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Pleistocene oceanographic changes indicated by deep sea benthic foraminifera in the northern Indian Ocean

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Abstract. An attempt has been made to understand the Pleistocene bottom water history in response to the paleoclimatic changes in the northern Indian Ocean employing quantitative analyses of deep sea benthic foraminifera at the DSDP sites 219 and 238. Among the 150 benthic foraminifera recorded a few species show dominance with changing percent frequencies during most of the sequence. The dominant benthic foraminiferal assemblages suggest that most of the Pleistocene bottom waters at site 219 and Early Pleistocene bottom waters at site 238 are of North Indian Deep Water (NIDW) origin. However, Late Pleistocene assemblage at site 238 appears to be closely associated with a water mass intermediate between North Indian Deep Water (NIDW) and Antarctic Bottom Water (AABW).

Uvigerina proboscidea is the most dominant benthic foraminiferal species present during the Pleistocene at both the sites. A marked increase in the relative abundance of *U. proboscidea* along with less diverse and equitable fauna during Early Pleistocene suggests a relative cooling, an intensified oceanic circulation and upwelling of nutrient rich bottom waters resulting in high surface productivity. At the same time, low sediment accumulation rate during Early Pleistocene reveals increased winnowing of the sediments possibly due to more corrosive and cold bottom waters. The Late Pleistocene in general, is marked by relatively warm and stable bottom waters as reflected by low abundance of *U. proboscidea* and more diverse and equitable benthic fauna.

The lower depth range for the occurrence of *Bulimina aculeata* in the Indian Ocean is around 2300 m, similar to that of many other areas. *B. aculeata* also shows marked increase in its abundance near the Pliocene/Pleistocene boundary while a sudden decrease in the relative abundance of *Stilostomella lepidula* occurs close to the Early/Late Pleistocene boundary.

Keywords. Pleistocene; benthic foraminifera; northern Indian Ocean; oceanography.

1. Introduction

The deep sea circulation influences the thermal structure of individual oceans, the distribution of deep sea biota and the state of preservation of deep sea sediments. It has now been established that the earth's climatic history is closely linked with the changes in the deep water circulation of the oceans (Weyl 1968; Newell 1974).

The study of benthic foraminifera is very useful in interpreting the changes in deep sea environment. They are the largest biomass present at the lower bathyal (> 1000 m) and abyssal depths in the modern oceans (Hessler and Jumars 1974) and are the dominant carbonate tests to be preserved in the deep sea sediments. Many benthic species have separate stratigraphic ranges, and their evolutionary and migratory patterns provide significant biostratigraphic and paleoecologic information about the deep sea environments (Douglas and Woodruff 1981; Kurihara and Kennett 1988).

Investigations on the benthic foraminiferal assemblages in the core tops show that different assemblages are associated with major bottom and deep water masses (Streeter 1973; Schnitker 1974; Lohmann 1978; Corliss 1979a, b; Ingle *et al* 1980; Douglas and Woodruff 1981; Kurihara and Kennett 1986; Sen Gupta 1988; Gupta and Srinivasan 1990a, b; Gupta 1992, 1994). These associations help in reconstructing the past distribution of the water masses and derive their physical and chemical characteristics.

In the present investigation DSDP sites 219 and 238 in the northern Indian Ocean were selected for quantitative benthic foraminiferal analysis to infer the Pleistocene bottom water oceanographic history of this region.

2. General setting of the area

The DSDP site 219 (Lat. 9°01·75′N; Long. 72°52·67′E) was drilled on the crest of the Chagos-Laccadive Ridge, a north-south trending structure extending southward from the eastern margin of the Arabian Sea at a water depth of 1764 m. Site 238 (Lat. 11°09·21′S; Long. 70°31·56′E) is situated east of the Central Indian Ridge near the southern end of the Chagos-Laccadive Ridge at a greater water depth of 2832 m. Locations of these two sites and prominent physiographic features of the Indian Ocean are shown in figure 1.

Antarctic Bottom Water (AABW) mostly confined to the deep basins (> 4,000 m) is the dominant bottom water mass in the Indian Ocean (Kolla *et al* 1976; Tchernia 1980). The Weddell Sea and the Ross Sea – Adelie coast are supposed to be two different sources for AABW in the Indian Ocean (Kolla *et al* 1976; Kolla and Kidd 1982). The Western Indian Ocean bottom waters are mainly of Weddell Sea origin whereas the bottom water from the Ross Sea is mostly confined to the Eastern Indian Ocean (Kolla and Kidd 1982). Kolla *et al* (1976) and Johnson and Damuth (1979) observed that the sea floor of the western and southern regions are more influenced by AABW than the northern regions of the Indian Ocean. Thus, at present the bottom waters at sites 219 and 238 are predominantly influenced by AABW although, the vigour of AABW appears to be somewhat subdued in this region compared to the southern part of the Indian Ocean. The bottom water potential temperatures in the Arabian basin and in the central Indian basin range from 1·00 to 1·20°C and 0·96 to 1·20°C respectively (Kolla *et al* 1976). The Calcium Carbonate Compensation Depth (CCD) in the Indian Ocean is at about 5,000 m (Kolla *et al* 1976). Both the examined sites lie above CCD and under Equatorial Water (EQW) and are ideal for calcium carbonate deposition.

The presence of uninterrupted Pliocene–Pleistocene sequences at both the sites enabled us to study the changes in the benthic foraminiferal distribution during the Pleistocene and also across the Pliocene/Pleistocene transition. The Pleistocene sections at sites 219 and 238 are dominated by foraminifera-rich nannofossil ooze.

