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

Allegato al Vol. XLIII, pagg. 375-387, 7 figg. e 5 tabb.
Padova, maggio 1992

JACQUES GIRAUDEAU *

COCCOLITH PALEOTEMPERATURE AND PALEOSALINITY ESTIMATES IN THE CARIBBEAN SEA FOR THE MIDDLE-LATE PLEISTOCENE (DSDP LEG 68 - HOLE 502B)

CONTENTS

Key words: Nannofossils, Pleistocene, Transfer Function, temperature, salinity, Caribbean.

ABSTRACT

Quaternary calcareous nannofossils from Hole 502B -DSDP Leg 68 - are studied in a paleoecological context. The combined using of coccolith (*Gephyrocapsa* group and *Emiliania*), isotopic (δO^{18}) and carbonate datums provides the stratigraphic framework. The method for quantitative paleoclimatology — Transfer Function — is tested on nannofossil distribution in surface sediments of tropical Atlantic and Caribbean. The application of this method is based on a limited number of taxa, and a two step transformation of exact counts (from coccoliths to coccospheres and abundance classes); it leads to dependable ecological equations connecting floral associations to SST and SSS. These transfer functions are used to reconstruct the Western Caribbean surface paleohydrology during the last 350000 years. Paleoecological estimates closely agree with isotopic measurements, warm and low salted conditions occurring during glacial stages, whereas cold and higher salted conditions characterized interglacial stages. These estimates are compared with those calculated previously with planktonic foraminifera from the same area: estimate discrepancies may have been caused by both ecological reasons (depth distributions of living organisms) and oceanographical and environmental characteristics of the studied area (fluvial inflow, tropical precipitations).

RIASSUNTO

I nannofossili calcarei quaternari del pozzo 502B (Leg 68 DSDP) vengono studiati in un contesto paleoecologico. Il supporto stratigrafico è fornito dall'uso combinato di dati ricavati dai coccoliti (gruppo *Gephyrocapsa* ed *Emiliania*), dagli isotopi (δO^{18}) e dai carbonati. Il metodo per la paleoclimatologia quantitativa, noto come "Transfer Function", viene verificato sulla base della distribuzione dei nannofossili nei sedimenti superficiali dell'Atlantico tropicale e dei Caraibi. L'applicazione di questo metodo si basa su un numero limitato di taxa e una trasformazione in due fasi dei con-

* Département de Géologie et Océanographie, Université de Bordeaux I, Avenue des Facultés, 33405 TALENCE CEDEX, France. Present address: c/o R.V. DINGLE Micropaleontology Research Unit., South African Museum, PO Box 61, 8000 CAPE TOWN, South Africa.
Financial support from Centre National de la Recherche Scientifique UA 197.

teggi esatti (da coccoliti a coccosfere e classi di frequenza); esso porta a stabilire delle equazioni ecologiche che connettono le associazioni floristiche alla temperatura ed alla salinità delle acque superficiali (SST e SSS). Queste "Transfer Functions" sono usate per ricostruire la paleoidrologia di superficie del mare Caraibico occidentale durante gli ultimi 350.000 anni. Le stime paleoecologiche sono in stretto accordo con le misure isotopiche che indicano condizioni di caldo e bassa salinità durante gli stadi glaciali e condizioni di freddo ed elevata salinità durante gli interglaciali. Queste stime sono comparate con quelle calcolate in precedenza nella stessa area mediante i foraminiferi planctonici; discrepanze nelle stime possono essere state causate sia da ragioni ecologiche (distribuzione in profondità di organismi viventi) sia da caratteristiche oceanografiche ed ambientali dell'area studiata (apporti fluviali, precipitazioni tropicali).

INTRODUCTION

Estimate of hydrological parameters using Transfer Function is the basic technic carried out by CLIMAP Project Members, 1976, 1984). This statistical manipulation created by IMBRIE and KIP (1971) was first established on counts of planktonic foraminifera (IMBRIE *et al.*, 1973; PRELL and HAYS, 1976; RUDDIMAN *et al.*, 1980; MOLFINO *et al.*, 1982). Now it is commonly applied to radiolarian (MORLEY, 1989) and diatom assemblages (PICHON *et al.*, 1987) but till now there are very few works about Transfer Function based on nannofossils. MC INTYRE and his staff are the only ones who had satisfying results although limited to the last climatic stages and they often did not mention the meaning of entering nannofossil count data (GEITZENAUER *et al.*, 1976; ROCHE *et al.*, 1975; MOLFINO *et al.*, 1982). *Coccolithophoridae* living in the upper layer of the oceans, are more sensitive to changes in physical-chemical (temperature, salinity, nutrients) and atmospheric parameters (precipitation, cloud cover, solar radiation) than other planktonic organisms as planktonic foraminifera.

The aim of this paper is thus to set up a new Transfer Function from nannofossil assemblages in order to estimate Sea Surface Temperatures (SST) and Salinities (SSS), and to apply it to a continuous middle to late Pleistocene section.

The model will be tested comparing the results with previous paleoenvironmental estimates in the same geographic area using planktonic foraminifera.

MATERIAL and METHOD

The Pleistocene of the Caribbean Sea is usually characterized by continuous and undisturbed sedi-

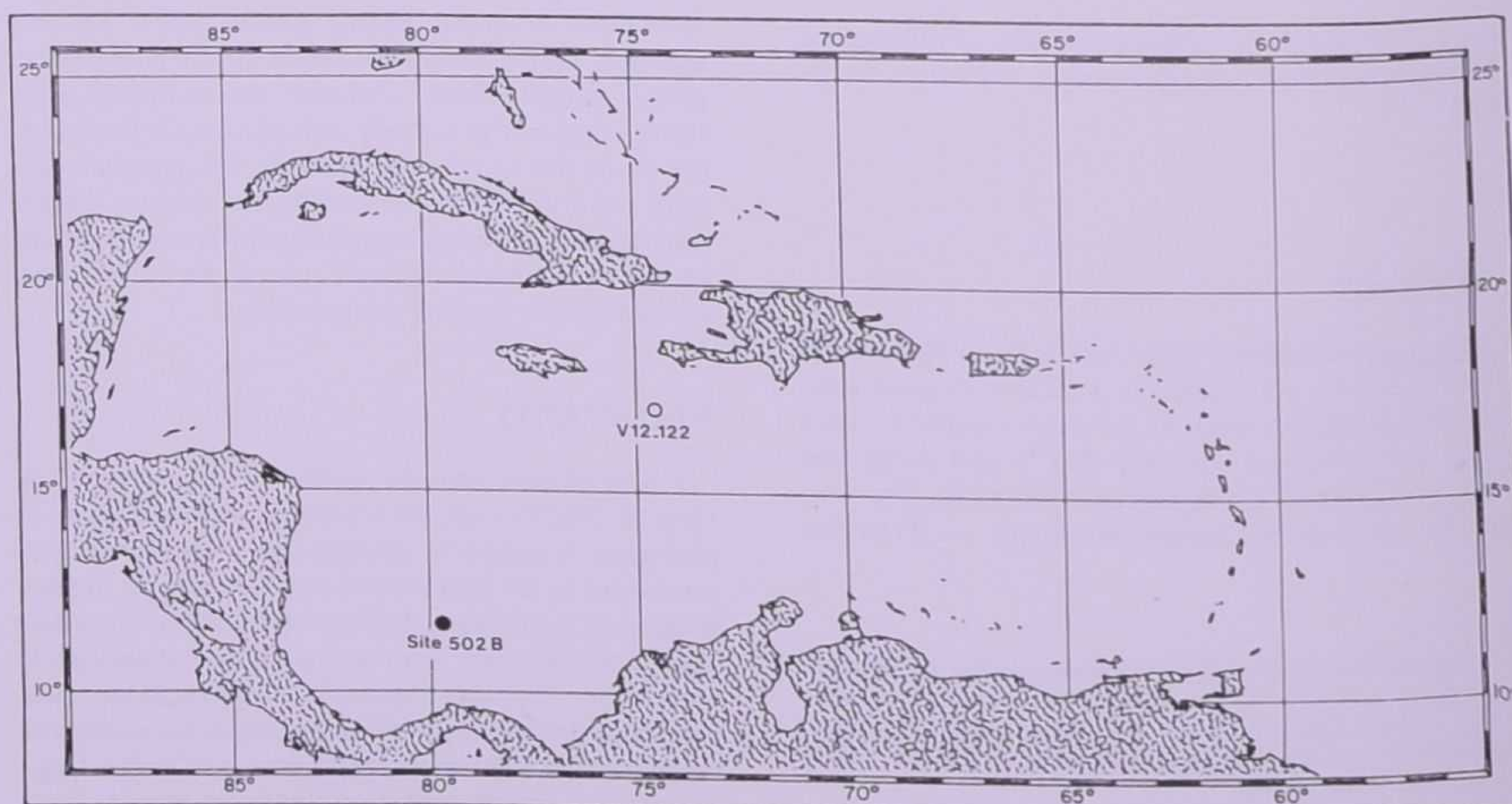

FIG. 1 - Locations of cores discussed in this study.

mentation. Hole 502B from DSDP Leg 68 is selected as study location because it has the most complete recovery and less disturbance for the whole Pleistocene among the other piston cores drilled in this area. This site is located West of Caribbean, in the Colombia Basin - lat.: 11°29' N; long.: 74°29'W - (Fig. 1).

