MEMORIE DI SCIENZE GEOLOGICHE
già *Memorie degli Istituti di Geologia e Mineralogia dell'Università di Padova*

Allegato al Vol. XLIII, pagg. 389-407, 14 figg., 1 tab. e 2 tavv.
Padova, maggio 1992

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ASSOCIATION OF LATE PLEISTOCENE CALCAREOUS NANNOFOSSIL ASSEMBLAGES AND ^{18}OXYGEN AND ^{13}CARBON ISOTOPIC CHANGES, ODP LEG 117, OMAN MARGIN, ARABIAN SEA

CONTENTS

Key words: Calcareous nannofossils, Pleistocene, isotopes, paleoceanography, Arabian Sea.

ABSTRACT

Site 723 of Leg 117 of the Ocean Drilling Program, located on the continental margin of Oman in the Arabian Sea, recovered a comparatively thick (285 meters), continuous section of Pleistocene sediment. This region of the world is unique in that every year during the summer monsoon, associated upwelling brings deeper, colder waters, enriched in nutrients, to the surface. ^{18}Oxygen and ^{13}Carbon isotopic analyses of foraminiferal carbonate provide a detailed record of the glacial and interglacial history of the late Pleistocene in this area which can be correlated with nannofossil assemblage changes.

Calcareous nannofossils, which are abundant throughout the sedimentary section at Site 723, exhibit moderate to good preservation. A total of 29,000 specimens of calcareous nannofossils was counted from 58 samples taken at approximately 1.0-meter intervals.

Gephyrocapsa caribbeanica appears to have been most abundant during transitional periods (transgressions and regressions). Small gephyrocapsids were most abundant during regressions or warm (interglacial) periods. *Emiliania huxleyi, Gephyrocapsa aperta, Gephyrocapsa oceanica, Helicosphaera* spp. and *Neosphaera coccolithomorpha* were most abundant during glacial periods.

The Milankovitch-mechanism may be responsible for overprinting a 21,000 year cyclicity of more intensive monsoonal upwelling which affects the composition of the nannofossil assemblages.

There is not a straight-forward relationship between the numbers of a specific taxon of nannofossils and the glacial-interglacial stages when interpreted in terms of the ^{18}Oxygen and ^{13}Carbon isotope values. It seems clear from the data gathered that the increased upwelling due to orbital forcing had a pronounced effect on the distributions of the calcareous nannofossils in the Arabian Sea.

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This study was supported by a generous grant from the United States Scientific Advisory Committee to one of us (S.A.S.).

RIASSUNTO

Il Site 723 del Leg 117 dell'Ocean Drilling Program, sul margine continentale dell'Oman nel Mare Arabico, ha fornito una sezione continua relativamente spessa (285 m) di sedimenti pleistocenici. Questa regione è caratterizzata dal fatto che ogni anno durante il monsone estivo fenomeni di *upwelling* portano in superficie acque fredde profonde ricche di nutrienti. Le analisi isotopiche dell'O-18 e del C-13 contenuti nei carbonati dei foraminiferi danno un record dettagliato della storia glaciale e interglaciale del Pleistocene superiore che può essere correlato con i cambiamenti nelle associazioni a nannofossili.

I nannofossili calcarei sono abbondanti in tutta la successione sedimentaria al Site 723, con preservazione da moderata a buona. In 58 campioni, presi ad intervalli di circa un metro, sono stati contati 29.000 esemplari.

Gephyrocapsa caribbeanica sembra essere stata più abbondante nei periodi transizionali (trasgressioni e regressioni). Le piccole gephyrocapse erano più abbondanti durante le regressioni o i periodi caldi (interglaciali). *Emiliania huxleyi, Gephyrocapsa aperta, G. oceanica, Helicosphaera* spp. e *Neosphaera coccolithomorpha* erano più abbondanti nei periodi glaciali.

Le variazioni dei parametri orbitali terrestri possono essere la causa della ciclicità di 21.000 anni osservata nei picchi di *upwelling* monsonico che influenza la composizione a nannofossili.

Non c'è una correlazione lineare diretta tra la frequenza di uno specifico taxon di nannofossili e gli stadi glaciali — interglaciali desunti dagli isotopi dell'Ossigeno e del Carbonio. Sembra chiaro dai dati ottenuti che l'aumento dell'*upwelling* dovuto ad influsso orbitale abbia avuto un marcato effetto sulla distribuzione dei nannofossili calcarei nel Mare Arabico.

INTRODUCTION

The Arabian Sea is both unique and paleoceanographically complex. Although this part of the Indian Ocean is located in tropical regions, colder, deeper waters are brought to the surface annually as a result of the summer monsoon. The oxygen minimum zone (OMZ) in the Arabian Sea extends from 200 meters to about 1500 meters. The high primary productivity and the salinity stratification of the waters are responsible for the formation, extent and maintenance of this intense OMZ (SLATER and KROOPNICK, 1984). Two separate oxygen minimum layers have been reported at depths between 100 meters to 400 meters and 800 meters to 1500 meters. The shallower OMZ is due to the decomposition of organics in oxygen-poor water coming in from the Persian Gulf. The deeper oxygen minimum has its origins in the water in the Gulf of Oman. This water mixes with water masses of similar compositions flowing in from the southern Arabian Sea (QASIM, 1982). A high proportion of the primary productivity is a direct result of the upwelling which occurs along the Arabian coast during the months coincident with the summer monsoon (May or June to September; WYRTIKI, 1971; PRELL and STREETER, 1982).

PRELL (1984) demonstrated that the upwelling index (based on the abundance of *Globigerina bulloides*) in the Arabian Sea shows cyclical variations of approximately 21,000 years. This periodicity correlates with orbital changes in the amount of solar radiation reaching low and mid latitudes. The annual southwest monsoons are the result of pressure gradients which form over Asia due to the repeated seasonal heating and cooling.

Site 723 of Leg 117 of the Ocean Drilling Program is located in approximately 800 meters of water at 18°03.079'N and 57°36.516'E (Fig. 1). The seafloor at this site is in the center of the OMZ. This site is in the central part of one of a series of linear sedimentary basins which lie along the upper portion of the continental slope. As a result, this basin collects sediments deposited in the intermediate water masses of the Arabian Sea (PRELL, NIITSUMA *et al.*, 1989). Hole 723A provides a very thick and continuous record of Pleistocene deposition on the continental margin of Oman. The sedimentation rate for this site during the Pleistocene is approximately 175 meters/my.

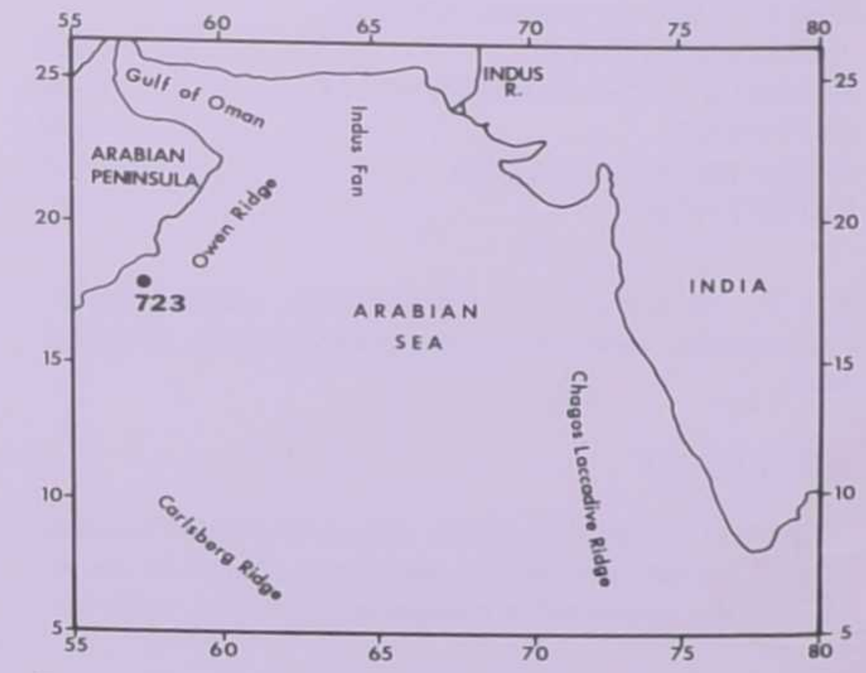

FIG. 1 - Location of Site 723, ODP Leg 117, Arabian Sea.

Changes in the species composition of Pleistocene nannofossil assemblages have been recognized by several workers from different parts of the world. COHEN (1964), GARTNER (1972) and

TABLE 1 - Distribution of calcareous nannofossils in Cores 117-723A-1H through 117-723-9H. Scale of abundance follows WATKINS and BOWDLER, 1984.

