

LATE QUATERNARY PALEOCEANOGRAPHIC FEATURES AS DEDUCED FROM CALCIUM CARBONATE AND FAUNAL CHANGES OF PLANKTONIC FORAMINIFERS IN CORE SAMPLES FROM NORTHEASTERN ARABIAN SEA

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ABSTRACT

Two pelagic core samples, ARB-52 and ARB-54 from 2240 m and 800 m depths respectively from the Arabian Sea off Bombay were analysed for determining climatic changes during the past 30,000 yr. based on the interpretation of changes in calcium carbonate and planktonic foraminifers, with implications on paleoceanography of the Arabian Sea during late Quaternary. Paleoclimatic curve based on per cent variations of carbonate is substantiated by the faunal characteristics. Low value of cold-water/warm-water faunal ratio was correlated with carbonate maximum. Frequency distribution of 10 selected species showed that 2 species, *Globorotalia menardii* complex (warm-water species group) and *Neogloboquadrina pachyderma* (cool-water species) were found to be reliable as climatic indicators. Two faunal zones, Z and Y were observed for the cores. Furthermore, faunal composition of the glacial and post-glacial periods in both the cores showed some similarity to the present-day fauna of the northern Indian Ocean. This faunal affinity suggests that changes in near-surface water temperatures during the last glacial period did not induce major alterations in the fauna and the fact that sea surface temperatures were slightly warmer in the Arabian Sea during Last Glacial Maximum reinforced the above point of observation.

INTRODUCTION

ALTHOUGH extensive studies have been made on planktonic foraminifers for the understanding of paleoecologic and paleoclimatic changes on a global basis in both the Atlantic and Pacific (Schott, 1935; Phleger *et al.*, 1953; Phleger, 1955; Olausson, 1965 and Blackman and Somayajulu, 1966), information available on this subject in Indian Ocean is still inadequate despite some earlier attempts by a few workers (Stubbings, 1939; Olausson, 1970; Vincent, 1976; Prell *et al.*, 1980; Borole *et al.*, 1982; Naidu *et al.*, 1989 and Singh and Srinivasan, 1993). It is obvious from the previous work that a great deal of research has to be carried out at different locations to study their biostratigraphy and paleoclimatic history with different approaches in Indian Ocean. The present paper, therefore, aims towards this line of work and recounts extensions of the results of a very preliminary study reported earlier

(Borole *et al.*, 1982), besides other points of view or relevant information with precise details on the climatic record in the northeastern Arabian Sea sediment since 30,000 years ago of late Pleistocene.

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MATERIAL AND METHODS

During the fifth cruise of *I.N.S. 'Darshak'*, two sediment cores were raised using a gravity corer from the Arabian Sea. Station locations

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were shown in Fig. 1. Samples of the length 2 cm thick were taken at 5 cm intervals for physical, chemical and faunal analyses. The grain size of the sediment samples was determined by the standard method of sieving and pipetting techniques (Krumbein and

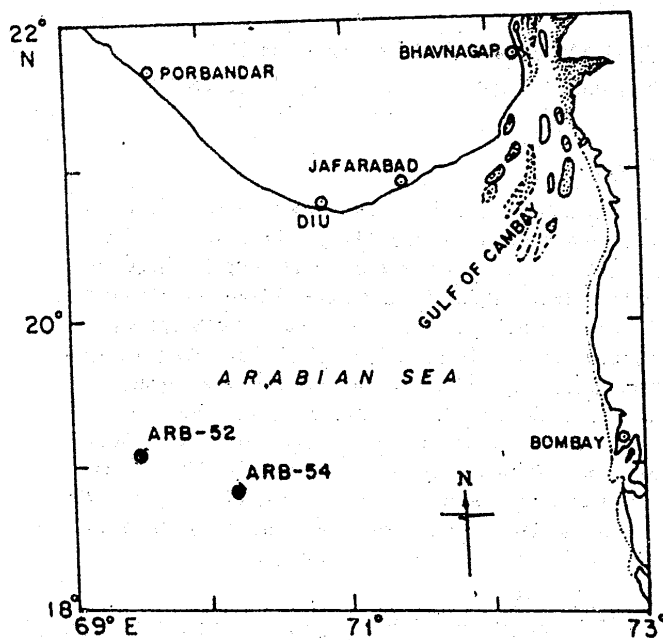


FIG. 1 Map showing sampling locations.