Nannofossils are studied in the upper 6.5 meters of the Site. These cores are composed of homogeneous foraminifer-bearing nannofossil marl with an average weight $CaCO_3$ of 45% (GARDNER, 1982).

Figure 2 shows the distribution of nannofossils against core-depth, weight $CaCO_3$, and σO18 measured in shells of *Globigerinoides sacculifer* (PRELL, 1982).

Coccoliths are observed and counted quantitatively on smear slides of raw sediment, every 10 cm of core, with an optical microscope at x 1200 magnification. Two groups of nannofossils are distinguished:

— the first one ("stratigraphic species") is composed of taxa with time limited distribution. They belong to the genera *Gephyrocapsa* and *Emiliania*, and are used for biostratigraphy. The distribution of this group is expressed globally in term of total abundance of 1 field of view (Fig. 2).

— the second ("ecological species") is composed of poorly represented taxa which are present almost all through the Pleistocene. Their individual abundance is expressed in percent, independently of the "stratigraphic species" and *Florisphaera* sp.

At last the overall abundance of *Florisphaera* sp. imposes to express it in term of total abundance on 1 field of view.

18 taxa are recognized in the upper 6/5 meters of the Site:

Ceratolithus sp. KAMPTNER, 1950

Coccolithus pataecus GARTNER, 1967

Cyclococcolithina leptopora (MURRAY and BLACKMAN) WILCOXON, 1970

Cyclolithella annula (COHEN) COHEN and REINHARDT, 1968

Emiliania huxleyi (LOHMAN) HAY and MOHLER, 1967

Florisphaera sp.

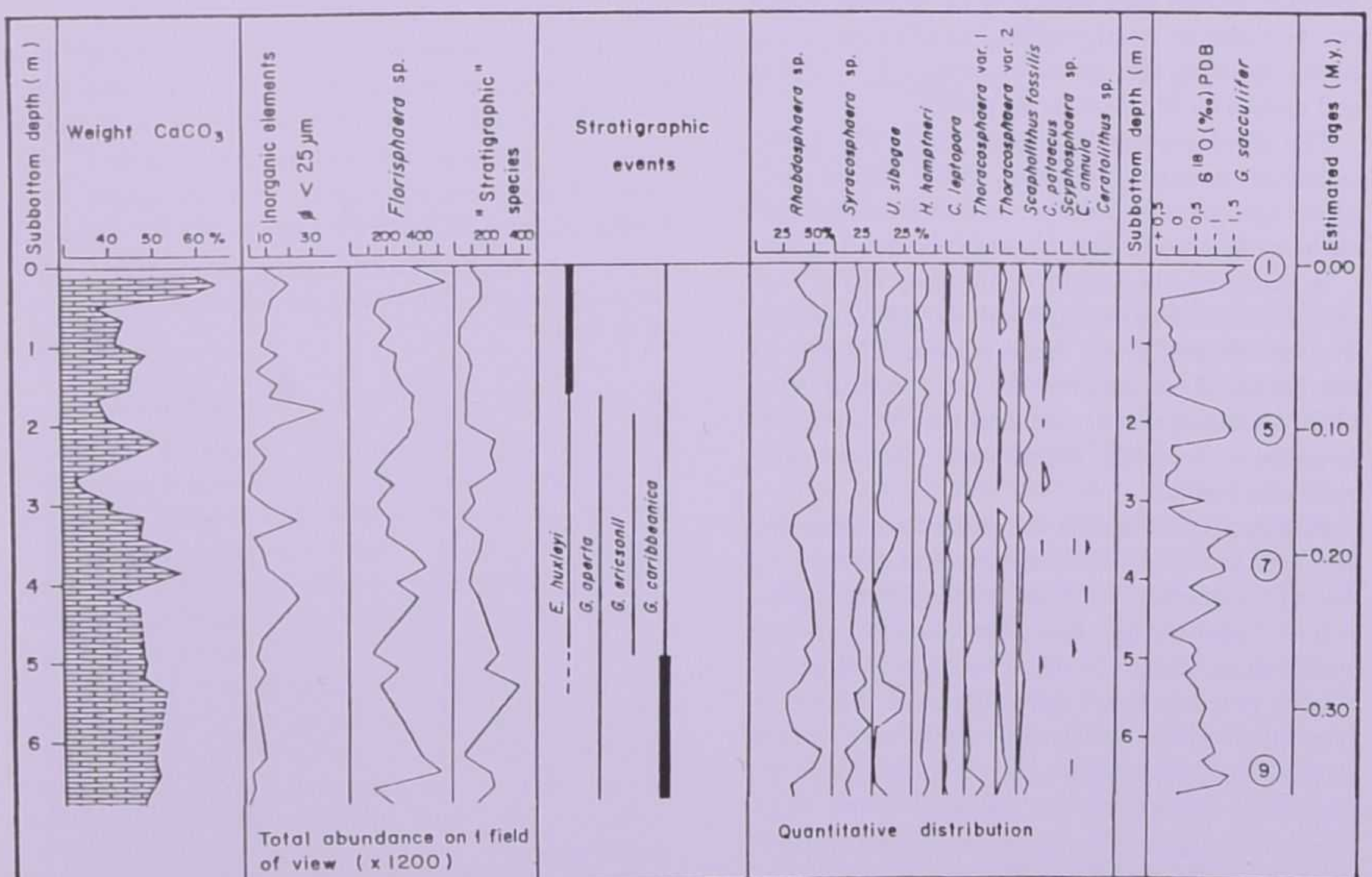

FIG. 2 - Hole 502B: Weight $CaCO_3$; Total abundance on 1 field of view (x 1200): inorganic elements (Ø<25µm); *Florisphaera* sp.; "Stratigraphic" species = "*Gephyrocapsa - Emiliania*" complex; Stratigraphic events: appearances -extinctions - acmes; Relative abundance of the other nannofossil taxa; δO^{18} measurements in shells of *Globigerinoides sacculifer*.

Gephyrocapsa aperta KAMPTNER, 1963
Gephyrocapsa caribbeanica BOUDREAUX and HAY, 1967
Gephyrocapsa ericsonii MC INTYRE and BE, 1967
Gephyrocapsa oceanica KAMPTNER, 1943
Helicopontosphaera kamptneri HAY and MOHLER, 1967
Rhabdosphaera div. sp.
Scapholithus fossilis DEFLANDRE and FERT, 1954
Scyphosphaera div. sp.
Syracosphaera div. sp.
Thoracosphaera var. 1 and 2
Umbilicosphaera sibogae (WEBER and VAN BOSSE) GAARDER, 1970

The stratigraphic framework is based on datums described by THIERSTEIN *et al.* (1977) and PUJOS (1988): the lowest occurrence of *G. ericsonii* synchronous with the top of *G. caribbeanica* acme, the highest occurrences of *G. ericsonii* and *G. aperta*; this last datum is synchronous with the base of *E. huxleyi* acme. The lowest occurrence of *E. hyxleyi* is excluded from this study because of the small size of this species and its scarcity between 150000 and 250000 years B.P.

The δO18 curve combined with nannofossils events allows to obtain a higher stratigraphic resolution; indeed each boundary of isotopic stages can be taken as stratigraphical marker according to the Specmap ages given by IMBRIE *et al.* (1984) and revised by WILLIAMS *et al.* (1989).

