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35. PALEOCEANOGRAPHIC CONDITIONS DURING THE QUATERNARY AT SITES 976 (ALBORAN SEA) AND 975 (MENORCA RISE) INFERRED FROM THE PLANKTONIC FORAMINIFERAL ASSEMBLAGES: BASIS FOR A BIOSTRATIGRAPHY[1]

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ABSTRACT

The assemblages of planktonic foraminifers at Sites 975 and 976 were studied quantitatively. The variations in the relative abundances of the species enabled us to identify four intervals during the Pleistocene. In Interval 1, there are frequent levels with high proportions of *N. pachyderma* (left-coiling) and very abundant *G. inflata.* In Interval 2, *N. pachyderma* (left-coiling) is virtually absent. Interval 3 consists of a long period with the frequent occurrence of *N. pachyderma* (left-coiling). Interval 4, covering the upper part of the Pleistocene, is dominated by *N. pachyderma* (right-coiling). In this interval, a first peak of *N. pachyderma* (left-coiling) was detected at both sites, together with a second, younger, peak at Site 976 only. A *Q*-mode principal-component analysis showed that the first five principal components (97.7% of the variance) are dominated by *N. pachyderma* (right-coiling), *G. inflata, N. pachyderma* (left-coiling), *G. ruber,* and *G. bulloides,* respectively. The modern analogs of the Quaternary samples were identified in a core-top data set, divided into groups by *k*-means clustering procedure. A discriminant analysis was used (to include each Quaternary sample in a present-day group) followed by calculating the similarity (cosine of the angle between vectors) between each down-core sample and the core-top samples of its group. On the whole, the results suggest that paleoceanographic conditions in the western Mediterranean during the Quaternary were equivalent to those currently prevailing between the parallels of North Cape and the Canary Islands. During the first Pleistocene interval, predominant conditions were similar to present-day ones, (although a little warmer at Menorca Rise), but were interrupted by very cold episodes. During Interval 2, the conditions were generally colder, but more stable, with no very cold episodes. Interval 3 had similar conditions to the first interval, although there was a higher incidence of the very cold episodes. Finally, Interval 4 is characterized by conditions similar to those of the second interval, although somewhat more regular and a little cooler.

INTRODUCTION

The qualitative and quantitative compositions of the assemblages of planktonic foraminifers within a sediment sample are determined, apart from biostratigraphic events, by three groups of factors: those characterizing the oceanographic environment of the area inhabited by the biocoenoses from which they are derived, taphonomic processes, and the sampling procedure. Within the first group, the most influential factors are temperature, productivity, and salinity of the superficial waters. These factors determine the production of each species during the year (Pujol and Vergnaud-Grazzini, 1995). Evidence reflecting the original oceanographic conditions is altered by taphonomic factors acting upon the assemblage. Most significant are differential dissolution of the tests as they sink or while they are within the sediment, and burrowing by other organisms that mixes fauna deposited at different times. Finally, the sampling process may exert an effect similar to that of burrowing, causing fauna to mix. This creates the effect of oceanographic variations appearing to have occurred during the time interval represented in the sample analyzed. This effect can be minimized by laminar sampling, but it is always influenced by the sedimentation rate (productivity and detritic contributions) and by taphonomic processes in the case of both dissolution and burrowing.

In samples with very little sediment thickness that come from places where the taphonomic processes are assumed to have not had a significant effect, the assemblage composition reflects the oceanographic conditions of the area during deposition periods. Ocean Drilling Program (ODP) Leg 161 provided the exceptional opportunity to study a fairly continuous record of Quaternary assemblages of planktonic foraminifers in the western Mediterranean.

Various studies have been published on assemblages of planktonic foraminifers of the Quaternary in the western Mediterranean, many of them in connection with studies of stable isotopes (Blanc et al, 1976; Thunell, 1976, 1978, 1979; Thiede, 1978; Loubere, 1981, 1982; Blanc-Vernet, 1982; Duprat, 1983; Blanc-Vernet et al., 1984; Vergnaud-Grazzini, 1985; Vergnaud-Grazzini et al., 1986; Capotondi et al., 1987; Pujol and Vergnaud-Grazzini, 1989; Thunell et al., 1991; Vergnaud-Grazzini and Pierre, 1991; Troelstra and van Hinte, 1995).

This paper describes studies of planktonic foraminifers obtained from Sites 976 (Alboran Sea) and 975 (Menorca Rise). From Site 976, 353 samples were examined at 1-m intervals, which was approximately equivalent to 4.9 k.y. From Site 975, 103 samples were examined with a mean intersample space of 1 m (~16.8 k.y.). Thus, at Site 975 there is a greater mean temporal separation between successive samples. The planktonic foraminifers are very abundant and well preserved with no signs of dissolution. Burrowing does exist in the Quaternary sediments for both sites as mentioned in Comas, Zahn, Klaus, et al. (1996), but, given the high rate of sedimentation at Site 976, it may be assumed that burrowing had no pronounced effect on mixing organisms that originated from different oceanographic conditions.

The objectives of the present study may be summarized in terms of three aspects:

1. Characterizing the assemblages that can be distinguished within the time intervals;
2. Identifying their temporal succession to establish the basis for a possible planktonic foraminiferal biostratigraphy (ecostratigraphy) of the Quaternary in the region; and
3. Interpreting such assemblages by comparing them with those currently found in the marine oceanic floors of the North At-

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lantic and the Mediterranean. Such interpretation is based on the assumption that, during the Pleistocene, the ecological response of the various species and morphotypes was similar to that shown by their present-day representatives.

The estimation of the values of the sea surface temperature, salinity, and productivity will be the subject of a later work.

MATERIALS AND METHODS

From Site 976, 348 samples of the Quaternary were examined (Table 1, on CD-ROM, back pocket, this volume); the quantitative study includes an additional five samples from the upper Pliocene. Most of the samples were obtained from Hole 976B, but some samples from Holes 976C and 976D were added to fill gaps encountered during the sampling process. For this purpose, we used the correlations between meters below seafloor (mbsf) and meters composite depths (mcd; Comas, Zahn, Klaus, et al., 1996). In the tables and figures, the samples are identified by their mbsf depths in Hole 976B or equivalent.

The mean spacing between samples was 103 cm, with only two important gaps: between 186.1 and 193.8 mbsf and between 279.7 and 285.7 mbsf. The remaining distances between successive samples were less than 1.5 m, except in six cases where this distance was between 1.5 and 2 m.

From the Quaternary sediments at Site 975, 100 samples were studied, all were obtained from Hole 975B (Table 1 on CD-ROM, back pocket, this volume); we also included three upper Pliocene samples. These samples are also identified by their mbsf depths in the figures and tables.

All the samples were soaked in water to which hydrogen peroxide and Calgon were added. To prevent the foraminiferal tests from dissolving, the maximum period of soaking was two hours. Subsequently, the samples were washed through 0.063- and 0.15-mm sieves. Given the fragility of the mostly hollow tests, ultrasonic cleaning was not performed.

To conduct the quantitative study, the fraction larger than 0.15 mm was divided to produce a split containing more than 300 foraminiferal tests. If, after the count, such a quantity was not achieved, the twin fraction was also counted.

Using the results of the counts, two matrices were created of 353 samples × 26 species (Site 976) and 103 samples × 26 species (Site 975). These matrices were submitted to a set of numerical analysis tests with three intentions: to reveal the temporal variation of the foraminiferal assemblages, to compare the sites, and to reach a paleoecological interpretation of the Quaternary assemblages by comparing them with those contained in present-day core-top samples from the North Atlantic and the Mediterranean. To perform these analyses, the programs MATHEMATICA (Wolfram, 1992), SYSTAT (Wilkinson et al., 1992), and SPSS (Norusis, 1990) were used. The analyses which are quoted in the following paragraphs are those that provided the best results (i.e., those which were more easy to interpret, or were more oceanographically coherent).

To reveal the structure of the matrices, a series of principal component analyses were carried out on the matrix for Site 976, selected because it contained the most detailed sampling: R-mode of the variance-covariance matrix of the relative abundances of the species, R-mode of the correlation matrix between species, and *Q*-mode of the cosine-theta matrix of the vectors representing the samples. To enable interpretation of the loads (R-mode) and the scores (*Q*-mode) of the principal components, these were submitted to a varimax rotation. As the *Q*-mode results were most clearly interpretable, the varimax principal component score matrix for Site 976 was used to calculate the varimax principal component loading matrix for Site 975.

To assign the Quaternary samples to a series of groups, defined in the core-top data set by the *k*-means clustering procedure, discriminant analysis was employed. As a measure of similarity, the cosine was used to identify the present-day sample most similar to each Quaternary sample.

RELATIVE ABUNDANCE OF SPECIES AND BIOCHRONOLOGY

To compare the Quaternary foraminiferal assemblages with those contained in core-top samples from the North Atlantic and the Mediterranean, the taxonomic scheme by Kipp (1976) was generally followed with some modifications (Table 2), aimed at forming a wide-ranging data set including core-top data from various authors.

