

Distribution of coccolithophores as a potential proxy in paleoceanography: The case of the Oman Sea monsoonal pattern

ELHAM MOJTAHEDIN¹✉, FATEMEH HADAVI¹ and RAZYEH LAK²

¹Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, IR Iran; ✉e.mojtahedin@yahoo.com

²Research Institute for Earth Sciences, Geological Survey of Iran, Tehran, IR Iran; lak@ries.ir

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Abstract: High abundances of coccoliths have been observed in surface sediment samples from near the coasts of the Oman Sea in February 2011. At the end of the NE monsoon, the locally observed high *Gephyrocapsa oceanica* production is hypothesized to respond to local injections of nutrient-rich deep water into the surface water due to sea-surface cooling leading to convection. The most abundant coccolithophore species are *G. oceanica* followed by *Emiliania huxleyi*, *Helicosphaera carteri*, *Calcidiscus leptoporus*. Some species, such as *Gephyrocapsa muelleri*, *Gephyrocapsa ericsonii*, *Umbellosphaera sibogae*, *Umbellosphaera tenuis* and *Florisphaera profunda*, are rare. The *G. oceanica* suggested a prevalence of upwelling conditions or high supply of nutrients in the Oman Sea (especially West Jask) at the end of the NE monsoon. *E. huxleyi* showed low relative abundances at the end of the NE monsoon. Due to the location of the Oman Sea in low latitudes with high temperatures, we have observed low abundances of *G. muelleri* in the study area. Additionally, we have identified low abundances of *G. ericsonii* at the end of the NE monsoon. *Helicosphaera carteri* showed a clear negative response with decreasing amounts (relative abundances) at the end of the NE monsoon. *C. leptoporus*, *U. sibogae* and *U. tenuis* have very low relative abundances in the NE monsoon and declined extremely at the end of the NE monsoon. *F. profunda*, which is known to inhabit the lower photic zone (< 100 m depth) was rarely observed in the samples.

Key words: Coccolithophores, northeast monsoon, nanoplankton distribution, paleoceanography, Oman Sea.

Introduction

Coccolithophores, being very sensitive to changing environmental conditions, play a vital role in reconstructing the paleoceanography of Quaternary sediments. Recently, coccolithophores have gained increased attention as they make an important contribution to oceanic primary production (Westbroek et al. 1993). However, a better understanding of coccolithophore ecology is necessary in order to use them successfully as a biotic proxy of past climate change and to assess the quality and accuracy of the information preserved in the sedimentary record (Ziveri & Thunell 2000). The hydrography of the Oman Sea is controlled by the Indian Ocean monsoon. This inter-hemispheric phenomenon represents one of the Earth's most dynamic interactions between atmosphere, oceans and continents, and influences climate seasonally from eastern Africa through to southeast Asia. Environmental gradients change distinctly between the SW-monsoon in summer and the NE-monsoon in winter (Fig. 1a). Plankton productivity is directly dependent on the seasonally changing wind system leading to strong seasonality in export production with peaks during the SW- and NE-monsoons (Nair et al. 1989; Haake et al. 1993; Ramaswamy & Nair 1994). Upwelling is one of the phenomena that occur in the West Oman Sea near West Jask.

A new insight into the reconstruction of the oceanographic variations in the Oman Sea related to the monsoon system is presented in this paper. A first step attempts to relate cocco-

lithophore assemblages with oceanographic conditions in the upper water column. Thereby, we hope to obtain information on the oceanographic response to the recent monsoonal system useful for the paleo-climatic and paleo-oceanographic interpretation of fossil coccolithophores in the Oman Sea sediments during the Holocene.

Previous studies

There is no report on coccolith distribution in the sediments of the Oman Sea, but some papers were produced on micropaleontology from the foraminifera point of view, including Moghaddasi et al. 2009a,b. The first report on the coccolithophores of the Persian Gulf was written by Martini (1971). Kessler (1971) observed the calcareous nannofossils in the Holocene soft and fine grain marls of the Persian Gulf as predominant microfossils which exist mainly in the surface sediments as well as in the area with huge amounts of carbonate. A list of 10 species of calcareous nanoplankton was reported by Al-Saadi et al. (1978). The first study of phytoplankton of the Iranian part of Persian Gulf was carried out by Hulbert et al. (1981). According to Andruleit et al. (2000), *G. oceanica*, *F. profunda* and *E. huxleyi* are abundant in the NE Arabian Sea samples and their productivity increases during the SW and NE monsoon. Andruleit et al. (2003) studied the samples from the North of the Arabian Sea. Andruleit et al. (2005) reported the origin and the oscillation of Coccolithophores in