	Abundance	Preservation	*Calcidiscus leptoporus*	*Coccolithus pelagicus*	*Crenalithus doronicoides*	*Dictyococcites productus*	*Emiliania huxleyi*	*Gephyrocapsa aperta*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa protohuxleyi*	*Gephyrocapsa* spp.	*Gephyrocapsa* spp. (small)	*Helicosphaera carteri*	*Helicosphaera* spp.	*Helicosphaera wallichi*	Miscellaneous	*Neosphaera coccolithomorpha*	*Oolithotus fragilis*	*Pontosphaera discopora*	*Pontosphaera* spp.	*Pseudoemiliania lacunosa*	*Reticulofenestra* spp. (small)	*Rhabdosphaera clavigera*	*Scapholithus fossilis*	*Scyphosphaera* spp.	*Syracosphaera pulchra*	*Syracosphaera* spp.	*Thoracosphaera heimi*	*Thoracosphaera operculata*
1H-1, 6 cm	A	M	106	—	7	2	11	—	9	183	6	1	72	6	7	2	—	21	54	1	1	—	—	3	—	13	—	1	7	—
1H-1, 100 cm	A	M	75	—	8	1	47	—	5	162	1	1	61	34	2	7	—	30	39	3	—	—	—	—	2	—	—	3	4	2	—
1H-2, 60 cm	A	M	58	—	—	10	37	—	1	184	9	—	43	53	5	4	—	37	50	—	—	—	—	1	—	3	—	4	—	1	—
1H-2, 145 cm	A	G	60	1	—	8	16	—	3	188	13	—	45	35	6	12	—	39	65	—	—	—	—	—	2	3	—	3	—	1	—
1H-3, 100 cm	A	G	11	—	—	9	140	11	1	131	8	2	16	41	4	6	1	49	57	—	—	—	—	1	—	5	—	2	1	3	1
1H-4, 60 cm	A	M	55	—	—	9	6	1	—	228	8	—	35	29	13	15	—	40	61	—	—	—	—	—	—	—	—	—	—	—	—
1H-4, 144 cm	A	M	48	—	—	8	15	—	1	144	3	—	90	13	10	32	1	52	74	—	—	1	—	—	—	—	1	—	4	—	1
1H-5, 100 cm	A	M	53	—	—	10	40	—	1	99	4	—	100	20	1	11	—	31	125	—	—	—	—	1	—	—	—	—	2	1	—
2H-1, 50 cm	A	G	51	—	—	7	54	3	8	126	5	—	40	57	2	7	—	66	69	—	—	—	—	—	—	—	—	—	1	3	—
2H-2, 52 cm	A	P	83	—	—	11	7	—	1	120	5	—	209	4	—	3	—	34	23	—	—	—	—	—	1	—	—	—	3	1	—
2H-3, 50 cm	A	M	101	—	—	10	11	—	5	157	3	—	119	7	—	25	—	19	43	—	—	—	—	—	—	—	—	—	—	—	—
2H-4, 52 cm	A	M	26	—	—	16	33	1	6	156	4	—	19	89	—	19	—	42	68	—	—	—	—	—	—	—	—	—	2	2	—
2H-5, 50 cm	A	M	17	1	—	7	61	16	47	66	—	—	25	143	—	14	—	52	41	—	—	1	—	—	—	2	—	2	3	2	—
2H-6, 52 cm	A	M	25	—	4	9	50	13	1	154	3	—	34	126	—	18	—	20	36	—	—	—	—	—	—	4	—	1	—	2	—
2H-7, 50 cm	A	G	29	—	—	3	21	19	4	95	—	1	24	179	—	14	—	38	68	—	—	—	—	—	—	3	—	—	1	1	—
3H-1, 140 cm	A	M	2	—	—	2	24	50	—	80	2	—	15	259	—	7	—	24	—	1	—	—	—	—	—	—	—	3	1	1	—
3H-2, 140 cm	A	M	20	—	—	10	14	31	1	152	3	—	31	165	—	6	1	24	33	—	—	—	—	1	—	3	—	3	1	1	—
3H-3, 140 cm	A	M	10	—	2	8	9	72	1	140	4	—	13	181	—	5	—	16	30	—	—	—	—	—	—	4	—	1	3	1	—
3H-5, 15 cm	A	M	13	—	—	9	14	53	1	180	3	—	12	144	—	9	—	—	34	—	—	—	—	—	—	5	—	—	3	3	—
3H-6, 15 cm	A	M	18	—	1	13	18	27	—	244	7	—	38	55	—	9	—	31	36	—	—	—	—	—	—	2	—	—	1	—	—
3H-7, 13 cm	A	M	13	—	—	7	8	38	2	229	12	—	15	75	—	12	—	10	74	—	—	—	—	—	—	2	—	1	1	1	—
4H-1, 140 cm	A	G	9	—	—	3	33	82	2	96	1	—	16	180	—	3	—	19	48	—	—	—	—	—	—	3	—	—	4	1	—
4H-2, 140 cm	A	M	34	—	2	5	10	32	23	104	2	—	56	97	—	6	—	46	78	—	—	—	—	—	—	1	—	—	2	2	—
4H-3, 140 cm	F	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4H-5, 140 cm	A	M	7	—	1	4	13	50	1	144	7	—	65	162	—	3	—	21	18	—	—	—	—	—	—	—	—	—	2	2	—
4H-6, 140 cm	A	M	4	—	—	6	5	78	—	129	9	9	28	192	—	1	—	14	20	—	—	—	—	—	—	2	—	3	—	—	—
5H-1, 90 cm	A	M	9	—	—	15	3	69	—	153	9	3	57	132	2	1	—	25	20	—	—	—	—	—	—	—	—	—	2	—	—
5H-2, 90 cm	A	M	21	—	—	1	8	68	2	121	3	3	48	168	—	2	—	10	36	—	—	—	—	—	—	3	—	—	4	2	—
5H-3, 90 cm	A	M	12	—	—	3	8	28	1	166	3	3	45	191	1	—	—	12	20	—	—	—	—	—	—	2	—	1	3	1	—
5H-4, 90 cm	A	M	13	—	3	1	12	50	3	142	2	1	35	183	—	—	—	16	32	—	—	—	—	—	—	3	—	1	3	—	—
5H-5, 90 cm	A	G	11	—	2	4	16	23	3	156	3	1	48	169	1	3	—	21	27	—	—	1	—	—	—	5	—	1	3	2	—
5H-6, 91 cm	A	M	29	—	—	11	5	5	2	216	7	—	81	82	1	15	—	7	31	—	—	—	—	—	—	2	—	1	4	1	—
6H-1, 11 cm	A	M	4	—	—	46	23	144		62	4	7	20	130	—	4	—	6	18	—	—	—	—	3	1	3	—	1	2	1	—
6H-2, 15 cm	A	G	15	—	—	88	19	49	27	125	12	3	21	99	1	7	—	10	13	—	—	—	—	6	—	3	1	1	—	—	—
6H-3, 15 cm	A	M	22	—	—	34	—	13	4	163	6	2	22	196	1	7	—	3	25	—	—	—	—	—	—	—	—	—	1	1	—
6H-4, 15 cm	A	M	13	—	—	161	—	4	8	108	2	6	41	123	1	—	—	16	11	—	—	—	—	—	—	1	2	—	3	—	—
6H-5, 65 cm	A	M	9	—	5	115	—	11	19	82	8	4	58	165	—	2	—	9	5	—	—	—	—	—	—	—	—	—	8	—	—
6H-6, 65 cm	A	M	51	—	—	24	—	3	10	108	3	—	207	81	—	1	—	6	6	—	—	—	—	—	—	—	—	—	—	—	—
6H-7, 65 cm	A	M	9	—	2	85	—	2	29	142	6	2	81	121	1	3	—	8	6	—	—	—	—	—	—	—	—	—	2	—	—
7H-2, 65 cm	A	M	40	—	5	84	—	47	21	92	1	—	50	106	2	4	—	26	21	—	—	—	—	—	—	—	—	—	—	—	—
7H-3, 65 cm	A	M	33	1	—	103	—	7	13	145	1	1	34	86	2	7	—	45	15	—	—	—	—	5	—	1	—	1	1	—	—
7H-4, 65 cm	A	M	8	—	2	124	—	51	25	56	1	—	12	197	—	5	—	11	6	—	—	—	—	—	—	1	—	1	2	1	1
7H-5, 67 cm	A	M	11	—	2	172	—	22	48	48	—	2	27	119	—	4	—	19	18	—	—	—	—	2	—	1	—	1	—	—	—
7H-6, 65 cm	A	M	3	—	3	98	—	1	16	83	3	—	40	241	—	2	—	3	7	—	—	—	—	—	—	—	—	—	1	1	—
7H-7, 65 cm	A	M	10	—	—	90	—	6	28	89	7	—	91	151	3	1	—	10	12	—	—	—	—	—	—	—	—	—	1	—	—
7H-8, 65 cm	A	M	9	—	—	113	—	5	28	90	5	1	83	132	2	2	—	21	2	—	1	—	—	5	—	—	—	—	3	—	—
8H-1, 90 cm	A	M	13	—	1	104	—	—	25	143	4	1	127	50	1	3	—	8	17	—	—	—	—	—	—	—	—	—	6	—	—
8H-2, 90 cm	A	G	4	—	—	46	—	—	67	237	4	1	1	29	—	—	—	8	17	—	—	—	—	—	—	—	—	—	—	1	—
8H-3, 90 cm	A	M	6	—	—	70	—	1	43	184	7	—	103	72	2	—	—	—	3	8	—	—	—	—	—	—	—	—	8	—	—
8H-4, 90 cm	A	M	13	—	—	67	—	1	29	193	11	1	103	54	2	—	—	4	14	—	—	—	—	—	—	—	—	—	—	—	—
8H-5, 90 cm	A	M	7	—	—	45	—	2	57	128	8	—	84	151	2	2	—	8	6	—	—	—	—	—	—	—	—	5	—	—	—
8H-6, 65 cm	A	M	2	—	—	46	—	4	44	105	2	2	161	118	—	—	—	9	2	—	—	—	—	—	—	2	—	1	5	—	—
8H-7, 84 cm	A	M	8	—	1	65	—	—	27	197	2	—	126	37	—	—	—	7	20	—	—	—	—	2	—	—	—	—	3	—	—
9H-1, 140 cm	A	M	12	—	—	89	—	2	29	136	5	2	102	90	—	—	—	8	11	—	—	—	—	11	—	—	—	—	4	—	—
9H-2, 140 cm	A	M	13	—	1	75	—	4	36	151	4	—	129	54	1	—	—	3	17	—	—	—	—	8	—	—	—	1	—	1	—
9H-4, 15 cm	A	M	12	—	—	125	—	—	25	131	3	1	124	52	—	—	—	3	12	—	—	—	—	4	—	—	—	—	1	—	—
9H-5, 23 cm	A	M	10	—	—	78	—	15	16	106	—	—	101	140	3	—	—	8	21	—	—	—	—	1	—	—	—	—	5	—	—
9H-6, 15 cm	A	M	15	—	3	28	—	6	3	164	6	1	92	141	—	—	—	6	21	—	—	—	—	5	—	4	—	—	—	—	—
9H-7, 15 cm	A	M	16	—	—	23	—	3	2	164	8	—	99	154	—	—	—	15	9	—	—	—	—	2	—	—	1	1	3	—	—

STEINMETZ and ANDERSON (1984) noticed these changes in Caribbean assemblages. GARD (1989) studied high - and mid - latitude assemblages from the Atlantic and Indian Oceans. According to these authors, these changes in the nannofossil assemblages are presumed to be related to shifts in sea surface temperatures, which are, primarily, the record of glacial and integlacial stages during this period of time. There are, however, other factors which may contribute to these nannofossil assemblage changes. It is the goal of this paper to use species counts together with the isotopic values to analyze the nannofossil assemblages and relate these assemblage changes to ^{18}O and ^{13}C isotopic changes in seawater during the late Pleistocene.

METHODS

Samples were taken from Hole 723A at approximately 40 cm-intervals for the analyses of foraminiferal ^{13}C and ^{18}O isotopic ratios. For an explanation of the methods used in the isotope studies refer to NIITSUMA *et al.* (1991). Subsamples of isotope samples from the top nine cores were used for making nannofossil smear slides prior to washing of the samples in preparation for removal of foraminifera for the isotope studies. Every fourth nannofossil slide was studied from the uppermost eighty-five meters of sediment. Based on the last appearance datum of *Pseudoemiliania lacunosa* it was calculated that seventy-five meters of sediments have been deposited at this site during the last 500,000 years. Assuming a constant sedimentation rate, this results in a spacing of 6700 years between samples. All samples contain abundant nannofossils (more than 15% of the sediment) except Sample 117-723A-4H-3, 140 cm, which has few nannofossils (1 to 5% of the sediment) (Table 1).

Because certain taxa are more susceptible to dissolution or overgrowth than others, the "average" state of preservation of the assemblage was determined and was denoted by one of the following letter designations:

G, good (coccoliths lack evidence of dissolution or overgrowth);

M, moderate (coccoliths exhibit some evidence of dissolution or overgrowth but the identification of them is not impaired);

P, poor (coccoliths exhibit profound dissolution or overgrowth but identification of some species is still possible).

Five hundred specimens were counted with the light microscope per slide (Table 1). Those specimens which could not be identified (*i.e.* tilted or strongly dissolved specimens) are assigned to the "Miscellaneous" category. *Gephyrocapsa* specimens less than 4 microns in length are assigned to the "*Gephyrocapsa* spp. (small)" category with the exceptions of *G. aperta* and *G. protohuxleyi*, which are assigned to separate categories. Specimens of *Gephyrocapsa* which are larger than 4 Microns in length and whose central bars have been dissolved have been assigned to the *Gephyrocapsa* spp. category.

According to PATTERSON and FISHBEIN (1989), 500 to 1000 counts are necessary to provide accurate percentages of species that comprise 5% of a given sample. Therefore, taxa which do not comprise more than 5% of the assemblage in any sample are not discussed further.

DISCUSSION OF FORAMINIFERAL ^{18}OXYGEN AND ^{13}CARBON ISOTOPE RECORDS OF THE LATE PLEISTOCENE

^{18}O and ^{13}C isotopic ratios were acquired from both planktonic and benthic foraminifera. The planktonic species utilized, *Pulleniatina obliquiloculata*, inhabits waters at intermediate depths of 50 to 100 meters (BÉ, 1977). In plankton tows conducted in the western Arabian Sea during the summers of 1984 and 1985 *P. obliquiloculata* was found in the upwelling assemblage but was a less important contributor (KROON, 1988; AURAS-SCHUDNAGIES *et al.*, in press). *Pulleniatina obliquiloculata* is one of a few species of planktonic foraminifer which secretes its test in isotopic equilibrium with seawater (SHACKLETON *et al.*, 1973; FAIRBANKS *et al.*, 1980). CURRY and MATTHEWS (1981) demonstrated that *P. obliquiloculata* secretes its test at constant temperatures. Therefore, this species should record changes in the isotopic composition of seawater. Because *Uvigerina* secretes its test in near isotopic equilibrium with seawater (SHACKLETON, 1974), it is usually used for the analysis of the benthic foraminiferal record if it is available in sufficient numbers. *Uvigerina excellens* was the species used for this study.

In the following section we will briefly consider some of the factors which influence the ^{18}O and ^{13}C isotopes of both planktonic and benthic foraminifers by comparing the results of the present study with the standard isotopic curve and discuss how these isotopic records may have changed during the late Pleistocene. NIITSUMA *et al.* (1991) also discussed the paleoceanography of the Arabian Sea off Oman using these isotopic results.

The $\delta^{18}O$ curves of both the planktonic and benthic foraminifers from this study (Fig. 2) are similar to the standard curve of SPECMAP (IMBRIE *et al.*, 1984). The oxygen isotopic curve of the planktonic foraminifers ($\delta^{18}O_P$) represents changes in the size of the continental ice sheets between glacial and interglacial stages. The amplitudes of the oxygen isotope curve of benthic foraminifers ($\delta^{18}O_B$) are smaller than those recorded by the planktonic foraminifers especially at the peaks of interglacial stages 5, 7, 9, 11, 13, and 15 and glacial stage 12. Because Site 723 is located at a water depth of 808 meters and in the middle part of the thermocline, it is expected that changes in the bottom water temperature should be recorded as oxygen isotope changes in benthic foraminiferal tests. These changes in the $\delta^{18}O_B$ are due to upward and downward movements of the thermocline. During glacial periods the average $\delta^{18}O_P$ value is +1.0 ‰, while the $\delta^{18}O_B$ value averages +3.2 ‰. This results in a relatively small $\Delta\delta^{18}O_{B\text{-}P}$ (difference between benthic and planktonic oxygen isotope values) of +2.2 ‰. This, in turn, indicates a deeper thermocline (*i.e.* warmer bottom water temperature) during the glacial periods. During interglacial periods, the average $\delta^{18}O_P$ value is -1.0 ‰, while the average $\delta^{18}O_B$ value is +1.6 ‰. This results in a relatively large $\Delta\delta^{18}O_{B\text{-}P}$ of +2.6 ‰. Therefore, the thermocline was shallower (*i.e.* colder bottom water temperature) during the interglacial periods. For a more detailed discussion of movements of the thermocline refer to NIITSUMA *et al.* (1991).