Pettijohn, 1938) and grain size parameters were computed using the formulae of Inman (1952). CaCO_3 content of the sediments was estimated by the rapid direct titration method as given by Barnes (1959). Samples used for foraminiferal investigations were washed on a 170-mesh sieve ($90 \mu\text{m}$ apertures).

^{14}C method was used for dating three layers of each core and radiocarbon dates of the samples were determined and reported for the cores earlier (Borole *et al.*, 1982). The age of these late Quaternary cores is approximately 30,000 years.

Shannon-Wiener diversity and evenness were calculated in accordance with procedures given by Lloyd and Ghelardi (1964) and Heip (1974) respectively.

RESULTS AND DISCUSSION

The core samples ARB-52 and ARB-54 have been collected from an area in the Arabian

Sea situated 100 to 200 km away from the west coast of India off Bombay. The present shape of this coast was attained during late Pleistocene and the coast is now marked by almost straight edge of the continental shelf. In the present paper, these cores are described in regard to their lithology, texture, carbonate and faunal contents of planktonic foraminifers in relation to climatic change.

Sediments

Core ARB-52

Latitude	Longitude	Depth (m)	Length (cm)
19°3.0'N	69°30.4'E	2240	133

The entire length of the core sample is pale greenish grey in colour dominated by pelagic sediment comprising of biogenic calcareous components with a less amount of terrigenous material. CaCO_3 contents in the core vary from 51.2 to 77.6%. Its values show an increasing trend at 0-50 cm of the core. From 50 cm down to 90 cm, a decreasing trend of it is observed in the sediment. From 90 cm to the bottom of the core, carbonate content increases again. On the whole, the sediments of the core are composed of fine silt range-size material, except at 30 cm and 70-90 cm levels, where relatively coarse-size material occurs, is represented by medium silt range sediment. Mean diameters range from 5.8 to 6.9 ϕ . The sorting is poor; standard deviations vary from 1.9 to 2.7 ϕ . At 0-30 cm, median diameter increases appreciably. This trend is reflected by the carbonate content, which also increases with mean grain size. Skewness values range between -0.003 and 0.59 ϕ . At intervals of 60 cm from core-top, the grain size distribution is symmetrical and at layers in between, it is positively skewed. Kurtosis values, varying from 0.24 to 0.92 ϕ suggest platykurtic distribution at 0-30 cm, 60-75 cm and ≥ 90 cm of the core (Fig. 2).

Core ARB-54

Latitude	Longitude	Depth (m)	Length (cm)
18°47.0'N	70°8.5'E	800	90

Top 0-45 cm of the core sample is dark greenish grey and is terrigenous in origin, the remaining part of the core sample being grey in colour. Carbonate content ranges between

0.28 and 2.3 ϕ indicating leptokurtic distribution for the layers between 15 cm and 60 cm and platykurtic distribution at ≥ 75 cm for the core (Fig. 4).