3. Pliocene/Pleistocene boundary

The availability of a large number of Late Cenozoic deep sea cores of continuous sequences from tropical to polar regions as a result of Deep Sea Drilling Project

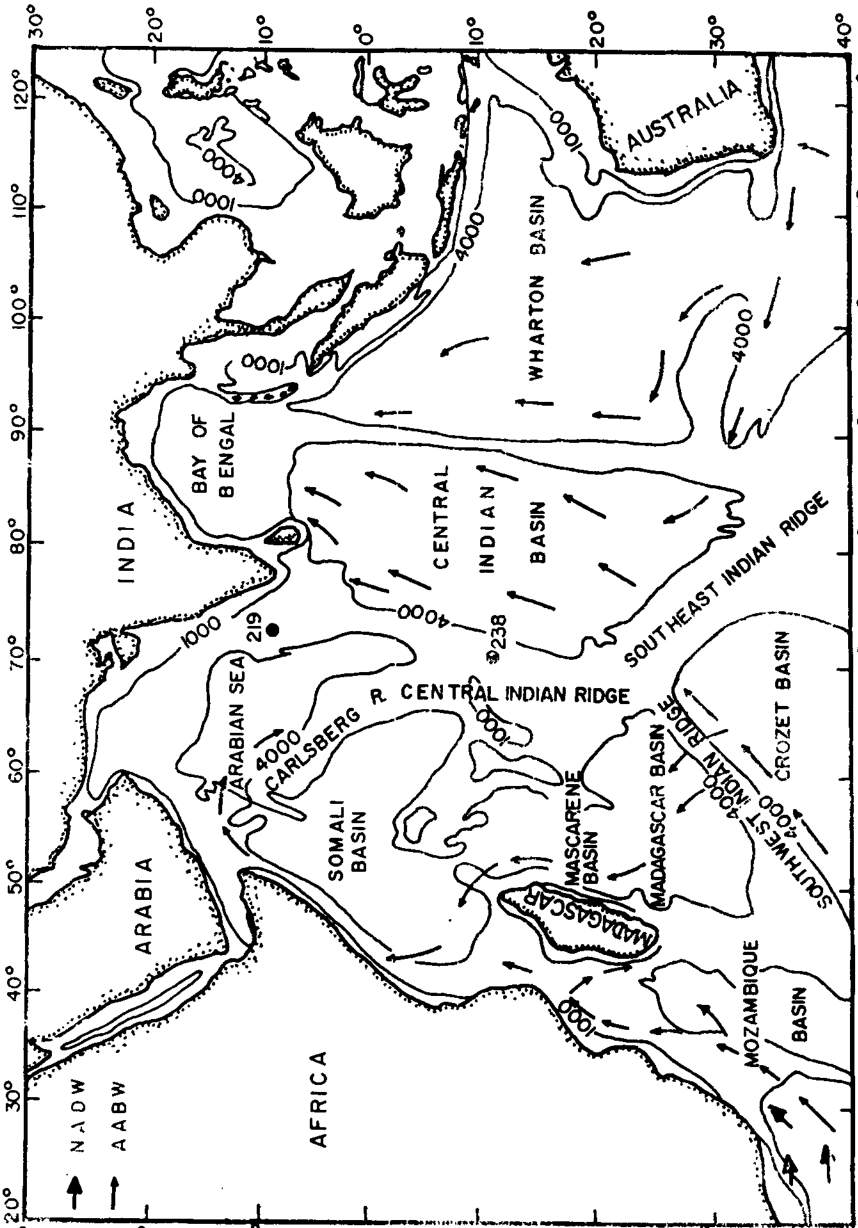

Figure 1. Location of DSDP sites (solid circles) examined and bottom water circulation in the Indian Ocean (modified after Kolla *et al* 1976).

(DSDP) provided a unique opportunity in delineating the Pliocene/Pleistocene boundary from widely separated regions of the world. Detailed integrated micropaleontological and paleomagnetic studies of the deep sea cores proved useful in identifying various physical and bio-events and the duration of the Pleistocene. Based on recent studies the last appearance of *Globigerinoides fistulosus* which occurs at the top of Olduvai Normal Paleomagnetic Event at 1·6 Ma appears to be an excellent marker for delineating the Pliocene/Pleistocene boundary in the Tropical Indo-Pacific deep sea sequences (Srinivasan and Singh 1991; Srinivasan and Sinha 1991, 1992). Following the above criteria Pliocene/Pleistocene boundary is well defined at the examined DSDP sites 219 and 238.

4. Method of study

The present investigation is based on a total of 19 samples from 33·0 m of core at site 219 and 22 samples from 34·5 m of core at site 238 at a regular interval of about 1·5 m. The samples (10 cc in volume) were treated with 15% hydrogen peroxide solution and water (1:3 ratio) and wet sieved over 63 μm and 149 μm tyler sieves. All the benthic foraminifera over 149 μm size fraction (dry sieved) were picked from each sample. At both the sites benthic foraminifera are well preserved and commonly do not constitute more than 5% of the total foraminiferal population. The benthic foraminifera were mounted on microfaunal slides, identified and counted.

5. Quantitative analyses of benthic foraminifera

Although much work has been carried out on generating qualitative benthic foraminiferal data, there are only few published records on the quantitative aspect of the Indian Ocean deep sea benthic foraminifera (Corliss 1979a, b, 1983, 1985; Gupta and Srinivasan 1990a, b, 1992a, b; Srinivasan and Gupta 1990; Gupta 1991, 1992, 1994; Rai and Srinivasan 1992, 1993). Most of the modern benthic foraminifera whose distribution pattern in the Indian Ocean is now well established also occur in the Pleistocene. Total of 137 and 107 benthic foraminiferal species were identified at sites 219 and 238 respectively (Appendix 1); of these only a few species dominate the assemblage and show changes in their relative abundances during the Pleistocene.

The relative percentages of dominant benthic foraminiferal groups and species (seven species at 219 and six at site 238) showing significant changes are plotted in figures 2–5. The Species Diversity, H(S) and Equitability, E′ were also calculated using Shannon-Wiener Diversity Index (Rai and Srinivasan 1992) and are shown in figures 3 and 5.