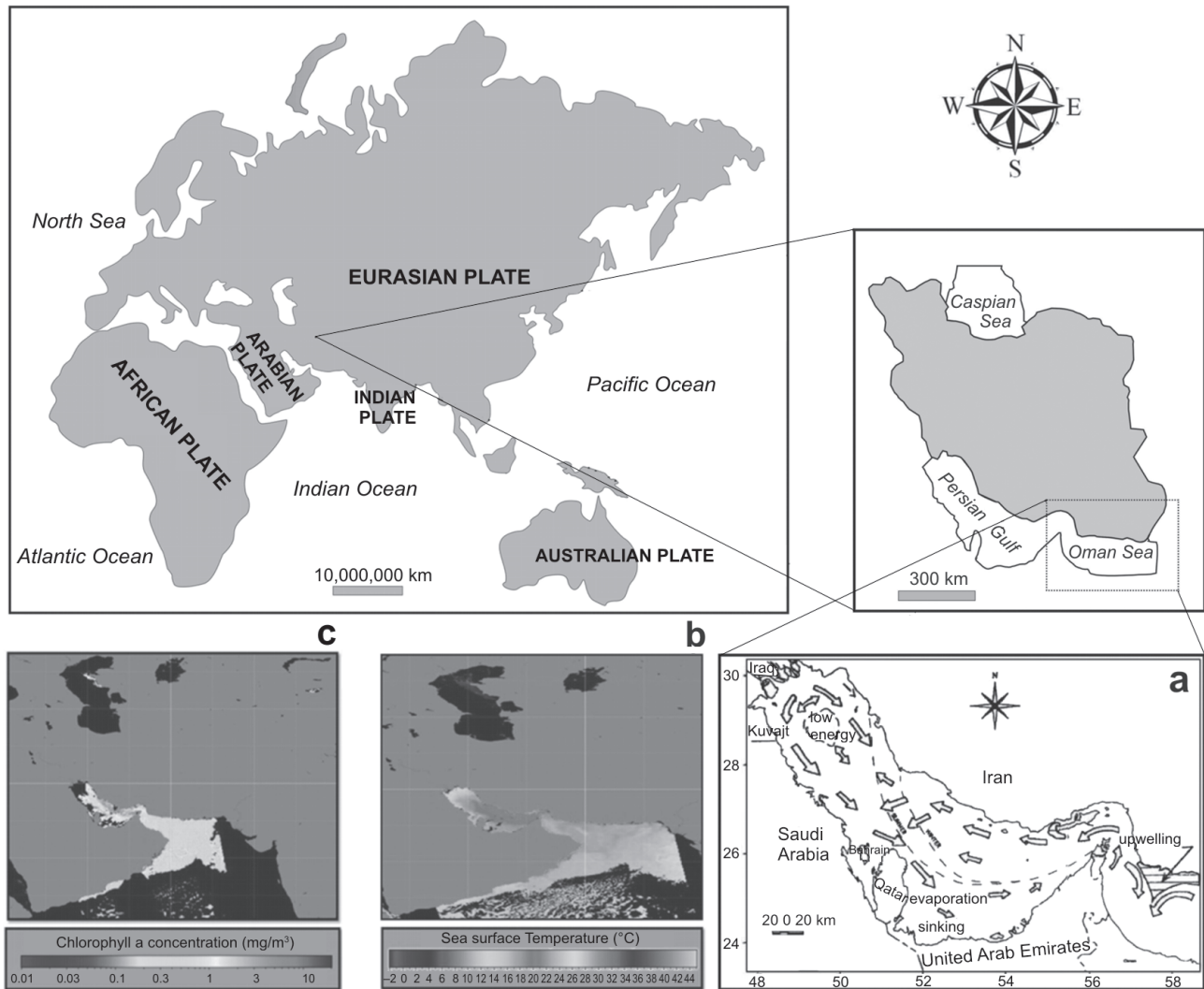


Fig. 1. a — General wind and surface water circulation in the Oman Sea and Arabian Sea, b — Sea surface Temperature in the Oman Sea in February 2011, c — Chlorophyll concentration (mg/m^3) in Oman Sea in February 2011.

the North of the Arabian Sea. The oscillation of Coccolithophores varies in the sediments which are deposited per season. The relationships between seasonal deposition, the abundance of index species and their calcification were investigated. Hadavi (2011) has sampled the Persian Gulf from various latitudes in order to investigate the variety of Coccolithophores and the paleoecological studies. Poursmaeil et al. (2012) studied Holocene surface sediments of the Persian Gulf.

Environmental settings

The Oman Sea is located between 22 and 26°N and 56 and 62°E. It opens onto the Northwestern Indian Ocean and Arabian Sea. The general orientation of the Oman Sea is northwest-southeast. In terms of geomorphology, this semi-enclosed basin is “a bathymetric triangle” featuring a range of depths of up to 3000 m in its oceanic part, but with the shallow Murray Ridge extending across the mouth of the Oman Sea. It is situated in the subtropical zone and has the total area

of 94,000 km^2 . The basin narrows down and gets shallower towards the Strait of Hormuz — the westernmost boundary of the Oman Sea, where depths of 70–110 m separate it from the inner part of the Oman Sea, with an average depth of ~35 m. The region is arid leading to substantial evaporation, greatly exceeding precipitation and river discharge.

White & Loudon (1982) showed that the crust beneath the Oman Sea is oceanic in nature, with about 6 km of oceanic igneous crust underlying 7 km of normally compacted sediments; from a refraction line on the Makran continental crust they found that the oceanic crust dips northward to an angle of 1.5° to 2° with a steadily thickening wedge of overlying sediment. This is in agreement with simple two dimensional gravity models across the margin (White 1979). These sediments mainly consist of a lower section with turbidite about 4 km thick called the Himalayas (Paleocene–Miocene) and an upper section with a thickness of about 3 km known as the Makran Sand (Pliocene–Pleistocene). Sediments known as the Makran Sand, are covered by a thin coating of Holocene sediments on them.

Being situated between the shallow high salinity waters of the Persian Gulf and the deeper Arabian Sea, the Oman Sea possesses a unique hydrological regime. The modern summer monsoon is primarily driven by differential (land-ocean) sensible heating and tropospheric latent heating (Clemens et al. 1991). These combined mechanisms result in a distinct atmospheric circulation system with seasonally changing wind directions. In winter, during the Northeast Monsoon, the current transporting the Arabian Sea water mass from the oceanic regions into the Oman Sea is headed towards its inner part along the northern (Iranian) coast. In summer, during the Southwest Monsoon, the sea is influenced by the outflow of high saline Oman Sea water mass. The current exits from the Oman Sea in the Strait of Hormuz at a depth of ~ 100 m, cascade down to the bottom and propagate along the Omani coast towards the open Arabian Sea. A well pronounced density front separates high saline deep water in the Oman Sea from fresher surface waters in it (Piontkovski et al. 2012). The most prominent

feature of the Oman Sea is the seasonal upwelling along the Iranian coast, with a peak in February–March, although the onset of the Northeast monsoonal winds could occur in December. During the Northeast Monsoon, the Oman Coastal Current reverses to a southeastward flow. The climate in the Oman Sea is markedly different from the climate in the Arabian Gulf. While the Oman Sea is affected mainly by extratropical weather systems from the northwest, the Oman Sea is situated on the northern edge of the tropical weather systems in the Arabian Sea and Indian Ocean.

The sea surface temperature (<http://seawifs.gsfc.nasa.gov/SEAWIFS.html>) distribution exhibits medium to relatively high temperature of the study area (Fig. 2b). This configuration clearly depicts the influence of the NE monsoon. During the NE-monsoon, low water temperatures in the northeast are caused by cool and dry winds. Chlorophyll concentrations (<http://seawifs.gsfc.nasa.gov/SEAWIFS.html>) have their maxima during the NE-monsoon in the entire Oman Sea (Fig. 2c).

