x	0.3	x	x	x	x	x	1.5	16.2	x	x	x	x	x	x	x	x	x
<i>O. fragilis</i>	x	0.3	x	x	x	x	x	1.6	17.1	x	x	x	x	x	x	x	x	x
<i>R. clavigera</i>	4.0	x	x	x	x	x	x	0.1	x	x	x	x	x	x	x	x	x	x
<i>A. brasiliensis</i>	x	0.5	x	0.6	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Scyphosphaera</i> sp.	x	x	x	x	0.6	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>M. adriaticus</i>	x	x	x	x	22.5	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>G. corolla</i>	x	x	x	x	x	x	x	4.5	x	x	x	x	x	x	x	x	x	x
<i>Sy. pulchra</i>	x	x	x	x	x	x	0.6	0.1	x	x	x	x	x	x	x	x	x	x
<i>Sy. prolongata</i>	x	x	x	x	2.3	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Sy. variabilis</i>	x	x	x	x	x	x	x	15.5	x	x	92.0	x	x	x	x	x	x	x
<i>Sy. variabilis</i> type D	x	x	x	15.6	9.8	x	x	4.5	x	4.0	x	x	x	x	x	x	11.0	x
<i>U. irregularis</i>	37.0	x	x	25.9	12.3	17.9	64.0	33.8	x	56.0	x	x	36.0	18.0	x	x	x	x
<i>U. tenuis</i>	41.0	x	x	0.6	x	x	x	1.6	x	x	x	x	x	x	x	x	x	x
<i>U. sib. var. foliosa</i>	x	x	50.0	x	1.7	47.0	x	0.1	67.0	x	x	54.0	x	x	x	43.0	84.0	x
indetermined	x	79.0	25.0	22.7	8.3	x	x	x	x	x	x	x	x	x	x	x	x	x

Tab. 3 - Percentage distribution of coccolithophorids.

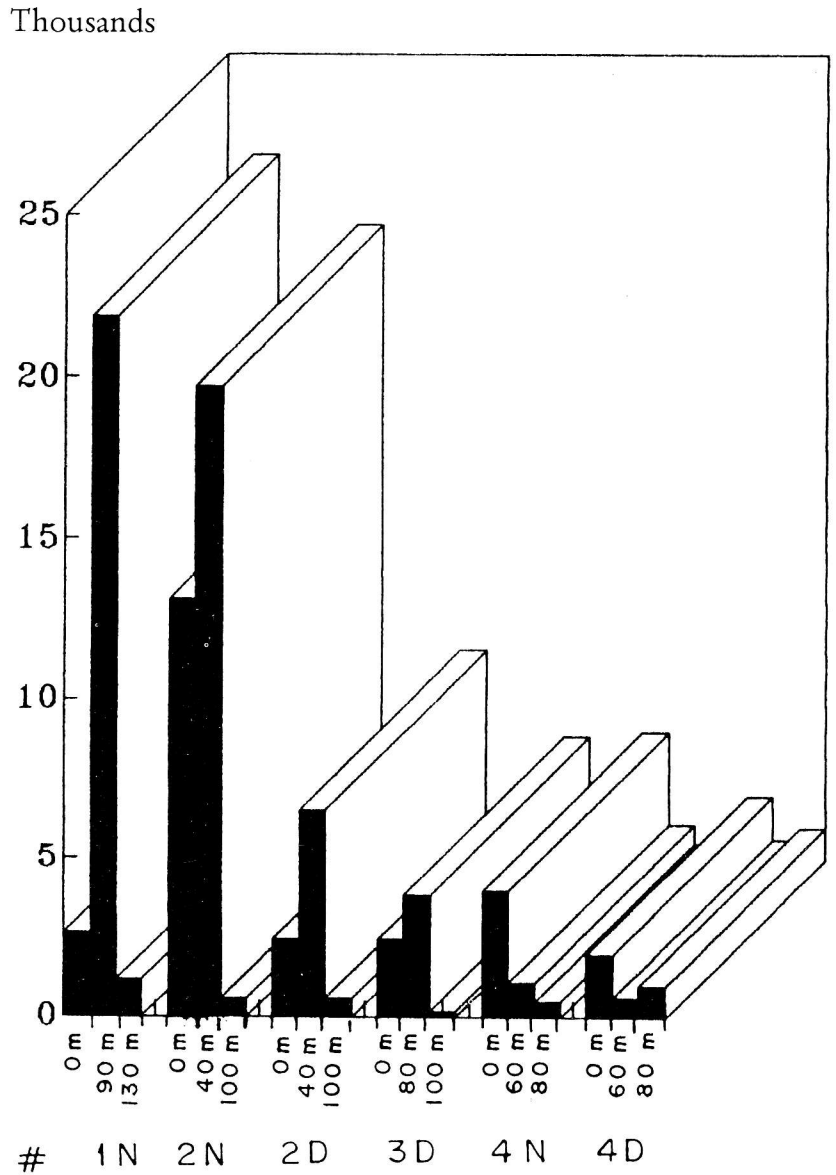


Fig. 4 - Distributional pattern of coccolithophorids.