Table 3 shows the mean and maximum relative abundances of these species and morphotypes of planktonic foraminifers. To facilitate interpretation of the table, the species are ordered by their winter optimum temperatures in the North Atlantic and the Mediterranean (González-Donoso and Linares, in press). The winter optimum temperature is estimated as the mean of the values of the winter temperature in the core-top data set (see "Modern Analogs" section below), weighted with the relative abundance of the species (Birks et al., 1990). The table contains several noteworthy features:

1. Three species present mean relative abundances of over 10% at the two sites: *Neogloboquadrina pachyderma* (Ehrenberg) (right-coiling), *Globigerina bulloides* d'Orbigny and *Globorotalia inflata* (d'Orbigny). All three are located in the coldest position in the table, with positions 3 to 5 in the temperature ranking. One species, *Globigerinoides ruber* (d'Orbigny), located at the bottom of the warmer half of the table (position 16), presents a mean relative abundance of over 10% at Site 975 (11.5%), but only 6.5% at Site 976. The four species present maximum percentages of over 35% and *N. pachyderma* (right-coiling) exceeds 90% at Site 976.
2. The two species with the lowest optimum temperatures, *N. pachyderma* (left-coiling) and *Turborotalita quinqueloba*

Table 2. List of species and morphotypes considered in the quantitative analyses.

- *Beella digitata* (Brady)
- *Globigerina bulloides* d'Orbigny including:
  - *Globigerina cariacoensis* Rögl & Bolli
  - *Globigerina riveroae* Bolli & Bermúdez
  - *Globigerina umbilicata* Orr & Zaitzeff
- *Globigerina calida* Parker
- *Globigerina falconensis* Blow
- *Globigerinella siphonifera* (d'Orbigny)
- *Globigerinita glutinata* (Egger)
- *Globigerinoides conglobatus* (Brady)
- *Globigerinoides ruber* (d'Orbigny) (pink and white)
- *Globigerinoides trilobus* (Reuss)
  - = *G. sacculifer* (with and without saclike final chamber)
- *Globorotalia crassaformis* (Galloway & Wissler)
- *Globorotalia cultrata* (d'Orbigny)
  - = *G. menardii*
- *Globorotalia hirsuta* (d'Orbigny)
- *Globorotalia inflata* (d'Orbigny)
- *Globorotalia scitula* (Brady)
- *Globorotalia truncatulinoides* (d'Orbigny) (left-coiling)
- *Globorotalia truncatulinoides* (d'Orbigny) (right-coiling)
- *Globorotalia tumida* (Brady)
- *Globoturborotalita rubescens* (Hofker)
- *Globoturborotalita tenella* (Parker)
- *Neogloboquadrina dutertrei* (d'Orbigny)
- *Neogloboquadrina pachyderma* (Ehrenberg) (left-coiling)
- *Neogloboquadrina pachyderma* (Ehrenberg) (right-coiling)
  - (plus "P-D intergrade")
- *Orbulina universa* d'Orbigny
- *Pulleniatina obliquiloculata* (Parker & Jones)
- *Sphaeroidinella dehiscens* (Parker & Jones)
- *Turborotalita quinqueloba* (Natland)

Table 3. Maximum and mean relative abundances of those morphotypes or species considered in the quantitative analyses ordered by winter optimum temperatures in North Atlantic and Mediterranean waters.

		Site 976		Site 975	
	OPTT	MN	MX	MN	MX
PCS	5.028	0.068	0.889	0.066	0.681
QNQ	8.294	0.050	0.407	0.042	0.148
PCD	11.130	0.349	0.936	0.264	0.699
BUL	13.200	0.163	0.678	0.167	0.406
INF	14.260	0.183	0.698	0.148	0.352
SCI	16.500	0.003	0.036	0.031	0.388
GLT	17.180	0.018	0.116	0.049	0.257
TRS	17.270	0.001	0.024	0.004	0.076
HRS	17.440	0.000	0.059	0.000	0.005
FAL	18.200	0.041	0.201	0.031	0.100
UNV	18.970	0.016	0.106	0.025	0.099
DIG	19.990	0.000	0.016	0.000	0.006
RBC	20.330	0.010	0.155	0.012	0.036
TRD	20.650	0.006	0.070	0.004	0.188
CAL	20.840	0.004	0.028	0.004	0.028
RUB	20.970	0.065	0.552	0.115	0.572
TEN	21.020	0.005	0.065	0.010	0.048
DUT	21.110	0.007	0.081	0.008	0.051
CGL	21.180	0.002	0.042	0.003	0.037
SPH	21.370	0.005	0.031	0.011	0.082
OBL	22.350	0.000	0.003	0.000	0.000
CUL	23.130	0.000	0.000	0.000	0.007
CRS	23.160	0.001	0.016	0.002	0.033
TRL	23.210	0.001	0.035	0.003	0.055
TUM	25.730	0.000	0.003	0.000	0.000
DEH	26.050	0.000	0.004	0.000	0.000

Notes: MX = maximum relative abundance, MN = mean relative abundance, OPTT = winter optimum temperature, PCS = *N. pachyderma* (left-coiling), QNQ = *T. quinqueloba*, PCD = *N. pachyderma* (right-coiling), BUL = *G. bulloides*, INF = *G. inflata*, SCI = *G. scitula*, GLT = *G. glutinata*, TRS = *G. truncatulinoides* (left-coiling), HRS = *G. hirsuta*, FAL = *G. falconensis*, UNV = *O. universa*, DIG = *G. digitata*, RBC = *G. rubescens*, TRD = *G. truncatulinoides* (right-coiling), CAL = *G. calida*, RUB = *G. ruber*, TEN = *G. tenellus*, DUT = *N. dutertrei*, CGL = *G. conglobatus*, SPH = *G. siphonifera*, OBL = *P. obliquiloculata*, CUL = *G. cultrata*, CRS = *G. crassaformis*, TRL = *G. trilobus*, TUM = *G. tumida*, DEH = *S. dehiscens*.

(Natland), have mean percentages of close to 5% at both sites. Of the remaining species, only *Globigerinita glutinata* (Egger) (position 7) reaches near 5% at Site 975. The maximum percentages of these three species are over 10% and *N. pachyderma* (left-coiling) reaches almost 90% at Site 976.

3. Of the remaining species, *Globorotalia scitula* (Brady), *Globigerina falconensis* Blow, *Orbulina universa* d'Orbigny, *Globoturborotalita rubescens* (Hofker), and *Globorotalia truncatulinoides* (d'Orbigny) (right-coiling) reach, on occasions, percentages of over 10%. All five have optimum temperatures below those of *G. ruber*. All the species having an optimum temperature higher than that of *G. ruber* are minority species.

The variation in the relative abundance of the planktonic foraminiferal species (Fig. 1) might have enabled us to establish a succession of biozones. However, because of the lack of equally detailed and complete references for other sectors of the western Mediterranean, it does not seem at this point advisable to formally propose a series of ecozones based on frequency changes with a presumably paleoecological significance. Thus, we have identified only four Pleistocene large intervals, which might form the basis for a future planktonic foraminiferal ecozonation of the Quaternary in the western Mediterranean.

The Base of the Pleistocene and Interval 1

Since the last century (De Stefani, 1876; 1891), the appearance of cold-water forms has been considered a good criterion with which to identify the beginning of the Pleistocene in the Mediterranean domain. In the field of planktonic foraminifers, Bizon and Bizon (1972) used the FAD (first appearance datum) of *G. truncatulinoides* to define the beginning of the Pleistocene in Mediterranean sections. However, *G. truncatulinoides* appears in the Mediterranean before the entry of cold water is detected (Sprovieri, 1976; Rio et al., 1984), and thus it is no longer being used as a Pleistocene indicator. Colalongo et al., (1981) noted that the appearance of *Globigerina cariacoensis* Rögl and Bolli is the closest planktonic foraminiferal event to the Pliocene/Pleistocene boundary in the Vrica section (proposed as Neogene/Quaternary boundary stratotype by Selli et al., 1977). However, *G. cariacoensis* is one form of the group of *G. bulloides* with a high trochospire and a wide aperture and umbilicus. These features fit well within the morphological variation of *Globigerina riveroae* Bolli and Bermúdez–*Globigerina umbilicata* Orr and Zaitzeff, which has been observed since at least the Messinian.

At present, the tendency is to approximate the Pliocene/Pleistocene boundary at the increase of the relative abundance of *N. pachyderma* (left-coiling). This event has thus been employed in Comas, Zahn, Klaus, et al. (1996), adopting the biozonation of Cita (1975), emended by Sprovieri (1992, 1993).

At both sites, an initial increase in the relative abundance of *N. pachyderma* (left-coiling) was detected, after the sharp increase of *G. inflata* (see Serrano et al., this volume) that characterizes the latest Pliocene. At Site 976, the increase of the *N. pachyderma* (left-coiling) occurs rapidly, in a short transition between 359 and 356 mbsf, where *N. pachyderma* (left-coiling) increases from 6.2% to 36% of total planktonic foraminifers. However, a gap exists in the record a little lower down, which prevents us from checking a larger time span. At Site 975 there is a continuous record of the Pliocene/Pleistocene transition and the increase was observed to occur throughout a relatively wide interval beginning shortly after the sharp increase in *G. inflata*. Consequently, it is necessary to define the datum more accurately. Provisionally, until we have more data, we set the limit at the first level fulfilling the double condition that *N. pachyderma* (left-coiling) exceeds 12.5% of total planktonic foraminifers and 25% of total *Neogloboquadrina* (Fig. 2). At present, these conditions correspond to the 9°C isotherm of the January SST (sea-surface temperature; Fig. 3). Thus, the Pliocene/Pleistocene boundary is located at 358 mbsf at Site 976 and at 108 mbsf at Site 975.