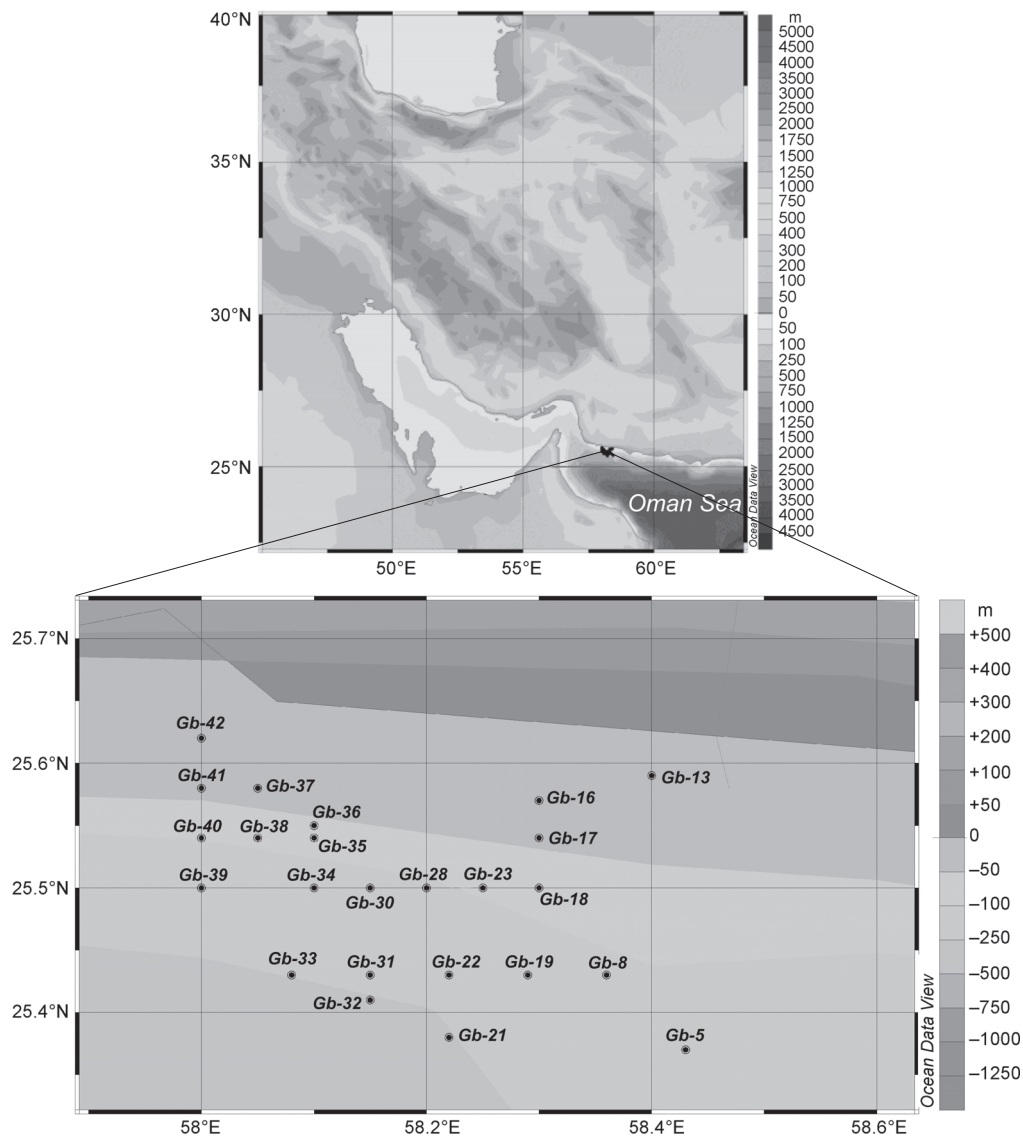


Fig. 2. Bathymetry of the study area with location of the samples (Gabrik area).

Materials and methods

Surface sediment samples for the present study were collected in the Oman Sea in February 2011 at the end of the NE-monsoon. The samples were collected with grabs by a research cruise. The materials were carefully taken from the average of 3–5 centimeters from beneath the Oman Sea. In this time of the year sea surface temperatures are still on a relatively high level with up to 23 °C (Fig. 1,b). A total of 72 surface sediment samples were collected at the end of the NE monsoon (February 2011) in the Oman Sea to define coccolith abundance from the Gabrik (Fig. 2) and West Jask areas (Fig. 3) from 0–250 m water depth. In order to study general changes in the floral composition light microscope study was undertaken using simple smear slides (Bown & Young 1998). A smear slide is a thin layer of unconsolidated sediment embedded on a glass slide for microfossil microscopic examination. This is a powerful method for ascertaining the

presence of microfossils. With experience, smear slides provide surprisingly accurate percentage data useful for recognizing trends in cored sequences and surface sediment samples. The slide was labelled temporarily with a felt marking pen. The hot plate was placed in a fume hood and it was set at about 150 °C (or about 300 F). The exact setting must be determined by experiment. A small amount of sample was placed in the center of the slide. A drop of distilled water was added and the sample was spread into a thin layer with a glass rod. The slide was placed on the hot plate to dry. Then, several minutes were allowed (exact time depends on the temperature and amount of xylene used as a thinner), before a glass cover slip was placed over the sample. The cover slip was pressed down with a pair of tweezers. The slide was removed from the hot plate and cooled. The slide was then permanently labelled with a glass scribe (carbide tip).

The samples were examined with an OLYMPUS BH-2 microscope using polarizing light at a magnification of X1000.

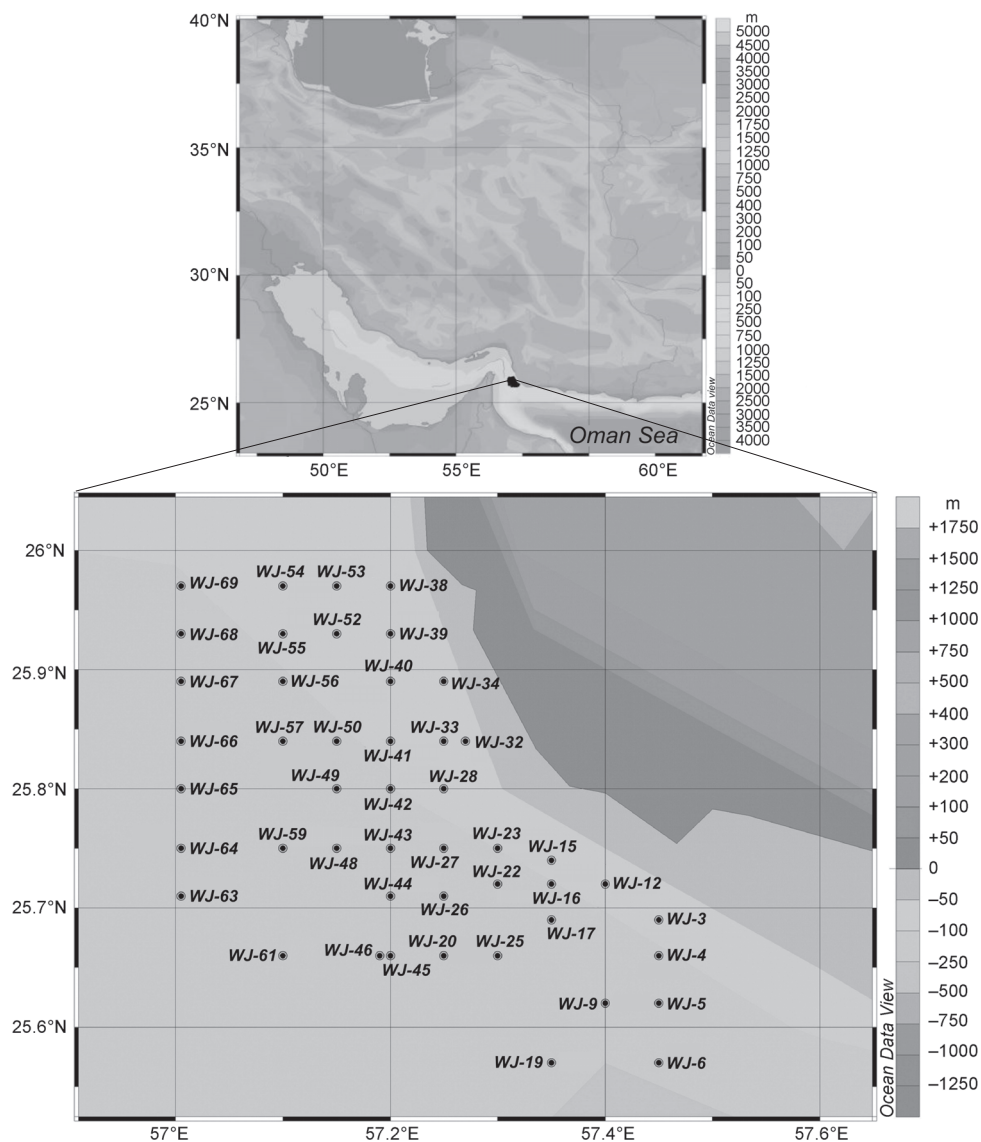


Fig. 3. Bathymetry of the study area with location of the samples (West Jask area).

At least 300 specimens per sample were identified following the taxonomic descriptions of Kleijne (1993), Jordan & Kleijne (1994) and Young et al. (2003).