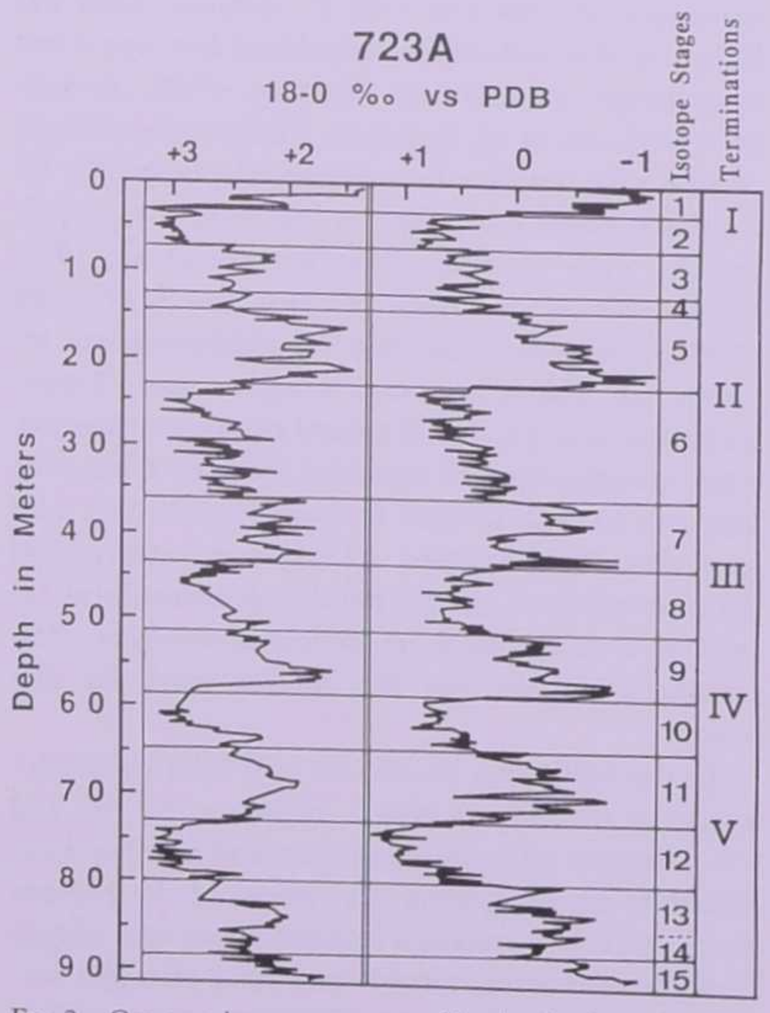

FIG. 2 - Oxygen isotope curves of both planktonic (*Pulleniatina obliquiloculata*-right) and benthic (*Uvigerina excellens*-left) foraminifers from ODP Hole 723A.

Globigerinoides bulloides, a typical upwelling index species (PRELL, 1978a), was most abundant in the Arabian Sea during termination I between 7,000 and 15,000 years ago (PRELL and CURRY, 1981). This peak coincides with low sea surface temperatures (SST) and the maximum number of foraminifers per gram/sediment. These relationship led PRELL (1978b) to conclude that during maximum upwelling conditions productivity increased and a more intense monsoon prevailed during termination I. In the present study, the $\delta^{18}O_B$ curve clearly demonstrates an apparent delay of several thousand years from the $\delta^{18}O_P$ curve typically at terminations I and IV, and, to a lesser degree, at terminations II, III and V (Fig. 2). The apparent delay of the $\delta^{18}O_B$ curve can also be explained by the upward movement of the thermocline as a result of intense upwelling during these terminations.

The carbon isotope of foraminiferal shells is determined by the $\delta^{13}C$ of ΣCO_2 in seawater (the temperature dependence of the carbon isotope is negligible, EMRICH *et al.*, 1970). The $\delta^{13}C$ in seawater is controlled primarily by the global change of the biomass between the land and the ocean [organic matter on the continental shelf (NIITSUMA and KU, 1977; BROECKER, 1982); forest and soils (SHACKLETON, 1977)]. In fact, the carbon isotopes of benthic foraminifers ($\delta^{13}C_B$) and planktonic foraminifers ($\delta^{13}C_P$) are depleted during glacial stages in deep-sea cores of ODP Hole 723A (Fig. 3) and Core V19-30 (Fig. 4). The $\delta^{13}C_B$ and $\delta^{13}C_P$ of Core V19-30, which was recovered from the eastern equatorial Pacific, were measured in the most detail from oxygen stage 9 to the present (SHACKLETON and PISIAS, 1985). These curves, especially the $\delta^{13}C_P$, are similar to those curves of several deep-sea cores taken from different oceans (WILLIAMS, 1985; MIX and FAIRBANKS, 1985; CURRY and CROWLEY, 1987). Although ZAHN *et al.* (1986) recognized the different amplitude of $\delta^{13}C_B$ values between the *Uvigerina peregrina* group and *Cibicidoides wuellerstorfi* in two deep-sea cores from the eastern Atlantic Ocean, the $\delta^{13}C_B$ curve of the *U. peregrina* group generally resembles the $\delta^{13}C_B$ curve of *C. wuellerstorfi* as well as the $\delta^{13}C_B$ curve of *Uvigerina senticosa* of Core V19-30. Therefore, the $\delta^{13}C_B$ and $\delta^{13}C_P$ curves of Core V19-30 represent the global $\delta^{13}C$ change of the deep and surface water, respectively, since oxygen isotope

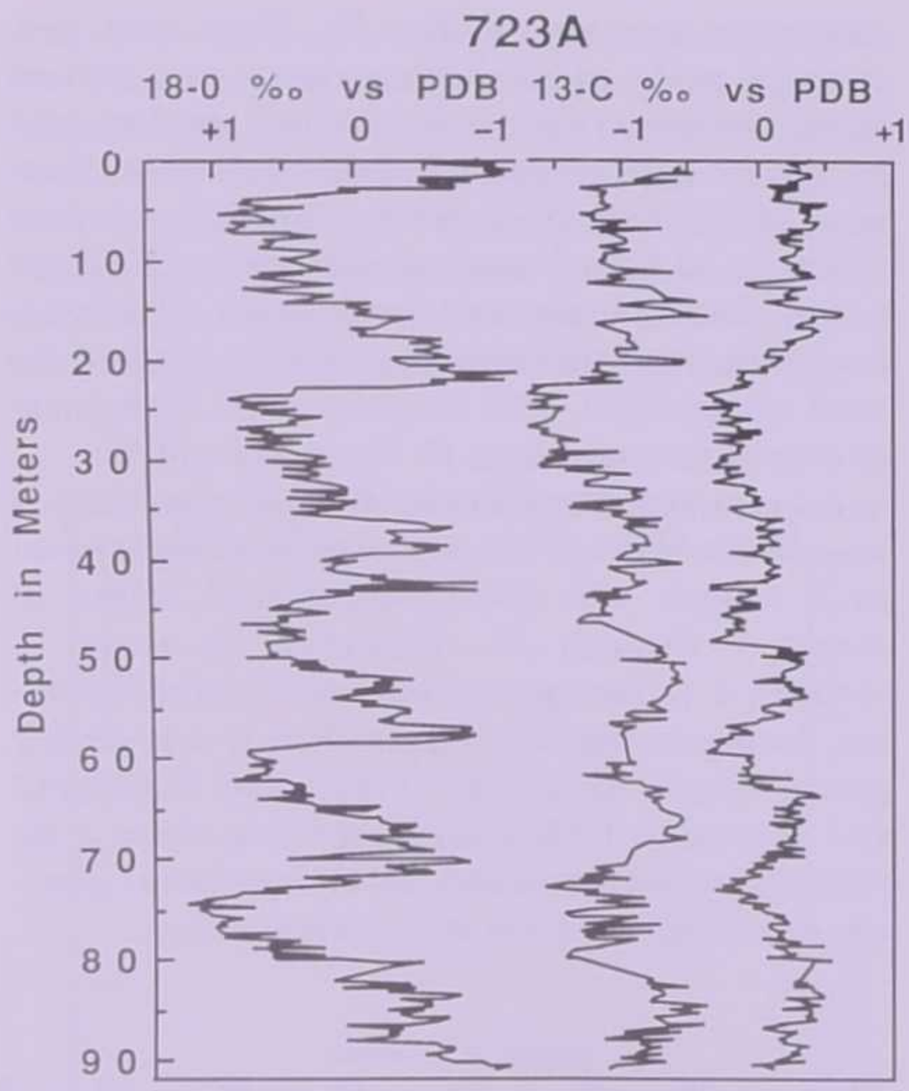

FIG. 3 - Carbon isotope curves of both planktonic (*Pulleniatina obliquiloculata*-right) and benthic (*Uvigerina excellens*-middle) foraminifers in ODP Hole 723A. The oxygen isotope curve for the planktonic foraminifer from this same hole is shown in the left column.

stage 9. A comparison of the $\delta^{13}C_B$ curve of Hole 723A with that of Core V19-30 (Fig. 4, middle) reveals that the values from Hole 723A are significantly heavier than those of Core V19-30 at glacial stages 8 (8.6-8.3) and 4, and slightly heavier at cold substages 7.4, 6.6 and 5.4, and transitional substages 9.2-9.0 and 5.1-5.0. Values from Hole 723A are lighter than those from Core V19-30 at interglacial substages 9.3, 7.3-7.1, 5.5, and 5.3, terminations I and II, and warm interstadial stage 3. The $\delta^{13}C_B$ values from Hole 723A are significantly lighter than those from Core V19-30 at glacial substages 6.5-6.2. These $\delta^{13}C_B$ differences are due to the local effect of the paleohydrology off Oman. The heavier $\delta^{13}C_B$ values from Hole 723A (when compared to those from Core V19-30) probably result from the low productivity in the surface water off Oman relative to the east equatorial pacific Ocean caused by the weak upwelling during the glacial stages and cold substages. The lighter $\delta^{13}C_B$ values from Hole 723A (when compared to those from Core V19-30), may be due to high productivity in the surface water off Oman during the interglacial stages and warm substages. Large amounts of organic matter were supplied to the dissolved oxygen minimum layer which was nearly the same depth as the minimum $\delta^{13}C$ content in the seawater and oxidized mainly in the oxygen minimum layer and on the sea floor. The light carbon isotope (^{12}C) derived from the oxidation of the organic matter was added to the bottom water at Site 723. As a result, the $\delta^{13}C$ values at Hole 723A became lighter during the interglacial stages and warm substages. The light $\delta^{13}C_B$ values during glacial substages 6.5-6.2 may be due to reduced circulation rates of the bottom water.

The $\delta^{13}C_P$ curve of Hole 723A coincides very well with that of Core V19-30 as shown in the right hand column of Figure 4. This relationship suggests that both curves represent the global change of the carbon isotope since oxygen isotope stage 9.

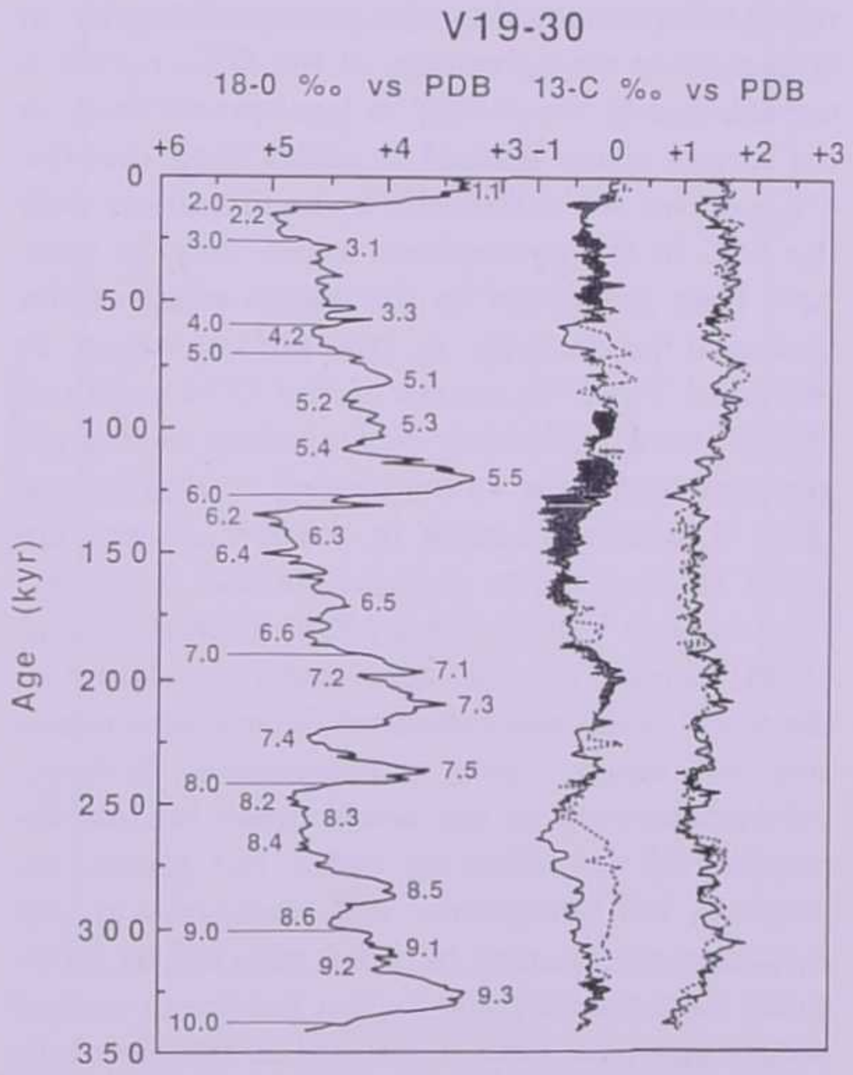

FIG. 4 - Comparison of carbon isotope curves of planktonic (right) and benthic (middle) foraminifers of Core V19-30 (solid line) and ODP Hole 723A (dashed line). The oxygen isotope curve for the planktonic foraminifers from Core V19-30 are shown in the left column. The isotope stages and substages follow PRELL *et al.* (1986). The ages of each horizon in Hole 723A was estimated from the oxygen isotope stage boundaries whose ages were defined by SHACKLETON and PISIAS (1985). The dashed lines of Hole 723A were adjusted to fit the mean value of $\delta^{13}C$ measurements between Core V19-30 and Hole 723A; *i.e.* all $\delta^{13}C_P$ values from Hole 723A are shifted by +1.26‰ and the $\delta^{13}C_B$ values by +1.59‰. Light areas indicate that the carbon isotope values from Hole 723A are heavier than those of Core V-19-30. Dark areas indicate that the carbon isotope values from Hole 723A are lighter than those from Core V19-30.