Michaelsarsia adriaticus which together constitute about 70% of the bulk coccolithophorids, followed by a relatively less abundant species *Umbilicosphaera sibogae* var. *foliosa*. Besides, there are twelve more species which are sporadically distributed viz.: *Umbellosphaera tenuis*, *Calcidiscus leptoporus*, *Syracosphaera prolongata*, *Gaarderia corolla*, *Oolithotus fragilis*, *O. antillarum*, *Homozgyosphaera triarcha*, *Anoplosolenia brasiliensis*, *Rhabdosphaera clavigera*, *Syracosphaera pulchra*, *Syracosphaera* sp. and *Scyphosphaera* sp. in

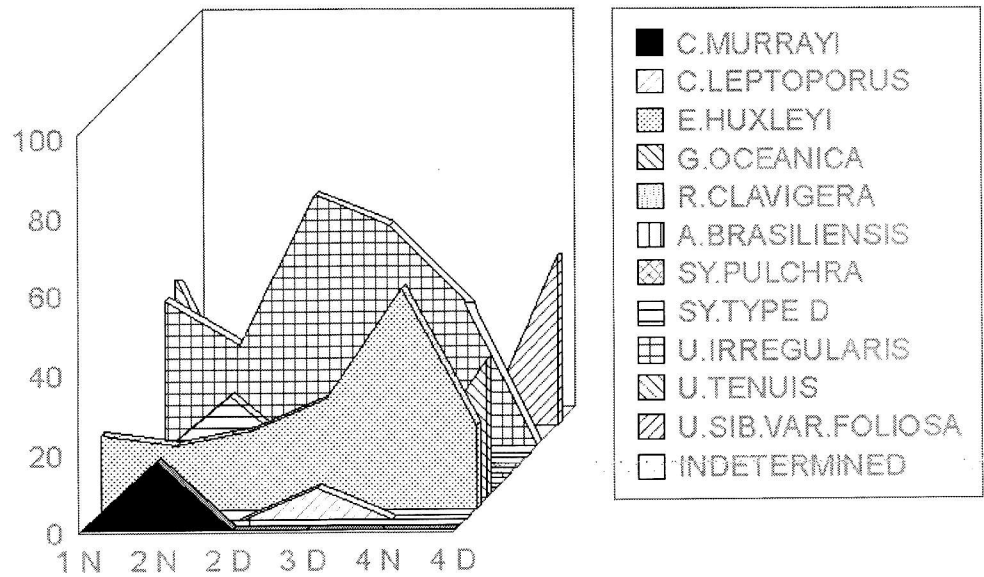


Fig. 5 - Surface samples from all the four stations including day and night at two stations (#2 and 4). Legend: 1) *C. murrayi*; 2) *C. leptoporus*; 3) *E. huxleyi*; 4) *G. oceanica*; 5) *R. clavigera*; 6) *A. brasiliensis*; 7) *Sy. pulchra*; 8) *Sy. variabilis* type D; 9) *U. irregularis*; 10) *U. tenuis*; 11) *U. sibogae* var. *foliosa*; 12) Indetermined. Less than 0.5 % abundances are not shown in the figures.

descending order. At station #1N & #2 N, we have also encountered a few basket-like nanoliths which are shown in Pl. 2, fig. 11 as indetermined.

Species composition in surface layer has yielded eleven species, among which *E. huxleyi* is most predominant followed by *U. irregularis*, *S. variabilis* and *G. oceanica* (Fig. 5).

40 m depth level at Stn.# 2N & D, the species composition increases to sixteen. The predominance of the above four species continues to this depth also (Fig. 6). Besides, it was also observed that the cell densities are higher during night collection than during daytime (Fig. 4).

Coccolithophorid species composition at deeper depth level of 60 m, shows significantly decreased number to six species at the northernmost station Stn.# 4N & 4D (Fig. 7), their cell density is also reduced. As has been noticed at Stn.# 2N, station 4N also displays significant increase in cell density during night collection by a factor of three (Fig. 4).

Species composition at 80 m & 90 m depths studied at Stn.# 3D, 1N and 4N have yielded a total of seven species, including an indetermined one. Apart from indetermined ones, *C. murrayi* and *A. brasiliensis* are the two species observed at Stn.# 1N. *Sy. variabilis* is the most dominant species at Stn.# 3D, while *C. leptoporus* is present at Stn.# 3D and 4N only. The remaining two species are represented by *G. oceanica* and *E. huxleyi* (Fig. 8).