The calcareous benthic foraminifera constitute the most dominant part of the Pleistocene assemblages at both the examined sites. Arenaceous foraminifera constitute about 5% of the total benthic foraminiferal population at both the sites whereas relative abundances of porcellaneous taxa range from 5 to 10% at site 219 and 5 to 15% at site 238 during the Pleistocene (figures 3 and 5). The dominant species at these two sites include *Uvigerina proboscidea, Cibicides wuellerstorfi, Globocassidulina subglobosa, Bulimina aculeata* and *Oridorsalis umbonatus*. Such a dominant assemblage has been recorded from the core top samples of the Indian

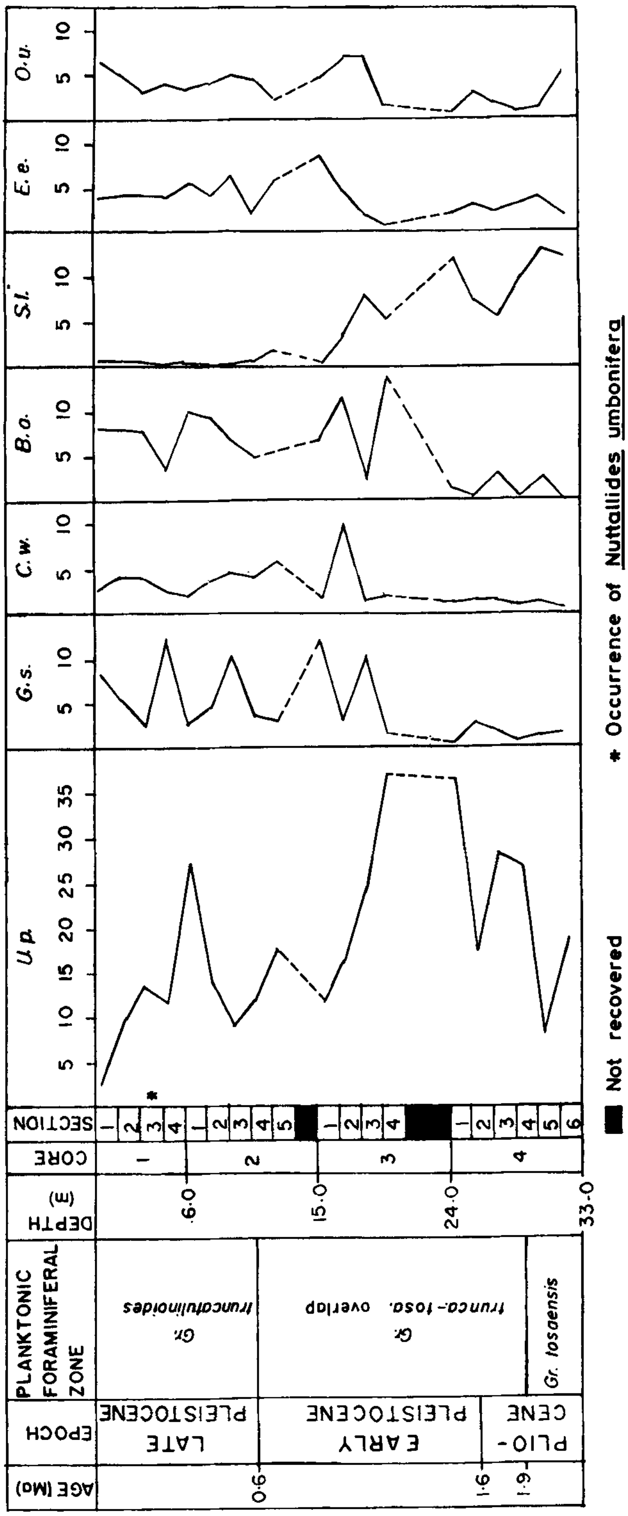

Figure 2. Percent distribution of important benthic foraminiferal species during the Pleistocene at the DSDP site 219. (*U. p. Uvigerina proboscidea; G. s. Globocassidulina subglobosa; B. a. Bulimina aculeata; S. l. Stilostomella lepidula; E. e. Epistominella exigua; O. u. Oridorsalis umbonatus*).