According to KROOPNICK (1985), the carbon isotope in surface water is controlled mainly by equilibration with the atmosphere and biological productivity. High productivity in surface water is reported during the glacial age from the east equatorial Pacific Ocean (PEDERSEN, 1983). The carbon isotope difference between the surface and bottom waters in Core V19-30 also suggests that productivity was higher during the glacial ages than during the interglacial ages (SHACKLETON *et al.*, 1983). On the other hand, the productivity in the surface water off Oman is estimated to have been higher during the interglacial stages than during the glacial stages by the present study as well as NIITSUMA *et al.* (1991), PRELL (1978b) and PRELL and CURRY (1981). In spite of an inverse relationship concerning the paleoproductivity in both regions, the agreement of the $\delta^{13}C_P$ curves is not affected by the change in local productivity in the surface water. Instead, it seems likely that the $\delta^{13}C_P$ curves are influenced by equilibration with the $\delta^{13}C$ in the atmosphere which may, in turn, have been influenced by the global effect of the biological productivity in the surface waters at that time. The $\delta^{13}C_P$ curves of Site 723A and Core V19-30 record relatively heavy values during regressions and light values during transgressions (Fig. 4). Similar changes in the $\delta^{13}C_P$ curve are found in even minor regressions and transgressions in Core V19-30 (OBA, 1986). DUPLESSY *et al.* (1984) pointed out that deep water circulation of the world ocean was enhanced during regressions and diminished during transgressions. Perhaps, paleoproductivity in the world ocean became intensified in the following order: full glacial, regression, full interglacial, and transgression. An exception to this may be areas affected by monsoons. Consequently, the carbon isotope in surface waters may have been controlled by the global effect of the biological productivity in the entire surface water in addition to the change in the biomass between the land and the ocean. If this interpretation is correct, the $\delta^{13}C_P$ curves presented in the right hand column of Figure 4 may monitor the $\delta^{13}C$ change in the atmosphere in the past. This will be confirmed by the $\delta^{13}C$ measurement of air trapped in ice cores.

DISCUSSION OF NANNOFOSSIL DISTRIBUTIONS

Calcidiscus leptoporus

The relative abundance of this species in sediments from Cores 117-723A-1H through 117-723A-9H ranges from 0.4% to 21.2% (2 to 106 specimens per sample-Fig. 5). Two very pronounced peaks in abundance occur: one in very young sediments (6 cm depth) and another peak in upper oxygen isotope stage 3. Sediments from stage 4 through 10 contain moderate numbers (0.4% to 10.2% of total assemblage) of *C. leptoporus*. Stage 11 through early stage 15 contain low numbers of this species (1.6% to 3.2% of the total assemblage). The numbers of *C. leptoporus* in stage 4 through stage 15 fluctuates widely.

An examination of Figure 5 shows that there is no relation between the numbers of *C. leptoporus* in a sample and glacial/interglacial stages in stages 5 through 15. However, in stages 1 through 4 *C. leptoporus* was much more abundant during interglacial stages than it was during glacial stages. GARTNER (1972) and STEINMETZ and ANDERSON (1984) concluded that there is no relation between numbers of *C. leptoporus* present in a sample and the water temperature.

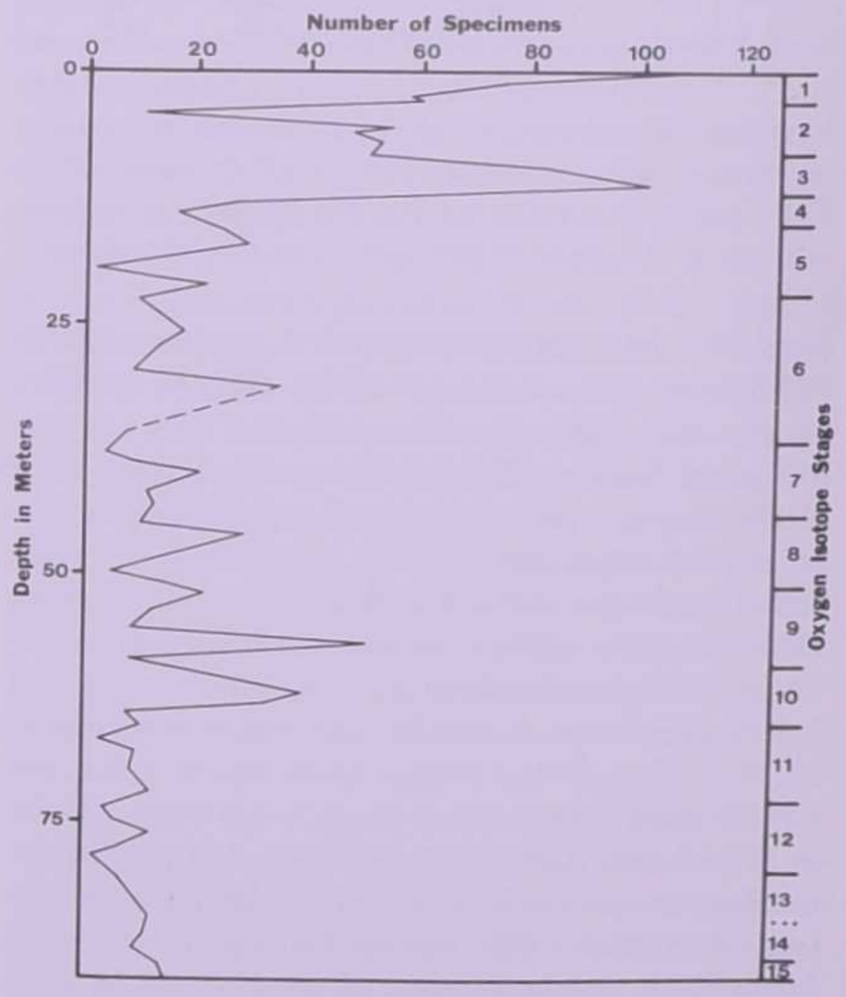

FIG. 5 - Abundances of *Calcidiscus leptoporus* in Cores 117-723A-1H through 117-723A-9H.

Dictyococcites productus

The relative abundance of this species in sediments from Cores 117-723A-1H through 117-723A-9H ranges from 0.2% to 34.4% (1 to 172 specimens per sample-Fig. 6). Relatively low numbers of *D. productus* (0.2% to 3.4% of the

total nannofossil assemblage) are present in samples from oxygen isotope stages 1 through 7. Samples from stages 8 through 15 contain higher numbers of this species. Fluctuations in abundance is characteristic of samples from stage 8 through stage 15. There does not appear to be a relationship between the numbers of *D. productus* in a sample and the glacial/interglacial stages.

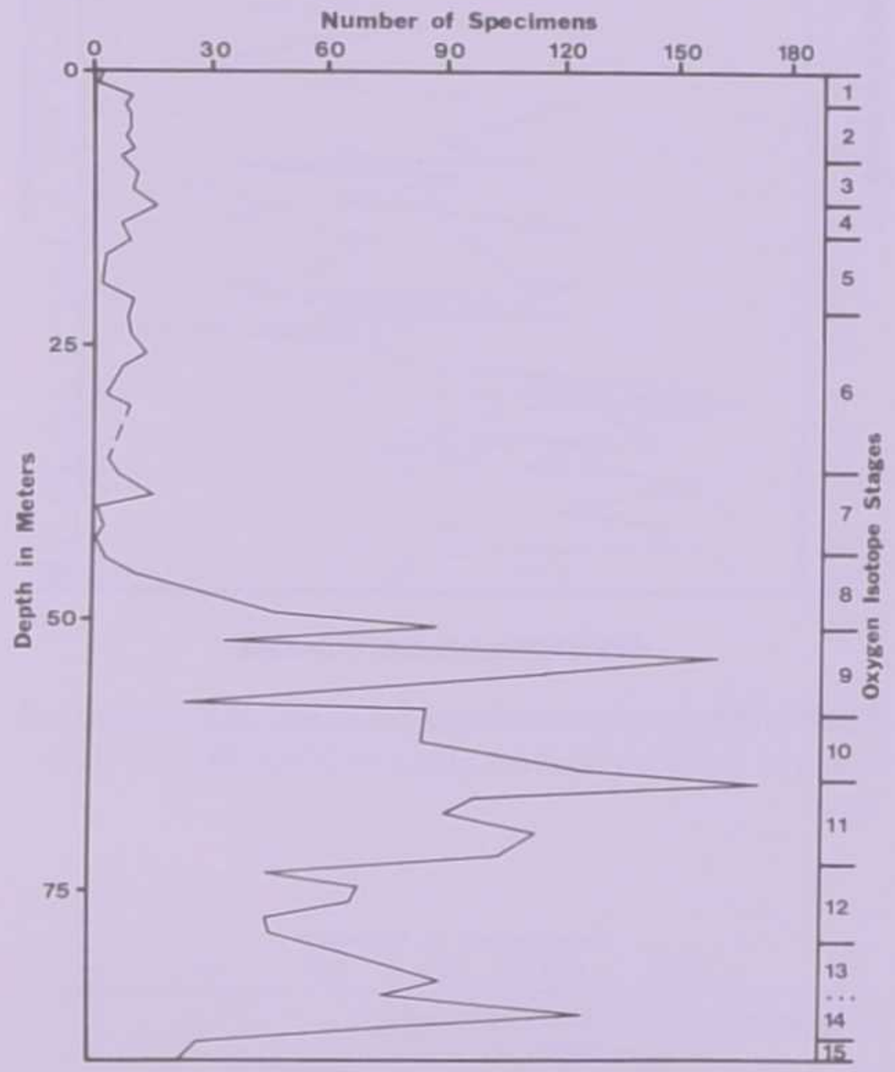

FIG. 6 - Abundances of *Dictyococcites productus* in Cores 117-723A-1H-1 through 117-723A-9H.

Emiliania huxleyi

Emiliania huxleyi comprises 1% to 28% of the nannofossil assemblage (5 to 140 specimens per sample). Pronounced fluctuations in abundance characterize the samples from stage 1 through mid stage 5 (Fig. 7). Slight fluctuations in abundance exist in samples from late stage 5 through stage 8. *Emiliania huxleyi* appears to be more abundant in sediments which were deposited during the glacial periods when nutrient levels, especially P and N, were higher. A comparison of the data on the distribution of nannofossils in the equatorial and northern Pacific with the chemical analyses of seawater from the same areas (MARUMO, 1970; OKADA and HONJO, 1973; HONJO and OKADA, 1974; HONJO, 1975) shows that higher numbers of *E. huxleyi* correlate with increased P and N levels in the seawater (GARTNER, 1988). OKADA and HONJO (1973) reported that *Emiliania huxleyi* is extremely dominant in subarctic and transitional regions of the North Pacific Ocean.

The first appearance datum (FAD) of *Emiliania huxleyi* occurs between Samples 117-723A-6H-2, 15 cm and 117-723A-6H-3, 15 cm (50.63 to 51.92 meters sub-bottom). This corresponds to a level date in oxygen isotope stage 8. THIERSTEIN *et al.* (1977) and STEINMETZ and ANDERSON (1984) also record the FAD of *E. huxleyi* in late oxygen isotope stage 8 worldwide.