The count was performed with the light microscope and only the check of species taxonomy was done with the SEM. The results are expressed as percentages. Samples were investigated using a Scanning Electron Microscope (SEM). The samples for the SEM examination were prepared using the filtration technique of Andruleit (1996). The freeze-dried

sediment was weighed on a high precision balance, wet separated with a rotary splitter (FRITTSCH Laborette 27) and filtered through polycarbonate filters (pore size 0.25 μm) by means of a vacuum pump. A wedge-shaped piece was cut out of the dry filter, mounted on an aluminium stub and sputter coated with gold. High-resolution images were taken from the tip to the margin of the filter wedge on a SEM (LEO 1450VP) and subsequently examined on a qualitative and quantitative basis (Fig. 4).

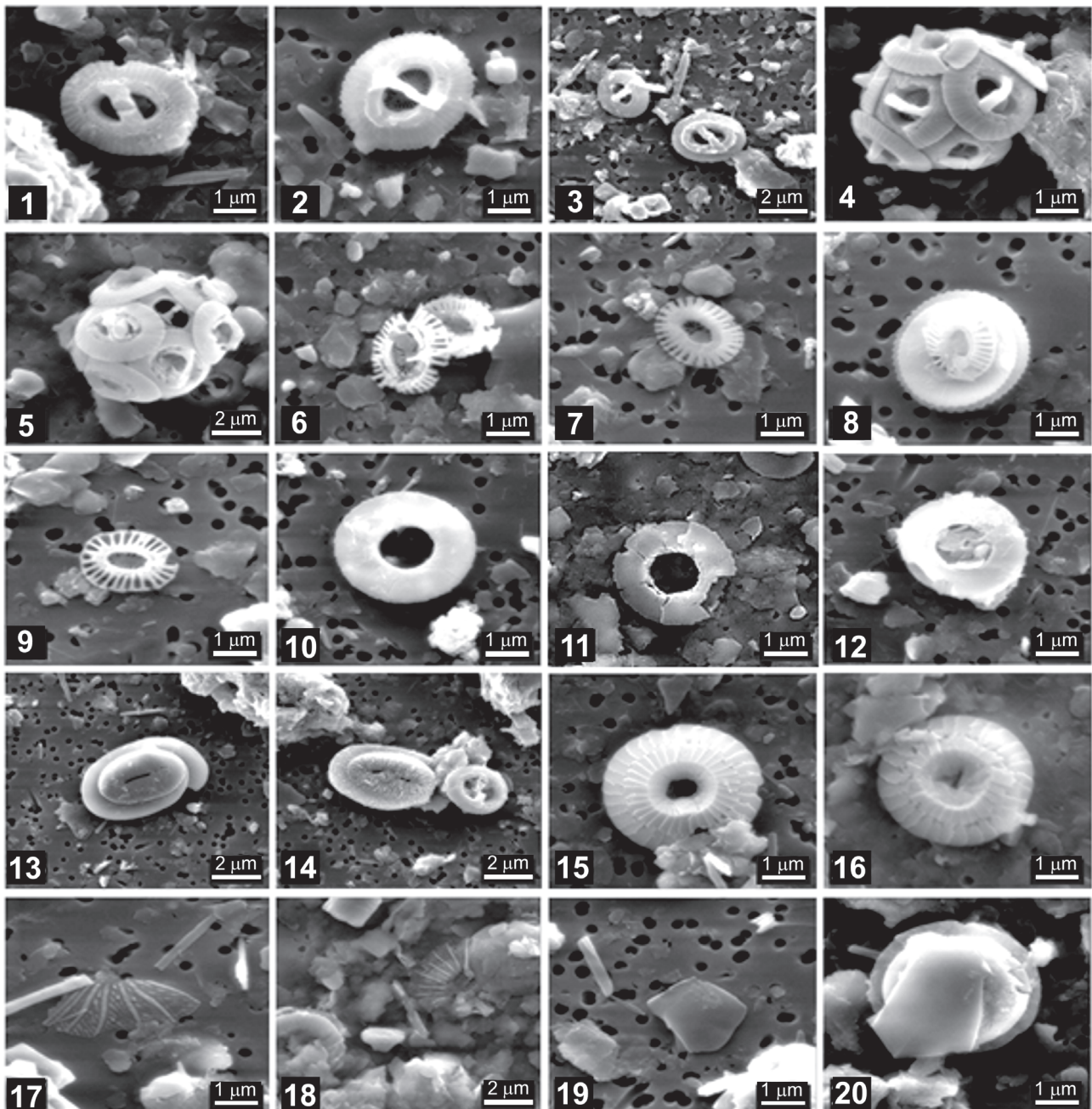


Fig. 4. 1-3 — *Gephyrocapsa oceanica* Kamptner, 1943; 4, 5 — Coccosphere of *G. oceanica* Kamptner, 1943; 6-9 — *Emiliania huxleyi* (Lohman, 1902) Hay & Mohler in Hay et al., 1967; 10-12 — *Umbilicosphaera sibogae* (Weber-van Bosse, 1901) Gaarder, 1968; 13, 14 — *Helicosphaera carteri* (Wallich, 1877) Kamptner, 1954; 15, 16 — *Calcidiscus leptoporus* (Murray & Blackman, 1898) Leoblich & Tappan, 1978; 17, 18 — *Umbellosphaera tenuis* (Kamptner, 1937) Paasche in Markali & Paasche, 1955; 19, 20 — *Florisphaera profunda* Okada & Honjo, 1973.

Results and discussion

The knowledge obtained from sinking coccolithophore assemblages as collected from surface sediments is a basic prerequisite for interpreting and validating the paleoceanographic and paleoecological significance of the fossil remains in the Oman Sea sediments.

We have drawn the following conclusions from our data:

(1) This study has enabled us to identify 41 species of coccoliths. This study is a part of an ongoing investigation aiming at the reconstruction of paleoenvironmental conditions in the Oman Sea as revealed by coccolithophores;

(2) From a total of 41 identified taxa *Gephyrocapsa oceanica* is the most important species of the assemblages. All coccoliths and coccospheres are well to moderately well preserved;

(3) Several species showed spatial trends according to the NE monsoon development which may be used to improve paleoclimatic reconstructions:

(a) The relative proportions of *E. huxleyi* are low in relative abundance compared to *G. oceanica*. *E. huxleyi* shows low relative abundances at the end of the NE monsoon in these areas suggesting that it is not a typical upwelling species;

(b) The Oman Sea is located at a low latitude and has high temperatures. Low abundances of *G. muelleriae* were observed in the study area. The relative abundance of *G. ericsonii* declines during the NE monsoon;

(c) *Helicosphaera carteri* has very lower relative abundances in the NE monsoon and declines with the NE monsoon;

(d) *Calcidiscus leptoporus*, *Umbilicosphaera sibogae* and *Umbellosphaera tenuis* responded negatively with decreasing amounts (relative abundances) at the end of the NE monsoon in these areas. These species are regarded as oceanic species but also seem not to be able to positively react to conditions.