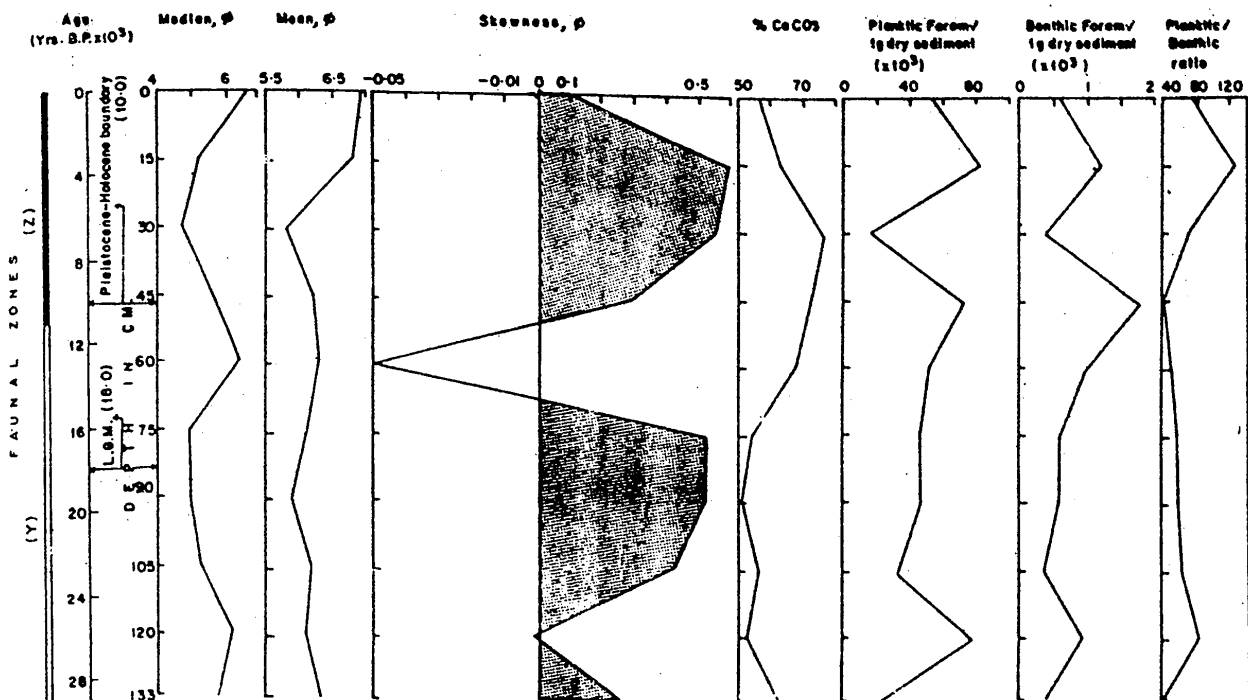


FIG. 2. Paleoclimatic analyses, median, ϕ , mean, ϕ , skewness, ϕ , CaCO_3 (%), planktonic foraminiferal number, benthic foraminiferal number and planktonic/benthic ratio of core ARB-52.

27 and 74.7% and shows an increasing trend at 0-40 cm and thereafter gradually decreases up to 65 cm, with very low values of 27 to 29.3% at 70-90 cm. In general, high carbonate values are associated with coarser sediments that are found at 30-45 cm. Mean diameter of the top 0-15 cm of the core is 6.2 ϕ , which is in fine silt range and poorly sorted; standard deviations being around 2.3 ϕ . From 15 cm level, median diameter decreases and the values fall in coarse silt and medium silt range; this sediment is confined up to 45 cm depth. The bottom, 75-90 cm of the core is mainly in fine silt range with median diameters ranging from 6.3 to 6.6 ϕ and is poorly sorted with standard deviations approximately 2.2 ϕ . Skewness values vary from -0.09 to 0.68 ϕ . Top of the core sample, 0-60 cm shows that grain size distribution is positively skewed and at 90 cm, it is symmetrical. Kurtosis values range between

Rates of sedimentation

On the basis of radiocarbon dating, it is found that rate of sedimentation for the cores in this study varies from 1.8 to 9.8 $\text{cm}/10^3$ yr. It is observed from the sedimentation rates for the top 45 cm length of core that relatively higher deposition rates have been noted for the core ARB-54 as compared with the other one ARB-52, which may be due to influx of ice-rafted material and proximity to land mass. Mean sediment deposition rate for core ARB-52 is 4.6 $\text{cm}/10^3$ yr. But in core ARB-54, a change in accumulation rate from 1.8 to 9.8 $\text{cm}/10^3$ yr has occurred at about 7500 yr B.P.

Pleistocene-Holocene boundary

The 13,000 yr B.P. environmental change as observed earlier (Borole *et al.*, 1982) for the cores of present study is visible on land

also. The Indian Ocean summer monsoon gained its vigour then to deliver heavy rains to east As illustrated previously (Fairbridge, 1972) in regard to the diachronous nature of the