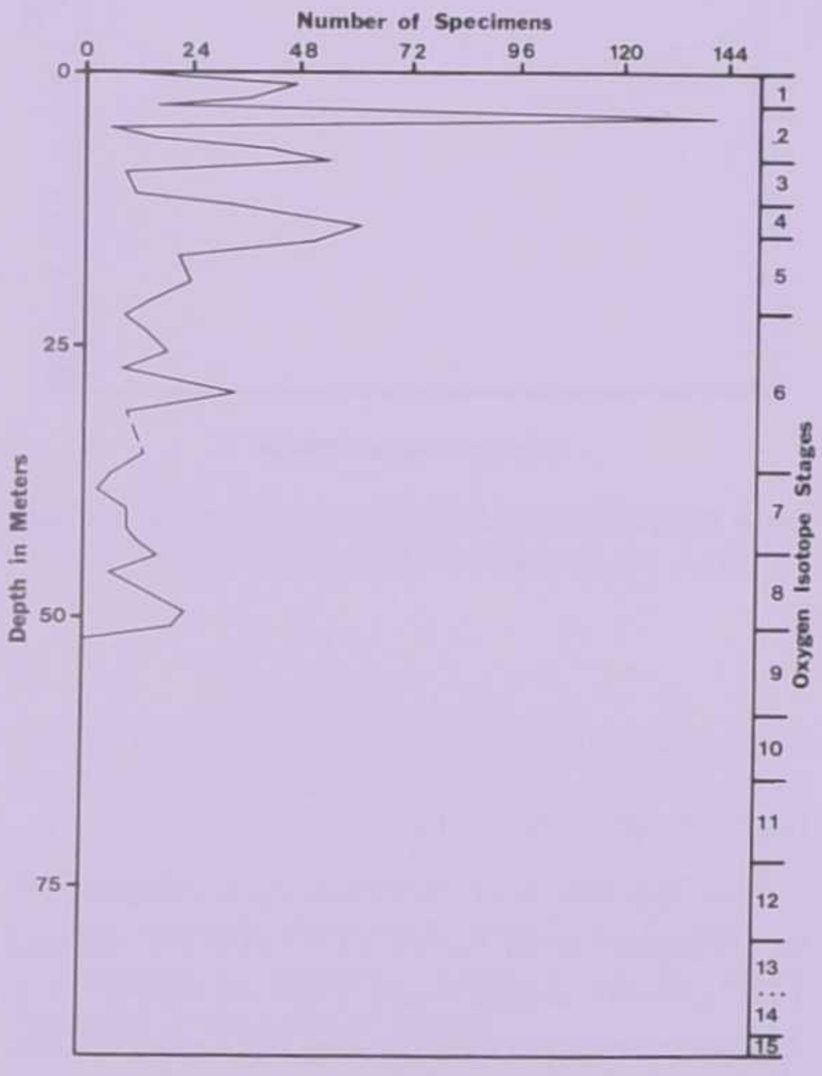

FIG. 7 - Abundances of *Emiliania huxleyi* in Cores 117-723A-1H through 117-723A-9H.

Gephyrocapsa aperta

The abundance of *G. aperta* in sediments from Samples 117-723A-1H through 117-723-9H ranges from 0% to 28.8% (0 to 144 specimens per sample-Fig. 8). Very low numbers (0% to 3% of the total nannofossil assemblage) of *G. aperta* are present in sediments which correspond to oxygen isotope stages 1 through 4 and stages 11 through 15. Fluctuations in abundances are present in samples from stage 5 through stage 10. A very high peak in abundance is present in stage 8. During stages 5 through 10 *G. aperta* seems to be more abundant during the glacial periods.

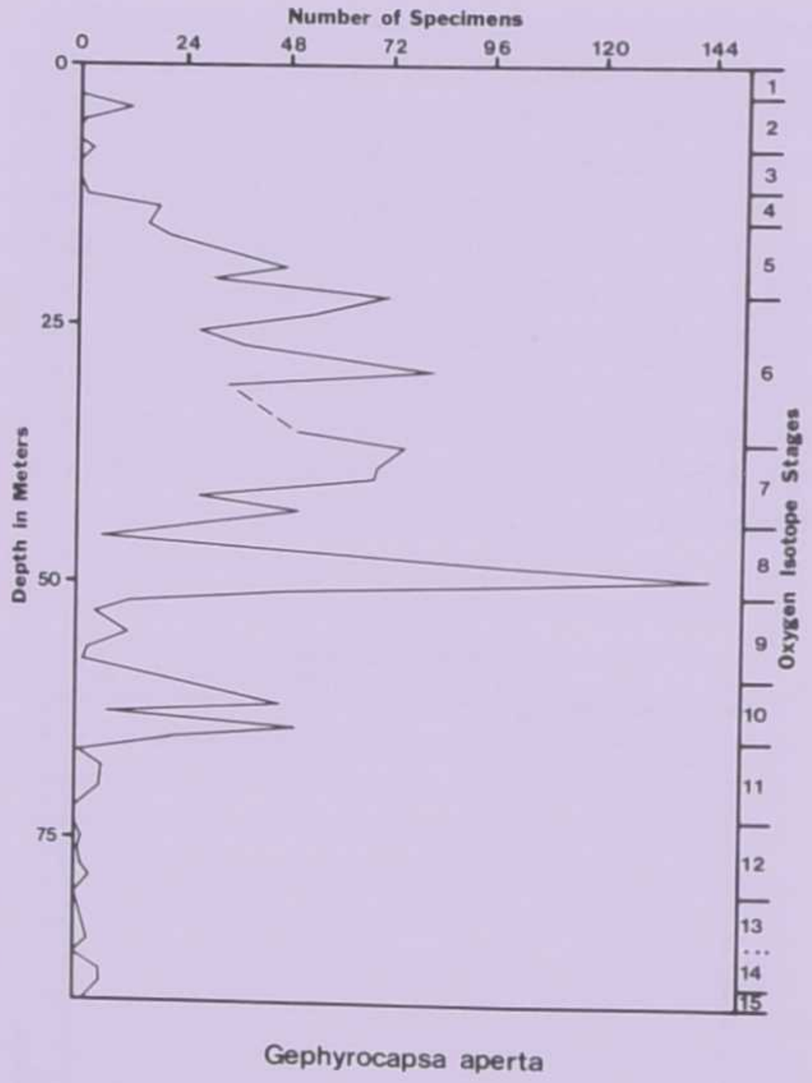

FIG. 8 - Abundances of *Gephyrocapsa aperta* in Cores 117-723A-1H through 117-723A-9H.

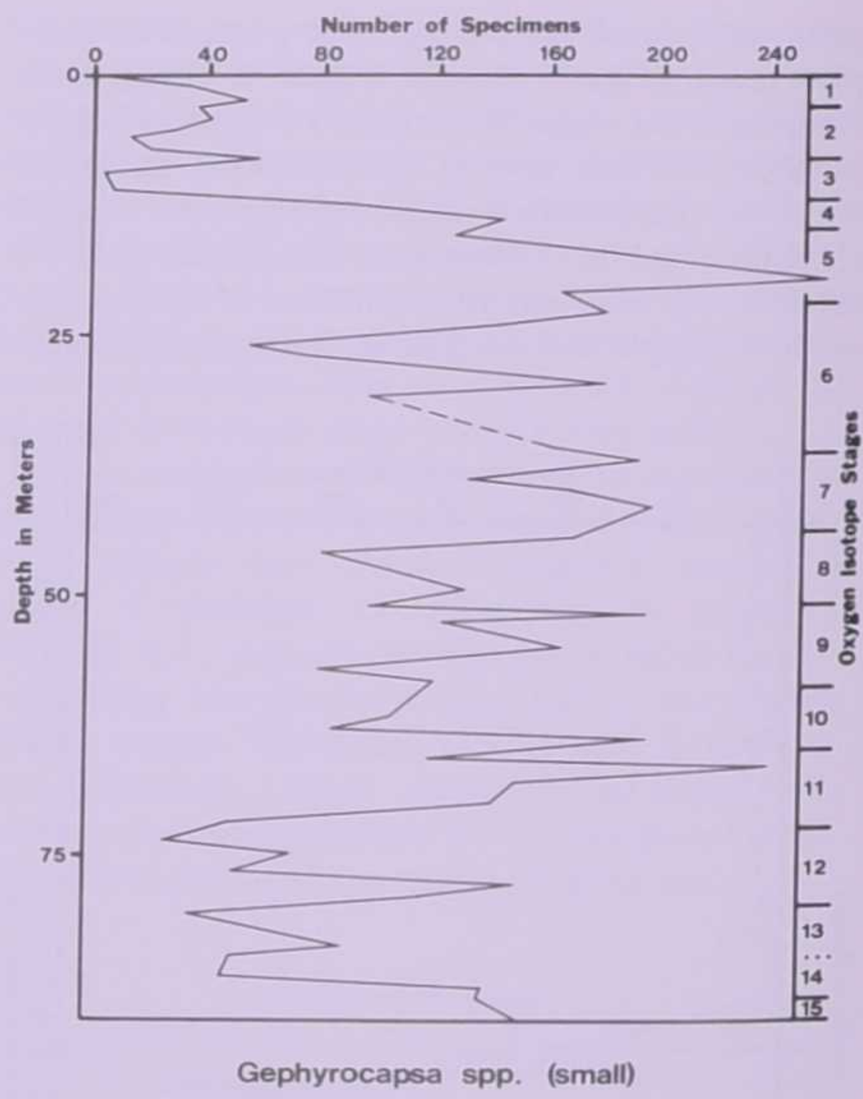

FIG. 9 - Abundances of *Gephyrocapsa* spp. (small) in Cores 117-723A-1H through 117-723A-9H.

Gephyrocapsa spp. (small)

The abundance of *Gephyrocapsa* (small) spp. in sediments from Cores 117-723A-1H through 117-723A-9H ranges from 0.8% to 48.8% (4 to 244 specimens per sample-Fig. 9). Large fluctuations in their abundance are present throughout oxygen isotope stages 1 through 15. Lower relative abundances are characteristic of stage 1 through stage 3.

Peaks in abundance are found in sediments which correlate with oxygen isotope stages 5 and 11. In sediments from stages 4 through 15, small gephyrocapsids are more abundant during regressions or interglacial stages. It seems quite likely that small gephyrocapsids are responding to the higher productivity associated with interglacial periods. GARTNER (1988) noted intervals of dominant small gephyrocapsids in mid-Pleistocene sediments. He suggested that large numbers of small *Gephyrocapsa* spp. were produced in areas with high nutrient availability and low temperatures which may have resulted from increased equatorial upwelling.

Gephyrocapsa spp. (medium)

Gephyrocapsa caribbeanica- The distribution of *G. caribbeanica* in oxygen isotope stages 1 through 15 is marked by large fluctuations in abundance (Fig. 10). The most pronounced abundance peak correlates with sediments from stage 12. Less pronounced peaks occur in stage 4 and late in stage 10. The overall abundance of this species ranges from 0% to 13.4% (0 to 67 specimens per sample) of the total nannofossil assemblage. *Gephyrocapsa caribbeanica* are most abundant in samples which correlate with ^{18}Oxygen isotope stages 10 through 12. This species appears to be more abundant at transitions (regressions and transgressions). GARTNER (1972) found that *G. caribbeanica* are more abundant during temperature minima.

Gephyrocapsa oceanica - This species is a dominant constituent of the nannofossil assemblage during the late Pleistocene. The overall abundance of this species ranges between 9.6% and 48.8% (48 to 244 specimens per sample). Large fluctuations characterize its abundance in Cores 117-723A-1H through 117-723A-9H (Fig. 11).

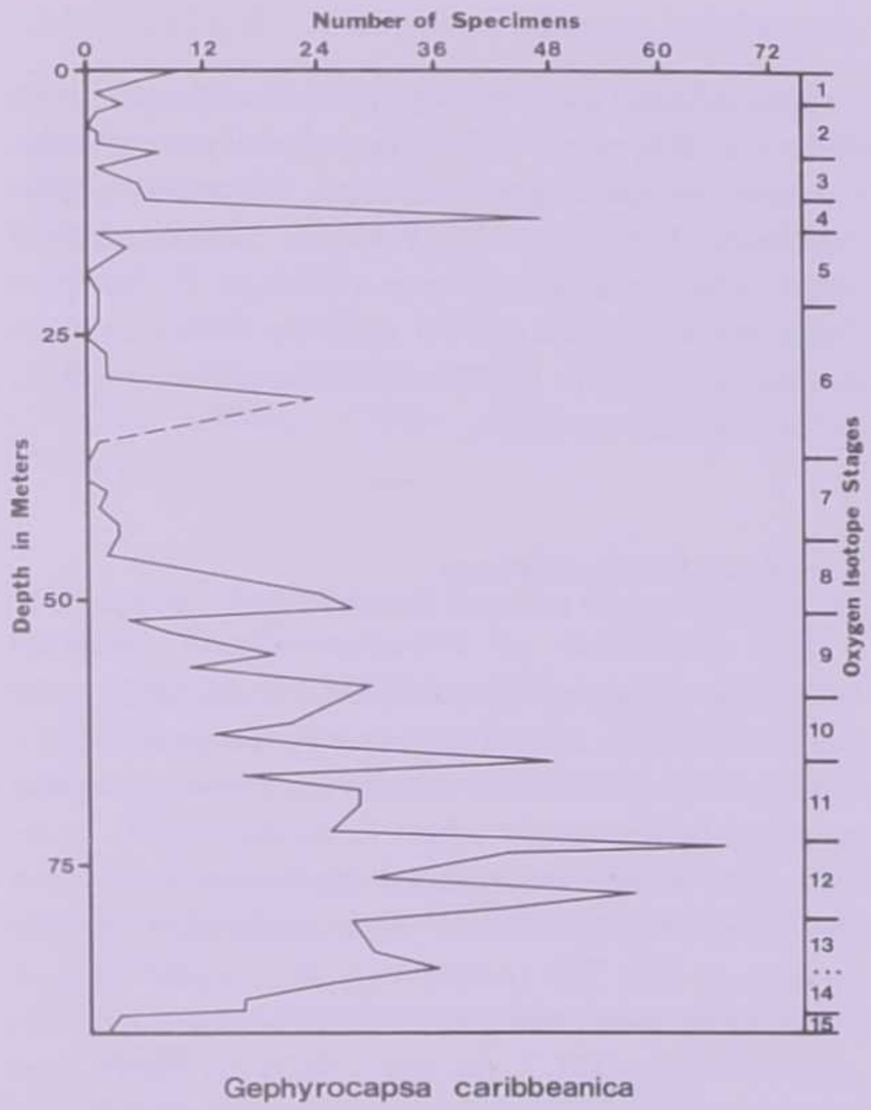

FIG. 10 - Abundances of *Gephyrocapsa caribbeanica* in Cores 117-723A-1H through 117-723A-9H.