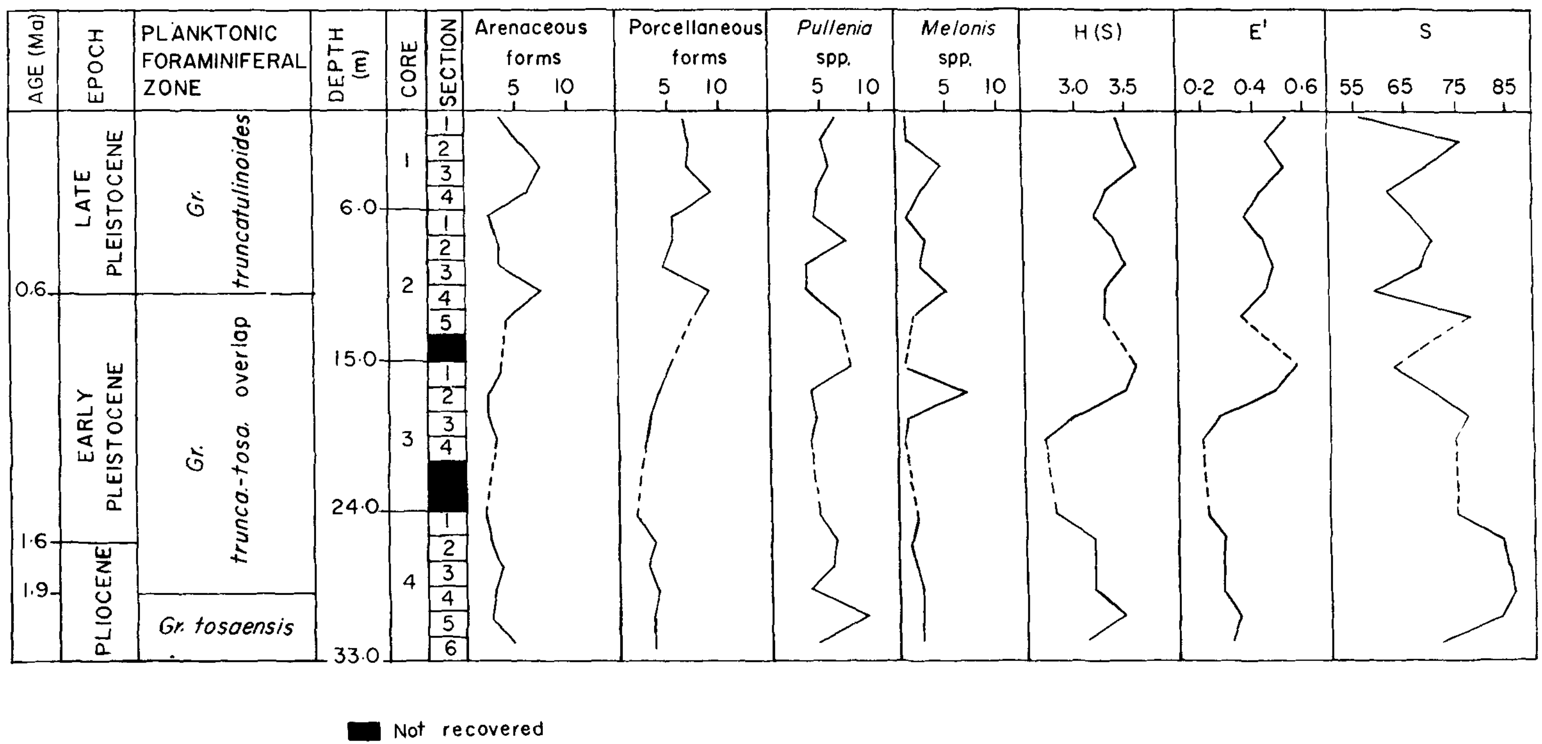

Figure 3. Percent distribution of important benthic foraminiferal groups and plots of Species Diversity, H(S); Equitability, E' and Number of Species, S during the Pleistocene at the DSDP site 219.

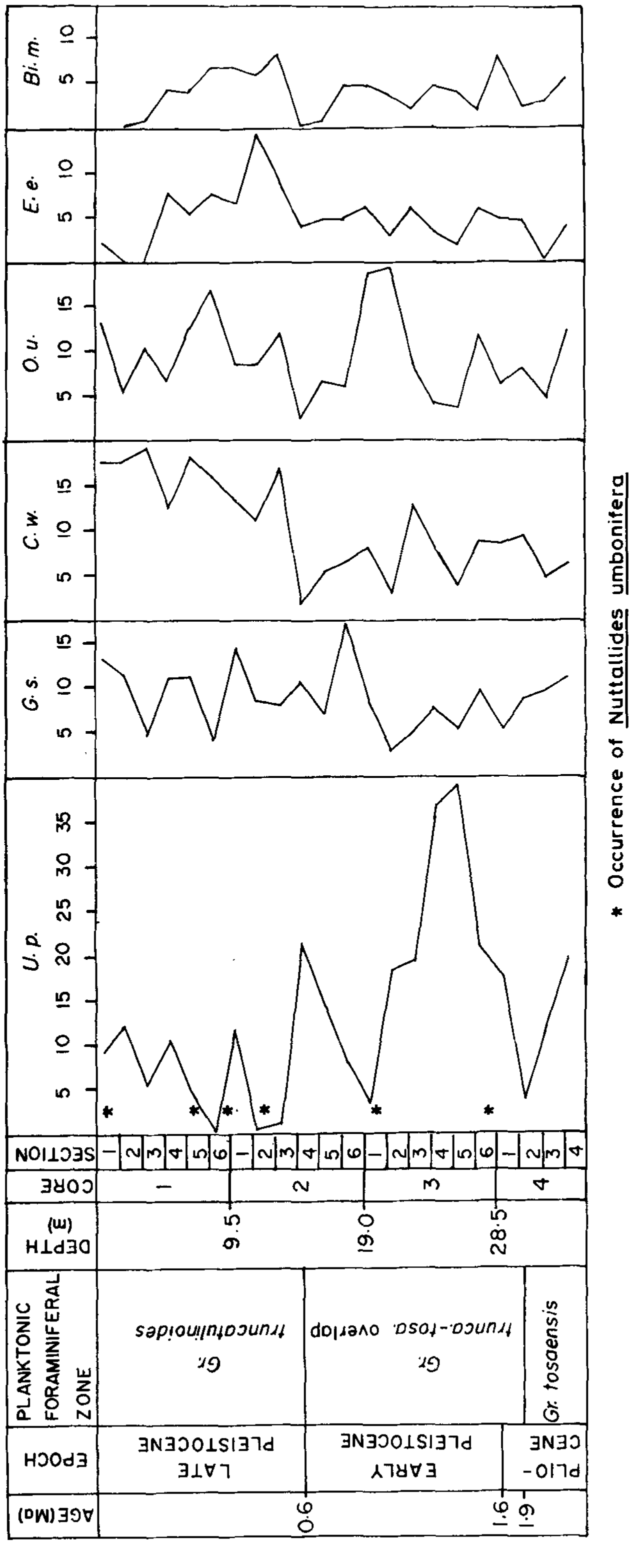

Figure 4. Percent distribution of important benthic foraminiferal species during the Pleistocene at the DSDP site 238. (*Bi. m. Biloculina murrhina*; See figure 2 for rest of caption).