High relative abundance of coccolithophores prevails during the NE monsoonal phase. This seems to be related to high coccolithophore productivity possibly triggered by high nutrient availability. The positive response of coccolithophores to improved nutrient availability within upwelling areas was mentioned by Kleijne et al. (1989). In the Oman Sea surface water productivity is very high during the NE monsoon. With the beginning of the NE monsoon, nutrients are injected into the upper layer due to surface water cooling and wind-induced deeper mixing by the relatively cold winter monsoonal winds (Madhupratap et al. 1996). This process is indicated by a decline in temperature. Coccolithophore production appears to respond to these environmental changes. This results in a strong increase in the relative abundance of some coccolith species as well as foraminifers (Moghaddasi et al. 2009a,b). Apparently, the input of nutrients rather than the decline in temperature during the winter monsoon is the controlling factor for coccolithophore distribution.

Relative species abundances and oceanographic conditions

Relative abundances of some coccolith species show specific spatial trends according to the monsoonal development and are used to discuss the pattern distribution of species. The

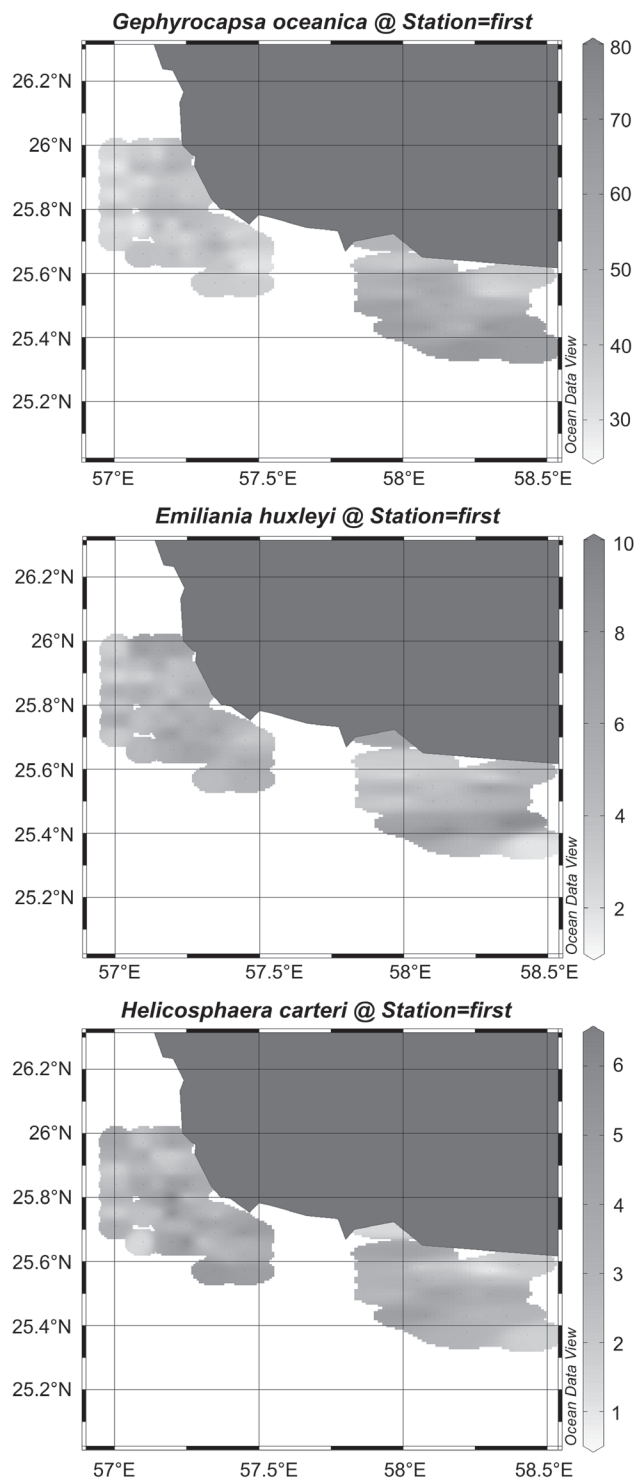


Fig. 5. Distribution pattern of *Gephyrocapsa oceanica*, *Emiliana huxleyi* and *Helicosphaera carteri* in the Oman Sea (Gabrik and West Jask areas).

relative abundance of the different species identified in the studied areas is as follow (the percentage of abundance from Gabrik and West Jask, respectively): *G. oceanica* (47.9 % and 38.92 %), *E. huxleyi* (4.71 % and 4.77 %), *H. carteri* (3.03 % and 3.27 %), *C. leptoporus* (0.34 % and 0.79 %), *G. muellerae* (0.43 % and 2.69 %), *G. ericsonii* (0.93 % and 2.62 %), *F. profunda* (0.14 % and 0.17 %), *U. sibogae* (0.22 %

and 2.51 %) and *U. tenuis* (0.16 % and 0.19 %). A spatial trend can be recognized in the calculated relative abundance of coccolith species. Data are shown in Tables 1 and 2 in alphabetical order, with only the important species presented here:

According to Bollmann (1997) at least one morphological group of the genus *Gephyrocapsa* is preferentially found in sediments from upwelling areas. Despite the very short sam-

Table 1: Location of the investigated surface sediment samples and data of species (% relative abundance) in the Gabrik area.