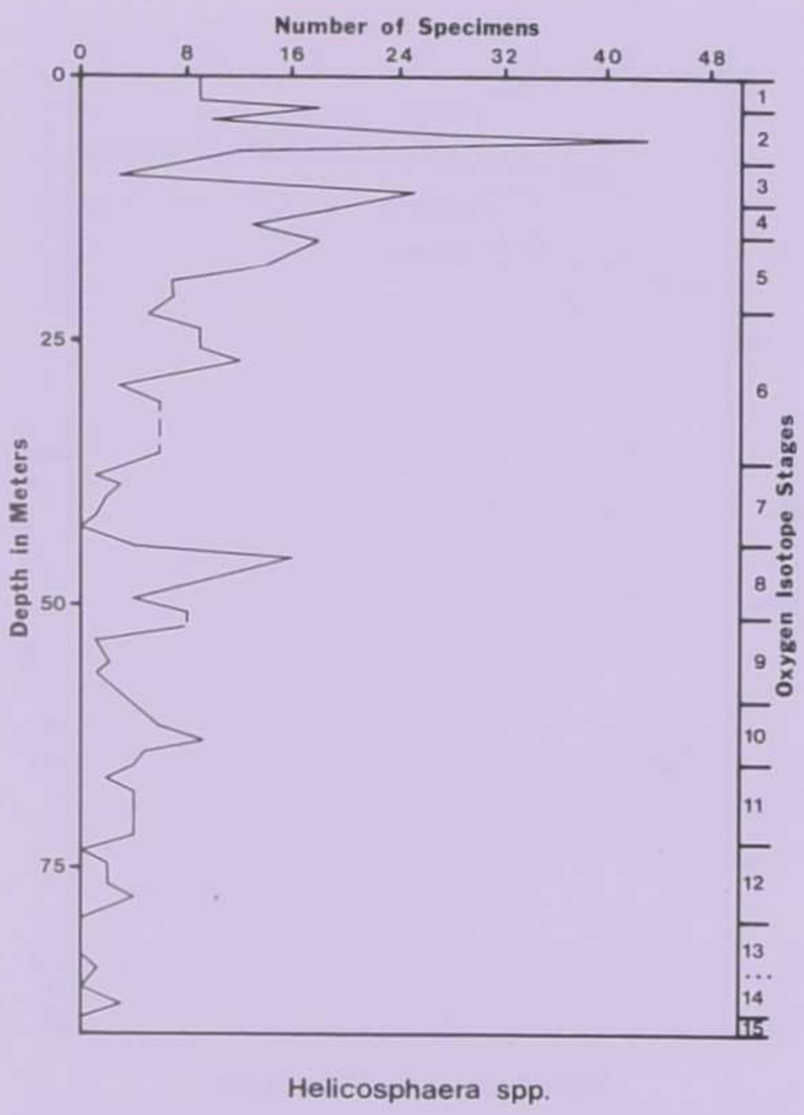

FIG. 12 - Abundances of *Helicosphaera* spp. in Cores 117-723A-1H through 117-723A-9H.

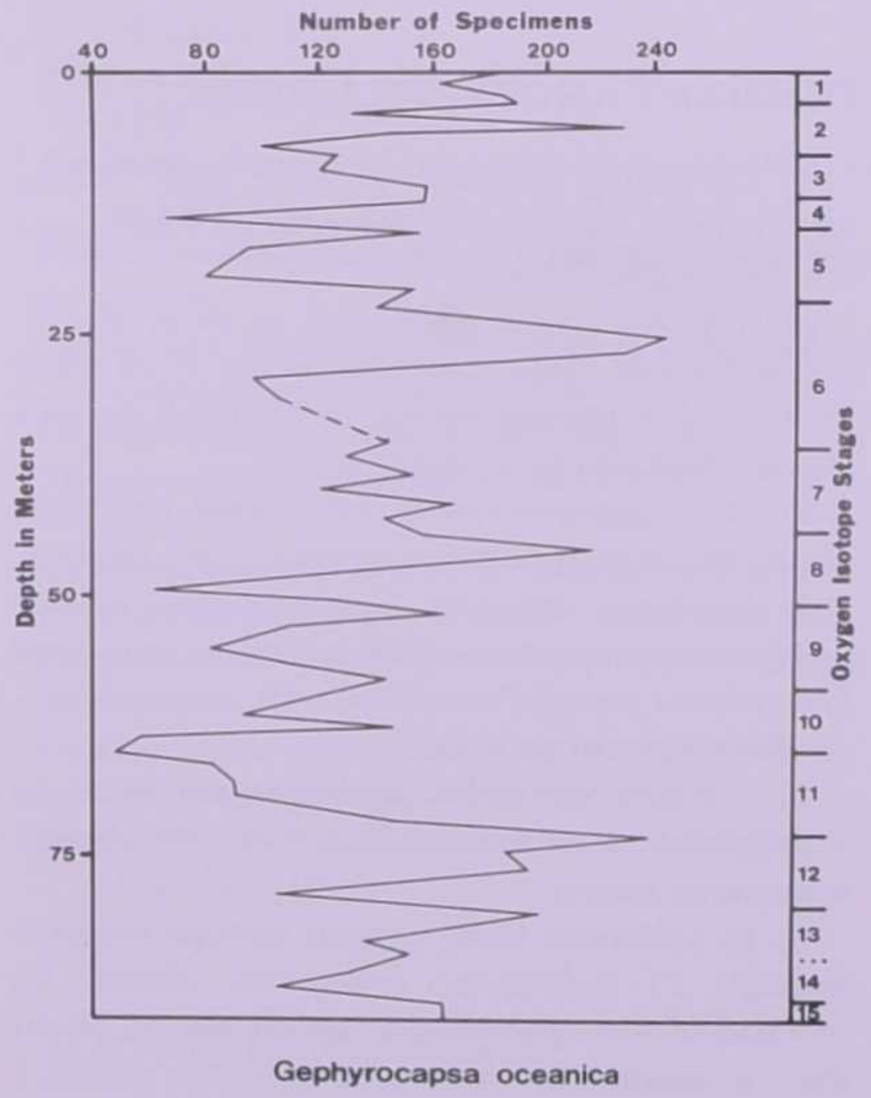

FIG. 11 - Abundances of *Gephyrocapsa oceanica* in Cores 117-723A-1H through 117-723A-9H.

COHEN (1964) found that higher numbers of *G. oceanica* correspond to temperature maxima. STEINMETZ and ANDERSON (1984) concluded that the abundance of *G. oceanica* has no relationship to temperature. However, based on Figure 11, *Gephyrocapsa oceanica* appears to be more abundant during glacial stages.

Helicosphaera spp.

The abundance of *Helicosphaera* species in sediments from Cores 117-723A-1H through 117-723A-9H ranges from 0% to 8.6% (0 to 43 specimens per sample-Fig. 12). It should be noted that the total member of specimens represented on Figure 12 as *Helicosphaera* spp. represents the total of *H. carteri, H. wallichi* and *H.* spp. shown in Table 1. Samples which correlate with oxygen isotope stages 1 through 3 contain higher numbers of *Helicosphaera* spp. relative to those samples from stages 4 through 15. The abundance in samples from stages 4 through 15 range from 0% to 2.6% (0 to 13).

PERCH-NIELSEN (1985) suggested that species belonging to the genus *Helicosphaera* prefer regions of upwelling. In this study, *Helicosphaera* seem to be more abundant during glacial stages.

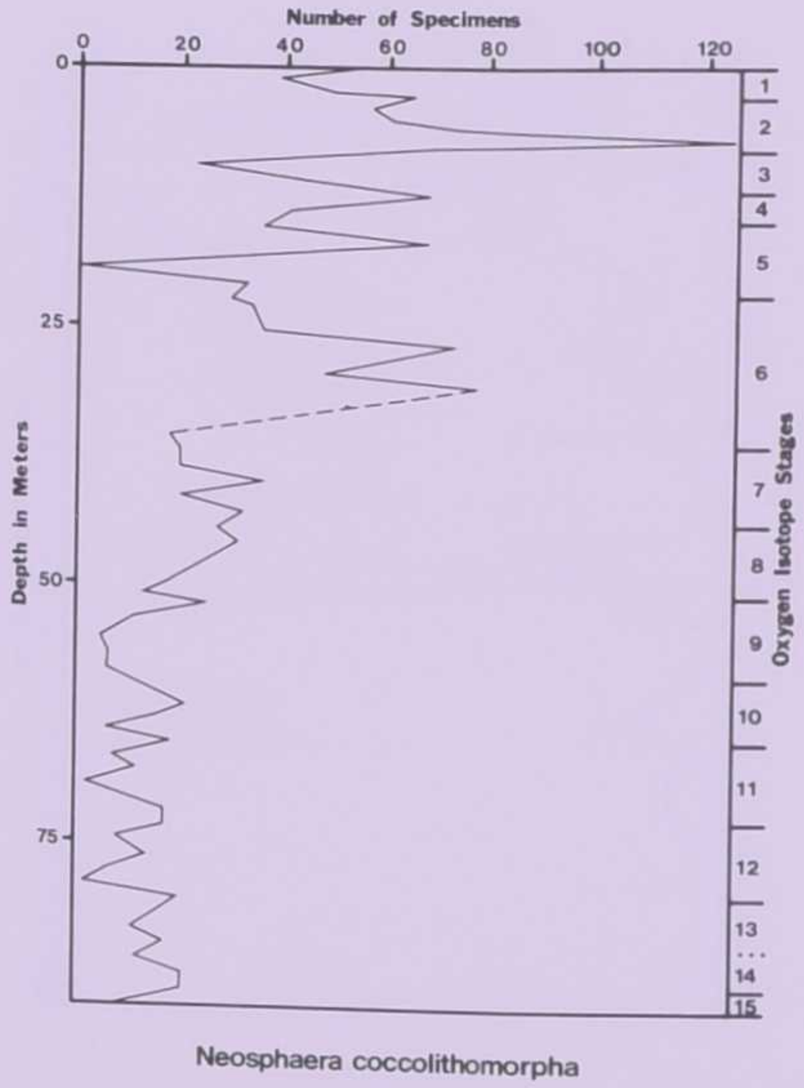

FIG. 13 - Abundances of *Neosphaera coccolithomorpha* in Cores 117-723A-1H through 117-723A-9H.

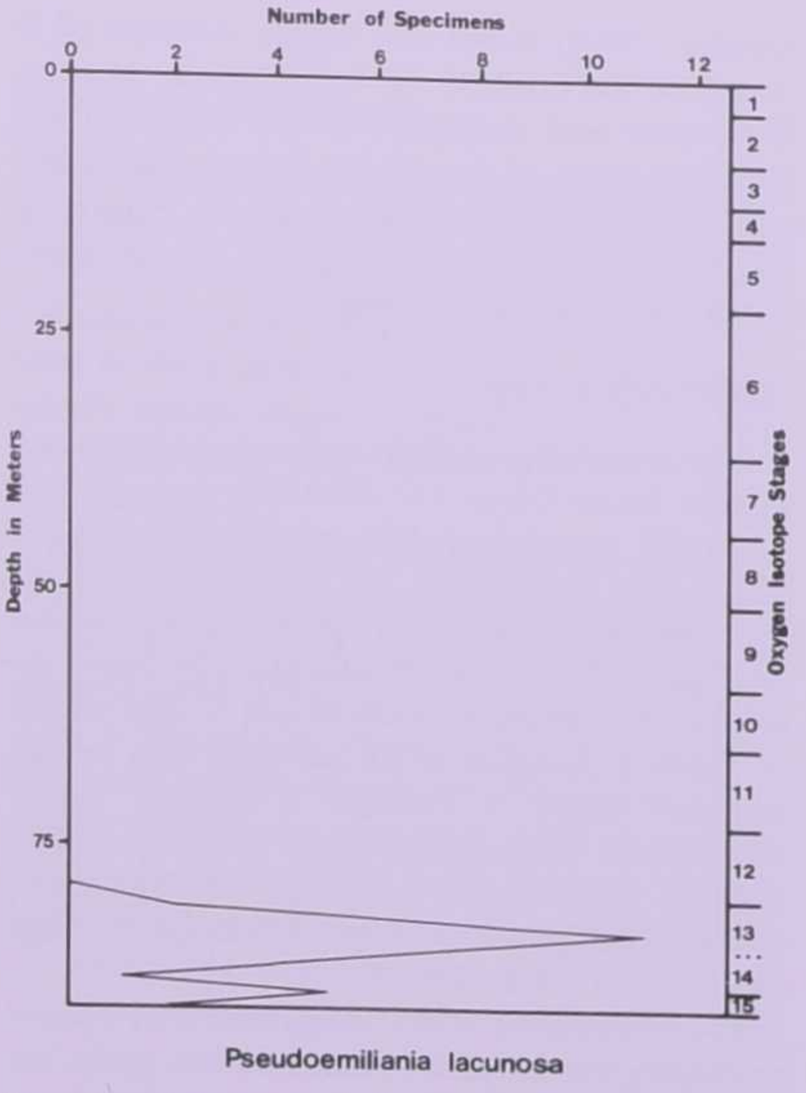

FIG. 14 - Abundances of *Pseudoemiliania lacunosa* in Cores 117-723A-1H through 117-723A-9H.