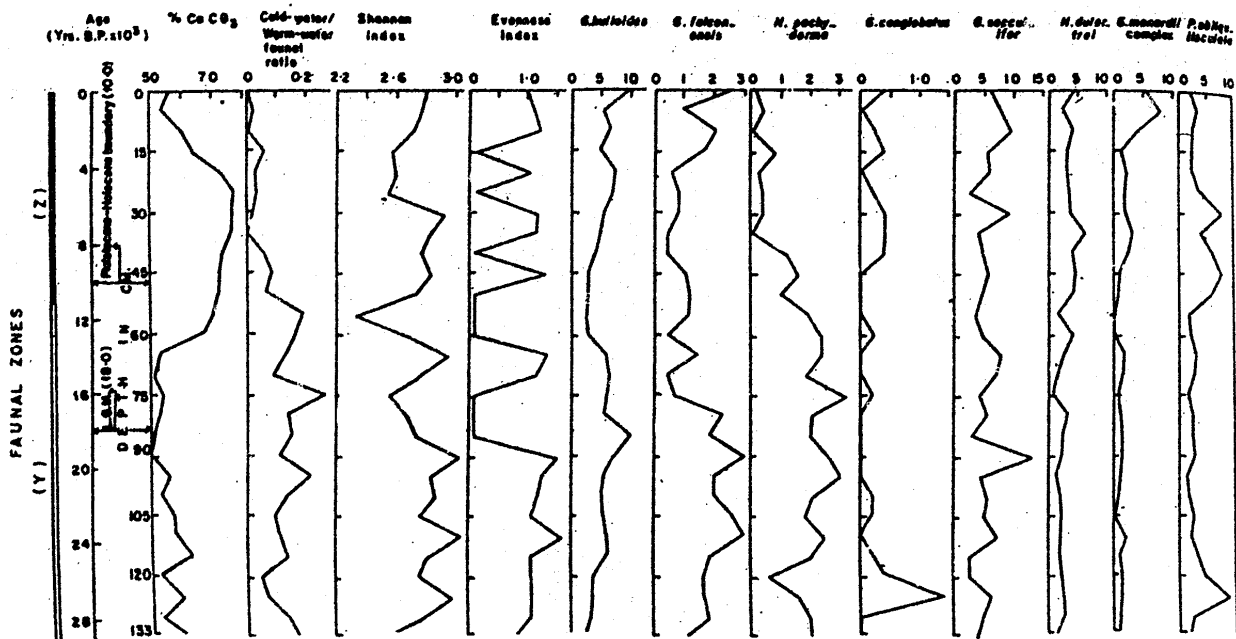


FIG. 3. Paleoclimatic analyses, CaCO₃ (%), cold/warm ratio, shannon diversity index, evenness index and relative abundance of selected foraminiferal species (*Globigerina bulloides*, *G. falconensis*, *Neogloboquadrina pachyderma*, *N. dutertrei*, *Globigerinoides conglobatus*, *G. sacculifer*, *Globorotalia menardii* complex, and *Pulleniatina obliquiloculata*) of core ARB-52.

Africa, causing Lake Victoria to overflow and bring flood waters to the Nile after hyperaridity during the last glacial period (Fairbridge, 1962).

post-glacial warming, the heating up started in the Indian Ocean ca. 13,000 yr B.P., but did not cause all the northern ice to melt till about

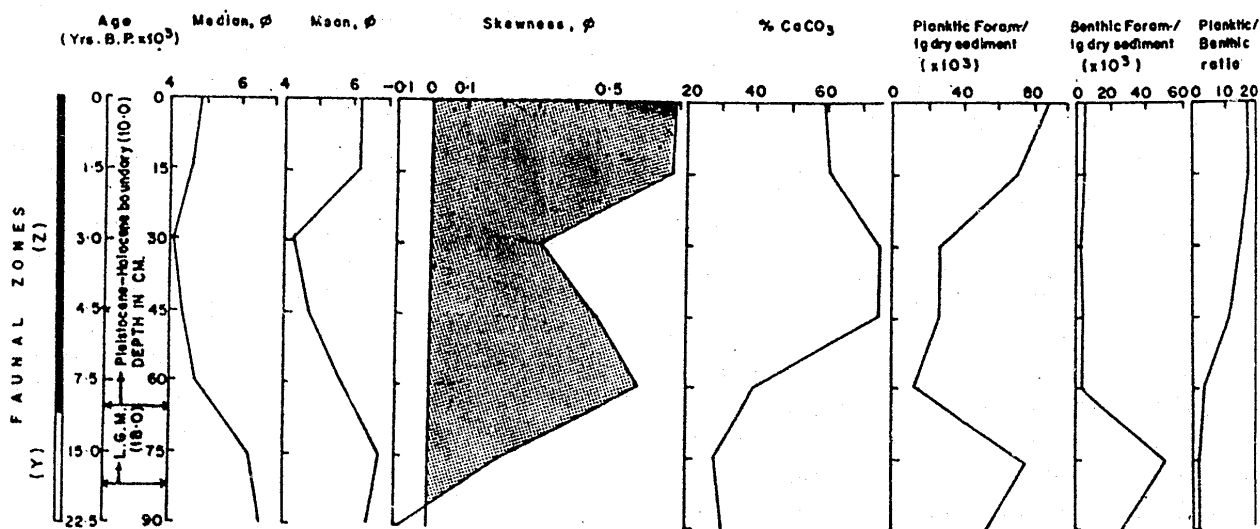


FIG. 4. Paleoclimatic analyses, median, ϕ , mean, ϕ , skewness, ϕ , CaCO₃ (%), planktonic foraminiferal number, benthic foraminiferal number and planktonic/benthic ratio of core ARB-54.