Station	Longitude	Latitude	<i>Calcidiscus leptoporus</i>	<i>Emiliania huxleyi</i>	<i>Florisphaera profunda</i>	<i>Gephyrocapsa ericsonii</i>	<i>Gephyrocapsa muellerae</i>	<i>Gephyrocapsa oceanica</i>	<i>Gephyrocapsa parallela</i>	<i>Helicosphaera carteri</i>	<i>Umbellosphaera tenuis</i>	<i>Umbilicosphaera sibogae</i>	Other
WJ-3	57.45	25.69	1	3	0	3.66	3	41.33	4.66	5	0	1.66	36.69
WJ-4	57.45	25.66	1.66	4.33	0	1.66	2	31.33	5.66	3	0.33	3.66	46.37
WJ-5	57.45	25.62	0.66	5.66	0.33	3	4.33	27.66	4.33	3.33	0	3	47.7
WJ-6	57.45	25.57	1.33	5	0	1	3.33	37	2.66	4.66	0.66	2	42.36
WJ-9	57.4	25.62	2.33	4.33	0	4	1.66	41	1.66	2.66	0	1	41.36
WJ-12	57.4	25.72	0.66	4	0.66	1	6.33	31.33	4	4	0	2.66	45.36
WJ-15	57.35	25.74	1	5.66	0	3.33	3.66	41.66	5.66	2	0	1.33	41.7
WJ-16	57.35	25.72	1.66	7	0	2	1.66	46	1.66	4.33	0.33	0.66	34.7
WJ-17	57.35	25.69	0.66	4.66	0	1.66	3	51.33	1.33	3	0	2	32.36
WJ-19	57.35	25.57	1.33	4	0.33	1.33	4	37.66	6	5	0	3	37.35
WJ-20	57.3	25.66	2.33	6.33	0	4.66	1	41.66	7	2	0.33	3.66	31.03
WJ-22	57.3	25.72	1	5.66	0.33	3	2	39.33	2.33	4.66	0.33	4.66	36.7
WJ-23	57.3	25.75	2	4.66	0	1.66	0.66	43	4.33	2.66	0.66	1.66	41.71
WJ-25	57.25	25.66	1	6.66	0.66	3.33	2.33	34.66	3	5.66	0	2.33	40.37
WJ-26	57.25	25.71	0.66	5	0	2	1	32.33	1.33	2.66	0	4	51.02
WJ-27	57.25	25.75	0	5.66	0.33	1.33	2	47.33	5.33	3.66	1	2.66	30.7
WJ-28	57.25	25.8	0	4.33	0	4.33	1.33	45	2.66	2	0	3.66	36.69
WJ-32	57.27	25.84	0	5.66	0.33	1.66	4.33	40.66	4.33	3	0	1.66	41.37
WJ-33	57.25	25.84	0.66	4.66	0.33	4	1.66	35	2	5.33	0.33	1	45.03
WJ-34	57.25	25.89	1.66	4	0	2.66	3	41.66	4	2.66	0	2	41.36
WJ-41	57.2	25.97	1	7	0	1.66	4.66	45.66	3	4.33	0	1.33	31.36
WJ-39	57.2	25.93	0.33	3.33	0.66	3.66	2	50.33	2.33	1.66	0	2	33.7
WJ-40	57.2	25.89	0	3.66	0	3	1.33	41.66	3.66	2	0	4.33	43.36
WJ-41	57.2	25.84	0.66	3	0	2.33	1.66	42.66	5	4.66	0.66	2.33	37.04
WJ-42	57.2	25.8	0	5.66	0	1	2.66	49	1.33	6.33	0	1.66	32.36
WJ-43	57.2	25.75	1.33	4	0.66	5	0.66	32	2.66	5.66	0	1	47.03
WJ-44	57.2	25.71	1	7.33	0	2.33	3.33	36.66	2	2.66	0	2.33	42.36
WJ-45	57.2	25.66	1.66	6	0	3.66	1.66	46.33	1.66	5	0	1	33.03
WJ-46	57.19	25.66	0.66	4.66	0	1.33	2.66	41.33	4	3.66	0.66	1.66	42.41
WJ-47	57.98	25.71	0.33	6.33	0.33	0.66	3	48	2.33	1.33	0	1.33	36.36
WJ-48	57.15	25.75	1	4.66	0.33	2.33	1.33	45	1.66	2	0	3	41.69
WJ-49	57.15	25.8	0	3.66	0	4.33	4	47.66	3.66	4	1	4.66	27.03
WJ-50	57.15	25.84	0.66	4.33	0	1.33	1.66	43	3	2.66	0	3.66	39.7
WJ-52	57.15	25.93	0	5.66	0	3.66	2	41.66	1.66	1.66	0.33	1.66	41.71
WJ-53	57.15	25.97	0.33	6.33	0	1.66	3.66	32	2	3	0.33	4	46.69
WJ-54	57.1	25.97	1.33	7.33	1	2.33	4.66	37.33	2.33	2	0	2.33	39.36
WJ-55	57.1	25.93	0	4	0	4	1	45	4.66	3.66	0	2	35.68
WJ-56	57.1	25.89	1	2.66	0.33	1	3	31	2.66	2.66	0	1.33	54.36
WJ-57	57.1	25.84	0.33	5.33	0.33	4.66	2.66	37	4	4	0	2.66	39.03
WJ-59	57.1	25.75	0.66	3.66	0	3.33	3.66	28	2	2.33	0.33	5	51.03
WJ-61	57.1	25.66	1.66	4.33	0	1.33	5	41.66	6.33	1.33	0	1.66	36.7
WJ-63	57	25.71	0	3	0	4	2	34.33	3.66	3.33	0	4	45.68
WJ-64	57	25.75	0	5.66	0.66	3	2.66	31.33	4.66	1.66	0.66	3	46.71
WJ-65	57	25.8	0	3.33	0	2.33	4	40.33	3	3	0.66	2.33	41.02
WJ-66	57	25.84	1	5	0	1.33	3	29.66	1.66	2.33	0	1.66	54.36
WJ-67	57	25.89	0.33	2.33	0.33	3.66	4.66	36	5	1.66	0	2.66	43.37
WJ-68	57	25.93	1.33	4	0.66	1	1	28	1.33	3.33	0.33	3.66	55.36
WJ-69	57	25.97	0	2.66	0	5	3.66	34	4	4	0.33	4.33	42.02

Table 2: Location of the investigated surface sediment samples and data of species (% relative abundance) in the West Jask area.

Station	Longitude	Latitude	<i>Calcidiscus leptoporus</i>	<i>Emiliania huxleyi</i>	<i>Florisphaera profunda</i>	<i>Gephyrocapsa caribbeanica</i>	<i>Gephyrocapsa ericsonii</i>	<i>Gephyrocapsa muelleriae</i>	<i>Gephyrocapsa oceanica</i>	<i>Gephyrocapsa parallela</i>	<i>Helicosphaera carteri</i>	<i>Umbellosphaera tenuis</i>	<i>Umbilicosphaera sibogae</i>	Other
Gb-5	58.43	25.37	0	1.66	0	0.66	2	1.33	63	3	1.66	0	1.66	25.03
Gb-8	58.36	25.43	0.66	9.66	0	1.33	2.33	0.66	62.33	1.66	3	0	0.66	17.71
Gb-13	58.4	25.59	1.33	4.66	0	1	0.33	1.66	39.33	0	2	0.33	1.33	48.03
Gb-16	58.3	25.57	0	2.33	0	0.33	0.66	0	35	0.33	0.66	0	0	60.69
Gb-17	58.3	25.54	0	7	0	0	0.66	0	30.33	4	2.33	0	0	55.68
Gb-18	58.3	25.5	1	4.66	0	0.33	1	1	50.33	2	4.33	0	1	34.35
Gb-19	58.29	25.43	0.33	6.66	0.33	0	0.33	0	76.33	0.33	2.66	0.33	0	12.7
Gb-21	58.22	25.41	0	4	0.66	0	2.66	0.66	69	0.66	3	0	1.33	18.03
Gb-22	58.22	25.43	0.33	6	0	0	0.33	0.66	35	3.66	2.66	0.66	2.33	48.37
Gb-23	58.25	25.5	0	5	0	0	0.66	0	45.66	1.66	2	0.33	2.66	42.03
Gb-28	58.2	25.5	0	3.33	0	0	1.66	0	41	0	3.66	0	0	53.35
Gb-30	58.15	25.5	1	4	0	0.33	0	0	67	1.33	5	0	0	21.34
Gb-31	58.15	25.43	0.66	7.33	0.33	0	0	2	46	0	3.33	0	1	39.35
Gb-32	58.15	25.41	1.66	9.33	0	0	1.33	0	50.66	3	3	0	0	31.02
Gb-33	58.08	25.43	0	6	0	0	0	0	70	0.33	5.33	1	1.33	16.01
Gb-34	58.1	25.5	0	4.66	0	0	0	0.66	40.66	0	4.33	0	0	49.69
Gb-35	58.1	25.54	0	2.66	0.66	0.66	0	0	64	1	2.66	0	2	26.36
Gb-36	58.1	25.55	0.33	3.66	0	0	1	0.66	55.66	0	2	0	0	36.69
Gb-37	58.05	25.58	0	3.33	0	0	0	0	61.66	0.66	1	0.33	0.66	32.36
Gb-41	58.05	25.54	0	4.66	0	0	0	2	43.66	2.66	4	0	0.33	42.69
Gb-39	58	25.5	0	2.66	0	0	1.33	0.33	65.66	0.33	2.33	0	0	27.36
Gb-40	58	25.54	1	5	0.33	0	0	0	41.66	2	3	0	0	47.01
Gb-41	58	25.58	0	2	0	0.33	0	0	47.33	1.66	3.66	0	0	45.02
Gb-42	58	25.62	0	3	0	0	0	1	37.33	1	4.33	0.33	0	53.01