Neosphaera coccolithomorpha

Neosphaera coccolithomorpha comprises from 0% to 25.0% of the total nannofossil assemblage. Oxygen isotope stages 1 through 6 contain higher numbers of this species (Fig. 13). A pronounced abundance peak occurs late in stage 2. Samples from stages 7 through 15 contain lower relative numbers (0.6% to 9.0% of the total assemblage) of *N. coccolithomorpha*.

Pseudoemiliania lacunosa

The abundance of *Pseudoemiliania lacunosa* ranges between 0.4% to 2.2% (2 to 11 specimens per sample-Fig. 14). Two abundance peaks occur during the relatively short interval of time spanned by this study when *P. lacunosa* was present. The more pronounced peak occurs before this species goes extinct. The extinction of this species at Site 723 occurs late in oxygen isotope stage 12 between Samples 117-723A-8H-6, 65 cm and 117-723A-8H-7, 84 cm (78.75 to 80.44 meters below sea floor). THIERSTEIN *et al.* (1977) and STEINMETZ and ANDERSON (1984) record the extinction of this species in the middle part of oxygen isotope stage 12.

SUMMARY AND CONCLUSIONS

1) Upwelling intensity is very high during terminations, high during interglacial stages, and low during glacial stages.

2) *Gephyrocapsa caribbeanica* is most abundant in the late Pleistocene sediments from ODP Hole 723A deposited during transitional periods (*i.e.* transgressions and regressions).

3) Small gephyrocapsids were most abundant during regressions or warm (interglacial) periods.

4) *Emiliania huxleyi, Gephyrocapsa aperta, Gephyrocapsa oceanica, Helicosphaera* spp., and *Neosphaera coccolithomorpha* were most abundant during glacial periods.

5) The numbers of *Dictyococcites productus* in a sample show no relationship with the glacial/interglacial stages.

6) In sediments from oxygen isotope stages 5 through 15 *Calcidiscus leptoporus* shows no correlation with glacial/interglacial stages. However, in sediments from oxygen isotope stages 1 through 4, *C. leptoporus* is more abundant during the warm (interglacial) periods.

APPENDIX

21 species and 16 genera have been recognized during this investigation. Bibliographic references for previously described taxa may be found in LOEBLICH and TAPPAN (1966, 1968, 1969, 1970a, 1970b, 1971, 1973), in STEINMETZ (1983a, 1983b, 1984a, 1984b, 1985a, 1985b, 1986a, 1986b, 1987a, 1987b, 1988a, 1988b) and in VAN HECK (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b).

Calcareous Nannofossil Species Considered in this Report
(Species listed alphabetically by species epithet)

Gephyrocapsa aperta KAMPTNER, 1963
Gephyrocapsa caribbeanica BOUDREAUX and HAY, 1963
Helicosphaera carteri (WALLICH) KAMPTNER, 1954
Rhabdosphaera clavigera MURRAY and BLACKMAN, 1898
Neosphaera coccolithomorpha LECAL-SCHLAUDER, 1950
Pontosphaera discopora SCHILLER, 1925
Crenalithus doronicoides (BLACK and BARNES) ROTH, 1973
Scapholithus fossilis DEFLANDRE *in* DEFLANDRE and FERT, 1954
Oolithotus fragilis (LOHMANN) MARTINI and MÜLLER, 1972
Thoracosphaera heimi (LOHMANN) KAMPTNER, 1941
Emiliania huxleyi (LOHMANN) HAY and MOHLER *in* HAY *et al.*, 1967
Pseudoemiliania lacunosa (KAMPTNER) GARTNER, 1969c
Calcidiscus leptoporus (MURRAY and BLACKMAN) LOEBLICH and TAPPAN, 1978
Gephyrocapsa oceanica KAMPTNER, 1943
Thoracosphaera operculata BRAMLETTE and MARTINI, 1964
Gephyrocapsa parallela HAY and BEAUDRY, 1973
Coccolithus pelagicus (WALLICH) SCHILLER, 1930
Dictyococcites productus (KAMPTNER) BACKMAN, 1980
Gephyrocapsa protohuxleyi MC INTYRE, 1970
Syracosphaera pulchra LOHMANN, 1902
Helicosphaera wallichi (LOHMANN), BOUDREAUX and HAY, 1969.

ACKNOWLEDGEMENTS

Dr. D.K. WATKINS provided assistance during numerous phases of this project. Discussions with DAVE ANDERSON, JONATHAN RICE and Drs. W. PRELL, N. NIITSUMA and H. OKADA are gratefully acknowledged. PURTYASTI RESIWATI helped in the darkroom during the production of the plates. JONATHAN RICE drafted many of the figures. Special thanks to Drs. J. FIRTH, J. MUTTERLOSE and J. STEINMETZ for critically reviewing this manuscript.

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EXPLANATION OF PLATE I

FIGS. 1-3 - *Calcidiscus leptoporus*, Sample 117-723A-1H-4, 80 cm; 1 = crossed nicols, 2 = transmitted light, 3 = phase contrast.

FIGS. 4-6 - *Dictyococcites productus*, Sample 117-723A-7H-5, 90 cm; 4 = crossed nicols, 5 = transmitted light, 6 = phase contrast.

FIGS. 7-9 - *Emiliania huxleyi*, Sample 117-723A-1H-1, 120 cm; 7 = crossed nicols, 8 = transmitted light, 9 = phase contrast.

FIGS. 10-12 - *Gephyrocapsa caribbeanica*, Sample 117-723A-9H-2, 140 cm; 10 = crossed nicols, 11 = transmitted light, 12 = phase contrast.

FIGS. 13-14 - *Gephyrocapsa caribbeanica* (small), Sample 117-723A-9H-3, 90 cm; 13 = crossed nicols, 14 = phase contrast.

FIGS. 15-16 - *Gephyrocapsa aperta*, Sample 117-723A-9H-2, 140 cm; 15 = crossed nicols, 16 = phase contrast.

FIGS. 17-18 - *Gephyrocapsa oceanica*, Sample 117-723A-9H-2, 140 cm; 17 = crossed nicols, 18 = phase contrast.

FIGS. 19-21 - *Scapholithus fossilis*, Sample 117-723A-10H-3, 118 cm; 19 = crossed nicols, 20 = transmitted light, 21 = phase contrast.

FIGS. 22-24 - *Syracosphaera pulchra*, Sample 117-723A-1H-5, 20 cm; 22 = crossed nicols, 23 = transmitted light, 24 = phase contrast.

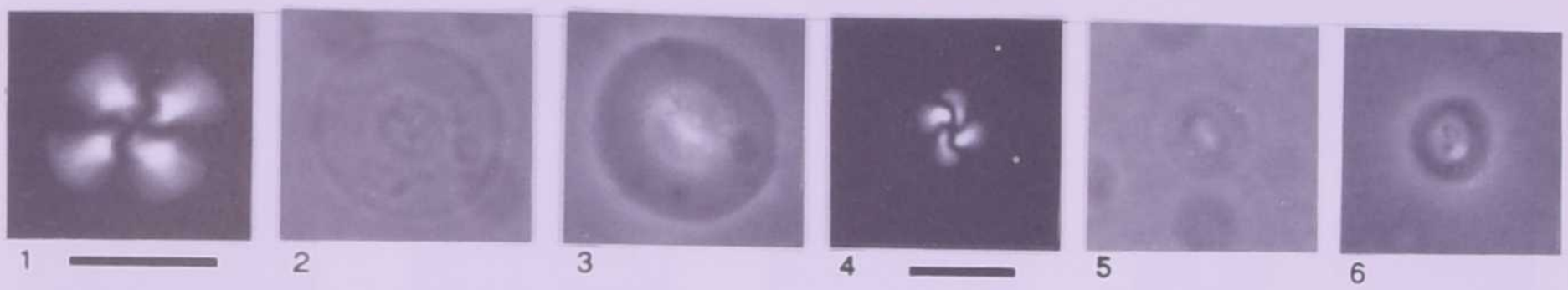
FIGS. 25-27 - *Pseudoemiliania lacunosa*, Sample 117-723A-9H-3, 90 cm; 25 = crossed nicols, 26 = transmitted light, 27 = phase contrast.

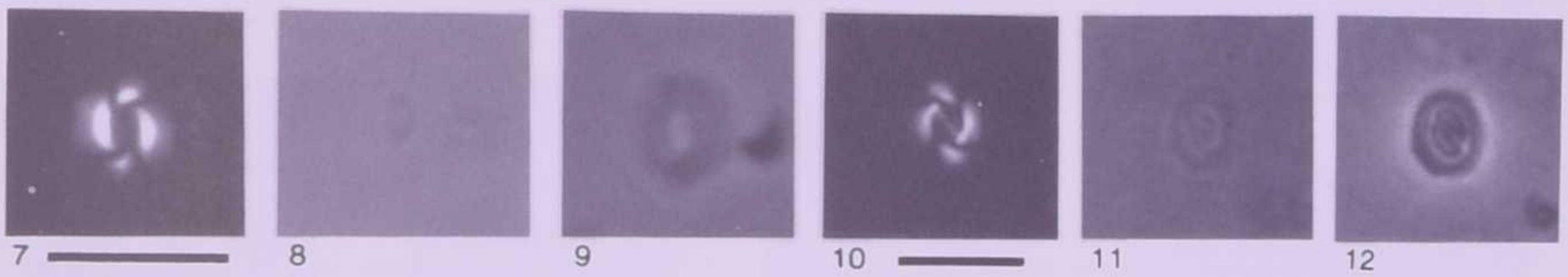
FIGS. 28-30 - *Rhabdosphaera clavigera*, Sample 117-723A-1H-3, 60 cm; 28 = crossed nicols, 29 = transmitted light, 30 = phase contrast.

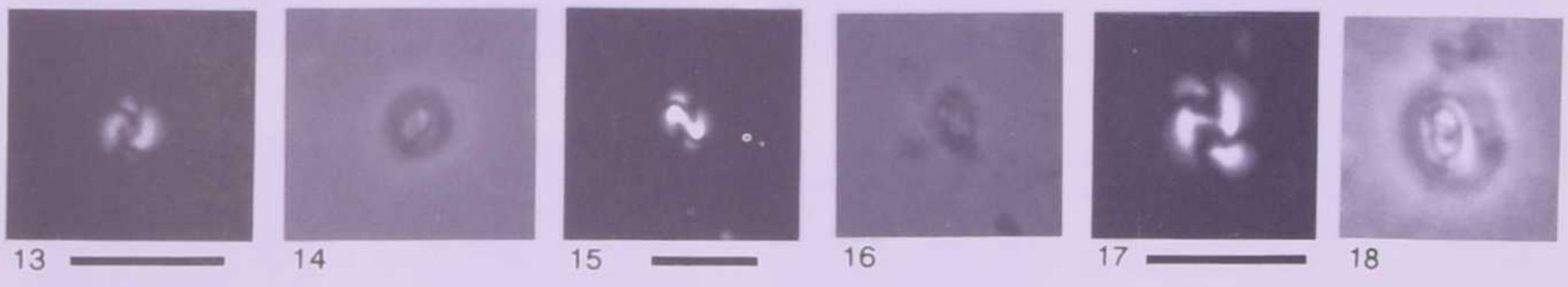
All scale bars are equal to five microns.