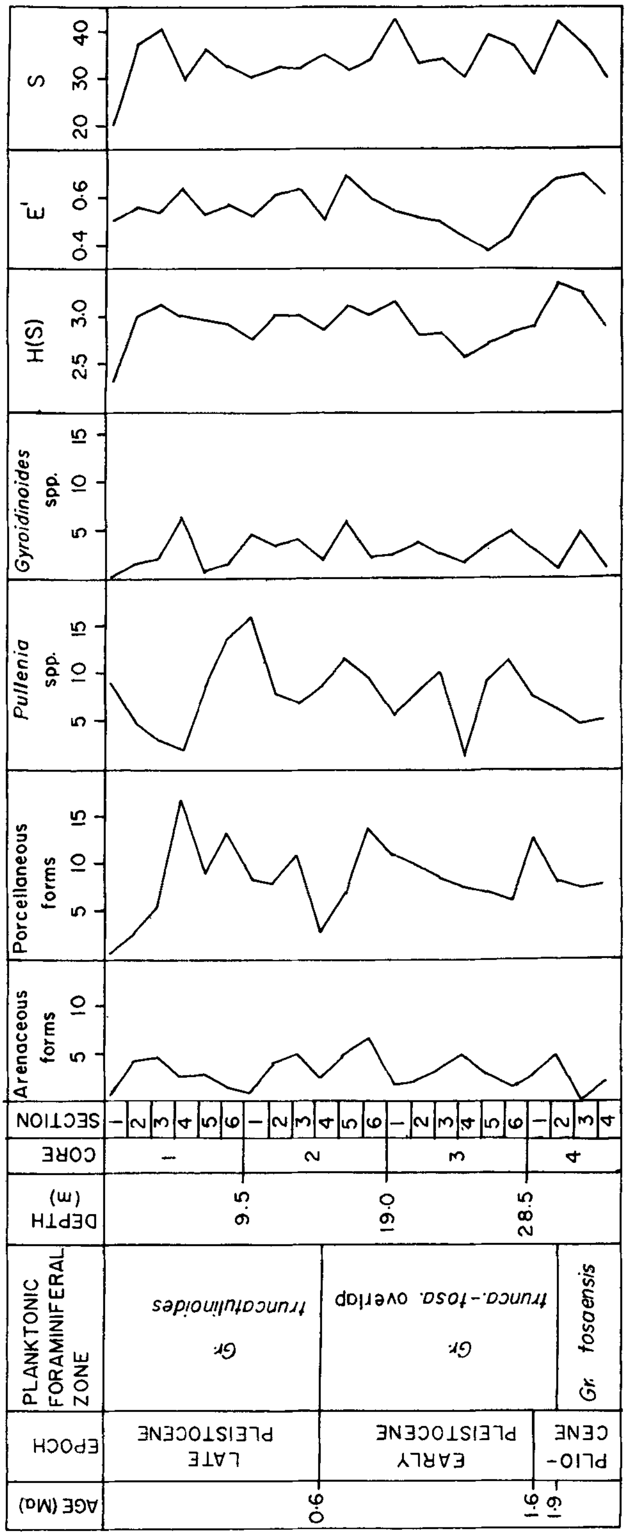

Figure 5. Percent distribution of important benthic foraminiferal groups and plots of Species Diversity, H(S); Equitability, E' and Number of Species, S during the Pleistocene at the DSDP site 238.

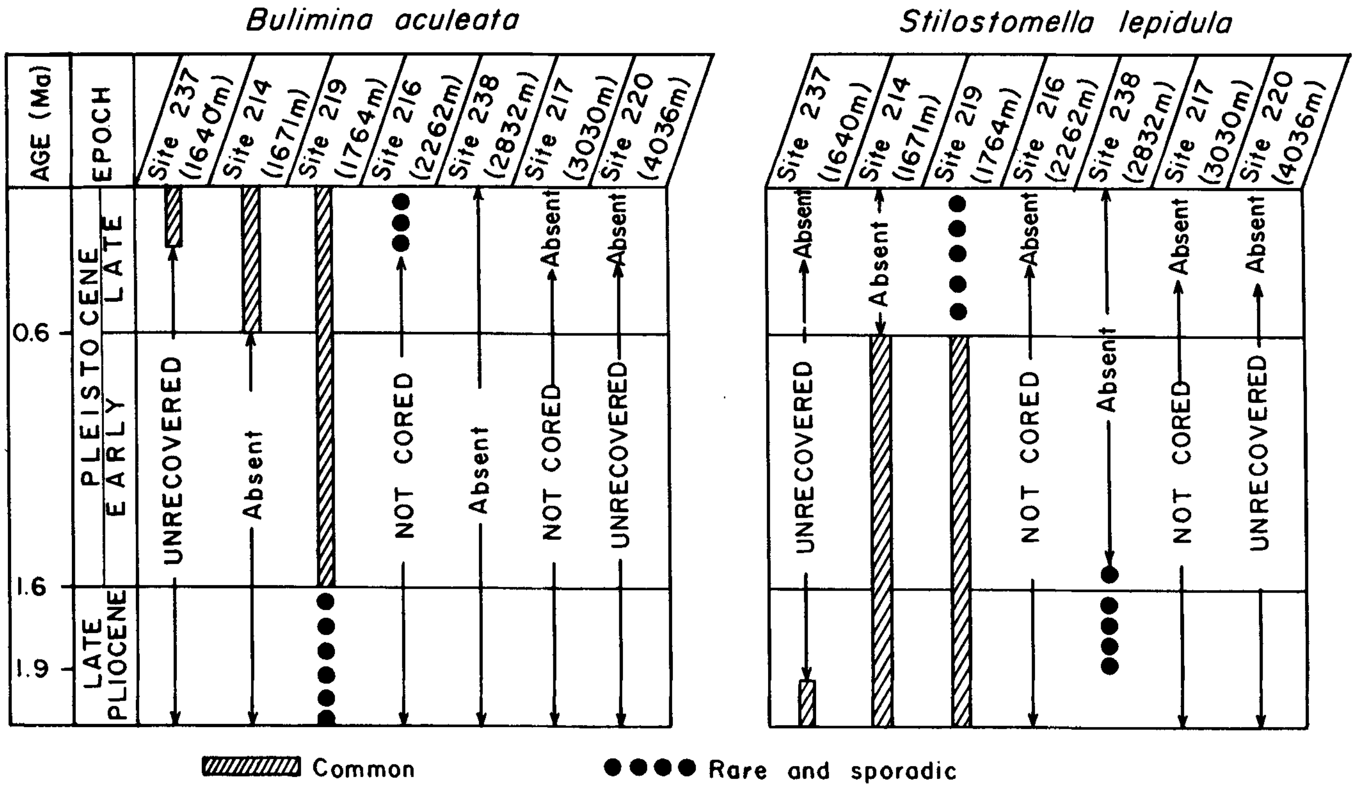

Figure 6. Distribution of *Bulimina aculeata* and *Stilostomella lepidula* during Pliocene–Pleistocene at seven DSDP sites in the Indian Ocean (Water Depth of each site is given in parenthesis) (Data of sites 214, 216 and 217 from Gupta 1987; and sites 220 and 237 from Rai 1992).