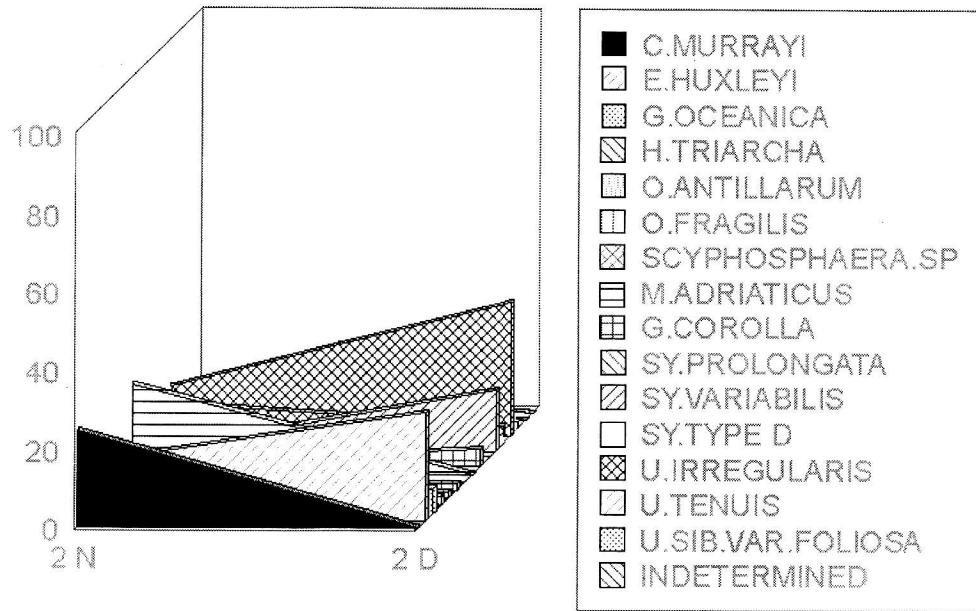


Fig. 6 - Samples from Stn. # 2D (60 m), # 2N (40 m). Legend: 1) *C. murrayi*; 2) *E. huxleyi*; 3) *G. oceanica*; 4) *H. triarcha*; 5) *O. antillarum*; 6) *O. fragilis*; 7) *Scyphosphaera* sp.; 8) *M. adriaticus*; 9) *G. corolla*; 10) *Sy. prolongata*; 11) *Sy. variabilis*; 12) *Sy. variabilis* type D; 13) *U. irregularis*; 14) *U. tenuis*; 15) *U. sibogae* var. *foliosa*; 16) Indetermined.

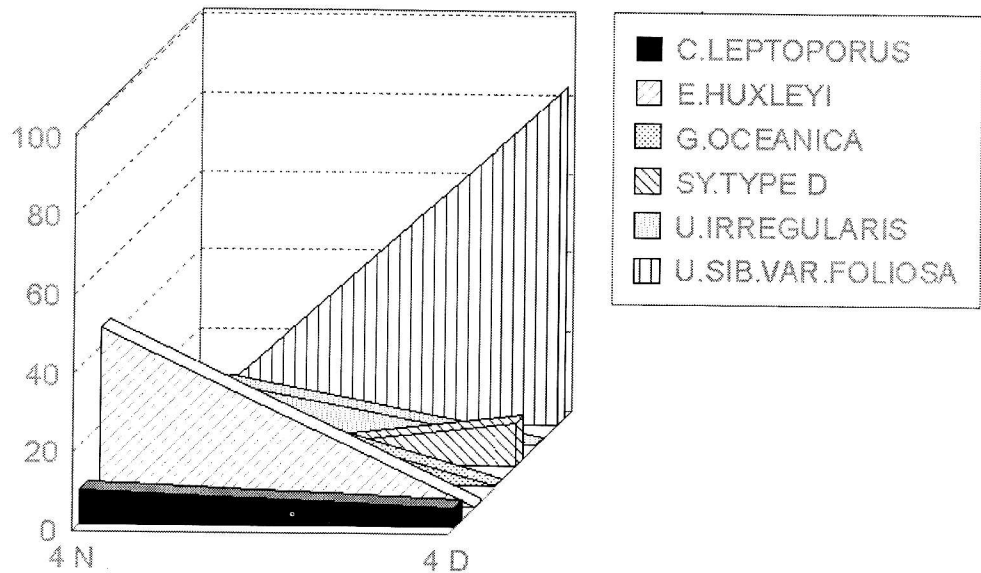


Fig. 7 - Samples from Stn. # 4D (60 m), # 4N (60 m). Legend: 1) *C. leptoporus*; 2) *E. huxleyi*; 3) *G. oceanica*; 4) *Sy. variabilis* type D; 5) *U. irregularis*; 6) *U. sibogae* var. *foliosa*.