The third stratigraphic tool used here is the carbonate content (GARDNER, 1982) which completes ages given by isotopic measurements, especially for Wisconsin ages (Isotopic Stages 4, 3, 2).

In summary, the stratigraphic study shows that the core has a continuous sedimentary record for the last 350.000 years, from isotopic stage 9 to the Recent. Ages assigned to every sample level (Tab. 5 - column 2) are determined by linear interpolation between nannofossil, isotopic and carbonate events.

Paleoecological factors are estimated using IMBRIE and KIPP's (1971) mathematical method — Transfer Function —. This statistical manipulation is based on the idea that quantitative and qualitative composition of a biotic group depends on the environmental parameters of its living area. So the floral composition of Recent surface samples and the measured hydrological parameters of sea surface are the adequate elements to estimate changes of the same environmental parameters in the past from Pleistocene sediments. The application of this method on nannofossil distributions requires special fittings of initial counting matrices; these modifications are described in the following chapter.

PALEOENVIRONMENTAL STUDY

The Transfer Function is a three step analysis depending on three Fortran programs named CABFAC, REGRESS, THREAD (Fig. 3):

CABFAC is a Q-mode factor analysis applied to nannofossils from a selection of Recent surface samples. I exclude from this selection (1) the samples which are not truly representative of modern sediment (*i.e.* samples in which the thanatocoenosis cannot be associated to the present biocoenosis), (2) the samples which present traces of dissolution in order to avoid diagenetic modification on assemblage composition. CABFAC provides two matrices where taxa are grouped in assemblages. Matrix 1 (Factor Score Matrix) represents the relative contribution of each specie to each assemblage. Matrix 2 (Varimax Factor Matrix) gives the composition of each sample in terms of the assemblages. These matrices will be used later, one in the second step, the other in the third step.

— REGRESS is a regression analysis which uses both environmental parameters readen in oceanographic Atlas and one of the matrices resulted from CABFAC. This program correlates each nannofossil assemblages from CABFAC to environmental parameters. Results are listed in a third matrix which will be used in the third step.

— THREAD is the projection of fossil samples into the scheme created with surface samples. This program uses both matrices from CABFAC and REGRESS, and the core coccolith matrix as well. The resulting final matrix provides estimates of the paleoenvironmental parameters.

SETTING UP OF NANNOFOSSIL COUNT MATRICES

Before applying Transfer Function to nannofossil assemblages, we have to make a selection among all the taxa so that they answer to the following requisites: (1) they are still living now and continuously present in the core sediments from 350000 years to the Present. (2) They occur in recent and fossil samples in adequate quantity, *i.e.* minimum 2% of total abundance. Thus 8 taxa were selected: *Cyclococcolithina leptopora, Coccolithus pelagicus Florisphaera* sp. *Helicopontosphaera* div. sp., *Rhabdosphaera* div. sp., *Scapholithus fossilis, Syracosphaera* div. sp., *Umbilicosphaera* sp.

Though *C. pelagicus* is absent from DSDP Site 502B, it is considered for statistics: this taxon is common in recent Atlantic surface samples, and is present in several Northern Caribbean cores (GIRAUDEAU and PUJOS, 1990).

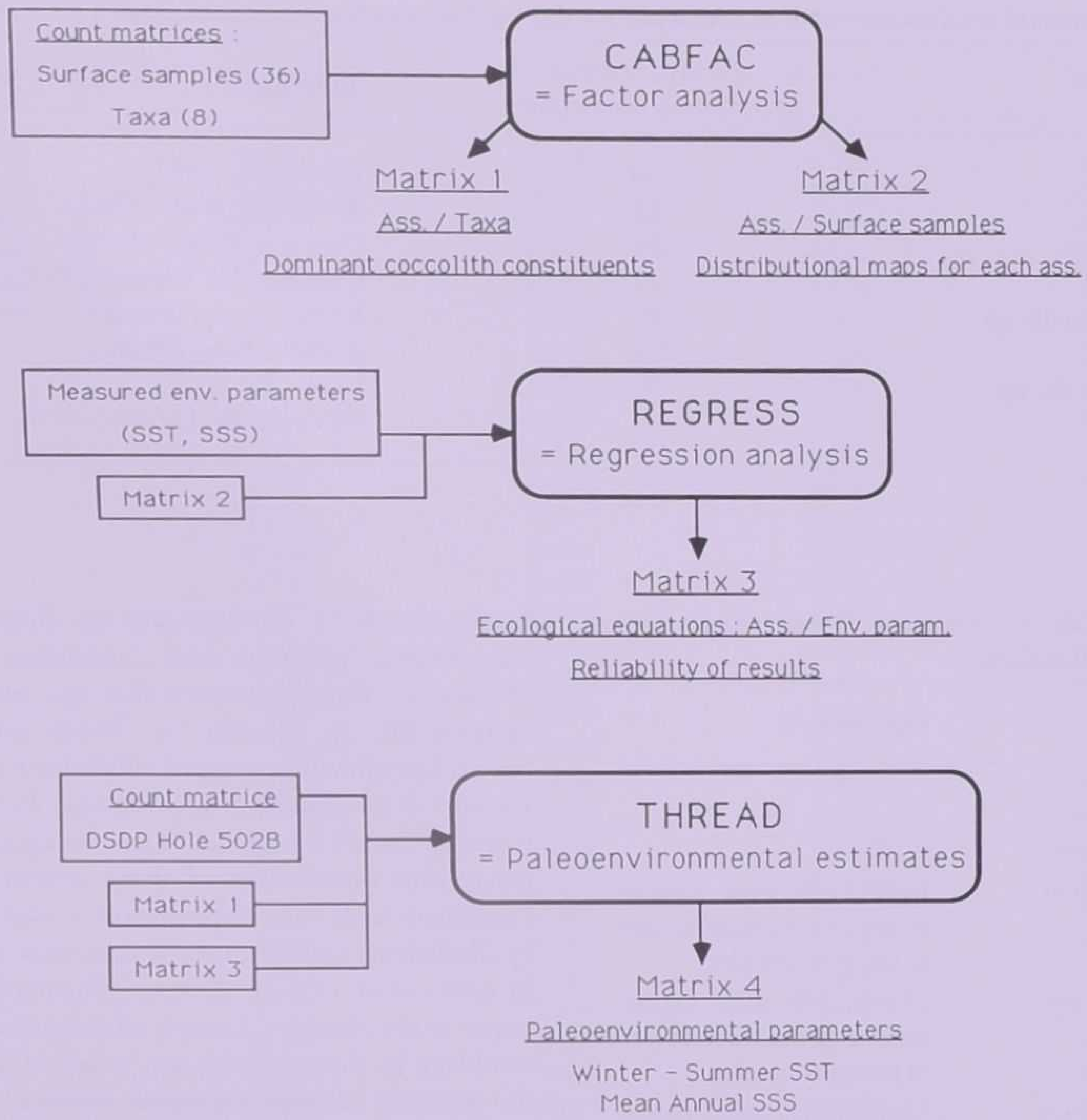

FIG. 3 - Flow diagram of Transfer function.

The taxa of the genera *Gephyrocapsa* and *Emiliania* are not taken into account in the paleoenvironmental study. They show appearances, disappearances and acme throughout the middle-late Pleistocene, and thus are not accurate with the requisite (1).

The major problem in using nannofossils for Transfer Function is that the coccoliths of one or two taxa (in our study *Florisphaera* sp. and to a lesser extent *Rhabdosphaera* sp.) are often dominant and mask representativeness of other species. To avoid this problem a two step transformation of original counting data is proposed here.

Answering to a biological reality, total abundance of nannofossils should not be expressed in number of coccoliths but in number of coccospheres. Despite the little knowledge we have about the biology of the living coccolithophorids, it is possible to tentatively assign to the 8 selected taxa an average number of coccoliths/coccosphere. Data come from descriptions and photographs in KAMPTNER (1951), MC INTYRE and BÉ (1967), OKADA and HONJO (1973), OKADA and MC INTYRE (1977), KLEINIE (pers. comm.), LECAL (1951) and are reported in table 1.