Ocean by Gupta (1994) in a water depth ranging 1500–2500 m, representing a high productivity region.

Most of the Pleistocene sequence at site 219 and Early Pleistocene at site 238 are dominated by *U. proboscidea* and *Globocassidulina subglobosa* assemblage (figures 2 and 4). Late Pleistocene in the latter site is marked by the abundance of benthic foraminiferal assemblage consisting of *C. wuellerstorfi*, *O. umbonatus*, *Epistominella exigua* and *Pullenia* spp. (mainly *P. bulloides*) (figures 4 and 5).

The most dominant species prevailing at both the sections is *U. proboscidea* which occurs in frequencies between 5 to 35% and shows remarkable changes through the Pleistocene. The earliest Pleistocene (*c.* 1·6 to *c.* 1·0 Ma) is marked by the highest relative abundance of *U. proboscidea* (> 35%) at both these sites (figures 2 and 4) which corresponds to the interval of less diverse and less equitable benthic fauna (figures 3 and 5). A distinct peak of abundance (> 25% at site 219 and > 15% at site 238) of *U. proboscidea* is also marked at about 0·4 Ma with corresponding low values of H(S) and E′ (figures 2–5). *U. proboscidea* shows declining trend during the Early/Late Pleistocene transition at both these sites (figures 2 and 4). In general, Early Pleistocene is characterized by comparatively high and changing abundance of *U. proboscidea* than the Late Pleistocene at both the examined sites (figures 2 and 4).

At site 219, *Stilostomella lepidula* abundantly occurs during the Early Pleistocene whereas Late Pleistocene is marked by rare occurrence of this taxon (figures 2 and 6). *Bulimina aculeata* occurs abundantly (commonly > 5%) during the Pleistocene at site 219 and declines suddenly at the Pliocene/Pleistocene boundary (figures 5 and 6). At site 238 *B. aculeata* and *S. lepidula* show very rare and sporadic occurrences. The relative abundances of *O. umbonatus* and *U. proboscidea* show mutually opposite trends reflecting different ecological preferences (figures 2 and 4).

6. Discussion

In the two DSDP sites studied here the assemblages are characterized by several benthic foraminiferal species. However, only a few species in the assemblages show marked changes in their abundances through time. To interpret these variations in terms of oceanographic changes we need to understand their response to the deep water characteristics.

The characteristic North Indian Deep Water (NIDW) assemblage (*U. proboscidea* and *G. subglobosa*) dominates most of the Pleistocene sequence at site 219 and the Early Pleistocene interval at site 238. Whereas, the Late Pleistocene interval at site 238 is dominated by an assemblage consisting mainly of *C. wuellerstorfi*, *Oridorsalis umbonatus*, *Epistominella exigua*, *Pullenia* spp. alongwith occasional occurrence of *Nuttallides umbonifera*. Studies reveal that *Nuttallides umbonifera* is a cosmopolitan deep water species found associated with AABW (Streeter 1973; Schnitker 1974; Anderson 1975; Bremer and Lohmann 1982; Kurihara and Kennett 1986; Gupta 1992, 1994).

Uvigerina spp. (mainly *U. proboscidea*) is the most dominant element present during the Pleistocene and changes in its relative abundance appear to be closely linked with some climatically induced paleoceanographic changes (Gupta and Srinivasan 1992a). Recently, Boyle (1990) argued that factors unrelated to the deep water properties, such as surface productivity or the depositional environment may play a significant role in controlling the distribution patterns of *Uvigerina* spp. This was supported by Gupta and Srinivasan (1992a), who pointed out that the peaks of abundance of *U. proboscidea* during the Late Neogene reflect intervals of increased upwelling leading to high surface productivity and perhaps high rates of biogenic sediment accumulation.

The Early Pleistocene interval (*c.* 1·6 to *c.* 1·0 Ma) at both the sites is marked by high relative abundance of *U. proboscidea* with corresponding low sediment accumulation. Gupta and Srinivasan (1990a, b) also recorded a similar change during the Early Pleistocene at site 214 (Ninetyeast Ridge). This reflects the high rate of surface productivity and increased winnowing of deep sea sediments due to dissolution by corrosive bottom waters during this interval. The Early Pleistocene is characterized by widespread deep sea hiatuses in global oceans (Ledbetter and Ciesielski 1986; Barker *et al* 1988). In general the presence of a hiatus reflects climatic cooling affecting the intensity of oceanic circulation (Kennett 1977; Barron and Keller 1982; Ciesielski *et al* 1982; Osborn *et al* 1983). The widespread deep sea hiatuses during the Early Pleistocene correspond to the times of enhanced Antarctic glaciation leading to low sea level stands during which an increase in AABW activity causes more erosion and dissolution of deep sea sediments (Moore *et al* 1978; Barron and Keller 1982). Keller and Barron (1987) suggested that increased polar cooling would cause high surface productivity due to upwelling and hence high rates of carbonate sedimentation. The low values of H(S) and E′ during this interval also reflect the instability in the deep sea environments. The role of species diversity in the environmental studies have been discussed by several workers. The integrated study of the species diversity pattern and stable isotopic records in the Indian Ocean revealed that the lower values of H(S) and E′ occurred during the intervals of higher $\delta\ ^{18}O$ and lower $\delta\ ^{13}C$ values reflecting global cooling and low sea level stands (Rai and Srinivasan 1992). The dominance of temperate planktonic foraminiferal assemblages in the northern Indian Ocean during the interval also reveals cooling of surface water due to climatic deterioration (Singh and Srinivasan 1993).

The low abundance of *U. proboscidea* and more diverse and equitable assemblage at both the sites during Late Pleistocene mark the onset of relative stability of the deep sea environments in the northern Indian Ocean. The intensity of deep and shallow hiatuses is low due to reduced velocity of AABW during the Late Pleistocene (Ledbetter and Ciesielski 1986). A short interval of high percent frequency of *U. proboscidea* at about 0·4 Ma represents the unstable deep sea environment of the northern Indian Ocean which corresponds to the high $\delta\ ^{18}O$ value in the North Atlantic (Shackleton and Hall 1984). This coherence in the faunal and isotopic data appears to be due to global climatic cooling leading to an increase in Northern and Southern Hemisphere ice sheets.