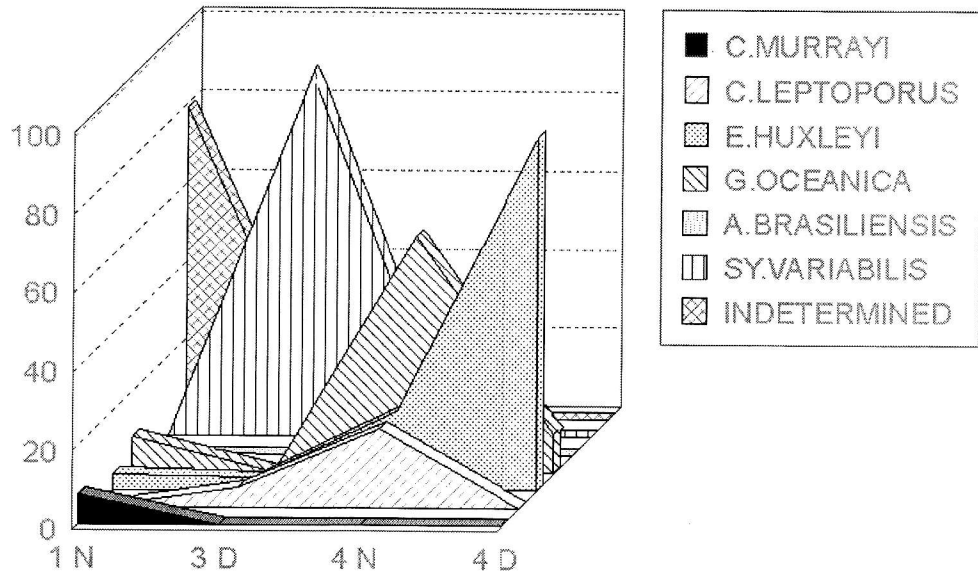


Fig. 8 - Samples from Stn. # 1N (90 m), #3D (80 m), # 4N (80 m), #4D (80 m). Legend: 1) *C. murrayi*; 2) *C. leptoporus*; 3) *E. huxleyi*; 4) *G. oceanica*; 5) *A. brasiliensis*; 6) *Sy. variabilis*; 7) Indetermined.

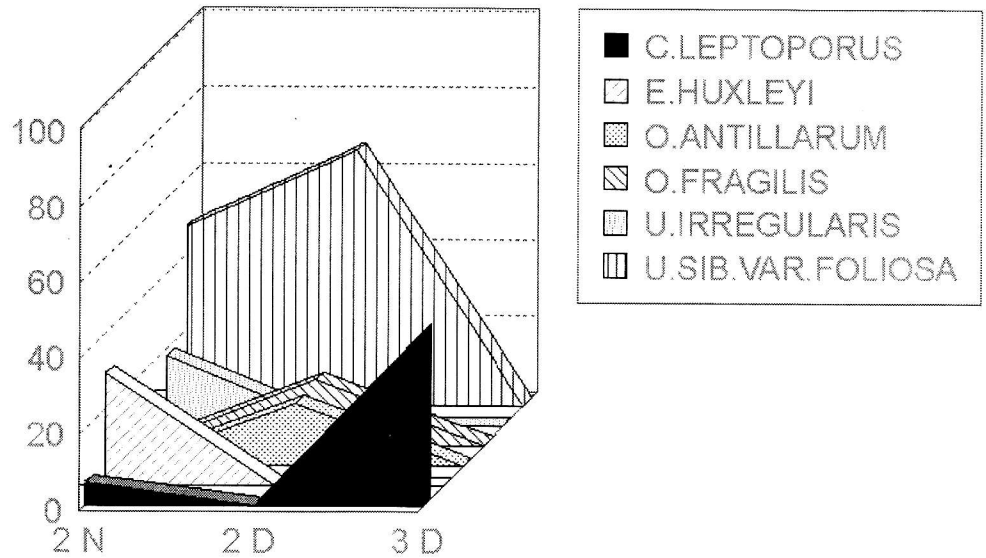


Fig. 9 - Samples from Stn. #2N (100 m), #2D (100 m), #3D (100 m). Legend: 1) *C. leptoporus*; 2) *E. huxleyi*; 3) *O. antillarum*; 4) *O. fragilis*; 5) *U. irregularis*; 6) *U. sibogae* var. *foliosa*.

At 100 m level a total of six species are recorded. Among them, *E. huxleyi* and *U. irregularis* are the two species which are present only at Stn. # 2N. *O. antillarum* and *O. fragilis* are present only at Stn. # 2D. *C. leptoporus* at # 2N & 3D. *U. sibogae* var. *foliosa* is present at all the three stations with percentages ranging from 47 to 67% (Fig. 9).