N. pachyderma (left-coiling) is still commonplace, although in a discontinuous form, up to 314 mbsf at Site 976 and to 102 mbsf at Site 975. Within this interval most of the levels do not fulfill the above-defined conditions, though it is frequent for *N. pachyderma* (left-coiling) to reach 5% of total planktonic foraminifers. The predominant group is usually *G. inflata,* which presents a significant decrease in relative abundance at the end of the interval. At both sites, the end of this first interval of common presence of *N. pachyderma* (left-coiling) occurs a little after the FO (first occurrence) of *Gephyrocapsa* spp. >5.5 µm (1.44 Ma, Shackleton et al., 1995) and before the LO (last occurrence) of *Helicosphaera sellii* (1.27 Ma; Sprovieri, 1993), in accordance with Comas, Zahn, Klaus, et al. (1996).

Interval 2

Above the interval 1, the sediments between 313 and 273 mbsf at Site 976 and between 101 and 88 mbsf at Site 975 are characterized by the virtual absence of *N. pachyderma* (left-coiling) (<3% at all levels), whereas *N. pachyderma* (right-coiling) and *G. ruber* are usually abundant.

Interval 3

A new, very extensive interval featuring the common presence of *N. pachyderma* (left-coiling) was detected between 271.7–151 mbsf

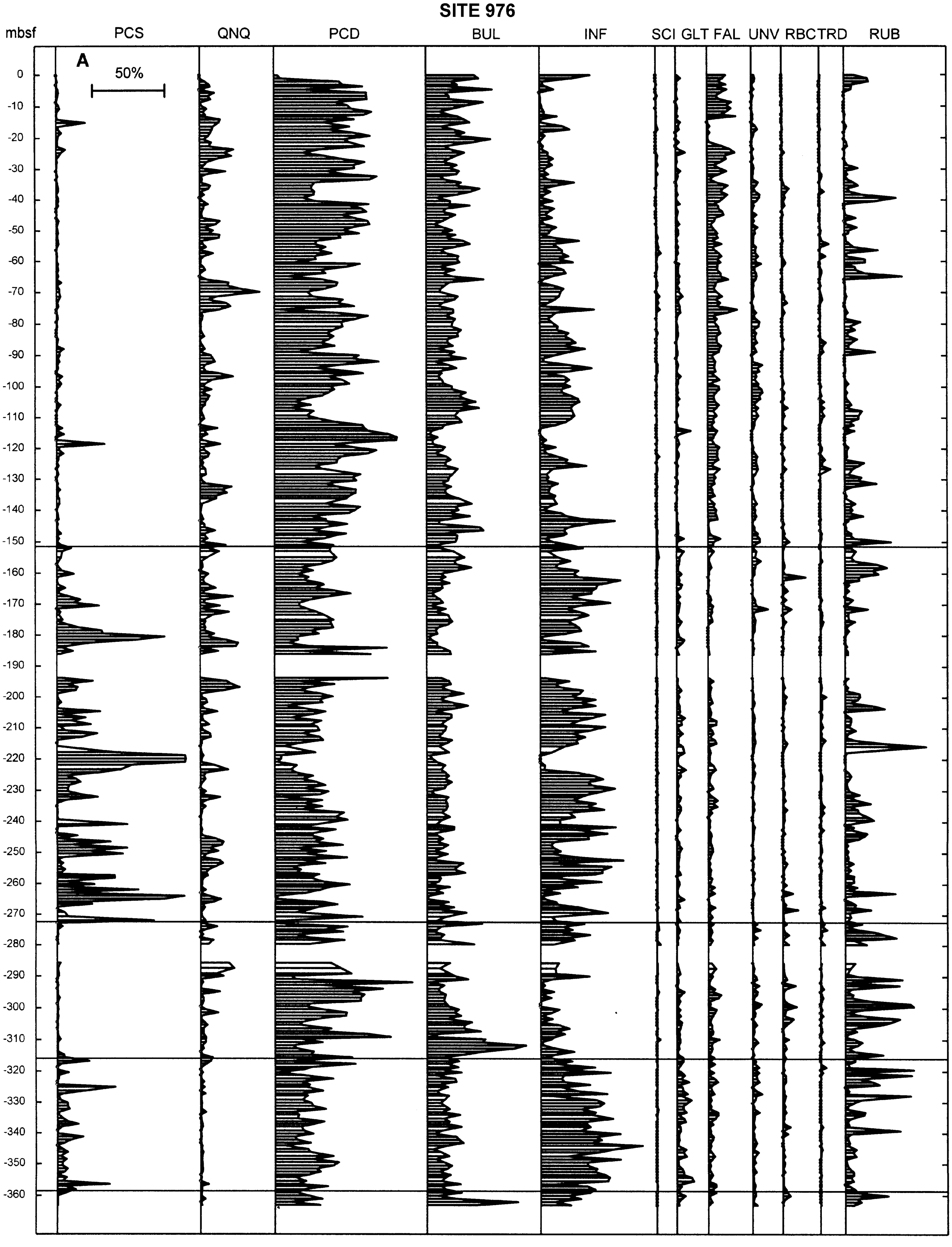

Figure 1. Relative abundance of the morphotypes and species in the samples analyzed. Only those whose maximum relative abundance exceeds 10% have been represented. PCS = *N. pachyderma* (left-coiling), QNQ = *T. quinqueloba,* PCD = *N. pachyderma* (right-coiling), BUL = *G. bulloides,* INF = *G. inflata,* SCI = *G. scitula,* GLT = *G. glutinata,* FAL = *G. falconensis,* UNV = *O. universa,* RBC = *G. rubescens,* TRD = *G. truncatulinoides* (right-coiling), RUB = *G. ruber.* **A.** Hole 976B. (Continued next page.)

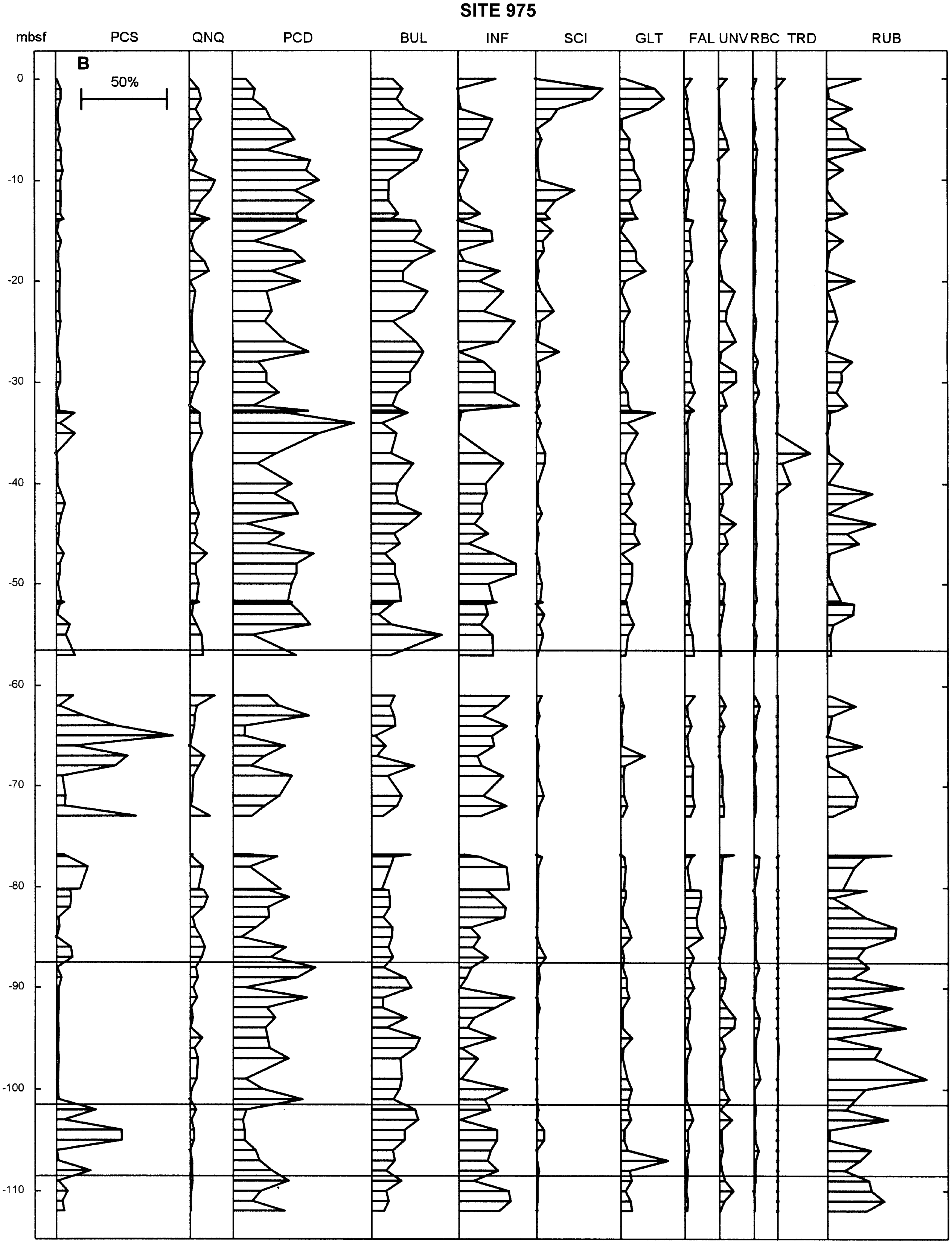

Figure 1 (continued). **B.** Hole 975B.