The quantitative benthic foraminiferal analyses at sites 219 and 238 as well as site 214 (Gupta and Srinivasan 1990a, b) reveal that in general, the Early Pleistocene was relatively cooler than the Late Pleistocene and marked by more intensified bottom water circulation. However, several short intervals of marked faunal changes represent the oscillations in the deep sea environments due to enhanced bottom water activity representing the intervals of frigid and unstable conditions. Because of the paucity of core samples at required sampling intervals it is not possible at this stage to identify various Pleistocene glacial and interglacial episodes.

The distribution pattern of *B. aculeata* during the Pleistocene at various DSDP

Table 1. Major faunal, isotopic and paleoceanographic events in the northern Indian Ocean and their relation with global climatic events (modified after Gupta and Srinivasan 1990a).

Age (Ma)	Epoch	Faunal events	Isotopic events	Paleoceanographic events	Global climatic events
		Changing abundance of cold and warm fauna		Cold/warm cycles	Major glacial/interglacial episodes
	Late Pleistocene	Less diverse benthic assemblage increase in *U. proboscidea*	$\delta^{18}O$ increase	Distinct bottom water cooling	Increase in polar ice sheets.
		Increase in benthic foraminiferal diversity and – low abundance of *U. proboscidea*		Stable and warm bottom water	Low intensity of shallow and deep sea hiatuses.
0·6		Abrupt decline in *S. lepidula*			
	Early Pleistocene	Major increase in *U. proboscidea* abundance	$\delta^{18}O$ increase	Significant bottom water cooling, increased	Enhanced glaciation, sea level low stands and
		and lowest diversity of benthic foraminifera	$\delta^{13}C$ decrease	upwelling and high organic carbon flux	widespread deep sea hiatuses
1·6		Sudden increase in *B. aculeata*			

sites in the Indian Ocean reveals that it does not occur at water depths greater than 2300 m (figure 6). In other areas also the lower depth range for the occurrence of *B. aculeata* is around 2300 m (Kaiho and Nishimura 1992) suggesting that the distribution of this species is mainly controlled by the water depth. It is interesting to note that *B. aculeata* shows sudden increase in abundance close to Pliocene/Pleistocene boundary while abrupt decline in relative abundance of *S. lepidula* occurs near Early/Late Pleistocene boundary (*c.* 0·6 Ma).

7. Conclusions

A detailed quantitative study of the Pleistocene benthic foraminifera at the DSDP sites 219 and 238 as well as available data from site 214 (Gupta and Srinivasan 1990a, b) in the northern Indian Ocean has led to the following inferences (table 1).

1. The dominance of *U. proboscidea* and *G. subglobosa* assemblage during most of the Pleistocene at site 219 and beginning of the Pleistocene at site 238 suggests the influence of North Indian Deep Water (NIDW). However, during the later part of Pleistocene the nature of watermass at site 238 appears to be intermediate between NIDW and AABW as evidenced by the dominance of *C. wuellerstorfi, O. umbonatus, E. exigua* and *Pullenia* spp. assemblage along with occasional occurrences of *Nuttallides umbonifera.*
2. The peaks of abundance of *U. proboscidea* along with low values of H(S) and E′ at both the sites during *c.* 1·6 to *c.* 1·0 Ma (Early Pleistocene) and at *c.* 0·4 Ma (Late Pleistocene) reflects marked cooling, intensified oceanic circulation and upwelling of the nutrient rich bottom waters giving rise to high surface productivity.
3. In general, the northern Indian Ocean bottom waters were relatively cooler during the Early Pleistocene than the Late Pleistocene as evidenced by the high abundance of *U. proboscidea* along with less diverse and equitable benthic fauna. The high dissolution due to cold and corrosive bottom waters during the Early Pleistocene possibly resulted into the low sediment accumulation.
4. The modern distribution pattern of *B. aculeata* in the Indian Ocean DSDP sites reveals that the lower depth range for this taxon is about 2300 m.

Acknowledgements

The Deep Sea Drilling Project (DSDP) is thankfully acknowledged for providing the core samples. This research was supported by the grant of SAP (UGC) to the Department of Geology, Banaras Hindu University, Varanasi.

Appendix 1. Benthic foraminifera recorded from the examined sites.

Benthic foraminifera	Found in DSDP sites
Textularia halkyardi Lalicker	219, 238
T. lythostrota (Schwager)	219, 238
T. porrecta (Brady)	238
Siphotextularia rolshauseni Phleger and Parker	219, 238
S. solita (Schwager)	219, 238
Gaudryina solida Schwager	219
Dorothia brevis Cushman and Stainforth	219
Eggerella bradyi (Cushman)	219, 238
Karreriella baccata (Schwager)	219
K. bradyi (Cushman)	219, 238
K. subrotundata (Schwager)	219, 238
Martinottiella communis (d'Orbigny)	219, 238
Spiroloculina antillarum d'Orbigny	219
Quinqueloculina cf. *pygmaea* Reuss	219, 238
Q. seminulum Linne'	219
Q. venusta Karrer	219, 238
Q. weaveri Rau	219, 238
Pyrgo depressa (d'Orbigny)	219, 238
Biloculina comata Brady	219
B. lucernula Schwager	219, 238
B. murrhina Schwager	219, 238
Triloculina tricarinata d'Orbigny	219, 238
Nummoloculina irregularis (d'Orbigny)	219
Sigmoilopsis asperula (Karrer)	219
S. schlumbergeri (Silvestri)	219, 238
Nodosaria aff. *lamnulifera* Boomgart	219
N. raphanus Schwager	219
N. spirostriolata Cushman	219
Astacolus crepidulus (Fichtel and Moll)	219, 238
A. increscens (Reuss)	219
A. insolitus (Schwager)	238
A. reniformis (d'Orbigny)	238
Chrysalgonium equisetiformis (Schwager)	219, 238
Dentalina costai (Schwager)	219, 238
D. intertenuata (Schwager)	219
D. intorta (Dervieux)	238
D. neugeboreni (Schwager)	219, 238
D. stimulea (Schwager)	219, 238
D. subsoluta (Cushman)	219, 238
Lagena spp.	219, 238
Robulus aff. *gibbus* (d'Orbigny)	219, 238
R. nicobarensis (Schwager)	219
Marginulina obesa Cushman	219, 238