Data are transformed into "Classes of abundance for each taxa" according to the mathematical method created by PICHON *et al.* (1987) and first applied to diatom assemblages from high latitudes. This manipulation replaces the relative percentages of each of the 8 taxa by a ranking in 5 abundance classes defined for each taxon (Tab. 2). Total absence (rank 0) and traces or abundance less than 1% are arbitrarily separated with the three last ranks couvering the remaining range of the distribution.

These transformations are applied on nannofloral assemblages of both Recent surface samples and core matrices; with such new matrices the Transfer Function will take into account the changes in abundance of the 8 taxa equally.

TABLE 1 - Conversion of coccoliths into coccospheres for each of the 8 selectioned taxa

Taxa	Average number of coccoliths/coccosphere	References
C. leptopora	30	KAMPTNER (1951)
C. pelagicus	18	MC INTYRE & BÉ (1967)
Florisphaera sp.	200	OKADA & HONJO (1973)
H. kamptneri	20	OKADA & MC INTYRE (1977)
Rhabdosphaera div. sp.	40	KLEINIE (pers. comm.)
S. fossilis	250	KLEINIE (pers. comm.)
Syracosphaera div. sp.	50	LECAL (1951)
U. sibogae	80	OKADA & MC INTYRE (1977)

TABLE 2 -Mode of conversion of percentages into 5 classes of abundance

Rank value	Equivalent %
0: absent taxon	0%
1: present taxon	0-1%
2: common taxon	1<N<25% max. coccospheres of the taxon in one of the surf. samples
3: frequent taxon	25<N<25% max. coccospheres of the taxon in one of the surf. samples
4: abundant taxon	50<N<100% max. coccospheres of the taxon in one of the surf. samples

RESULTS

— CABFAC, the first step is applied on a selection of 36 surface samples located between 0° and 40° N of latitudes and between 20 and 90°W of longitudes. The location, water-depth and counting matrices for each surface sample are given in GIRAUDEAU and PUJOS (1990). This factor analysis provides 3 factors corresponding to 3 assemblages which account for 97% of the distributional variance of the species data base (Table 3). The communality, and index of how much the compositional information in the original sample is accounted for by the varimax model, is greater than 0,9 in all the samples. These factors are characterised by one or two dominant taxa of nannofossils (Table 4): *Florisphaera* sp. (factor 1), *Cycloccolithina leptopora* and *Coccolithus pelagicus* (Factor 2), *Rhabdosphaera* div. sp. and *Syracosphaera* div. sp. (Factor 3). These assemblages have a latitudinal geographic distribution (Fig. 4): Factor 1 is an equatorial assemblage, Factor 2 subtropical, Factor 3 tropical. Taxa composition and geographic distribution of these assemblages are consistent with coccolithophorid zones described by MC INTYRE and BÉ (1967), ROCHE *et al.* (1975), MOLFINO *et al.* (1982). A new information in this paper is the characterization of the equatorial assemblage by *Florisphaera* sp., a taxon ignored in the previous paleoceanographic studies.

In the second step (REGRESS) these three assemblages are compared to measured environmental parameters (U.S. Naval Oc. Off., 1967; World Ocean Atlas Members, 1978; WÜST, 1964). Winter and summer SST, and mean annual SSS are considered. Although nutrient availability and fertility have an influence on nannofloral assemblages, they are not included in the analysis; indeed phosphate and nitrate surface distributions generated from the station data file of U.S. Naval Oc. Off. (1967) prove to have sparse data coverage. Estimates of environmental conditions from nannofossils distribution of surface samples show low standard error: ± 0.97°C and ±0.56°C for winter and summer SST, ± 0.45‰ for annual SSS. Multiple correlation coefficients are close to 0.95 for the three parameters.

Finally, THREAD, the programm of paleoecological estimates, is applied on vertical distribution of nannofossils from Hole 502B. Paleoenvironmental estimates are listen in table 5 and plotted against ages and isotopic stages in figure 5.

SST and δO18 curves show the same trend: Maxima of temperature correspond to warm

TABLE 3 - Varimax factor matrix produced by CABFAC (36 samples)

Samples	Communality	Factor 1	Factor 2	Factor 3
INMD 42 BX	0,971	0,546	0,763	-0,302
INMD 50 BX	0,967	0,471	0,824	-0,256
INMD 65 BX	0,995	0,403	0,86	-0,306
INMD 68 BX	0,995	0,411	0,889	-0,189
INMD 69 BX	0,921	0,355	0,884	0,112
INMD 70 BX	0,972	0,352	0,921	0,002
02 KS 2	0,982	0,823	0,495	-0,245
02 KS 3	0,981	0,788	0,59	-0,112
02 KS 10	0,983	0,777	0,615	-0,031
02 KS 11	0,961	0,74	0,641	-0,048
TR 75215	0,927	0,476	0,835	-0,061
TR 75231	0,977	0,917	0,365	-0,056
M2 74215	0,978	0,499	0,853	-0,029
M2 74226	0,991	0,395	0,876	-0,260
M2 74227	0,975	0,433	0,847	-0,264
TR 74229	0,944	0,435	0,777	-0,391
GU 7603	0,994	0,809	0,493	-0,311
GU 7609	0,976	0,87	0,416	-0,216
GU 7610	0,978	0,866	0,476	0,042
GU 7613	0,976	0,881	0,445	0,042
GU 7615	0,991	0,894	0,416	-0,138
GU 7616	0,993	0,909	0,379	-0,154
KI 85103	0,979	0,937	0,312	0,067
KSP 85137	0,994	0,809	0,493	-0,311
KSP 8583	0,986	0,767	0,579	-0,252
KSP 8565	0,991	0,82	0,564	-0,017
KSP 8576	0,976	0,858	0,465	-0,154
KSP 8585	0,994	0,809	0,493	-0,311
KS 85195	0,968	0,877	0,38	-0,235
KS 85182	0,991	0,837	0,447	-0,382
KS 85178	0,991	0,837	0,447	-0,382
KS 85202	0,991	0,837	0,447	-0,302
EMIL 63040	0,949	0,813	0,513	-0,161
TR 7532	0,957	0,833	0,485	-0,164
TR 7537	0,961	0,687	0,546	-0,436
TR 7529	0,933	0,743	0,396	-0,463
Variance		54,312	37,823	05,180
Variance cum.		54,312	94,134	97,314

TABLE 4 - Varimax factor score matrix produced by CABFAC (8 taxa)

		Factor	
Taxa	1	2	3
Helicopontosphaera	0.326	0.384	0.019
C. leptopora	-0.059	0.602	0.196
C. pelagicus	-0.090	0.443	0.493
Syracosphaera	0.226	0.179	-0.534
Rhabdosphaera	-0.006	0.298	-0.606
Scapholitus fossilis	0.211-	0.051	-0.076
Umbilicosphaera	0.011	0.404	-0.130
Florisphaera	0.887	0.093	-0.208