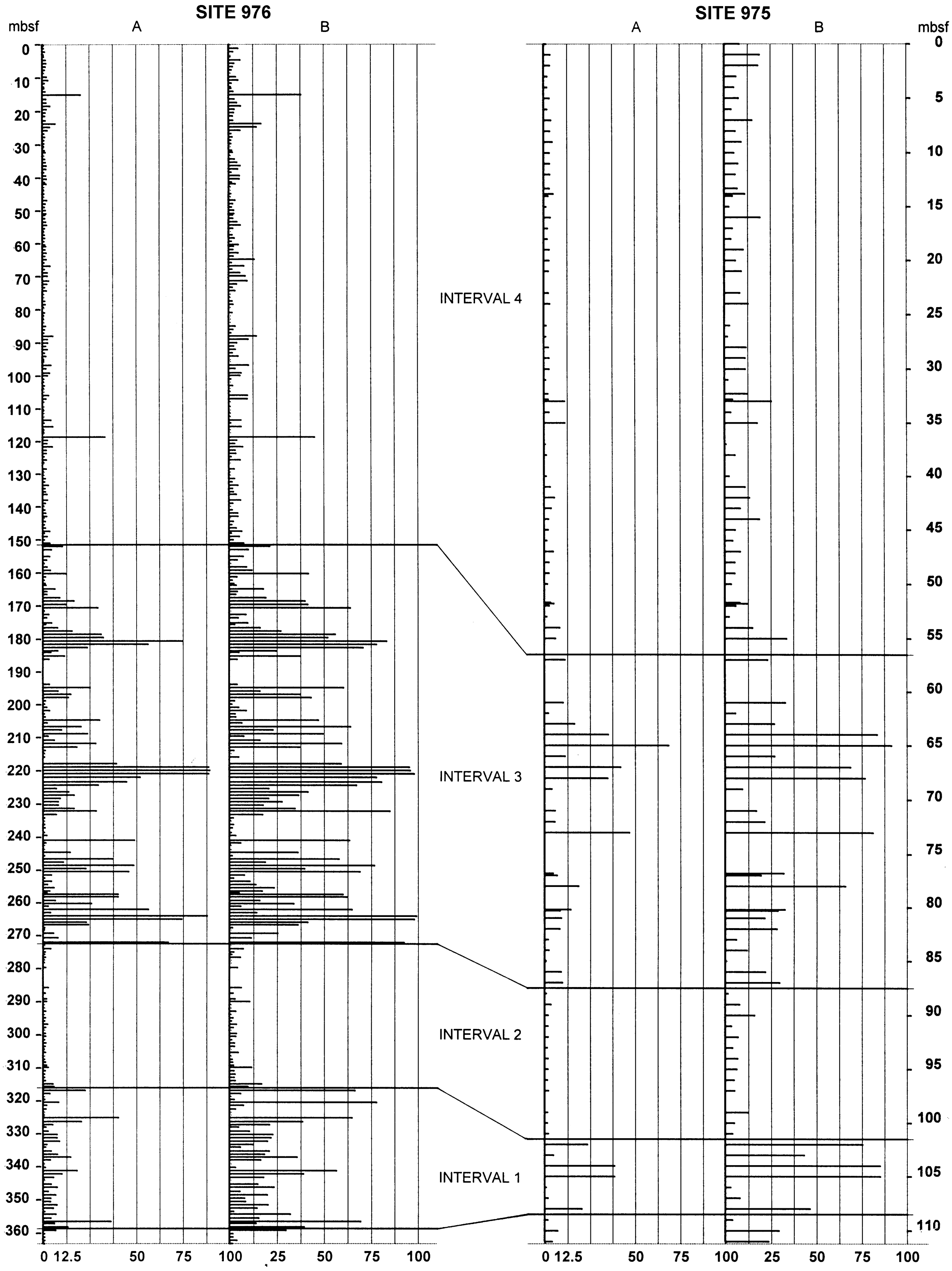

Figure 2. Relative abundance of *N. pachyderma* (left-coiling): (**A**) calculated in relation to total of planktonic foraminifera; (**B**) calculated in relation to total of *Neogloboquadrina*.

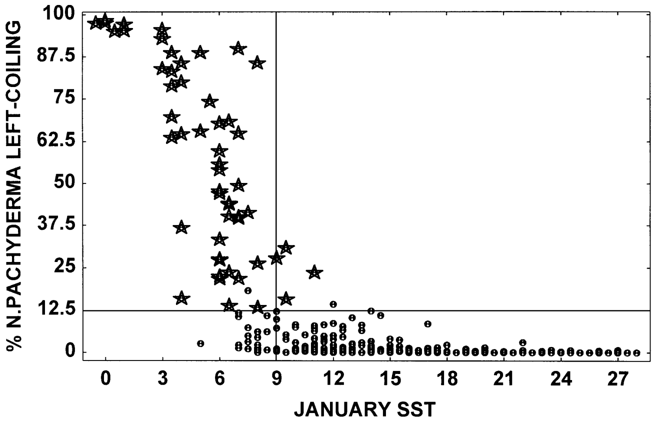

Figure 3. North Atlantic and Mediterranean January sea-surface temperature (SST) vs. relative abundance of *N. pachyderma* (left-coiling) in core-top samples. Stars = samples with *N. pachyderma* (left-coiling) >0.125 and *N. pachyderma* (left-coiling)/*Neogloboquadrina* >0.25. Open circles = samples without either of the above.

at Site 976 and between 87–55 mbsf at Site 975. As in the first interval, there is a sharp increase in the frequency of *N. pachyderma* (left-coiling) at Site 976, whereas it is more gradual at Site 975. The FOD (first occurrence datum) of *G. truncatulinoides excelsa,* shown in Comas, Zahn, Klaus, et al. (1996), coincides with the base of the interval at Site 975 and lies somewhat before it at Site 976. However, we have observed that when *G. truncatulinoides* is abundant, the *"excelsa"* form is also found at lower levels, and so it does not seem appropriate to use this biohorizon. Concerning the calcareous nannofossil events noted in Comas, Zahn, Klaus, et al. (1996), the base of this interval of common appearance of *N. pachyderma* (left-coiling) is near the LO of *Gephyrocapsa* spp. >5.5 µm (1.24 Ma) and the FO of *Reticulofenestra asanoi* (1.10 Ma). The relative abundance of *N. pachyderma* (left-coiling) within this interval is extremely variable, and there are small episodes in which it is virtually absent. The decrease in *N. pachyderma* (left-coiling) at the end of the interval presents peaks of gradually decreasing intensity. The last level in which it exceeds 10% of total planktonic foraminifers is at 154.0 mbsf at Site 976 and 57 mbsf at Site 975. This level is located between the LOD (last occurrence datum) of *R. asanoi* (0.93 Ma) and the LOD of *Pseudoemiliania lacunosa* (0.46 Ma).

Interval 4

The upper part of the Pleistocene is characterized by the abundance of *Neogloboquadrina* (right-coiling). Within this interval a peak has been detected, presenting a relatively high abundance of *N. pachyderma* (left-coiling) at 118 mbsf at Site 976, reaching 33.1% of total planktonic foraminifers and 45.5% of total *Neogloboquadrina*. This peak lies in a short span (between 121 and 113 mbsf), characterized by the extreme abundance of *Neogloboquadrina* (>60% of total planktonic foraminifers) and the scarcity of *G. inflata* and *G. ruber*. A correlatable section was observed at Site 975 between 35.0 and 33.0 mbsf, where two of the three samples analyzed contained more than 10% *N. pachyderma* (left-coiling) within total planktonic foraminifers and about 25% of total *Neogloboquadrina*. Furthermore, *Neogloboquadrina* in two samples exceeded 60% of the total planktonic foraminifers, whereas *G. inflata* and *G. ruber* were extremely scarce (<2%) in the three samples. Considering the data of Comas, Zahn, Klaus, et al. (1996) on calcareous nannofossils, this peak of frequent *Neogloboquadrina* (left-coiling) must be very close to the LO of *P. lacunosa* (0.46 Ma).

The *G. ruber rosea* form was detected at Site 976 from 88 mbsf and appears constantly at all levels where *G. ruber* is abundant. Considering a homogeneous sedimentation rate of 244 m/m.y. for the upper Pleistocene, calculated in Comas, Zahn, Klaus, et al. (1996), the appearance of *G. ruber rosea* occurred 0.36 Ma. At Site 975, *G. ruber* rosea was detected above 33 mbsf.

A final peak of abundant *N. pachyderma* (left-coiling) was detected at Site 976 at 15.13 mbsf, where it forms 20.1% of total planktonic foraminifers and 37.78% of total *Neogloboquadrina*. As in the above case, this spike lies within an interval (28.72–4.72 mbsf) where *G. ruber* is very scarce (<2.5% of total planktonic foraminifers) and where *G. inflata* only exceeds 10% in three samples. On the contrary, *Neogloboquadrina* is normally in excess of 50% and *Turborotalita* is also frequently present. According to the results of Comas, Zahn, Klaus, et al. (1996), this peak lies very close to the beginning of the acme of *Emiliania huxleyi* (0.085 Ma).