Appendix 1. *Continued*

Benthic foraminifera	Found in DSDP sites
Orthomorphina aff. *antillea* (Cushman)	238
O. challengeriana (Thalmann)	219
O. koina (Schwager)	219
O. modesta (Bermudez)	219
O. perversa (Schwager)	219, 238
Guttulina austriaca d'Orbigny	219
Pyrulina cylindroides (Roemer)	219, 238
P. extensa (Cushman)	219, 238
P. fistulosa (Thalmann)	219, 238
P. labiata Schwager	219, 238
Fissurina spp.	219, 238
Oolina spp.	219, 238
Ceratobulimina pacifica Cushman and Harris	219
Hoeglundina elegans (d'Orbigny)	219
Buliminella andamanica (Srinivasan and Singh)	219
Sphaeroidina bulloides d'Orbigny	219, 238
Bolivinita pseudoplicata (Heron-Allen and Earland)	219, 238
Bolivina pseudopunctata Hoeglund	219, 238
Brizalina pusilla (Schwager)	219
Favocassidulina australis Eade	219, 238
F. decorata (Sidebottom)	238
F. favus (Brady)	219, 238
Stilostomella consobrina (d'Orbigny)	219
S. fistuca (Schwager)	219
S. insecta (Schwager)	219, 238
S. lepidula (Schwager)	219, 238
Bulimina aculeata d'Orbigny	219, 238
B. alazanensis Cushman	219, 238
B. jarvisi Cushman and Parker	238
B. striata d'Orbigny	219
B. subacuminata Cushman and Stewart	219
Protoglobobulimina affinis (d'Orbigny)	238
P. pacifica Cushman	219
Praeglobobulimina spinescens (Brady)	219
Uvigerina hispida (Schwager)	219, 238
U. cf. *longa* (Cushman and Bermudez)	238
U. peregrina (Cushman)	219, 238
U. porrecta (Brady)	219
U. proboscidea (Schwager)	219
U. schencki (Asano)	219
Noviuva interrupta-costata (LeRoy)	219, 238
Rectuvigerina royoi Bermudez and Fuenmayor	219
Discorbis subvilardeboanus (Rhezak)	219, 238

Appendix 1. *Continued*

Benthic foraminifera	Found in DSDP sites
Discopulvinulina bertheloti (d'Orbigny)	219, 238
Epistominella exigua (Brady)	219, 238
Gavelinopsis lobatulus (Parr)	219
Laticarinina pauperata (Parker and Jones)	219, 238
Planulina ariminensis d'Orbigny	238
Heronallenella boltovskoyi Gupta and Sen Gupta	219, 238
Nuttallides umbonifera (Cushman)	219, 238
Cibicides bengalensis Srinivasan and Sharma	219, 238
C. bradyi (Trauth)	219, 238
C. cicatricosus (Schwager)	219
C. kullenbergi Parker	219, 238
C. lucidus (Reuss)	219
C. robertsonianus (Brady)	219, 238
C. aff. *soendaensis* Le Roy	219
C. telisaensis Le Roy	219, 238
C. wuellerstorfi (Schwager)	219, 238
Pleurostomella acuminata Cushman	238
P. alternans Schwager	219, 238
P. bolivinoides Schubert	238
P. brevis Schwager	219, 238
P. obtusa Berthelin	219, 238
P. sapperi Schubert	219
Ellipsoidella sp.	219
Fursenkoina bradyi (Cushman)	219
F. bramletti (Galloway and Morrey)	219
F. schreibersiana (Czjzek)	238
F. texturata (Brady)	219, 238
Francesita advena (Cushman)	219, 238
Cassidulina carinata (Silvestri)	219, 238
C. laevigata d'Orbigny	219, 238
Ehrenbergina carinata Eade	219, 238
E. praebicornis n. sp.	219, 238
Evolovocassidulina bradyi Norman	219, 238
E. seranensis Germeraad	219
Globocassidulina elegans (Sidebottom)	219, 238
G. oblonga (Reuss)	219, 238
G. murrhina (Schwager)	219
G. subglobosa (Brady)	219, 238
G. tumida (Heron-Allen and Earland)	219, 238
Chilostomella oolina Schwager	219, 238
Allomorphina pacifica Hofker	219, 238
Quadrimorphina laevigata (Phleger and Parker)	219, 238
Astrononion stelligerum (d'Orbigny)	219, 238

Appendix 1. *Continued*

Benthic foraminifera	Found in DSDP sites
A. umbilicatulum Uchio	219, 238
Nonionella auris (d'Orbigny)	219, 238
N. clavata Cushman	219
N. japonicum (Asano)	219, 238
Pullenia bulloides (d'Orbigny)	219, 238
P. osloensis Feyling-Hanssen	219, 238
P. quadriloba Reuss	219, 238
P. quinqueloba (Reuss)	219, 238
P. salisburyi Stewart and Stewart	219, 238
Oridorsalis prominula (Stache)	219, 238
O. umbonatus (Reuss)	219, 238
Osangularia culter (Parker and Jones)	219, 238
Gyroidinoides broeckhianus (Karrer)	219, 238
G. cibaoensis (Bermudez)	219, 238
G. nitidula (Schwager)	219, 238
G. polius (Phleger and Parker)	219, 238
Anomalina globulosa Chapman and Parr	219, 238
Anomalinoides glabratus (Cushman)	219
Melonis barleeanum (Williamson)	219, 238
M. nicobarensis (Cushman)	219, 238
M. pompilioides (Fichtel and Moll)	219, 238

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