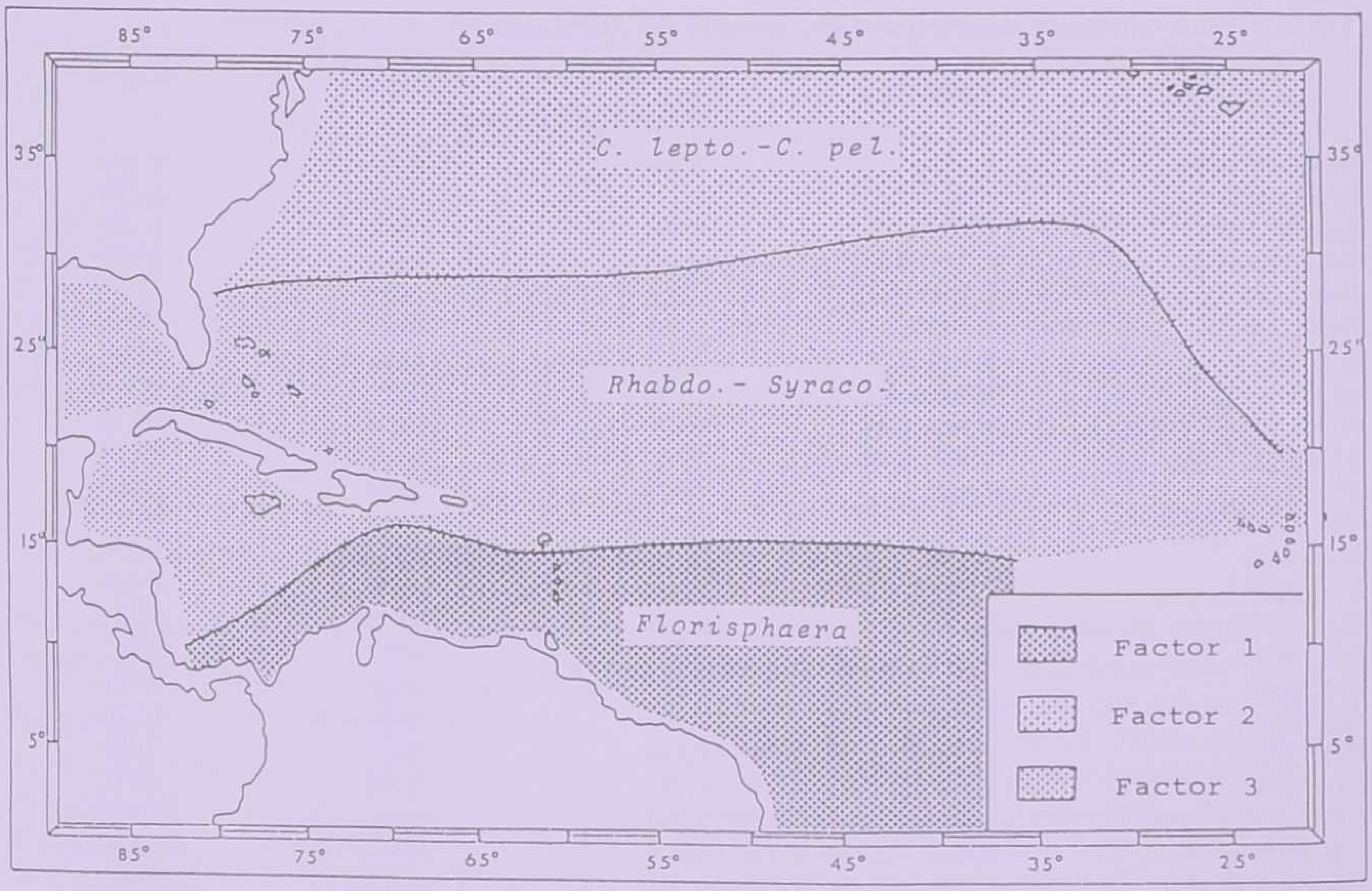

FIG. 4 - Synthetic geographic distribution of the three factors extracted by CABFAC.

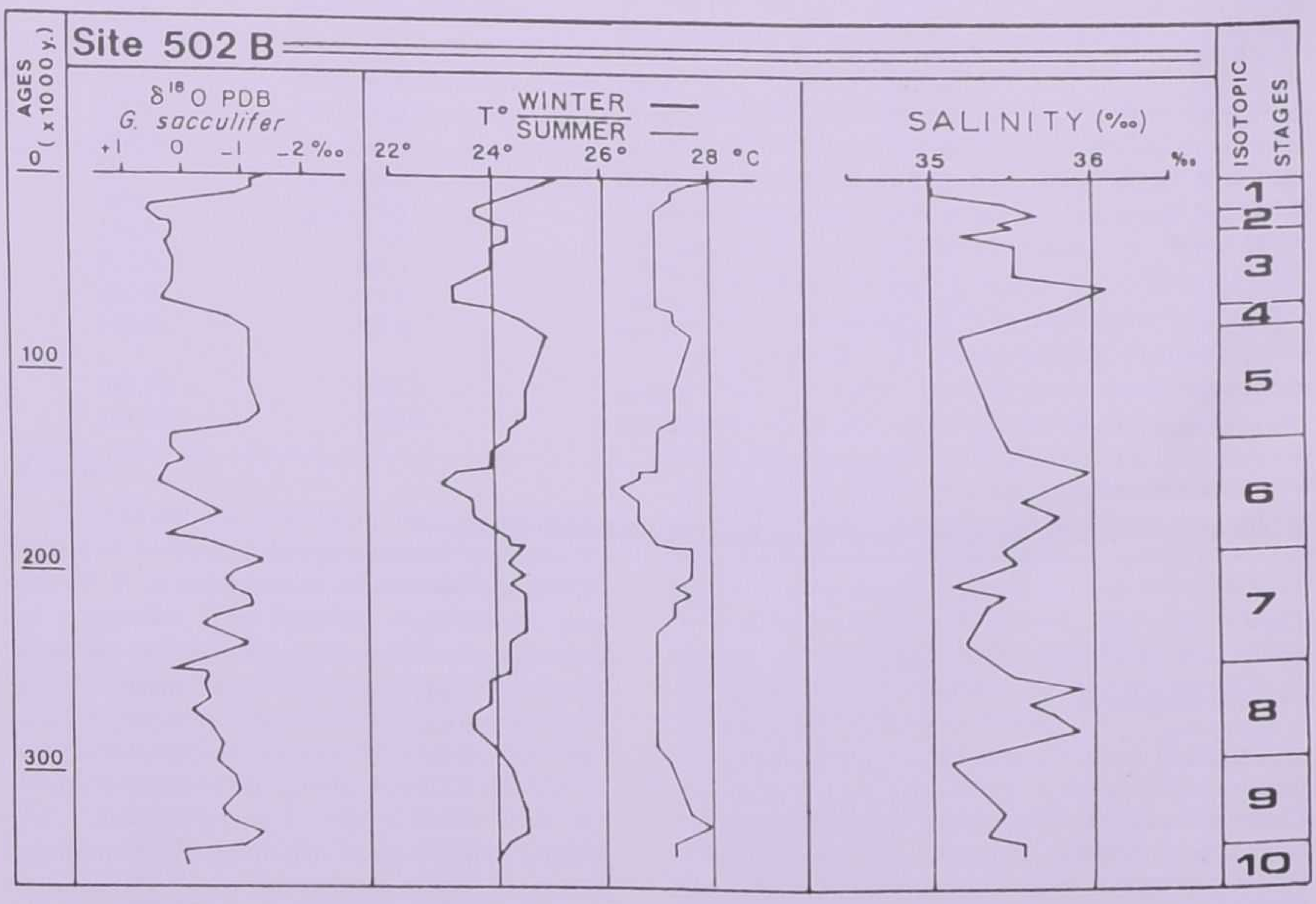

FIG. 5 - Estimated paleotemperatures and paleosalinities from nannofossils of Hole 502B; δO18 measurements from PRELL (1982). Three sample running average of winter-summer SST given in table 3.

stages 9, 7, 5, 1; minima to cold ones 10, 8, 6, 4. Gradients of variance between two successive climatic stages are weak: 1 to 2°C for winter SST, 0.5°C for summer ones; these low gradients are in harmony with SST calculated by Mc Intyre *et al.* (1989) on planktonic foraminifera of low latitudes: they document the presence of a warm water reservoir with a stable thermal character in the western equatorial Atlantic through the Late Pleistocene.

SSS curve shows an opposite trend to SST: Maxima of salinity correspond to cold stages 8, 6, 4; minima to warm stages 9, 7, 5, 1. Maximum gradient of variance between two successive stages is 1‰. The correspondence of high SSS in cold stages confirms previous results based on palynological and mineralogical studies in this area. They used the present winter and summer climatic pattern in the Caribbean as an analogue, and concluded that glacial climates were characterised by increased evaporation and decreased precipitation, involving increased SSS (Van der Hammen, 1961; Van der Hammen *et al.*, 1971; Ward, 1973).