pling periods, the important monsoonal phase, the NE monsoon during winter, was covered by *Gephyrocapsa oceanica*, which is clearly the most important species throughout the investigated period showing a relative abundance of up to 50 % of the total coccolith assemblage. This species is known to preferentially thrive in high-nutrient environments, such as upwelling areas or continental shelves (Mitchell-Innes & Winter 1987; Houghton & Gupta 1991; Giraudeau 1992; Young 1994). It was suggested by Broerse et al. (2000) that this species indicates maximum upwelling conditions and that it positively responds to the input of nutrients (Andrulleit et al. 2000). Although nutrient data are lacking, maximum abundances in the near shore samples support the impression of it being a r-selected species. The trophic preference of this species is confirmed by our study, generally, during the NE monsoon, nutrient contents increase (Madhupratap et al. 1996). *G. oceanica* exhibits the widest range in abundance of all species, ranging from 27.66 % to 76.33 %. Its distribution pattern is opposite that of *Emiliania huxleyi*, with the highest values in the Gabrik and lowest values in the West Jask (Fig. 5).

In contrast, *E. huxleyi* is low in relative abundance compared to *G. oceanica* (Tables 1–2). The species *E. huxleyi* is the most ubiquitous coccolithophore species on the Earth (McIntyre & Be 1967; Winter & Siesser 1994), and able to form strong blooms with coccosphere densities of up to

>106 cells per litre in the North Atlantic (Holligan et al. 1983, 1993). Its distribution in the surface waters was found to be largely independent of water temperature and thermocline depth (Samtleben et al. 1995). In our study, *E. huxleyi* showed low relative abundances at the end of the NE monsoon. Therefore, *E. huxleyi*, being a cosmopolitan species, may not be regarded as an indicator of convection processes, but be more typical for stable regimes with relatively high nutrient availability. In addition, in our study temperatures may be already above the optimum level for *E. huxleyi*. This species is rare in West Jask, and its relative abundances decrease from Gabrik to West Jask (Fig. 5). A rather negative connection to the monsoonal phases can be seen in the relative abundance pattern of *Helicosphaera carteri* and *Calcidiscus leptoporus*. *H. carteri* showed a clear negative response with decreasing amounts (relative abundances) at the end of the NE monsoon (Fig. 5). The relative abundance of *H. carteri* decreases from West Jask to Gabrik (from 3.27 % to 3.03 %) which shows a spatial trend. *C. leptoporus* also decreases from West Jask to Gabrik (from 0.79 % to 0.34 %) also showing a spatial trend.

Due to the fact that coccolithophore species like *Gephyrocapsa muelleriae* prefer cold and high-nutrients conditions (Bollmann 1997; Flores et al. 1997; Knappertsbusch et al. 1997), while the condition in the Oman Sea is high temperature. This species is very rare or missing in Gabrik (Fig. 6).

Gephyrocapsa ericsonii thrives in high nutrient environments (Takahashi & Okada, 2000) between 13 and 22 °C (Okada & McIntyre 1979). We observed low abundances of *G. ericsonii* at the end of the NE monsoon. This species appears with the lowest abundance in Gabrik (Fig. 6).

Florisphaera profunda is well known as a deep dwelling species living in the lower photic zone (Winter & Siesser 1994). It was suggested that this species can be used to monitor variations in the depth of the nutricline (Molfinio & McIntyre 1990). The species dominates coccolithophore as-

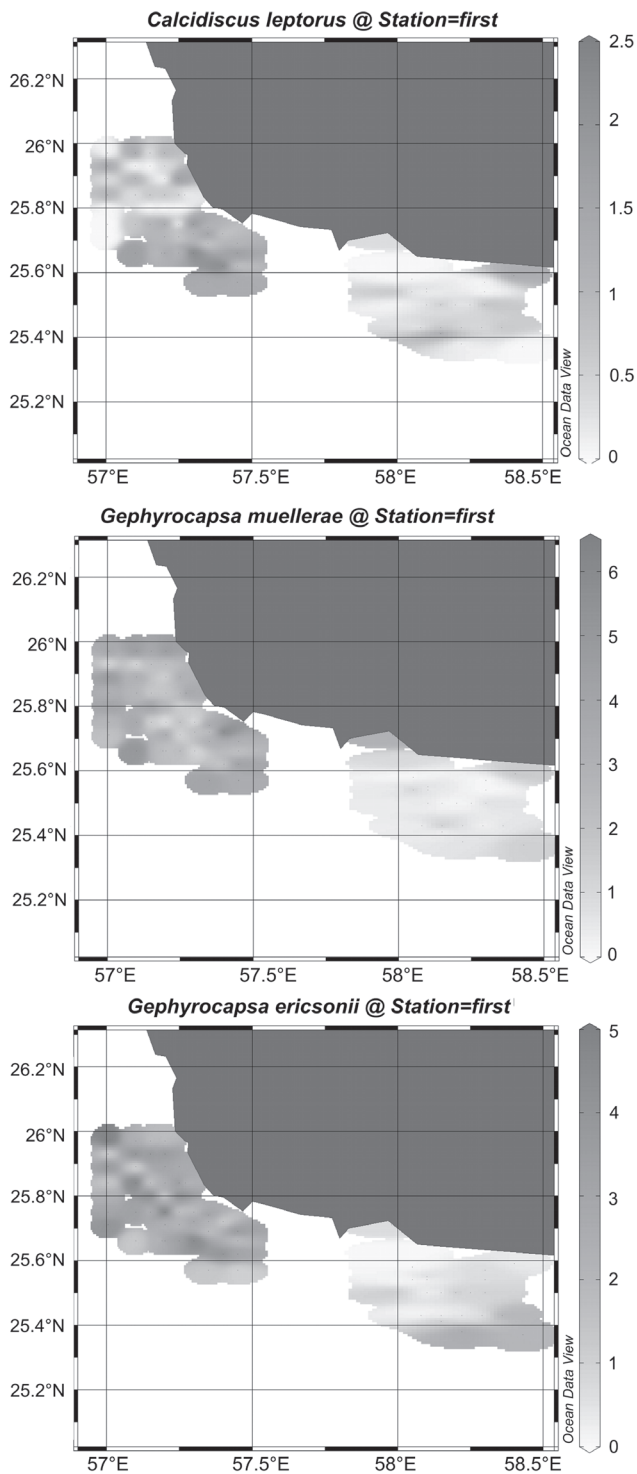


Fig. 6. Distribution pattern of *Calcidiscus leptorus*, *Gephyrocapsa muelleriae* and *Gephyrocapsa ericsonii* in the Oman Sea (Gabrik and West Jask areas).