We did not observe a peak of *N. pachyderma* (left-coiling) at Site 975 correlatable to the final one at Site 976. Nevertheless, a more detailed sampling would be required to discount its existence, taking into account the distinctly lower rate of sedimentation. On the contrary, there is an evident increase in the group of *G. scitula* above 27 mbsf; this species is particularly frequent at 2 and 1 mbsf, where it represents over 30% of total planktonic foraminifers.

Holocene

Although the sampling density was rather low for detecting events at intervals of less than 10 k.y., at Site 976 we observed a final increase in G. ruber and G. inflata from 4.72 m, the exit of *G. scitula* between 3.22 and 2.22 mbsf, and a decrease in *Neogloboquadrina* and *Turborotalita* above 2.22 m. These events were observed at Site 975 between 1.20 and 0.20 mbsf.

PRINCIPAL COMPONENT ANALYSIS

The first five principal components of the *Q*-mode analysis of the cosine matrix (Klovan and Imbrie, 1971; Imbrie and Kipp, 1971) for the Site 976 data set account for 97.7% of the variance of the system; the communalities of the samples lay between 0.49 and 0.99.

The first varimax principal component score (72.8% of the variance) is clearly dominated by *N. pachyderma* (right-coiling) (Fig. 4), the second (10.8%) by *G. inflata,* the third (6.4%) by *N. pachyderma* (left-coiling), the fourth (4.5%) by *G. ruber,* and the fifth (3.2%) by *G. bulloides,* these being the five most important species in terms of mean and maximum relative abundances (Table 3).

If six principal components are retained, the above variance becomes 99% and the minimum communality increases to 0.873. The first five principal components remain the same, with minimal variations, and the sixth is dominated by the most important remaining species: *T. quinqueloba.* A *Q*-mode analysis performed by Thunell et al. (1991) for the Pliocene/Pleistocene at Site 653 provided largely comparable results. Indeed, four of their six principal components are dominated by *G. bulloides, G. ruber, G. inflata,* and *T. quinqueloba;* another, the fourth, is dominated by *N. pachyderma,* although these authors do not distinguish the left- and right-coiling morphotypes. Finally, the sixth component is dominated by *G. obliquus* and by *G. quadrilobatus* (= *G. trilobus*), species that are common in the lower Pliocene but not in the Quaternary.

If four principal components are retained, they account for 94.5% of the variance, the minimum communality becomes 0.46, and *G. bulloides* and *G. ruber* are combined in one component, with the other three remaining unchanged. The percentage of the variance accounted for by four principal components is sufficiently high for this number of components to be considered reasonable, but the problem

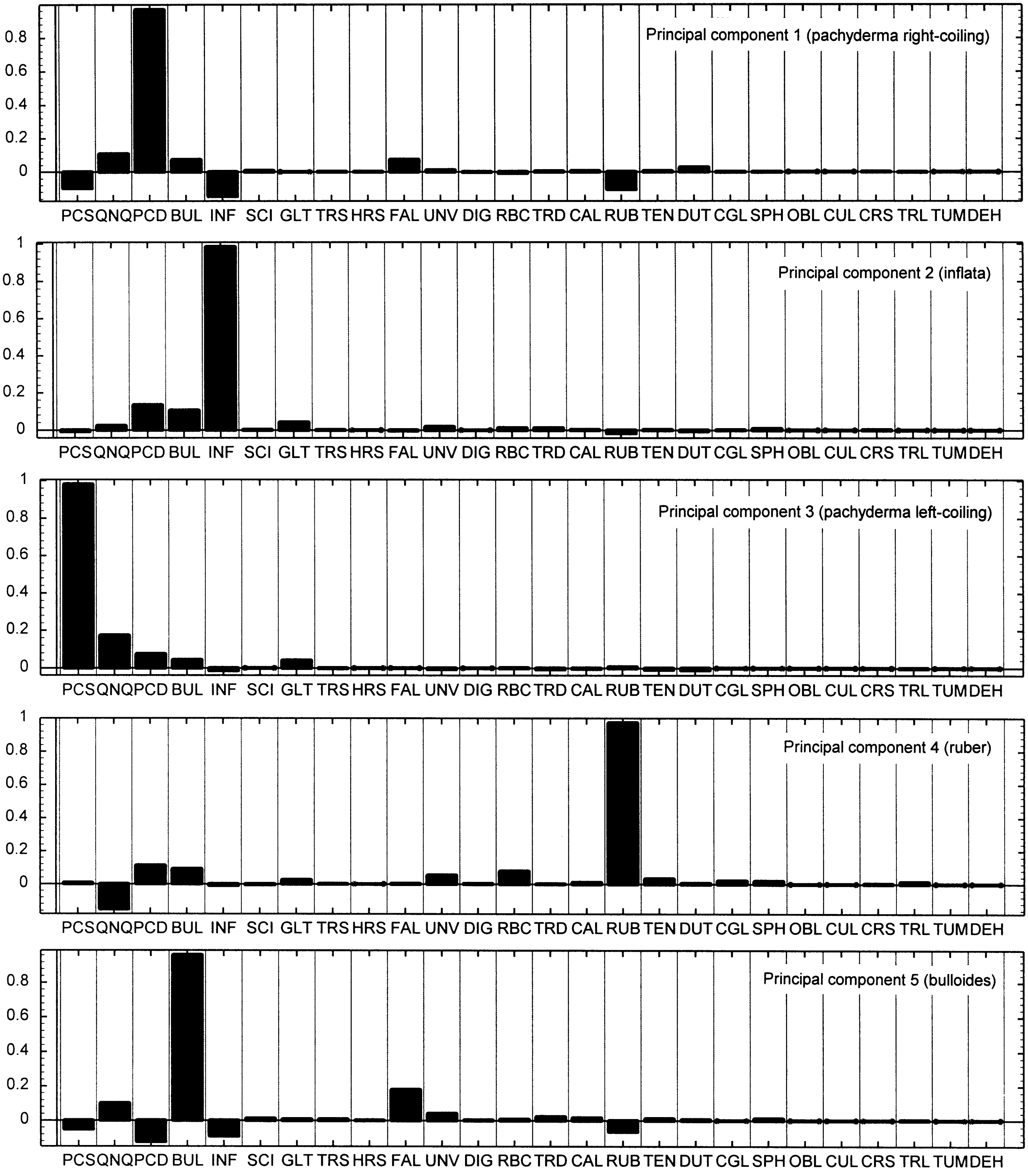

Figure 4. Site 976. *Q*-mode principal component analysis. Varimax principal component scores of the species and morphotypes in the first five principal components. Abbreviations of species names as in Table 3.

lies in the *G. ruber-G. bulloides* combination, two species whose respective mean and maximum frequencies currently lie in two different groups, the subtropical and the intermediate, as shown further, in the "Modern Analogs" section below. Using four principal components, therefore, would obscure the comparison of the result of the two methods. As for using six components, although this would account for almost all the variance of the system, it would also obscure the comparisons, as the two species, *N. pachyderma* (left-coiling) and *T. quinqueloba,* are essential members of the polar group.

Figure 5 shows the five varimax principal component loadings and communalities for the two sites (varimax principal component loadings for Site 975 were calculated from the varimax principal component score matrix of Site 976); to facilitate interpretation; only those values greater than 0.5 have been shown. In addition, the principal components have been ordered according to the optimum temperatures in the North Atlantic and the Mediterranean (González-Donoso and Linares, in press) of the dominant species: *N. pachyderma* (left-coiling) (third component), *N. pachyderma* (right-coiling) (first component), *G. bulloides* (fifth component), *G. inflata* (second component) and *G. ruber* (fourth component). In the following discussion, each component will be identified by the name of the dominant species.

Interval 1

Site 976 was characterized by the dominance of the *inflata* component and by the total absence of samples with high values of *bulloides* component. The other three principal components are represented, but are not specially noteworthy. At Site 975, there are few samples within this interval, but we should note the absence of the *pachyderma* right-coiling component, the scarcity of the *bulloides* component and the greater abundance of the *ruber* component.

Interval 2

At Site 976 there is an almost complete absence of samples with noteworthy values of the *inflata* component. The samples with high values of the *bulloides* component are located in the lower part of the interval, whereas those of the *pachyderma* right-coiling component are found throughout the interval. Obviously, the samples with noteworthy values of the *pachyderma* left-coiling component are absent. At Site 975 the samples with notable values of the *ruber* component are more numerous than those with the *pachyderma* right-coiling component, whereas those with the *inflata* and *bulloides* components are scarce.

Interval 3

At Site 976 there is a striking relative abundance of samples with high values of the *pachyderma* left-coiling component, although the most common are those dominated by the *inflata* component. There are fewer samples with notable values of the *pachyderma* right-coiling component, and only scarce samples with the ruber component, whereas samples with the *bulloides* component are almost totally lacking. A similar situation is to be found at Site 975 although there is a greater proportion of noteworthy values of the *ruber* component.

Interval 4

At Site 976 the most significant feature is the predominance of the *pachyderma* right-coiling component. Following this in importance is the *inflata* component, and then the *bulloides* component; the two extreme components are scarcely represented. At Site 975 the situation is similar, although the differences between the *pachyderma* right-coiling and *inflata* components are not so marked.