Comparisons with previous estimates using planktonic foraminifera

Paleoenvironmental parameters calculated with nannofossils from Hole 502B are compared to estimates previously obtained from planktonic foraminifera in the same area. The reference core is V12 - 122 - 17°00' W, 2800 m depth - studied by Imbrie *et al.* (1973), and located West of Carib-

Table 5 - Estimated Surface Temperatures (°C) and Salinities (per mil) for Hole 502B

1	2	3	4	5	1	2	3	4	5
2.5	0.9	24.86	28.03		290.5	163.15	23.86	27.00	35.55
10.5	3.81	25.19	27.75	35.02	300.5	171.00	24.16	27.64	35.77
20.5	7.45	25.96	28.17	35.01	310.5	183.00	24.43	27.45	35.53
30.5	11.09	24.87	27.80	35.48	320.5	184.50			35.31
43.5	16.34	24.56	27.38	35.31	330.5	186.00	24.37	28.04	
51.5	19.09	24.07	27.48	35.73	340.5	194.00	25.02	28.03	35.51
59.5	21.39	23.99	27.28	35.43	350.5	199.50	25.00	27.93	35.38
69.5	23.19	24.57	27.48	35.29	360.5	205.00	25.90	28.31	35.09
79.5	24.86	24.42	27.56	35.40	370.5	209.31	24.88	27.84	35.48
89.5	26.43	24.26	27.47	35.58	380.5	213.62	25.12	28.12	35.48
99.5	28.00	25.04	27.79	35.16	390.5	218.39	25.25	27.94	35.32
109.5	33.68	24.26	27.47	35.58	408.5	228.00	24.56	27.47	35.58
112.5	35.39	24.99	27.94	35.48	420.5	233.58	25.34	27.93	35.17
118.5	38.80	24.26	27.47	35.58	472.5	249.00	24.42	27.56	35.40
129.5	45.06	24.99	27.94	35.48	486.5	253.38	24.43	27.45	35.53
137.5	49.61	24.54	27.54	35.52	490.5	254.23	24.56	27.38	35.31
143.5	56.44	23.21	27.28	36.09	496.5	258.00			35.93
157.5	65.00	23.41	27.17	35.90	506.5	261.48	24.87	27.80	35.48
166.5	67.63	24.38	27.60	35.63	510.5	263.46	24.46	27.32	35.14
181.5	73.33	24.86	28.03	35.17	525.5	271.06	24.54	27.93	35.75
191.5	80.00	25.34	27.93		546.5	278.53	23.62	27.37	35.90
201.5	107.00	24.65	27.83	35.49	566.5	285.74	24.85	27.80	35.49
210.5	122.00	24.51	27.66		585.5	295.65	25.25	27.71	35.03
220.5	125.63	24.97	27.72	35.25	631.5	320.27	24.80	28.00	35.52
230.5	131.06	24.07	27.21	35.53	640.5	325.22	24.86	28.03	
240.5	138.45	24.42	27.56	35.40	651.5	321.23	25.80	28.28	35.16
252.5	146.00	23.90	27.47		660.5	335.47	24.49	27.69	35.53
259.5	147.55	24.45	27.23	35.95	671.5	341.27	24.13	27.35	35.53
270.5	150.00	22.96	26.89						
280.5	155.31	23.68	27.43						

Column 1: Depth in core (cm). 2: Estimated ages (x 1000 years). 3: Estimated winter SST. 4: Estimated summer SST. 5: Estimated mean annual SSS.

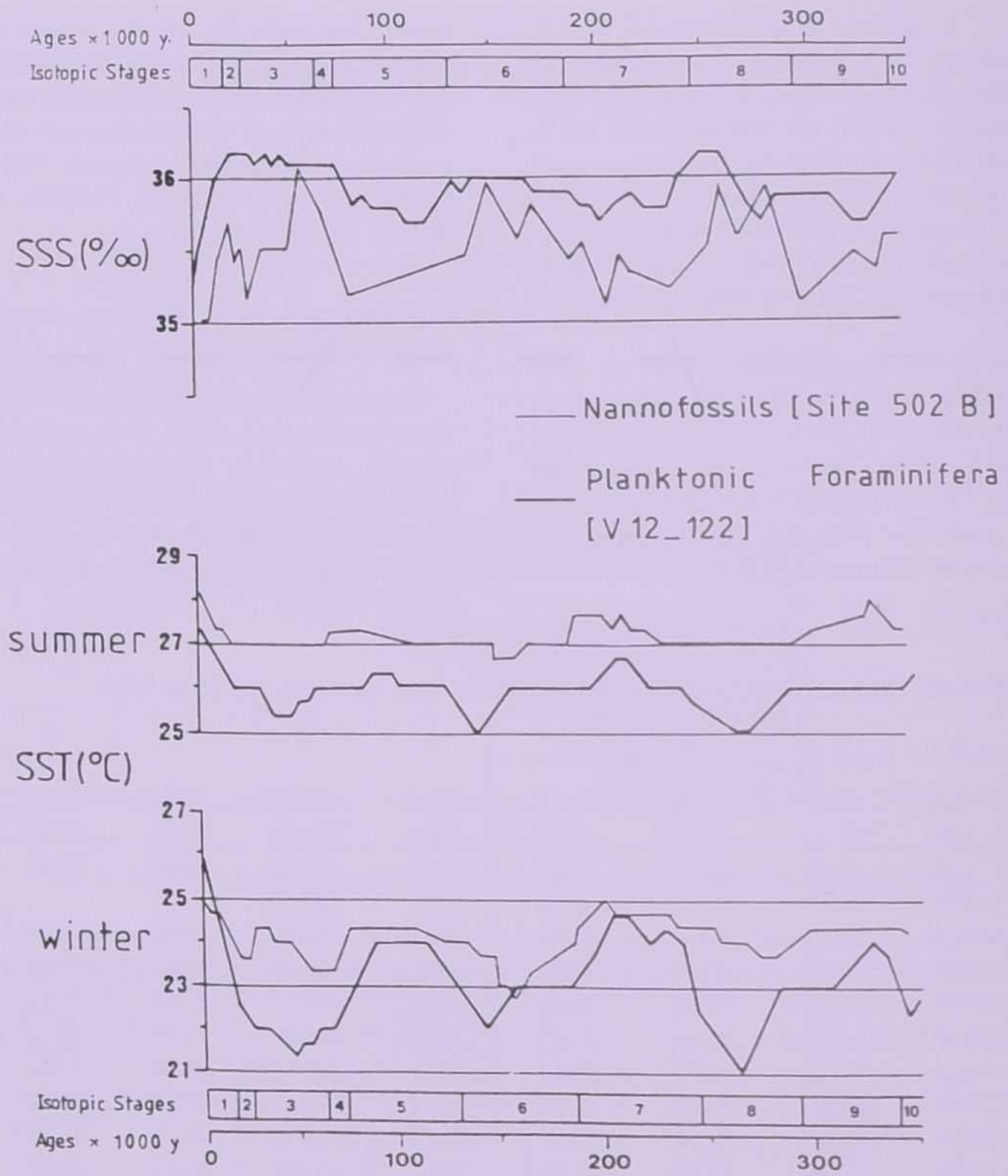

FIG. 6 - Comparison between curves of paleotemperatures and paleosalinities estimated from nannofossils (Hole 502B - this paper) and planktonic foraminifera (V12-122 - IMBRIE *et al.*, 1973).

bean in the Colombia basin close to Hole 502B (Fig. 1).

Figure 6 reports mean annual SSS, winter and summer SST, against ages and isotopic stages, estimated with both nannofossils and planktonic foraminifera.

Temperatures derived from nannofossils are on average 1.5°C higher than those estimated from foraminifera. An opposite trend is observed on SSS curves: salinities calculated from nannofossils are 0.5% lower than those estimated from foraminifera.

These differences were already recognized by MOLFINO *et al.* (1982) in SST from tropical South Atlantic for the last glacial. They explain them as an accentuation of the stratification in the water column and an intensification of seasonal upwelling at about 18.000 y. B.P. in my study these differences concern both SST and SSS and occur continuously for the last 350000 years in both warm and cold climatic stages. A plausible explanation could regard the different depths of life of the two biotic groups. Coccolithophoridae live preferentially in the photic zone between 0 and 50 m water-depth, whereas the maximum concentration of living planktonic foraminifera is located in tropical areas between 50 and 100 m water-depth (JONES, 1971; BÉ and HUTSON, 1977; FAIRBANKS, 1985). In Caribbean, 50 m depth is an hydrological limit which separates warm and low salted Surface Water from colder and high salted Subtropical Under Water; the (SUW) formed at the surface of the Atlantic central waters is characterized by a high salinity maximum of nearly 37‰