6000 yr B.P. Hence the 10,000 yr B.P. selection as defined by radiocarbon dating for the Pleistocene-Holocene boundary is a compromise, but marks a readily identifiable fluctuation. In this paper, the Holocene boundary levels for the cores are given in Table 1. These depths are at approximately 10,000 yr radiocarbon years B.P., which according to INQUA Holocene Commission is an accepted age for this boundary though it was inadvertently shifted earlier (Borole *et al.*, 1982) for these cores. The present study shows that the Holocene interval is characterized by low cold-water/warm-water planktonic foraminiferal

Last Glacial Maximum (LGM)

In Indian Ocean, mean age of the Last Glacial Maximum has been placed at about 18,000 yr B.P. (Prell and Husson, 1979 and Prell *et al.*, 1980). As shown in Table 1, in both core samples of the present study, the LGM lies at about 83 cm below top of core sample. The LGM in the Arabian Sea is demonstrated earlier (Caratini *et al.*, 1978 and Van Campo *et al.*, 1982) by its typical pollen stratigraphy in the core samples taken from the Arabian Sea. Arid vegetation types were dominant about 18,000 yr B.P. During this time, the land masses in the tropics were much

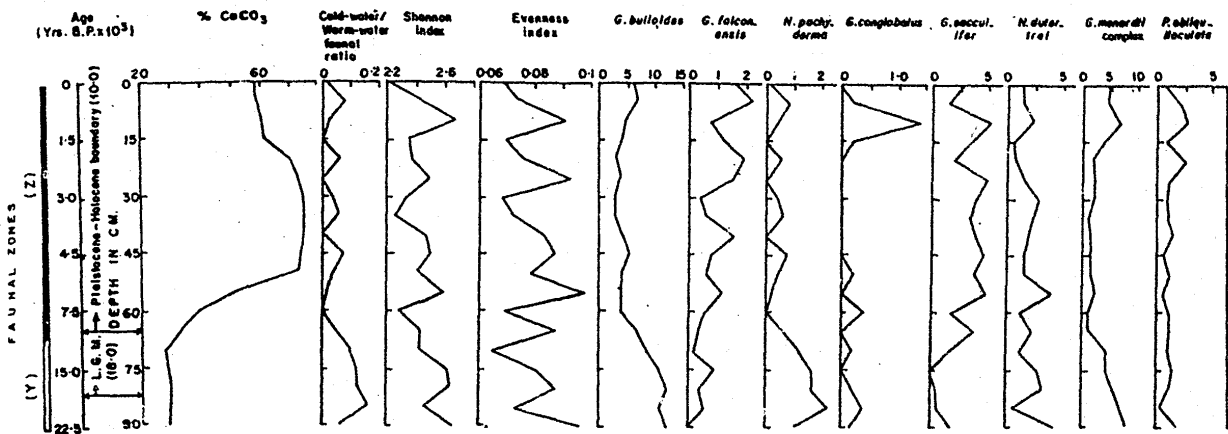


FIG. 5. Paleoclimatic analyses, CaCO₃ (%), cold/warm ratio, shannon diversity index, evenness index and relative abundance of selected foraminiferal species (*Globigerina bulloides*, *G. falconensis*, *Neogloboquadrina pachyderma*, *N. dutertrei*, *Globigerinoides conglobatus*, *G. sacculifer*, *Globorotalia menardii* complex and *Pulleniatina obliquiloculata*) of core ARB-54.

ratio (or cold/warm ratio), which coincides with maximum CaCO₃ for both the cores (Figs. 3, 5). The fauna of the Holocene period is warmer than the last glacial and can be recognized also by changes in coiling direction in some foraminiferal species. Lamb and Beard (1972) and Boersma (1978) showed index species like *Globorotalia unguolata* and *G. fimbriata* respectively, while Zobel (1978) indicated changes in the number of solution resistant species for the Pleistocene-Holocene boundary. But these faunal changes are found to be of local significance, but cannot be applied on a global scale.

dry. This Peak of aridity correlates with a zone of maximum 18 foraminifers in these cores (Duplessy, 1982) or an increase in the proportion of cold-water species as indicated by cold/warm ratio in the present study (Figs. 3,5) and the maximum extent of continental glaciers during the last glacial period (CLIMAP 1976). This cold dry phase shown in the Arabian Sea core samples was a world-wide phenomenon in the tropics during which sea-surface temperatures were reduced (CLIMAP 1976).