MODERN ANALOGS

The modern analog technique is based on the assumption that the faunal similarities between a down-core sample and a core-top one reflect two types of affinities: environmental ones (the areas inhabited by the biocoenoses from which they are derived) and taphonomic ones (the sedimentary conditions in which they are deposited) (Hutson, 1979; Prell, 1985; Le, 1992; Pflaumann et al., 1996; González-Donoso and Linares, in press).

From this assumption it is possible to estimate the values of the environmental variables corresponding to a down-core sample, when the values of the environmental variables corresponding to the core-top samples with the most similar fauna are known. But the assumption may also be employed to identify the association of present-day environmental and taphonomic conditions that is most similar to those existing when the down-core sample was deposited, without exactly characterizing every environmental variable.

To identify such present-day assemblages of environmental conditions, we used a data set composed of the relative abundances of 26 species and morphotypes of planktonic foraminifers from 605 core-top samples obtained from the North Atlantic and the Mediterranean (Gardner and Hays, 1976; Kellogg, 1976; Kipp, 1976; Balsam and Flessa, 1978; Thunell, 1978; Brunner, 1979; Pujol, 1980; Loubere, 1981) compiled by González-Donoso and Linares (in press). First, the data set was divided into groups, using the *k*-means clustering procedure (Davis, 1986; Wilkinson et al., 1992). After repeating the procedure with different numbers of groups and comparing the area occupied by the groups in each case, we drew the conclusion that the most oceanographically coherent results corresponded to a division into five groups (Table 4). It should be noted that the five species with the greatest mean and maximum relative abundances (Table 3) in the Quaternary for Sites 975 and 976 (*G. bulloides, G. inflata, N. pachyderma* [left-coiling], *N. pachyderma* [right-coiling], and *G. ruber*) are among the eight species with the greatest *F*-ratio, that is, the better discriminators between groups.

The reliability of the separated groups was tested by means of discriminant analysis. Of the 605 core-top samples, only 14 (2.3%) were reassigned to other groups. Discriminant analysis was also used to assign the Quaternary samples to the groups identified in the core-top data set.

For each Quaternary sample, we determined which present-day sample was most similar within the group of core-top samples to which it was assigned. As a measure of similarity, we used the cosine of the angles of the vectors representing the samples in a 26-dimension space (the relative abundances of the 26 species identified). Our assumption was that the lower the cosine of the angle between a Quaternary sample and a present-day sample, the more similar were the superficial water conditions inhabited by the biocoenoses from which both the modern and fossil assemblages are derived.

As shown in Figure 6A, the Quaternary assemblages studied have modern equivalents, between the parallels of the North Cape and the Canary Islands.

The first group of present-day samples (Fig. 6B) is located, according to the maps from Gorshkov (1978), to the north of the 7°C isotherm in January. As shown in Table 5, these samples consist of over 37% *N. pachyderma* (left-coiling) and less than 44% *N. pachyderma* (right-coiling). In this group, *T. quinqueloba* attains its greatest mean and maximum relative abundances (35%), and the remaining species are absent or are only represented at under 10%, except *G. bulloides* and *G. inflata,* which attain proportions of 18% and 24%, respectively. The Quaternary assemblages similar to those of this present-day polar group must have lived during particularly cold glacial periods during which the polar fauna migrated to the latitudes of the Mediterranean.

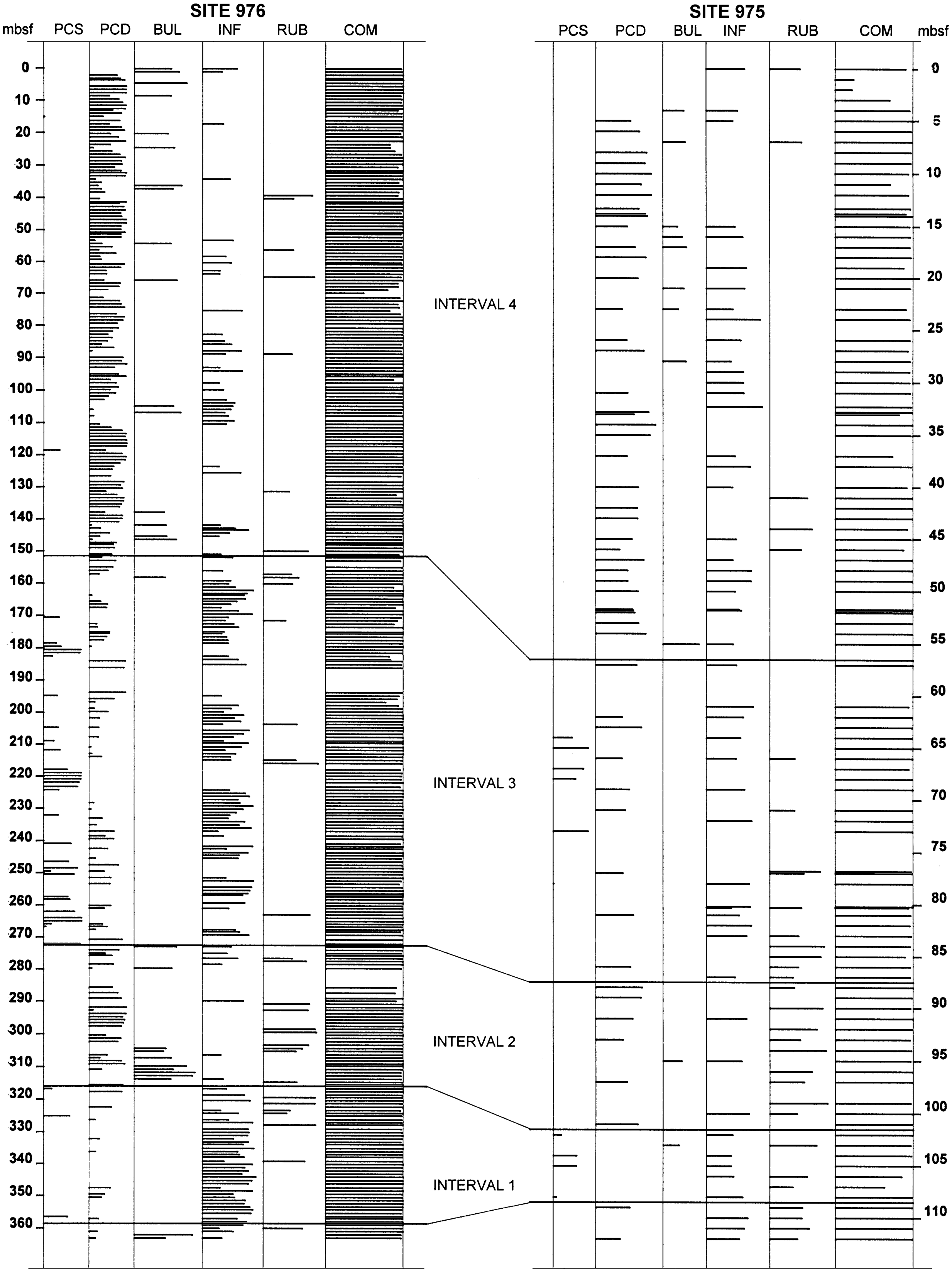

Figure 5. *Q*-mode principal component analysis. Varimax principal component loadings (only values >0.5) and communalities have been represented. PCS = *N. pachyderma* (left-coiling) component; PCD = *N. pachyderma* (right-coiling) component; BUL = *G. bulloides* component; INF = *G. inflata* component; RUB = *G. ruber* component; COM = communalities.

Table 4. North Atlantic and Mediterranean core-top data set.

	BSS	DF	WSS	DF	FR	P
BUL	2.682	4	3.512	600	114.561	0.000
CAL	0.014	4	0.073	600	28.440	0.000
CGL	0.004	4	0.045	600	12.952	0.000
CRS	0.009	4	0.029	600	47.683	0.000
DEH	0.012	4	0.017	600	103.166	0.000
DIG	0.001	4	0.014	600	13.867	0.000
DUT	1.160	4	1.081	600	161.015	0.000
FAL	0.153	4	0.555	600	41.311	0.000
GLT	0.214	4	1.248	600	25.707	0.000
HRS	0.018	4	0.085	600	32.350	0.000
INF	2.527	4	3.050	600	124.280	0.000
CUL	0.432	4	0.698	600	92.806	0.000
OBL	0.207	4	0.504	600	61.581	0.000
PCD	17.775	4	2.898	600	919.957	0.000
PCS	17.088	4	2.489	600	1029.957	0.000
QNQ	0.338	4	0.863	600	58.747	0.000
RBC	0.012	4	0.110	600	15.933	0.000
RUB	21.873	4	3.854	600	851.320	0.000
TRL	1.239	4	2.915	600	63.769	0.000
SCI	0.007	4	0.070	600	14.755	0.000
SPH	0.201	4	0.229	600	131.526	0.000
TEN	0.016	4	0.063	600	37.733	0.000
TRD	0.074	4	0.293	600	37.960	0.000
TRS	0.111	4	0.374	600	44.505	0.000
TUM	1.666	4	1.817	600	137.489	0.000
NV	0.011	4	0.219	600	7.576	0.000

Notes: Summary statistics for five groups obtained by *k*-means clustering. BSS = between groups sum of squares; DF = degrees of freedom; WSS = within groups sum of squares; FR = *F*-ratio statistics (one-way ANOVA); P = probabilities. Abbreviations of species names as in Table 3.