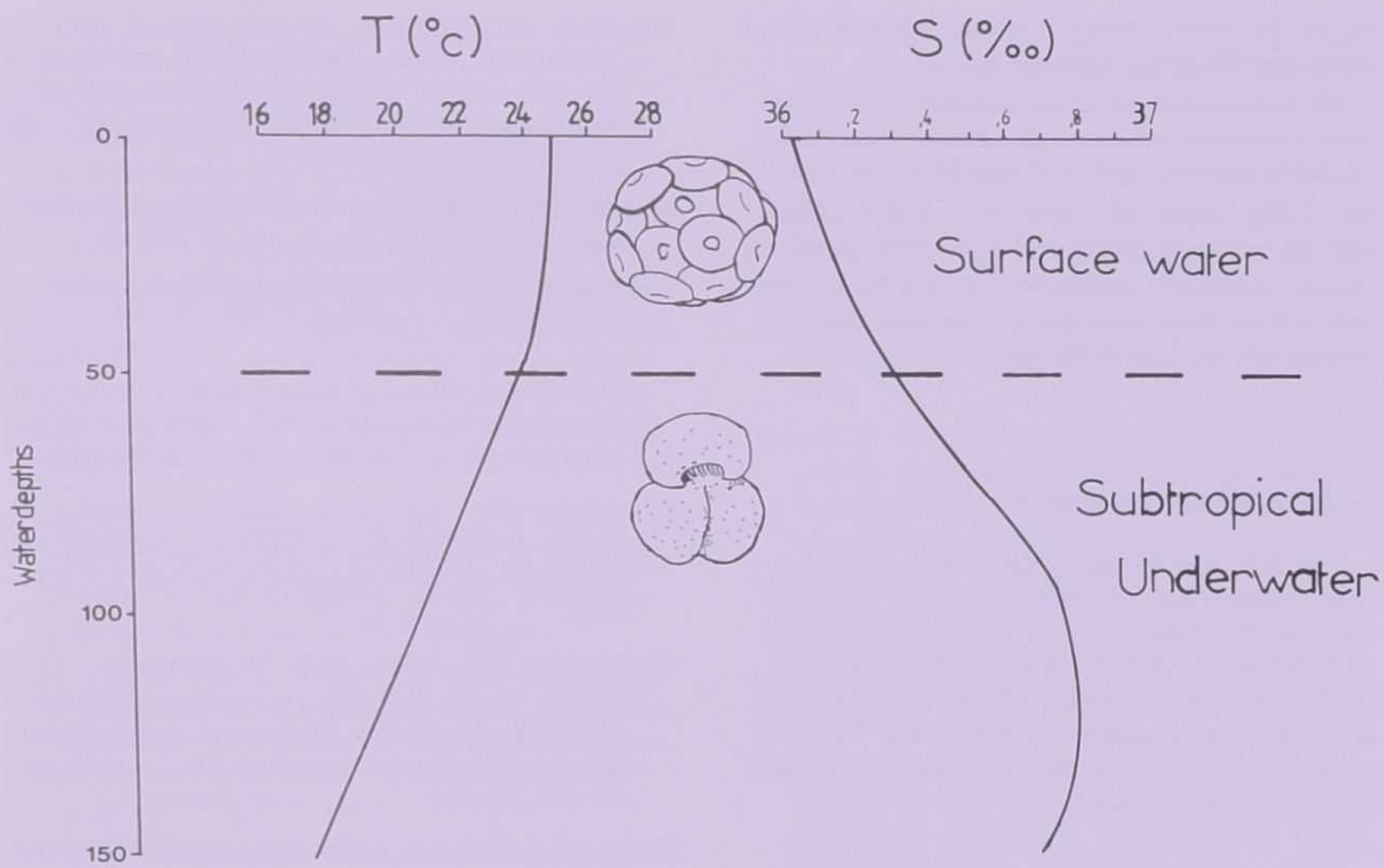

FIG. 7 - Temperature and Salinity vertical distribution against water-depths, at a station close to Hole 502B. Data measured in March 19, 1958 (in FÜGLISTER, 1960).

at 50 to 200 m (Fig. 7) which coincides with the thermocline (WÜST, 1964). Therefore foraminifera living in the SUW display environmental estimates which are characteristic of this water mass *i.e.* high salinity and low temperature, whereas estimates derived from nannofossils document warm and low salted conditions of the surface waters.

Gaps in SSS estimates are strenghtened in warm climatic stages 9, 7, 5, 3; as the present summer, that climatic events are characterized in Caribbean by increased precipitation among evaporation; these rainfalls are greatest in the West of Colombia Basin due to the orographic effect of Costa-Rica and Panama (greater than 1000 cm from June to Nov. Magdalena River waters extending North from Colombia (PRELL, 1974). These two phenomena which influence mainly the first 50 m depth, are responsible for the increased differences in warm stages between low surface salinities and higher ones of deeper water mass (SUW) as seen on estimated SSS curves from nannofossils and foraminifera (Fig. 6).

CONCLUSIONS

(1) The upper 6.5 meters of Hole 502B -DSDP Leg 68 - consist of a continuous sedimentary record representing the last 350000 years.

(2) The stratigraphic framework is provided by the coccolith distribution of *E. huxleyi* and *Gephyrocapsa* group, isotopic measurements (δO^{18}) and carbonate data.

(3) The paleoenvironmental study is based on 8 nannofossil taxa selected for their continuous occurrence and relatively high abundance throughout the studied interval. The original data set is modified taking into account the estimated number of coccoliths in coccosphers, and abundance classes introduced to minimize the influence of dominant taxa.

(4) Factor analysis extracts 3 factors from the North-Western Atlantic surface samples. These factors have a latitudinal geographic distribution. A statistically good correlation exists between nannofossil assemblages and Sea Surface Temperatures (winter and summer) and Salinity (mean annual) as seen on both low standard errors of estimates and high multiple correlation coefficients.

(5) Estimates of SST and SSS from Hole 502B provide a significant signal closely in phase with the climatic curve derived from $\delta O18$ values measured on planktonic foraminifera. The opposite trend between SSS and SST estimates is explaina-

ble by the present winter-summer climatic pattern in the Western Caribbean Sea.

(6) Comparison of these estimates with previous ones obtained from planktonic foraminifera, shows gaps in both SST and SSS. The different living depth of these two biotic groups coupled with environmental conditions peculiar of the studied area (precipitation and freshwater inflow from Magdalena River) are most probably responsible for these differences.

ACKNOWLEDGEMENTS

I thank E. Erba for her useful reviews and suggestions. I acknowledge the National Science Fundation which provided abundant samples from DSDP Hole 502B. Discussions and critical suggestions from A. Pujos enriched this manuscript. I thank Prof. B.K. Sen Gupta for help in manuscript preparation. Financial support was provided by Centre National de la Recherche Scientifique UA 197.

REFERENCES

Bé A.W.H., Hutson W.H., 1977 - *Ecology of planktonic Foraminifera and biogeographic patterns of life and fossil assemblages in the Indian Ocean.* Micropaleontology, v. 23, pp. 369-414, New York.

Boudreaux J.E., Hay W.W., 1969 - *Calcareous nannoplankton and biostratigraphy of the Late Pliocene-Pleistocene-Recent sediments in the Submarex cores*, Revista Esp. Micropal., v. 1, pp. 249-292, Madrid.

Climap Project Members, 1976 - *Glacial North Atlantic 18000 years ago; a Climap reconstruction.* Mem. Geolog. Soc. Am., v. 145, pp. 43-75, Boulder.

Climap Project Members, 1984 - *The Last Interglacial Ocean.* Quaternary Research, v. 1, pp. 123-144, New York.

Cohen C.L.D., Rheinhardt P., 1968 - *Coccolithophorids from the Pliocene Caribbean deep-sea core CP-28.* N. Jahrb. Geol. Paläontol., v. 131, pp. 289-304, Stuttgart.

Deflandre G., Fert C., 1954 - *Observations sur les coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique.* Annales de Paléontol., v. 15, pp. 117-176, Paris.

Fairbanks R.G., Sverdlove M., Free R., Wiebe P.H., Bé A.W.H., 1982-*Vertical distribution and isotopic fractionation of living planktonic foraminifera from the Panama Basin.* Nature, v. 298, pp. 841-844, London.

Füglister F.C., 1960 - *Atlantic Ocean Atlas of Temperatures and Salinity profiles and data from the International Geophysical Year of 1957-1958.* Woods Hole Oceanographic Institution (ed.), 209 pp., Woods Hole, Mass.

Garder K.R., 1970 - *Three new taxa of Coccolithineae*, Nytt. Mag. for Bot., v. 17, pp. 113-126.