Faunal trends in distribution

The distribution patterns of the total planktonic foraminifers, *i.e.*, number of

specimens per 1 g of dry sediment with depth in both the core samples are shown in Figs. 2,4. This number, in core ARB-52, varies from 17600 to 82200 specimens at 0-45 cm and below the Holocene boundary with the exception at 120 cm, its variation is from 23000 to 52000 specimens. In the other core ARB-54, its range is between 11200 and 86400 specimens in the Holocene section, while in the last glacial sediment, it varies from 52800 to 76000 planktonic specimens. Further, the trend of planktonic/benthic ratio for these core samples indicates nature of their productivity or abundance. This ratio is of immense help in paleoenvironmental interpretations. Higher planktonic/benthic ratio has been observed at 0-45 cm in core ARB-54 and between 0 and 30 cm (barring the layer at 120 cm) for core ARB-52 in the Holocene sections. In general, this study depicts that warm periods are characterized by high planktonic foraminiferal abundances and is in agreement with similar observations made elsewhere (Phleger, 1939, 1951; Cushman, 1941 and Schott, 1952). Furthermore, foraminiferal species are categorized into cold-, temperate- and warm-water fauna as per the faunal groupings given by Belyaeva (1964) and their per cent ranges in different periods during late Quaternary are given in Table 2. Since the core samples are from the tropical region, both the cold- and temperate-water fauna are low in abundance, but they show relatively higher concentrations during the last glacial (cold) period, whereas the Holocene (warm) period of the core samples rich in carbonate content is marked by very high abundances of warm-water fauna.

Species diversity and evenness

In core ARB-52, a deep (2240 m) core, there is a wide variation in the values of diversity (2.3 to 3.05) and of evenness (0.06 to 1.55), while in core ARB-54, which is relatively from a shallower depth (800 m), diversity ranges from 2.21 to 2.68 and evenness from 0.06 to 0.1. In core ARB-54, diversity peaks are coinciding with foraminiferal abundances, but in core ARB-52, they are not. Further, diversity with cold/warm ratio is not significantly correlated for the cores (ARB-52,

$r = -0.253$ and ARB-54, $r = 0.248$). However, relationship between diversity and warm-water fauna is highly positively correlated for the core samples ($r = 0.822$, $p > 0.01$ for core ARB-52 and $r = 0.812$, $p > 0.01$ for core ARB-54). Evenness also shows the positive correlation with warm-water fauna for the cores ($r = 0.601$, $p > 0.01$ for ARB-52 and $r = 0.558$, $p > 0.05$ for ARB-54). Furthermore, evenness and diversity are linearly related for the cores and their relationship is significantly positive (ARB-52, $r = 0.693$, $p > 0.01$ and ARB-54, $r = 0.679$, $p > 0.01$), (Figs. 3,5).

Frequency patterns

Of the twentyeight foraminiferal species that have been identified from the core samples, 10 species are chosen and studied with regard to their frequency oscillations for deciphering of climatic change, they being included under the following groups: (i) most sensitive warm-water species include *Globorotalia menardii* complex (comprising *G. menardii*, *G. flexuosa* and *G. tumida*) and *Pulleniatina obliquiloculata*; (ii) marginally warm-water forms are represented by *Globigerionides conglobatus*, *G. sacculifer* and *Neogloboquadrina dutertrei* and (iii) most sensitive cool-water species being *Globigerina bulloides*, *G. falconensis* and *Neogloboquadrina pachyderma* (Figs. 3,5).

Warm-water forms—In the Atlantic and Caribbean, paleoclimatic events of the Quaternary have earlier been successfully interpreted for the first time by Ericson and Wollin (1968) using the frequency of *G. menardii* complex. Since then, numerous researchers have used this group as a paleoclimatic tool elsewhere, though it is of no consequence in some geographic areas. In the present study, in core ARB-52, it is relatively higher in concentration at 0-40 cm representing the post-glacial period, but sparsely present between 40 and 133 cm during the last glacial period as they are 'warm' species. In contrast, in core ARB-54, there is no such significant changes in distribution patterns of this species group between glacial and post-glacial periods.