Since 130 m level samples were examined only at station # 1N, the floral assemblages are not represented by any figure. Three species were encountered, among which, *U. sibogae* var. *foliosa* is predominant followed by *E. huxleyi* and *G. oceanica*.

Discussion.

The relative increase in coccolithophorid cell densities observed at subsurface depths (90 m, 40 m, 40 m and 80 m) at three southern stations # 1N, 2N, 2D & 3D (Fig. 4), may be due to suspected seasonal coccolithophorid blooms and the occurrence of thermocline. In Banda Sea and adjacent areas Kleijne (1990) has observed that coccolithophorid standing crop and species diversity was zero or very low, while floating sediment trap data at subsurface depth (60-100 m) indicated the presence of coccolithophorids. This is attributed to the occurrence of coccolithophorid bloom in the deeper layers of euphotic zone. The increase in abundance and diversity of coccolithophorids in the subsurface layer at 40 m depth, may be due to the occurrence of thermocline. As for example, a well defined thermocline, according to Tsujita (1970) differentiates the surface and bottom layers in the shallow waters with a maximum depth of 65 m. Similar situation was also reported by Okada and Honjo (1975) from Arafura Sea. Although, lateral advection does take place in foraminifera at deeper depths (>1000 m) as evidenced by sediment trap experiments in the Arabian Sea (Curry et al., 1992; Guptha et al., paper under preparation), it is not very clear whether such processes influence the coccolithophorid distribution in the shallower depths of euphotic zone.

Low frequency of coccolith cell densities encountered (Fig. 4) in the surface water of southern stations # 1N, 2N, 2D and 3D may be explained by the fact that the sinking motion as set by the clockwise wind stress curl is a typical characteristic of the SW monsoon over the central Arabian Sea, which results in the inaccessibility to the nutrient rich upwelled water either from the Somali region or the SW coast of India (Sastri & Ramesh Babu, 1985). Further, they have also observed that the spreading of cold water is limited to the coasts of Somalia, Arabia and SW India during May-July. Similarly, Kleijne (1991) also reported moderate density in the Arabian Sea during June-July, 1985, which further confirms that this part of the Arabian Sea experiencing oligotrophic conditions.

E. huxleyi and *G. oceanica* are widely believed to be the most common Recent coccolithophorid species occurring in the low-mid latitudes (McIntyre & Be, 1967; Roth & Coulbourn, 1982). *E. huxleyi* is a cosmopolitan species being found largely in tropical to subtropical waters with a temperature range of 2-30°C and salinity between 16 and 45 ‰ (Okada & McIntyre, 1977).

The abundance of *E. huxleyi* may be explained by the weakened upwelling in September - October during the tail end of summer monsoon season. This results in the depletion of nutrients and deepening of the mixed layer, which must have facilitated *E. huxleyi* blooms, suggesting its preference for low nutrient waters. Recently, Naidu (1993) has observed that in September the mixed layer was at a maximum (>100 m) in the central Arabian Sea which is substantiated by the predominance of foraminiferal warm water species *G. ruber* and almost total absence of upwelling indicator species *G. bulloides* (Guptha et al., 1994). Winter (1982) has also reported high abundance of *E. huxleyi* below the low fertility waters in the sediment along a traverse from Gulf of Aden to Gulf of Aquaba.

U. irregularis is one of the most common species often reported from tropical water, the distribution of which is restricted to water temperatures between 21 and 28°C (McIntyre & Be, 1967).

The occurrence of *U. irregularis*, as the second abundant species presumably indicates prevailing low nutrient levels. It has been further substantiated by Kleijne et al. (1989) who have reported from the western Arabian Sea that the relative frequency of *U. irregularis* shows negative correlation with upwelling conditions indicating its preference for oligotrophic conditions. This is further supported by Parson and Takahashi (1973) who observed this species preference for low nutrient stratified waters. Besides, being a tropical species, the abundance of *U. irregularis* may also be attributed to the warming of surface water. Similarly, evidence of seasonal blooms of *U. sibogae* has been reported from the Panama Basin by Honjo et al. (1982), and Honjo (1982). In spite of the fact that *U. irregularis* being upper photic layer species reported in the central Pacific ocean by Okada & Honjo (1973), this species is largely distributed in the surface layers. Similarly, Okada & Honjo (1975) have also reported the occurrence of *U. irregularis* in the surface layers of the Arafura Sea and Gulf of Carpentaria.