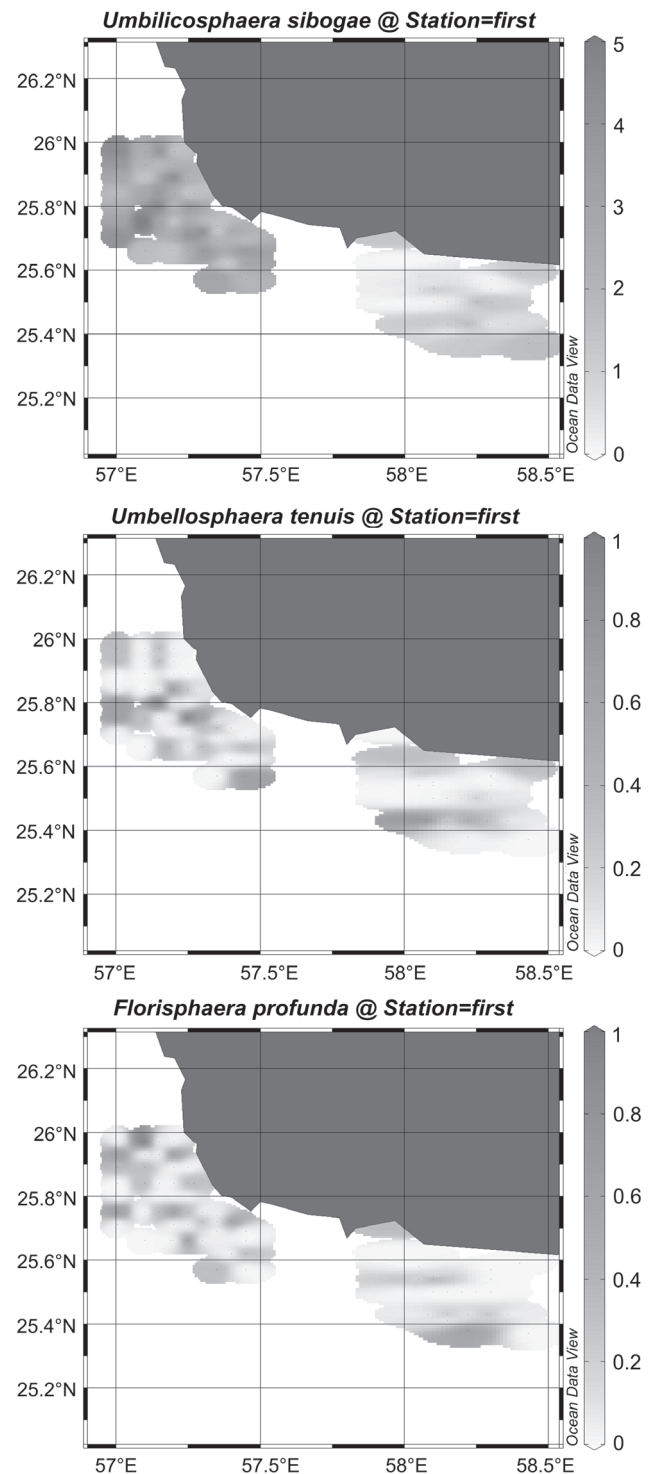


Fig. 7. Distribution pattern of *Umbilicosphaera sibogae*, *Umbellosphaera tenuis* and *Florisphaera profunda* in the Oman Sea (Gabrik and West Jask areas).

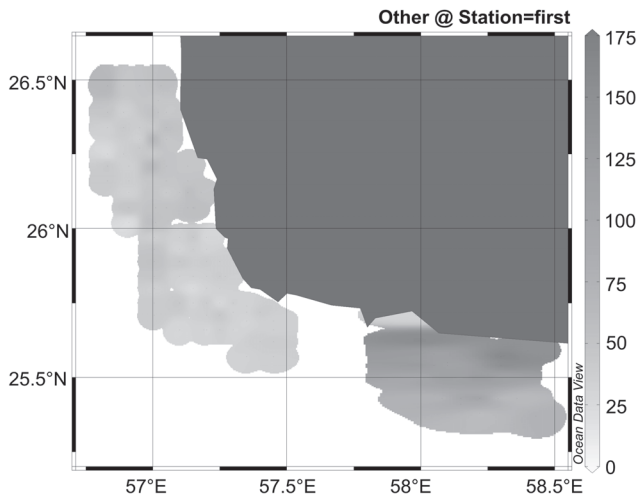


Fig. 8. Distribution pattern of reworked species in the Oman Sea.

semblages in the lower photic zone (> 100 m) (Cortes et al. 2001; Haidar & Thierstein 2001). *F. profunda* had very low abundance in the studied samples (from 0.14 % to 0.96 %, in Gabrik and West Jask) (Fig. 7). *F. profunda* is known as a key species to trace nutricline depth etc. The rare occurrence in the samples can be explained by the fact that the sampling area was not deep enough for this species to thrive. According to Young (1994), *Umblicosphaera sibogae* belongs to the “placolith-bearing coccolithophores” which often superficially appear to exhibit an erratic biogeographical distribution worldwide, but all typical environments exhibit similar ecological conditions in that they are all eutrophic. *U. sibogae* and *Umbellosphaera tenuis* are extremely low in relative abundance at the end of the NE monsoon. *U. sibogae* exhibits a rather similar distribution to *G. ericsonii* and *G. muelleriae*, with the highest values only in West Jask (Fig. 7). Here, in some cases, *U. sibogae* reaches 5 % of the assemblages, but it is very low in number or even missing in Gabrik. *U. tenuis* ranges in abundance from only 0 to 1 % (Fig. 7). Generally this species shows low abundances in all parts of the study area.

Sporadically occurring fossil coccoliths older than the Quaternary (e.g. *Discoaster brouweri*, *D. deflandrei*, *D. kugleri* or *Sphenolithus abies*, *S. heteromorphus*, *S. ciperoensis*, *S. radians*, *S. moriformis*, *Reticulofenestra minuta*, *R. pseudoumbilica*, *R. umbilica*, *Cyclicargolithus abisectus*, *C. floridanus*, *Pseudoemiliana lacunosa*, *Coccolithus pelagicus*, *Watznaueria biporta*, *W. barnesiae*), were grouped together as ‘Reworked’. The reworked species may be related to the rivers or floor sediments. According to Fig. 8, the values of reworked species increase in abundance from West Jask to Gabrik.

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Appendix (Taxonomic list)

Identification of coccolithophore taxa followed Jordan & Kleijne (1994) (all species references are given here), Kleijne (1993) and Young et al. (2003). Most of the taxa were identified to species level. Fossil species older than Quaternary were grouped together as 'Reworked'.

The taxonomic list includes all taxa cited in the manuscript:

<i>Calcidiscus leptoporus</i> (Murray & Blackman, 1898) Loeblich & Tappan, 1978	<i>Gephyrocapsa oceanica</i> Kamptner, 1943
<i>Emiliana huxleyi</i> (Lohmann) Hay & Mohler, 1967	<i>Helicosphaera carteri</i> (Wallich) Kamptner, 1954
<i>Florisphaera profunda</i> Okada & Honjo, 1973	<i>Umbellosphaera tenuis</i> (Kamptner, 1937) Paasche in Markali & Paasche, 1955
<i>Gephyrocapsa ericsonii</i> McIntyre & Bé, 1967	<i>Umbilicosphaera sibogae</i> (Weber-van Bosse, 1901) Gaarder, 1970
<i>Gephyrocapsa muelleriae</i> Bréhéret, 1978	