It may be because this core is from a shallower depth. The above group of species shows relatively higher abundance in this core at 0-15 cm, very low abundance between 15 and 65

relatively abundant *G. falconensis* and *N. pachyderma*, but no definite trend is indicated by *G. bulloides* as *G. falconensis* exhibited in core ARB-54 in which the other species namely

TABLE 1 Details of paleoclimatic/faunal zonation in the sediment core samples

Core	Pleistocene-Holocene boundary level, cm	Z-Y boundary level, cm	LGM (18,000 yr B.P.) level, cm
ARB-52	47	53	83
ARB-54	65	67	83

cm and an increase in abundance at the bottom of the core, 65-90 cm. Another warm-water species, *P. obliquiloculata* shows higher densities between 30 and 50 cm and at 120-125

G. bulloides and *N. pachyderma* show an increase at the bottom of the glacial zone. The prominent peaks of left-coiling specimens of *G. bulloides* and *N. pachyderma* at different

TABLE 2 Per cent ranges of different faunal groups in the sediment core samples during different epochs of late Quaternary.

Period	Core ARB-52		Core ARB-54	
	Post-glacial (Z)	Last glacial (Y)	Post-glacial (Z)	Last glacial (Y)
Climate	warm	cold	warm	cold
Faunal groups:				
Warm-water fauna	12.0-26.0	10.8-26.2	8.4-19.6	12.0-17.0
Temperate-water fauna	2.4-10.2	2.6-9.8	2.8-8.0	8.0-12.8
Cold-water fauna	0.0-1.6	0.6-3.2	0.0-0.9	0.9-2.2

cm levels in core ARB-52, while in core ARB-54, similar trend is seen with higher abundance at the top of Holocene section and at the base of last glacial. Thus its distribution shows that it is not a good climatic indicator species.

Marginally warm-water forms — *G. conglobatus*, *G. sacculifer* and *N. dutertrei* show no definite trend in core ARB-52. With the exception of *G. sacculifer*, other species show the same trend in core ARB-54 also; the aforementioned species shows high percentage abundance in the Holocene part, but low abundance at 70-90 cm of last glacial in the core. Generally all these forms based on observations made on the cores in this study and elsewhere, they are not reliable as climatic indicators.

Cool-water forms—They include *G. bulloides*, *G. falconensis* and *N. pachyderma*. In core ARB-52, the last glacial zone contains

levels of the glacial zone in both the core samples represent perhaps relatively more cool conditions.

Faunal zones

Two faunal zones namely Z and Y of late Quaternary recognized in the core samples of present study are based on the criteria adopted by Ericson *et al.*, (1961) (Figs. 3,5). Details of faunal zonation regarding levels in the core samples are given in Tables 1 and 2. Salient features which characterize the following biostratigraphic zones in the cores, ARB-52 and ARB-54, are as follows:

Z-zone is characterized by the dominance of the tropical groups of species, *G. menardii* complex, but in the core ARB-54 it shows an increase in abundance between 75 and 90 cm. Also, this zone is further marked by lower

cold/warm ratio. Here, as in the tropical and sub-tropical Atlantic, zone Z represents warm conditions coupled with carbonate maximum of post-glacial period.

Y-zone typified by higher abundances of cold-water species, *N. pachyderma* and by higher cold/warm ratio. As the aforementioned species is a polar species (sinistral or left-coiling), its dominance in this zone suggests its migration towards north during last glacial period. Thus, it is a cool faunal zone with carbonate minima corresponding to the Y-zone of Atlantic (Ericson *et al.*, 1961) and of Caribbean (Imbrie and Kipp, 1971).

Coiling direction

The direction of coiling of the tests in some planktonic foraminiferal species (*G. bulloides*, *N. pachyderma* and *G. truncatulinoides*) is temperature dependent—left-coiling or sinistral in cold waters and right-coiling or dextral in warm waters. As a corollary, coiling direction in planktonic foraminifers is useful in establishing proper correlation of Quaternary strata. In the case of *G. bulloides* and *N. pachyderma*, mixed dextral and sinistral populations occur in the present study due to various ecological factors in the stratigraphic sequence of the cores, while the specimens of *G. truncatulinoides* are exclusively dextral in post-glacial sediments except in the core ARB-54 at 60 cm level, coiling direction changes to sinistral type in this species, suggesting inception of the climatic change. Further, an attempt has been made to use relative abundance curves of sinistral populations of *G. bulloides* and *N. pachyderma* for indication of climatic change (Fig. 6). These curves also show that left-coiling specimens are more dominant in the sediment representing the last glaciation (cold) than that of interglaciation or the Holocene (warm) during which period it occurs slightly thereby enabling paleoclimatic interpretation of the cores.