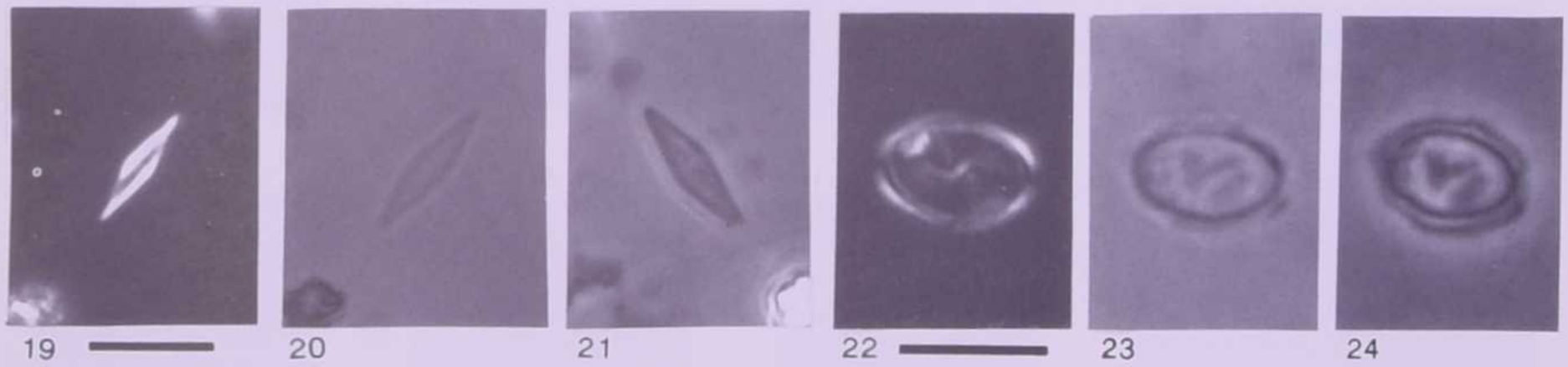
S.A. SPAULDING, T. OBA - *Association of late Pleistocene calcareous nannofossil assemblages and oxygen and carbon isotopic changes, ODP LEG 117, Oman margin, Arabian sea*

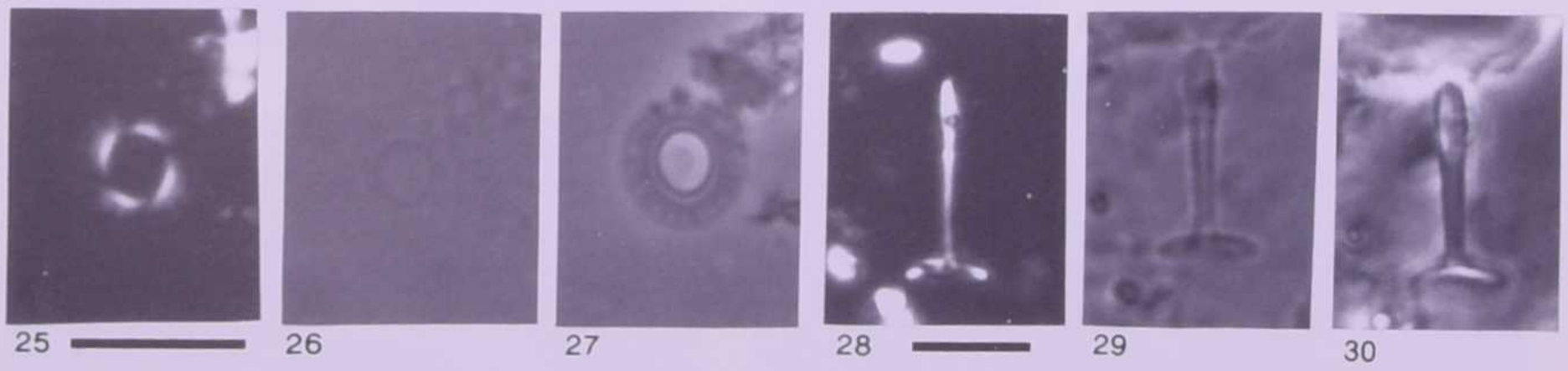
PLATE I











EXPLANATION OF PLATE II

FIGS. 1-3 - *Helicosphaera carteri*, Sample 117-723A-1H-3, 60 cm; 1 = crossed nicols, 2 = transmitted light, 3 = phase contrast.

FIGS. 4-6 - *Helicosphaera wallichi*, Sample 117-723 A-2H-1, 50 cm; 4 = crossed nicols, 5 = transmitted light, 6 = phase contrast.

FIGS. 7-9 - *Pontosphaera discopora*, Sample 117-723A-1H-3, 60 cm; 7 = crossed nicols, 8 = transmitted light, 9 = contrast.

FIGS. 10-12 - *Neosphaera coccolithomorpha*, Sample 117-723A-7H-5, 90 cm; 10 = crossed nicols, 11 = transmitted light, 12 = phase contrast.

FIGS. 13-15 - *Thoracosphaera heimi*, Sample 117-723A-7H-5, 90 cm; 13 = crossed nicols, 14 = transmitted light, 15 = phase contrast.

FIGS. 16 - *Emiliania huxleyi*, Sample 117-723A-1H-1, 118 cm. Cold water form with solid proximal shield slits in distal shield only, and completely covered central area (prior to partial dissolution). S.E.M. Photograph.

FIGS. 17 - *Gephyrocapsa parallela*, Sample 117-723A-1H-1, 118 cm. S.E.M. Photograph.

Scale bars are equal to five microns for Figs. 1 to 15; in Figs. 16 and 17 scale bars are equal to one micron.

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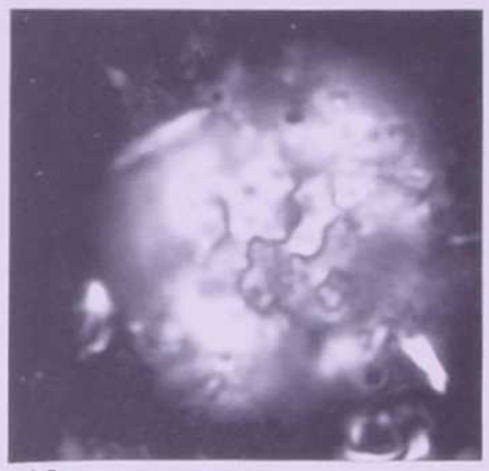

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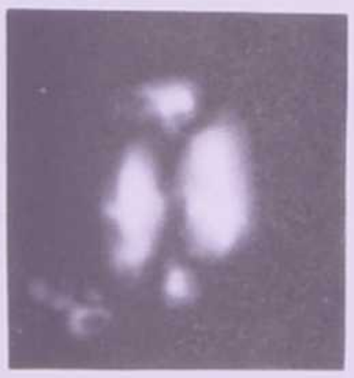

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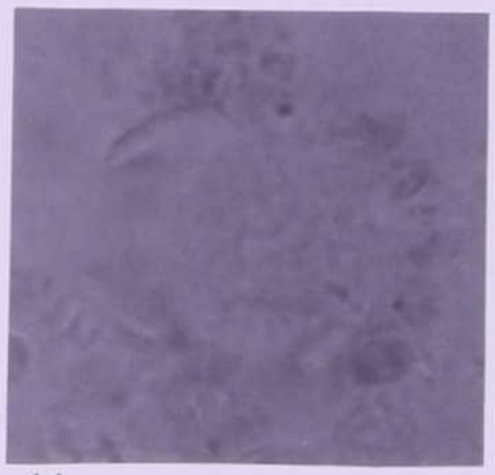

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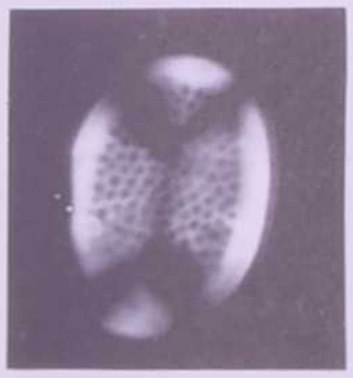

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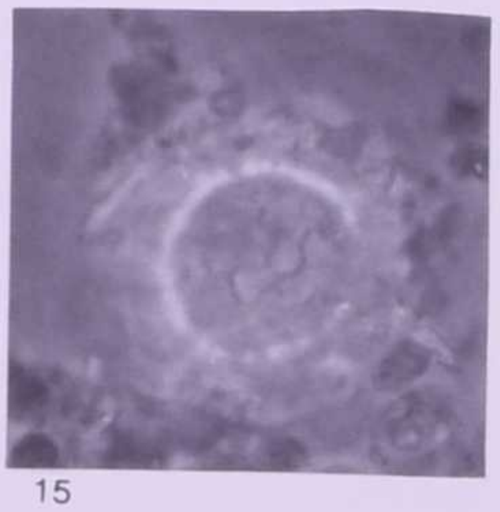

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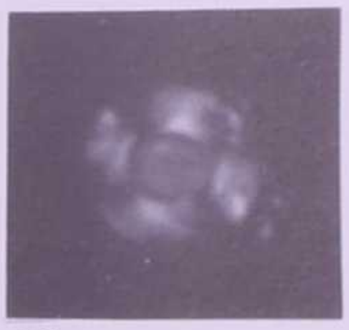

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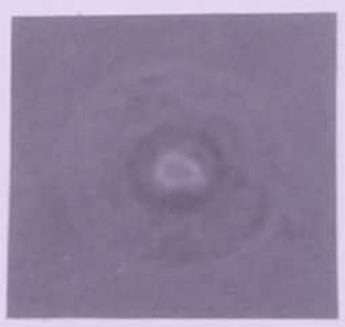

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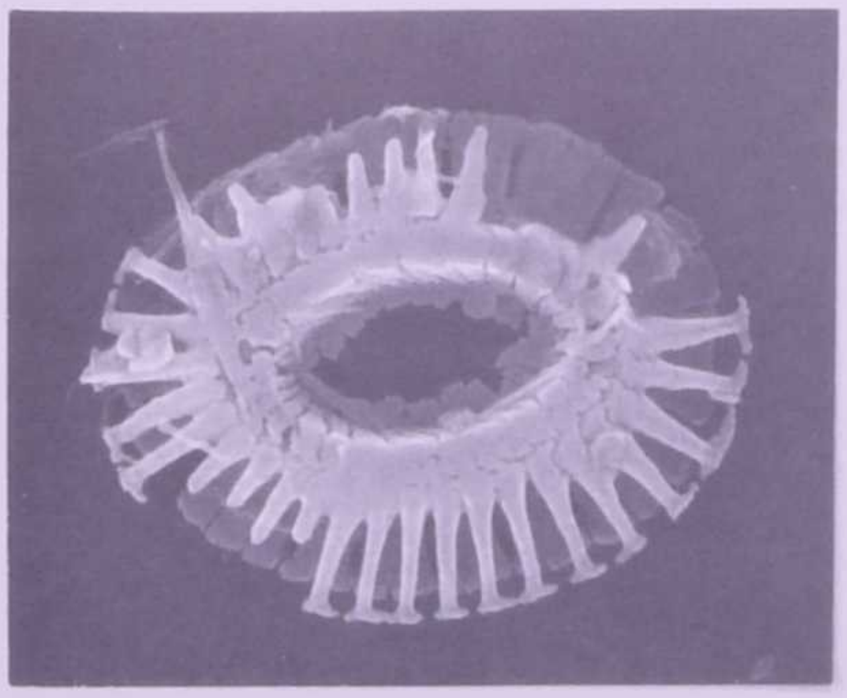

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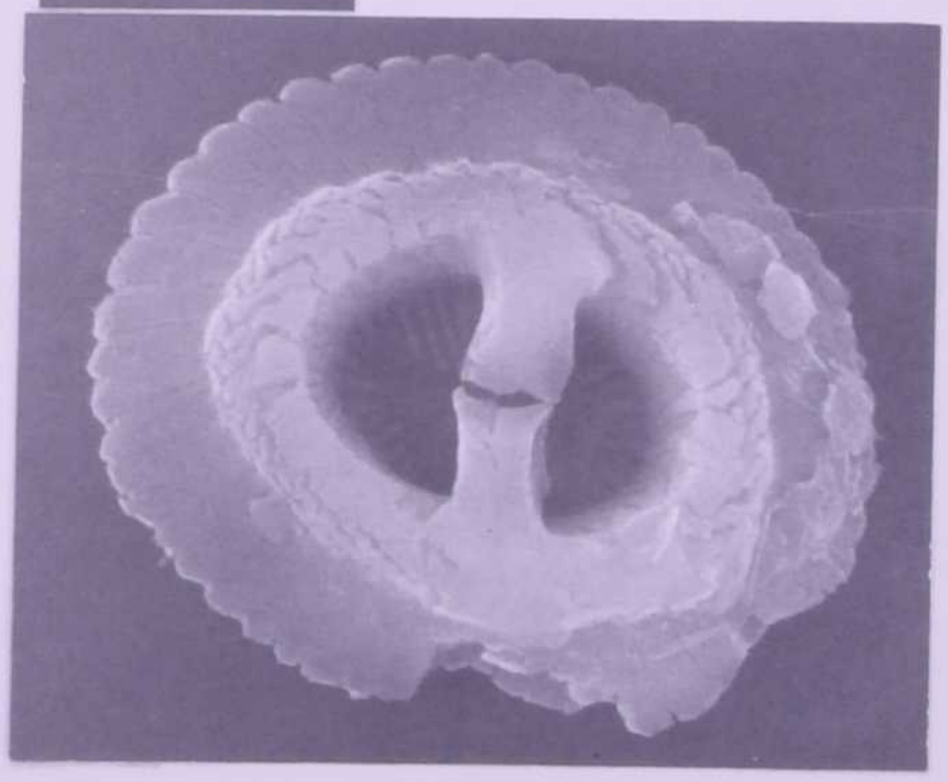

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