In addition to the above, the presence of malformed specimens of *E. huxleyi* at stations # 2 D, 2 N & 4 N (Pl. 3, fig. 4, 6, 7) was frequently noticed and interpreted as the results of stresses in the hydrographic environment. Malformation may either be caused by dissolution (Schneidermann, 1977; Roth & Berger, 1975) or by incomplete formation (Kleijne, 1990). Woellner et al. (1988) have reported that 86% of *E. huxleyi* specimens in the Arabian Sea were malformed during the summer upwelling. Okada and Honjo (1975) and Wang and Samtleben (1983) interpreted malformed coccoliths as affected by rapid disintegration and dissolution which ultimately result in rarity or absence of *E. huxleyi* in the sediment. Based on the data from Arafura Sea and Gulf of Carpentaria, Okada and Honjo (1975) have concluded that no direct relationship exists between the malformation and sea surface temperature, salinity, ammonium, phosphate and dissolved oxygen. However, malformation was negatively correlated with nitrates. Furthermore, they have tentatively attributed malformations to the lack of nutrients in the water induced by the overcrowding of the phytoplankton. While, Watabe & Wilbur (1966) and McIntyre & Be (1967) have attributed malformation to temperature. Kleijne (1990) suggested the nitrogen deficiency along with low sea-sur-

face salinity as a causative mechanism for malformation in coccoliths. Young and Westbroek (1991) have suggested that the shortage of trace nutrients is responsible for malformation in cultured specimens of *E. huxleyi*. The lack of data on nutrients in the Arabian Sea prevents the testing of the proposed models of coccolith malformation as a response to nutrient availability. In contrast, Giraudeau et al. (1993) have contradicted the nutrient deficiency as the main cause of malformation. Their study suggests that the population of malformed coccoliths has been transported into their study area off Namibia. Houghton and Guptha (1991) have stated that the poor preservation potential of malformed coccoliths may have impact on the dominance of coccolithophorid species in the sediment.

G. oceanica is predominantly a low latitude species which prefers a temperature range of 12-30°C (Okada & McIntyre, 1977). Although *G. oceanica* is the dominant species in Recent continental shelf and marginal sea of the Indo-Pacific (Houghton & Guptha, 1991), its occurrence in the southern Arabian Sea waters is moderate or less abundant. This may be due to the fact that since *G. oceanica* has preference for elevated nutrient levels, it could not flourish well in prevailing oligotrophic conditions. Previous studies by Martini & Muller (1972), Dmitrenko (1985) and Guptha (1979, 1983, 1985, 1986) have demonstrated that *G. oceanica* is the most dominant species in the Arabian Sea. Similarly, Okada and Honjo (1975) have reported dominant *G. oceanica* in the plankton of the Timor Sea. Hallegraeff (1984) based on his studies from NW shelf of Australia has also suggested that *G. oceanica* is the most abundant coccolithophorid in the marginal seas and oceanic waters of northern equatorial and southern mid latitudes of the Indian Ocean.

Following *E. huxleyi* and *U. irregularis*, *C. murrayi* is the third major species comprising of about 11% of the total coccolithophorids; it is restricted to the southernmost stations # 1N & 2N. It is also noticed that this species occurs during night collection and presumably prefers shallow depth. Kleijne (1993) has recorded its rare occurrence from the southern Arabian Sea (south of India).

Similarly, *M. adriaticus*, *Sy. variabilis* and *Sy. variabilis* type D which altogether constitute about 16% are also not consistent in all the stations. The remaining species which are sporadically distributed are considered as subordinate, hence not discussed. Although it has been well established that the zooplankton tend to migrate vertically and increase their abundance during night in the surface, there are no reports available on the increasing abundance of phytoplankton during night as noticed in Stn. # 2 & 4. Owing to very limited data, it is not possible to arrive at any conclusion.

The most striking feature noticed in the present assemblage is an apparent absence of some taxa, such as *Helicosphaera*, *Pontosphaera* and *Ceratolithus* which are quite common in the sediment of the Arabian Sea (Guptha, 1976, 1979, 1986). However, Kleijne (1993) has reported specimens of *C. cristatus* and *H. carteri* from the Indian Ocean during June-July 1985 sample collection. Thus, the tail end of summer monsoon period may not be favourable for the above species, however, they may flourish during different seasons of the year.

The overall assemblage of coccolithophorids is a tropical assemblage. Since this study is based on a few snap shot samples of indeterminate water depths collected during September-October, it may not be possible to compare the coccolithophorid assemblage with the changing temporal hydrography. This is our first attempt in our endeavour to study living coccolithophorids. However, in order to understand the temporal relationship between hydrography and coccolithophorid assemblages, sediment trap samples from both the Arabian Sea and Bay of Bengal are being examined and will be reported elsewhere.

Notes on individual species

Calcidiscus leptoporus (Murray & Blackman) Kamptner

Pl. 1, fig. 9

C. leptoporus is fairly widely distributed in all the three northern stations (Tab. 2 & 3) and with higher relative abundances in the subsurface layer in the photic zone.

Calciosolenia murrayi Gran

Pl. 2, fig. 12

C. murrayi is present in the two southern stations # 1, 2 (Tab. 2 & 3) in the surface and subsurface layers of the photic zone.