The second group (Fig. 6C) is located to the south and east of the first. There is a relatively distinct frontier between the two groups, extending as far as the 13°C isotherm in January. In the Mediterranean, it is represented only in the area with coldest waters, the Gulf of Lyon–Ligurian Sea. The proportion of *N. pachyderma* (right-coiling) is always in excess of 25%, whereas that of *N. pachyderma* (left-coiling) is below 40% and its mean abundance falls to 5%. The remaining species, excepting *T. quinqueloba,* may show higher percentages than in the first group. *O. universa* and *G. glutinata* attain their maximum abundances and the latter its greatest mean abundance. The Quaternary assemblages similar to that of this subpolar group would correspond to non-extreme glacial conditions, colder than the present-day ones.

The third group (Fig. 6D) is located to the south of the second and extends as far as the 16°C isotherm in January in the western Mediterranean. In the North Atlantic, its southern border is less precise: a line moving between the 16°C and 20°C isotherms in January. Some samples assigned to this group are located farther to the north in colder waters, following the Gulf Stream, or farther to the south in warmer waters, following the Canary current. Such anomalies may be derived from the overall circulation system of the North Atlantic (González-Donoso and Linares, in press). The percentages of *N. pachyderma* are usually lower than in the previous group and the mean abundance of the two morphotypes falls sharply, whereas *G. bulloides*, *G. falconensis, Globorotalia hirsuta* (d'Orbigny), *G. inflata, G. scitula,* and *G. truncatulinoides* (left-coiling) attain their great-

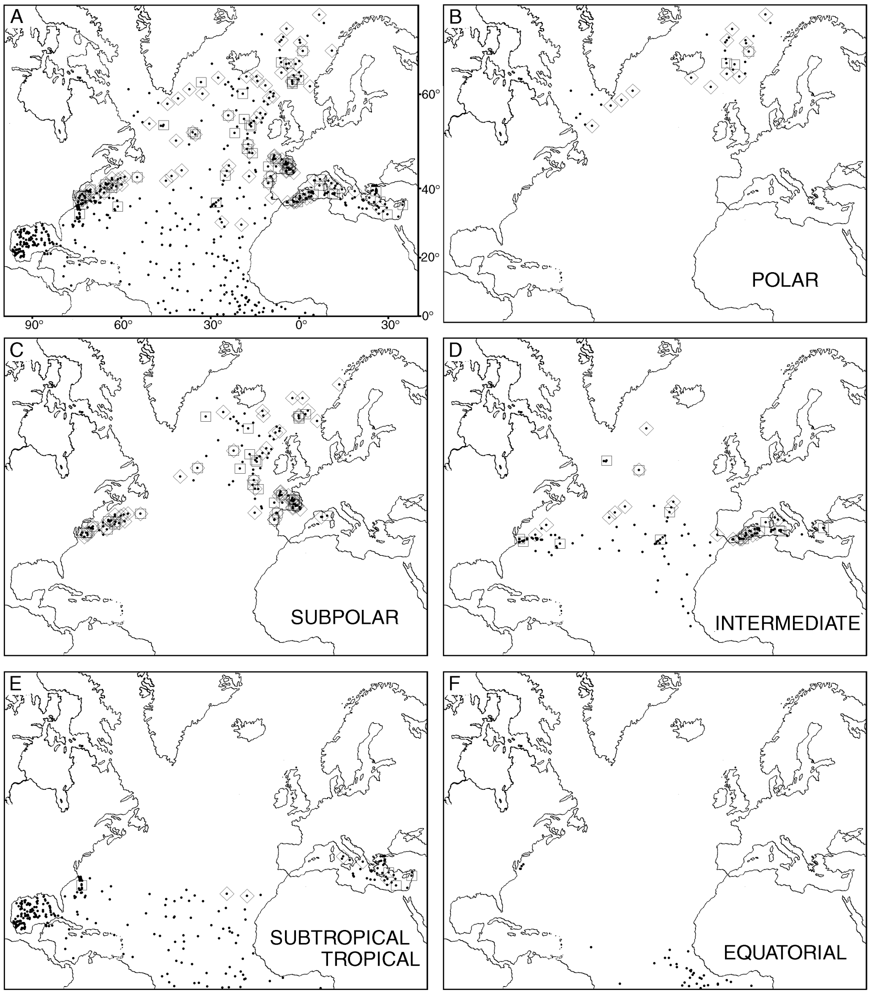

Figure 6. Locations (dots) of 605 North Atlantic and Mediterranean core-top samples and groups obtained by *k*-means clustering. Diamonds = modern analogs of the Quaternary samples from Site 976. Squares = modern analogs of the Quaternary samples from Site 975. **A**. All the samples. **B.** Polar group. **C.** Subpolar group. **D.** Intermediate group. **E.** Subtropical-tropical group. **F.** Equatorial group.

Table 5. Minimum, mean, and maximum relative abundance of species and morphotypes in the five groups of samples obtained by *k*-means clustering.

	Polar			Subpolar			Intermediate			Subtropical-Tropical			Equatorial		
	Min	Mn	Max	Min	Mn	Max	Min	Mn	Max	Min	Mn	Max	Min	Mn	Max
BUL	0.000	0.030	0.180	0.000	0.160	0.430	0.010	0.180	0.450	0.000	0.040	0.340	0.000	0.020	0.170
CAL	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.010	0.050	0.000	0.010	0.080	0.000	0.000	0.010
CGL	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.030	0.000	0.010	0.100	0.000	0.010	0.100
CRS	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.070	0.000	0.000	0.040	0.000	0.020	0.070
DEH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.020	0.000	0.020	0.090
DIG	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.020	0.000	0.000	0.040	0.000	0.010	0.030
DUT	0.000	0.000	0.000	0.000	0.010	0.190	0.000	0.020	0.280	0.000	0.040	0.190	0.050	0.200	0.540
FAL	0.000	0.000	0.010	0.000	0.010	0.050	0.000	0.050	0.200	0.000	0.030	0.170	0.000	0.000	0.040
GLT	0.000	0.010	0.070	0.000	0.080	0.360	0.000	0.050	0.170	0.000	0.060	0.290	0.000	0.020	0.090
HRS	0.000	0.000	0.030	0.000	0.000	0.030	0.000	0.020	0.080	0.000	0.000	0.050	0.000	0.000	0.010
INF	0.000	0.010	0.240	0.000	0.120	0.390	0.000	0.170	0.430	0.000	0.020	0.180	0.000	0.030	0.210
CUL	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.010	0.230	0.000	0.040	0.170	0.000	0.110	0.310
OBL	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.010	0.080	0.000	0.030	0.210	0.000	0.070	0.260
PCD	0.000	0.110	0.440	0.250	0.450	0.810	0.000	0.090	0.260	0.000	0.010	0.140	0.000	0.030	0.140
PCS	0.370	0.720	0.980	0.000	0.050	0.400	0.000	0.020	0.330	0.000	0.000	0.030	0.000	0.000	0.010
QNQ	0.000	0.100	0.350	0.000	0.030	0.220	0.000	0.020	0.260	0.000	0.000	0.090	0.000	0.000	0.020
RBC	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.010	0.070	0.000	0.010	0.140	0.000	0.000	0.000
RUB	0.000	0.000	0.000	0.000	0.020	0.130	0.000	0.180	0.340	0.220	0.450	0.820	0.000	0.060	0.210
TRL	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.040	0.160	0.000	0.100	0.510	0.000	0.140	0.470
SCI	0.000	0.000	0.030	0.000	0.010	0.050	0.000	0.010	0.090	0.000	0.000	0.030	0.000	0.000	0.010
SPH	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.020	0.070	0.000	0.050	0.140	0.000	0.020	0.050
TEN	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.030	0.000	0.010	0.110	0.000	0.000	0.010
TRD	0.000	0.000	0.000	0.000	0.010	0.070	0.000	0.010	0.090	0.000	0.030	0.140	0.000	0.000	0.020
TRS	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.040	0.200	0.000	0.010	0.170	0.000	0.000	0.010
TUM	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.050	0.000	0.000	0.050	0.000	0.220	0.840
UNV	0.000	0.000	0.020	0.000	0.010	0.180	0.000	0.020	0.080	0.000	0.020	0.090	0.000	0.020	0.130

Notes: Min = minimum relative abundance; Mn = mean relative abundance; Max = maximum relative abundance; species names as in Table 3.

est mean and maximum abundances. *O. universa* presents the highest mean percentage in this group. The Quaternary samples with assemblages similar to those of this intermediate group would be deposited under conditions resembling western Mediterranean present-day ones.

The fourth group (Fig. 6E) is located to the south of the third, from the 15°C isotherm in January in the Mediterranean, predominantly occupying the eastern sector. In the North Atlantic it is located to the south of a line joining the Canary Islands to Cape Hatteras. *G. ruber* presents proportions exceeding 22%. *Globigerina calida* Parker, *Globoturborotalita rubescens* (Hofker), *Globigerinella siphonifera* (d'Orbigny), *Globoturborotalita tenella* (Parker), and *G. truncatulinoides* right-coiling show their highest mean and maximum percentages. *Globigerinoides conglobatus* (Brady), *Beella digitata* (Brady), and *Globigerinoides trilobus* (Reuss) attain their maximum relative abundances. All the present-day samples with equivalents in the Quaternary are located in the subtropical, northernmost, coolest part of this subtropical-tropical area. The Quaternary assemblages would therefore have been deposited during interglacial periods in which warmer temperatures than those of the present-day western Mediterranean existed.