Gardner J.V., 1982 - *High-resolution carbonate and organic-carbon stratigraphies for the Late Neogene and Quaternary from the western Caribbean and eastern equatorial Pacific.* In W.L. Prell, J.V. Gardner, *et al.* (ed.), Init. Repts. DSDP, v. 68, pp. 455-464, U.S. Govt. Printing Office, Washington.

Gartner S., 1967 - *Calcareous nannofossils from Neogene of Trinidad, Jamaica, and Gulf of Mexico.* Paleont. Contrib. Univ. Kansas, v. 26, pp. 1-7, Lawrence.

Geitzenauer K.R., Roche M.B., Mc Intyre A., 1976- *Modern Pacific coccolith assemblages: derivation and application to Late Pleistocene paleotemperature analysis.* Mem. Geol. Soc. Am., v. 145, pp. 423-448, Boulder.

Giraudeau J., Pujos, A., 1990 - *Fonction de Transfert basée sur les nannofossiles calcaires du Pléistocène des Caraïbes.* Oceanologica Acta, v. 13, n. 4, pp. 453-469, Paris.

Hay W.W., Mohler H.P., Roth P.H., Schmidt R.R., Boudreaux J.E., 1967 - *Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean Area and transoceanic correlation.* Gulf Coast Ass. Geol. Soc. Trans., v. 17, pp. 428-480, Miami.

Imbrie J., Kipp N.G., 1971 - *A new micropaleontological method for quantitative paleoclimatology: application to a Late Pleistocene Caribbean core.* In K.K. Turekian (ed.), The Late Cenozoic glacial ages, Yale Univ. Press, pp. 71-181, New Haven.

Imbrie J., Van Donk J., Kipp N.G., 1973 - *Paleoclimatic investigation of a late Pleistocene Caribbean deep-sea core; comparison of isotopic and faunal methods.* Quaternary Research, v. 3, pp. 10-38, New York.

Imbrie J. *et al.*, 1984 - *The orbital theory of Pleistocene climate, support from a revised chronology of the marine δ018 record.* In A.L. Berger (ed.), Milankovitch and climate. Nato ASI série C: Math. et Phys. Sci., v. 126, pp. 269-305.

Jones J.I., 1971 - *The ecology and ditribution of living planktonic. Foraminifera in the straits of Florida.* Mem. Geol. Soc. Miami, v. 1, pp. 175-191, Miami.

Kamptner E., 1943 - *Zur Revision der Coccolithinean - Spezies* Pontosphaera huxleyi Lohmann. Anz. Akad. Wiss. Wien, Math.-Naturw. kl., v. 11, pp. 43-49, Wien.

KAMPTNER E., 1951 - *Die Coccolithineen der Südwestküste von Istrien.* Ann. naturhist. Mus. Wien, v. 51, pp., 54-149, Wien.

KAMPTNER E., 1963 - *Coccolithineen-Skelettreste aus Tiefseeablagerungen des Pazifischen Ozeans.* Ann. Naturhistor. Mus. Wien, v. 66, pp. 139-204, Wien.

LECAL J., 1951 - *Recherches morphologiques et biologiques sur les coccolithophorides Nord Africains.* Ann. Inst. Oceanog. Monaco, v. 26, pp. 255-362, Monaco.

MC INTYRE A., BÉ A.W.H., 1967 - *Modern Coccolithophoridae of the Atlantic Ocean, placoliths and cyrtoliths.* Deep Sea Research, v. 14, pp. 561-597, Oxford.

MC INTYRE A., RUDDIMAN W.F., KARLIN K., MIX A.C., 1989 - *Surface water response of the Equatorial Atlantic Ocean to orbital forcing.* Paleoceanography, v. 4, n. 1, pp. 19-55, Washington.

MOLFINO B., KIPP N.G., MORLEY J.J., 1982 - *Comparison of foraminiferal, coccolithophorid, and radiolarian paleotemperature equations: assemblage coherency and estimate concordancy.* Quaternary Research, v. 17, pp. 279-313, New York.

MORLEY J.J., 1989 - *Radiolarian-based Transfer Functions for estimating paleoceanographic conditions in the South Indian Ocean.* Marine Micropal., v. 13, pp. 293 293-307, Amsterdam.

OKADA H., HONJO S., 1973 - *The distribution of oceanic coccolithophorids in the Pacific.* Deep Sea Research, v. 20 pp. 355-374, Oxford.

OKADA H., MC INTYRE A., 1977 - *Modern coccolithophores of the Pacific and North Atlantic Oceans.* Micropaleontology, v. 23, pp. 1-55, New York.

PICHON J.J., LABRACHERIE M., LABEYRIE L.D., DUPRAT J., 1987 - *Transfer Functions between diatom assemblages and surface hydrology in the southern Ocean.* Paleo 3, v. 61, pp. 79-95, Amsterdam.

PRELL W.L., 1982 - *Oxygen and carbon isotope stratigraphy for the Quaternary of Hole 502B: evidence for two modes of isotopic variability.* In W.L. PRELL, J.V. GARDNER, *et al.* (eds.), Init. Repts. DSDP, v. 68, pp. 455-464, U.S. Govt. Printing Office, Washington.

PRELL W.L., HAYS J.D., 1976 - *Late Pleistocene faunal and temperature patterns of the Colombia Basin, Caribbean Sea.* Mem. Geol. Soc. Am., v. 145, pp. 201-220, Boulder.

PUJOS A., 1988 - *Spatio-temporal distribution of some Quaternary coccoliths.* Oceanologica Acta, v. 11, n. 1, pp. 65-77, Paris.

ROCHE M.B., MC INTYRE A., IMBRIE J., 1975 - *Quantitative paleoceanography of the late Pleistocene-Holocene North Atlantic: coccolith evidence.* In T. SAITO, L. BURCKLE (eds.), Late Neogene Epoch boundaries, Micropaleontology Press, pp. 199-225, New York.

RUDDIMAN W.F., MC INTYRE A., NIEBLER-HUNT V., DURRAZI J.T., 1980 - *Oceanic evidence for the mechanism of rapid Northern hemisphere glaciation.* Quaternary Research, v. 13, pp. 33-64, New York.

SCHILLER J., 1930 - *Coccolithinae.* In Dr. L. RABENHORST'S Kryptogamen-Flora von Deutschland, Österreich und der Schweiz, Akademische Verlagsgesellschaft, v. 10, 2. Abt., pp. 89-267, Leipzig.

THIERSTEIN H.R., GEITZENAUER K.R., MOLFINO B., SHACKLETON N.J., 1977 - *Global synchroneity of late Quaternary coccolith datum levels: validation by oxygen isotopes.* Geology, v. 5, pp. 400-404, Boulder.

U.S. NAVAL OCEANOGRAPHIC OFFICE, 1967 - *Oceanographic Atlas of the North Atlantic Ocean, Sec. II, Physical properties.* U.S. Naval Oceanogr. Office Pub. n. 700, 300 pp., Washington.

VAN W.C., 1973 - *Influence of climate on the early diagenesis of carbonates eolianites.* Geology, v. 1, n. 4, pp. 171-174, Boulder.

VAN DER HAMMEN Th., 1961 - *The Quaternary climatic changes on northern South America.* New York Acad. Sci. Annals, v. 95, pp. 676-683, New York.

VAN DER HAMMEN Th., WIJMSTRA T.A., ZAGWIJN W.H., 1971 - *The floral record of the late Cenozoic of Europe.* In "The late Cenozoic glacial ages", pp. 391-424, Yale Univ. Press, Newhaven, London.

WILCOXON J.A., 1970 - Cyclococcolithina *WILCOXON nom. nov. (nom. subst. pro* Cyclococcolithus *KAMPTNER, 1954)*, Tulane Studies in Geol. Paleontol., v. 8, pp. 82-83, New Orleans.

WILLIAMS D.F., THUNELL R.C., TAPPA E., RIO D., RAFFI I., 1988 - *Chronology of the Pleistocene oxygen isotope record: 0-188 millions years before present.* Paleo 3, v. 64, pp. 221-240, Amsterdam.

WORLD OCEAN ATLAS MEMBERS, 1978 - *Atlantic and Indian Oceans.* In S.G. GORSHKOV (ed.), World Ocean Atlas, Pergamon Press, 306 pp., Oxford.

WÜST G., 1964 - *Stratification and circulation in the Antillean-Caribbean Basins.* Columbia Univ. Press, 201 pp., New York.