Emiliania huxleyi (Lohmann) Hay & Mohler

Pl. 1, fig. 1-3; Pl. 3, fig. 1-7

E. huxleyi is widely reported as the common Recent coccolith species of the world's oceans at low latitudes (McIntyre & Be, 1967; Roth & Coulbourn, 1982). It is a cosmopolitan species abundantly occurring in tropical to temperate waters with temperature range of 2 to 30°C and salinities between 16 and 45 ‰. This is widely distributed in all the four stations in the Arabian Sea. Along with some disintegrated coccoliths, a few intact coccospheres were also encountered some of which at the northern station (#4) show signs of dissolution/malformation (Pl. 3, fig. 1-7).

Gephyrocapsa oceanica (Kamptner)

Pl. 1, fig. 4-6

G. oceanica is largely a low latitude coccolithophorid which prefers waters of wide temperature between 12 and 30°C (Okada & McIntyre, 1977). Although this species is encountered in all the stations, it is only moderately abundant. It is noted that some of the coccoliths in a coccosphere (Pl. 1, fig. 4), show variation in thickness of the bridge, apparently caused by differential dissolution or may be a primary variety.

Homozygosphaera triarcha Halldal & Markali

Pl. 2, fig. 9

These holococcoliths were frequently encountered during day at Station #2. It has previously been reported from the Indian Ocean by Norris (1985), Friedinger & Winter (1987) and Kleijne (1991).

Oolithotus antillarum (Cohen) Reinhardt

Pl. 2, fig. 5

Oolithotus fragilis (Lohmann) var. **cavum**

Pl. 2, fig. 6

The coccosphere and individual coccoliths of this variety resemble very closely the specimens illustrated by Okada and McIntyre (1977, p. 11, pl. 4, fig. 4-5), and Winter et al. (1979, p. 11, pl. 2, fig. 2). This species is present only at two stations (#1 and #2) in the southern Arabian Sea.

Rhabdosphaera clavigera Murray & Blackman

Pl. 2, fig. 10

R. clavigera is a very rare rhabdolite in the southern Arabian Sea.

Anoplosolenia brasiliensis (Lohmann) Deflandre

Pl. 2, fig. 8

This is a very rare coccolith found at Stn. #1 and #2 (N) of the southern Arabian Sea.

Michaelsarsia adriaticus (Schiller) emend. Manton et al.

Pl. 2, fig. 3

This coccolith species closely resembles the SEM photograph of Okada and McIntyre (1977, p. 43, pl. 7, fig. 7-8). This species is well represented at station #2 only.

Gardieria corolla (Lecal) comb. nov.

Pl. 2, fig. 4

This is a very rare species encountered at 40 m depth at station # 2D.

Syracosphaera prolongata Gran ex Lohmann

Like *G. corolla*, this is also a very rare species encountered only at 40 m depth in station # 2N.

Syracosphaera pulchra Lohmann

It is found in traces only at station # 2D.

Syracosphaera variabilis (Halldal & Markali) Okada & McIntyre, n. comp.

This species is fairly well distributed in the subsurface lower photic layer at station #2 and 3.

Umbellosphaera irregularis Paasche

Pl. 1, fig. 10-12

Typical salpingiform coccolith, *U. irregularis* is a tropical species occurring at all the stations of the Arabian Sea. It ranges in abundance from 12.3 to 64% and is predominantly distributed at stations #2 and #3.

Umbellosphaera tenuis (Kamptner) Paasche

Pl. 2, fig. 1,2

This species closely resembles the scanning electron micrograph of Winter et al. (1979, p. 205, pl. 3, fig. 1). It exhibits the characteristic radial ribs which extend continuously from the centre to the periphery of the coccolith. Besides, protruding knob like structures are common between the long radial ribs. It is warm/temperate in habitat.

Unlike *U. irregularis*, it is not widely distributed in the Arabian Sea. Although this species overlaps the *U. irregularis*'s distribution, its habitat extends into colder and deeper waters (Okada & McIntyre, 1977).

Umbilicosphaera sibogae (Weber-van Bosse) Gaarder var. **foliosa** (Kamptner) Okada & McIntyre

Pl. 1, fig. 7, 8

U. sibogae var. *foliosa* is one of the four dominant species at all stations. Its abundance ranges from 1.7% to 84.0% and is more abundant in the deeper layers of the photic zone at Stn.# 1,2 & 3, whereas in the northernmost station #4 it occurs in abundance in surface and subsurface layers of the photic zone.