On the other hand, some species are either exclusively sinistral (e.g. *G. tumida*) or dextral (e.g. *P. obliquiloculata*) in the areal distribution of recent sediments of the tropics. The present

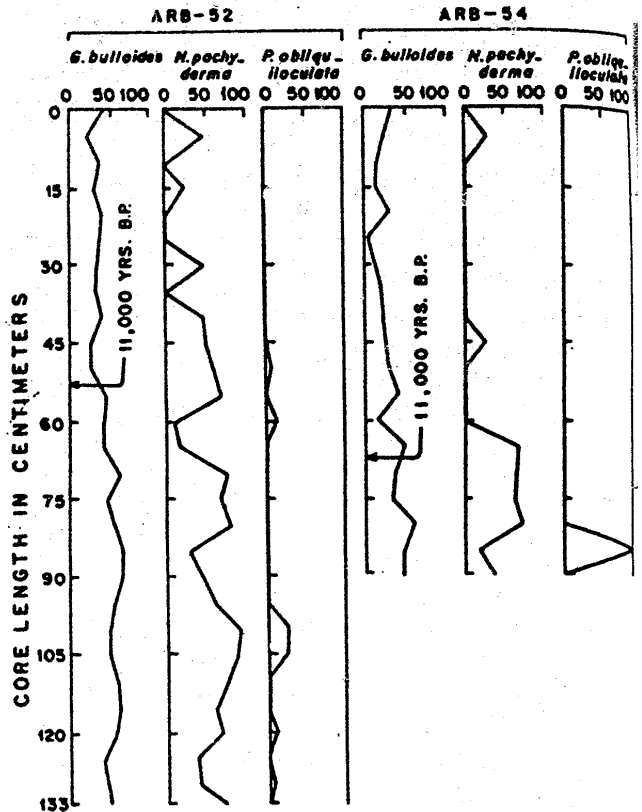


FIG. 6. Percentage curves of sinistral specimens of *Globigerina bulloides*, *Neogloboquadrina pachyderma* and *Pulleniatina obliquiloculata* in the cores ARB-52 and ARB-54 with radiocarbon dates.

study shows that there is a relative increase in the abundance of sinistral population of *P. obliquiloculata* at 100-105 cm in core ARB-52 and at 85 cm in core ARB-54 due to cooler climate of the last glaciation as evidenced by climatic curve based on carbonate content (Fig. 6).

Paleoclimatic curve

This curve based on per cent variations of CaCO_3 shows that the warm period is characterized by high carbonate, which in turn, has been imputed to high productivity of warm-water foraminifers and increased upwelling due to vigorous southwest monsoon

circulation in summer. Also, this finding is confirmed by the extensive growth of coralline algae and coral reefs on the outer shelf and high carbonate content in shelf sediments of the west coast of India during the Holocene (Nair and Hashimi, 1980). The plot of cold/warm ratio shows a cool interval at 47-133 cm in core ARB-52 and at 70-85 cm in core ARB-54. The stadial (cold) period or the Y-zone coincides with minimum carbonate, in both the cores (Figs. 3,5).

CONCLUSIONS

1. Twentyeight species of planktonic foraminifers have been identified and studied with regard to their frequency distribution from the subsamples of the cores ARB-52 and ARB-54. The fact that warm-water species forming a major component of the fauna during the Holocene epoch has been confirmed.
2. Faunal trends like planktonic number, planktonic/benthic ratio, species diversity, evenness, cold-, temperate-and warm-water fauna and the cold/warm ratio have all lent effective support as paleoecological indicators.
3. Foraminiferal species such as *G. menardii* complex and *N. pachyderma* are found to be most reliable as climatic indicators.
4. In this study, the use of peaks of sinistral populations of *G. bulloides* and

N. pachyderma as well as the presence of sinistral *P. obliquiloculata* and *G. truncatulinoides* has likely the signature of cooler climate in the Y-zone and has been recognised also for differentiating the stadial (cold) period from the interstadial (warm) period.

5. Carbonate was high during the last interglaciation or the Holocene has been attributed to enhanced productivity of warm-water fauna.
6. As regards plots of carbonate for the core samples, they have provided a panoply of evidence as useful paleoclimatic curves.
7. Palaeoclimatic curve inferred from per cent variations of carbonate is substantiated by the cold/warm ratio curve. This ratio is high during the last glaciation or in the Y-zone which coincides with minimum CaCO_3 in the cores.
8. Two faunal sections — Z and Y zones observed in the cores of this study find corroboration from the fact that they represent a warm episode approximately 11,000 years B.P. and a cold episode between 11,000 and 75,000 years ago respectively.
9. It is indicated that the Last Glacial Maximum (LGM) of late Quaternary lies at a depth of 83 cm from the top in both the core samples.

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