Finally, the fifth group (Fig. 6F) is mainly located off the African coast, south of Cape Verde. Its assemblages contain over 5% of *N. dutertrei*, and *G. trilobus* attains high percentages and its greatest relative abundance, whereas *G. ruber* only attains a maximum abundance of 21% and the mean falls to 6%. *S. dehiscens*, *G. cultrata*, *P. obliquiloculata*, and *G. tumida* reach their greatest mean and maximum percentages, although it should be noted that the high percentages attained by this latter species (up to 84%) are probably linked to dissolution phenomena. *G. conglobatus* and *G. digitata* present their greatest mean percentages. None of the Quaternary assemblages studied resembled those of this equatorial group; this, together with the comment regarding the previous group, would seem to indicate that during the Quaternary in no case were there surface temperatures much higher than present-day ones.

The arrangement of the Quaternary samples from Sites 976 and 975 (Fig. 7), both by their group and mbsf depth, shows that in Intervals 1 and 2, subpolar and intermediate conditions succeed each other with no discernible pattern. The samples of the subtropical group are relatively more abundant at Site 975, and only one polar sample was located at Site 976.

In Interval 3 the subpolar and polar samples are relatively more abundant at Site 976, whereas the intermediate and subtropical ones are relatively more abundant at Site 975.

In Interval 4, there is a clear predominance of the subpolar samples at Site 976, except in some subintervals of intermediate samples. At Site 975 this predominance is not so marked. Polar samples are absent from both sites and subtropical ones are only present, in scarce numbers, at Site 976.

Of the 354 Quaternary samples from Site 976, 20 (5.6%) belong to the polar group, 229 (64.7%) to the subpolar group, 97 (27.4%) to the intermediate group and 8 (3%) to the subtropical group. Given that the Quaternary record of Site 976 presents few interruptions and that the samples are evenly spaced, it may be concluded that the Alboran Sea was occupied, for almost three-quarters of the Quaternary, by subpolar or polar surface waters, similar to those currently found to the north of a line joining Lisbon and Cape Hatteras or, in the coldest Mediterranean area, in the Gulf of Lyon. These would be, therefore, of colder and/or much colder waters than those of today.

Of the samples studied from Site 975, 3 (3.1%) belong to the polar group, 47 (48.5%) to the subpolar group, 40 (41%) to the intermediate group, 7 (7.2%) to the subtropical group and none to the equatorial group. Taking into account all possible reservations, the polar and subpolar samples are seen to be relatively more scarce at Site 975 than at Site 976.

According to the maps by Gorshkov (1978), the superficial waters of the area in which Site 975 is located are slightly colder between December and April than those of the area containing Site 976. The reverse is true during the warmer months (July to September), when a notable temperature gradient is formed in the Alboran Sea, increasing from west to east. The most recent samples from the two sites, probably representative of these conditions, correspond to the intermediate group.

A generalized fall in temperatures with such a relation being maintained, would suppose an increase in the absolute abundance of polar and subpolar organisms during the colder months, which would be greater at Site 975 rather than at Site 976. Consequently, it might be expected that the proportion of samples assigned to the polar and

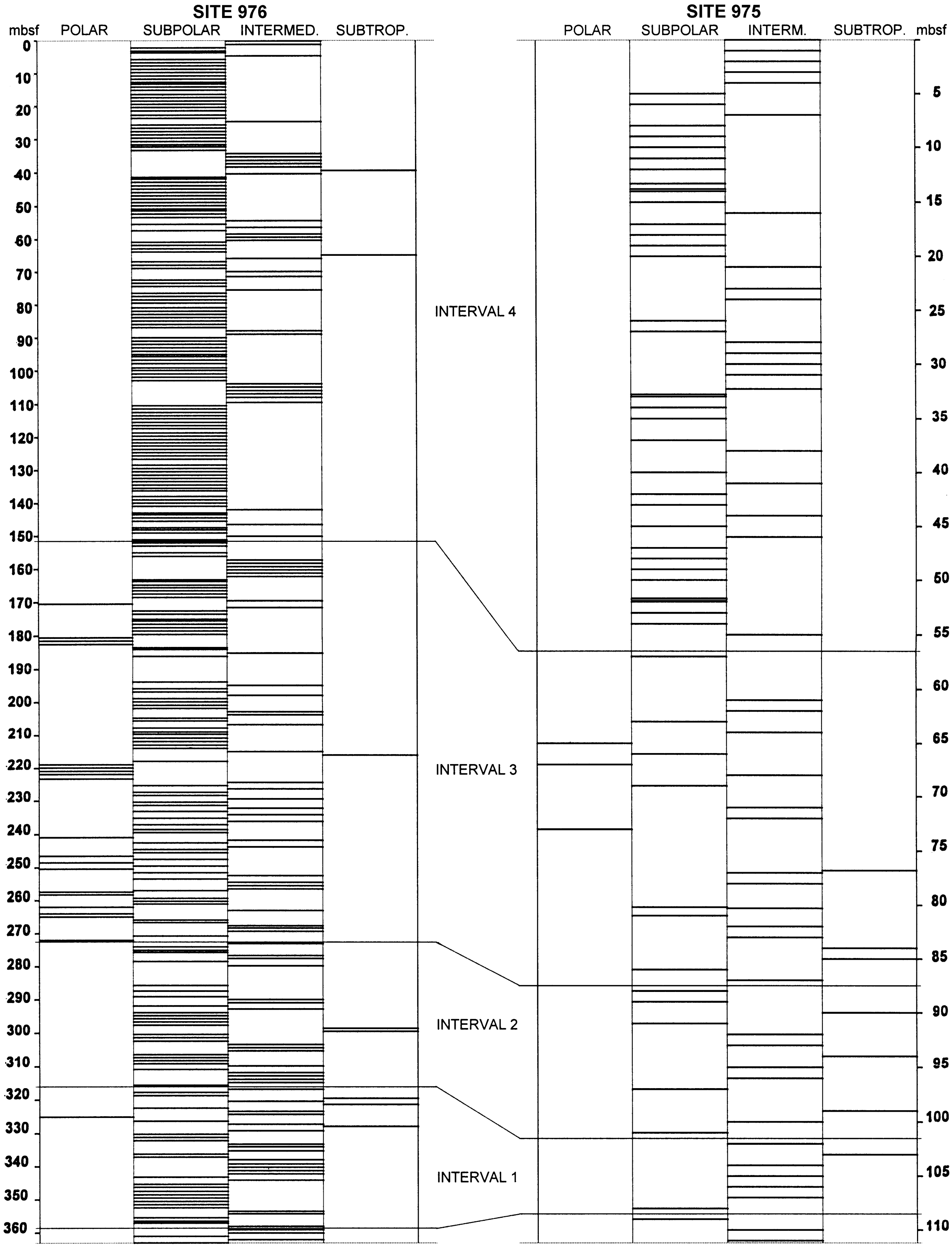

Figure 7. Present-day groups of core-top samples in which Quaternary samples are distributed according to discriminant analysis.

subpolar groups were greater at Site 975, contrary to actual observations. Two alternatives may be evaluated: a) that the abundance of intermediate and subtropical fauna in the biocoenoses during the summer months at Site 975 managed to maintain a part of their assemblages within the intermediate or subpolar groups during colder periods than the current one; or b) that the relation between the summer and winter temperatures at the two sites varied during the Quaternary.

In the case of a generalized rise, as the maximum temperature is greater in the region of Menorca, the samples of the subtropical group should be relatively more common at Site 975, as, in fact, occurs.

CONCLUSIONS

The varying frequency of occurrence of *N. pachyderma* (left-coiling) enables the identification of four Pleistocene intervals at Sites 976 and 975. In two of these intervals, samples with significant proportions of this morphotype are relatively common. In the other two, it is a minority constituent, except for occasional, very localized, peaks.

Independently of this alternation of frequent presences and almost generalized absences of polar fauna, a greater relative abundance was observed at both sites of elements indicative of more benign conditions (samples of the intermediate and subtropical groups, samples in which there is a predominance of the *inflata* and *ruber* components) in the first three intervals, even though two of these presented significant proportions of polar fauna. In the most recent interval, particularly at Site 976, there is a predominance of the subpolar fauna and of the samples dominated by the *pachyderma* right-coiling component.

To summarize the discussion of the different intervals, it could be concluded that during Interval 1, the predominant conditions were similar to those of today, perhaps being slightly warmer at Site 975 though interrupted by episodes of great cold. However, the relative abundance of subpolar forms, especially at Site 976, leads us to imagine colder winter conditions than those of today.

During Interval 2, the conditions at Site 976 would have been, in general, less benign but more stable, without the very cold episodes of the previous interval, whereas the variations from the norm would be, in general, warmer episodes. At Site 975 the conditions would vary from cold (though not extremely cold) to warm, with neither achieving any strong dominance.

Interval 3 would be comparable to Interval 1, although with more strongly marked features: a greater general incidence of the very cold periods and warm episodes at Site 975 concentrated near the lower half of the interval.

Finally, Interval 4 would be similar to Interval 2, although more regular and somewhat colder, with an almost complete absence of the very cold episodes and with very few warm ones.

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