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PLATE 1

- Fig. 1 - *Emiliania huxleyi* (Lohmann) Hay & Mohler. Intact coccosphere. Stn.# 2D, 40 m; x 17,000.
- Fig. 2 - *Emiliania huxleyi* (Lohmann) Hay & Mohler. Partly disintegrated coccosphere. Stn.# 2D, 40 m; x 12,000.
- Fig. 3 - *Emiliania huxleyi* (Lohmann) Hay & Mohler. Individual coccolith. Stn.# 2D, Surface; x 40,000.
- Fig. 4 - *Gephyrocapsa oceanica* (Kamptner). Intact coccosphere. Stn.# 2D, 40 m; x 13,000.
- Fig. 5 - *Gephyrocapsa oceanica* (Kamptner). Individual coccolith with marked thickening of the bridge. Stn.# 2D, 40m; x 14,000.
- Fig. 6 - *Gephyrocapsa oceanica* (Kamptner). Individual coccolith, note thinning of bridge. Stn.# 2D, 40 m; x 22,000.
- Fig. 7 - *Umbilicosphaera sibogae* var. *foliosa* (Kamptner) Okada & McIntyre. Intact coccosphere. Stn.# 4N, 60 m; x 7,000.
- Fig. 8 - *Umbilicosphaera sibogae* var. *foliosa* (Kamptner) Okada & McIntyre. Individual coccolith. Stn.# 2D, 40 m; x 14,000.
- Fig. 9 - *Calcidiscus leptoporus* (Murray & Blackman) Kamptner. Individual coccolith. Stn.# 4N, 60 m; x 6,000.
- Fig. 10 - *Umbellosphaera irregularis* Paasche. Intact coccosphere. Stn.# 2D, 40 m; x 5,000.
- Fig. 11 - *Umbellosphaera irregularis* Paasche. Individual coccolith. Stn.# 2N, Surface; x 3,000.
- Fig. 12 - *Umbellosphaera irregularis* Paasche. Broken coccolith along with *E. huxleyi* & *Syracosphaera* sp. Stn.# 2D, 40 m; x 8,500.

PLATE 2

- Fig. 1 - *Umbellosphaera tenuis* (Kamptner) Paasche. Individual coccolith along with coccoliths of *U. irregularis*. Stn.# 1N, Surface; x 9,000.
- Fig. 2 - *Umbellosphaera tenuis* (Kamptner) Paasche. Individual coccolith. Stn.# 2D, 40 m; x 17,000.
- Fig. 3 - *Michaelsarsia adriaticus* (Schiller) emend. Manton et al. Individual coccolith. Stn.# 2D, 40 m; x 25,000.
- Fig. 4 - *Gaarderia corolla* (Lecal) comb. nov. Individual coccolith. Stn.# 2D, 40 m; x 14,000.
- Fig. 5 - *Oolithotus antillarum* (Cohen) Reinhardt. Intact coccosphere. Stn.# 2D, 40 m; x 12,000.
- Fig. 6 - *Oolithotus fragilis* (Lohmann) Martini & Muller. Individual coccolith. Stn.# 4D, 80 m; x 4,000.
- Fig. 7 - *Syracosphaera variabilis* type D of Kleijne. Intact coccosphere. Stn.# 2N, 40 m; x 3,500.
- Fig. 8 - *Anoplosolenia brasiliensis* (Lohmann) Deflandre. Individual coccolith. Stn.# 1N, 90 m; x 4,000.
- Fig. 9 - *Homozygospaera triarcha* Halldal & Markali. Stn.# 2D, 40 m; x 16,000.
- Fig. 10 - *Rhabdosphaera clavigera* Murray & Blackman. Individual helatiform rhabdolite. Stn.# 1N, Surface; x 4,000.
- Fig. 11 - *Indetermined coccolith* (?). Individual coccolith. Stn.# 1N, 90 m; x 23,000.
- Fig. 12 - *Calciosolenia murrayi* Gran. Showing polymorphism. Stn.# 2N, 40 m; x 3,000.

PLATE 3

Emiliania huxleyi (Lohmann) Hay & Mohler; x 4,000.

- Fig. 1 - Partly disintegrated coccosphere with dissolved (?) coccoliths. Stn.# 4D, 60 m.
- Fig. 2 - Partly dissolved (?) coccoliths. Stn.# 2N, 40 m.
- Fig. 3 - Intact coccoliths showing very good preservation. Stn.# 1N, Surface.
- Fig. 4 - Partly broken coccoliths. Stn.# 2D, 40 m.
- Fig. 5 - Solitary coccolith. Stn.# 4N, 80 m.
- Fig. 6 - Coccoliths corroded by dissolution. Stn.# 4N, 80 m.
- Fig. 7 - Malformed coccolith showing absence of outer rim that joins the elements at the periphery. Stn.# 4N, 80 m.
- Fig. 8 - Malformed coccolith. Stn.# 1N, 130 m.
- Fig. 9 - Corroded coccolith. Stn.# 1N, 130 m.
- Fig. 10 - Corroded/broken coccolith. Stn.# 1N, 130 m.

