

STUDY OF SUB-SURFACE SEDIMENTS FROM NORTHERN INDIAN OCEAN : OCEANIC RESPONSES TO CLIMATIC CHANGES

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ABSTRACT

The mean diameter and variation in isotopic composition ($\delta^{18}O$) in tests of *Orbulina universa* d'Orbigny have been measured in a sediment core collected from 3869 m water depth near the Carlsberg Ridge, northern Indian Ocean. It has been found that changes in test's mean diameter precede isotopic responses by about 1000 years in the samples from this core. The distribution of illite and smectite suggests that fresh water discharge from the River Indus, due to ice melting in the Himalayan region, played a more important role in reducing salinity than did melting ice in the Antarctic region or the intrusion of low salinity water from the Bay of Bengal.

INTRODUCTION

Records of past climates preserved as proxy climatic indicators in sub-surface marine sediments have been examined with the objectives of understanding physical, chemical and biological mechanisms affecting the environment and complex interactions among internal and external factors which generate climatic changes. These studies should also give a better perception of the processes by which climatic changes are amplified through response in the Earth's atmosphere-ocean-ice system.

Various authors, e.g. McIntyre *et al.* (1972); Shackleton and Opdyke (1973); Berger (1973); Thompson and Saito (1974) have noted changes in the surface water circulation, in continental ice volume as recorded by oxygen isotope studies of foraminiferal tests, and in the corrosiveness of near bottom water to calcium carbonate. However, few attempts have been made to establish whether the various changes are synchronous or whether there are lags among them. (Luz and Shackleton, 1975). Moore *et al.* (1977), using cross-correlations, found that in tropical Pacific cores, changes in global ice volume preceded local temperature changes by about 4000 years. No such phase shift was found in the North Pacific. Pisias *et al.* (1975) studied a core from eastern equatorial Pacific and concluded "For the last three glacial maxima, the carbonate peak precedes the isotopic (ice volume) peak by about 5600 years." From the temperate southern Indian Ocean region, Hays *et al.* (1976) suggested a 1500 year's lag of $\delta^{18}O$ with respect to palaeotemperature for the last 300,000 years. Since such information is critical in evaluating theories and models of climatic change, and to distinguish between cause and effect, the authors undertook the study of a core from the northern Indian Ocean:

The objectives of the present study are (i) to determine whether changes in the mean test size of *Orbulina universa* in core SK 12/1 could reflect temperature changes in the surface water, and (ii) to determine if lag/lead relationships exist between faunal responses and isotopic changes as observed in same species, (iii) to explain the possible causes for differential responses (if any).

CONCEPTUAL FRAME WORK

The planktic foraminifer *O. universa* d'Orbigny is a common and widely studied species in all the oceans. Be' *et al.* (1973) and Hecht *et al.* (1976) studied the variation in diameter of the spherical test (external shell) of this species in surface sediment samples from the Indian ocean and found that a direct correlation can be demonstrated between mean test diameter of *O. universa* and surface water temperature. Haenel (1987) re-analysed the data of Be' *et al.* (1973) statistically, and showed that the mean diameter of this species is (i) directly proportional to temperature ($r = -0.90$) and (ii) inversely proportional to salinity ($r = -0.46$). Since this species has a short life span of 9 to 15 days (Caron *et al.*, 1987), and settling time for planktic tests to bottom (in laboratory conditions) is approximately 400 m/day (Takahashi and Be', 1984), the diameter of tests of this species preserved in these sediments may be expected to reflect the regional sea-surface temperature prevailing at that time. One such study for this area has already been made by Nigam (1990).

Although isotopic ($\delta^{18}O$) analysis of the test of *O. universa* should reveal the isotopic composition of sea-surface water, Shackleton (1967) showed that isotopic changes in foraminiferal tests are not entirely caused by temperature changes but also by changing volume of terrestrial ice. Therefore, during a warm

period an introduction of isotopically light melt water due to melting of continental ice is to be expected. A time lag may exist between changes in temperature and isotopic composition. This lag (if any) should be detectable by comparing time equivalent morphometric parameters (e.g. the test diameters of species such as *O. universa*) with the isotopic compositions of the same species.

MATERIALS AND METHODS

During the 12th cruise of *ORV Sagar Kanya* in the Arabian Sea, one 5 m long box core (SK 12/1) was collected from the eastern flank of the Carlsberg Ridge at a water depth of 3869 m (fig. 1). The core has been sub-sampled at 5 cm interval downwards up to 1 m. All samples were washed through a 125 μ m mesh sieve and tests of *O. universa* were picked from the +125 μ m fraction. A total of 1115 specimens (minimum 10 at 68-70 cm; maximum 148 at 90-95 cm levels in core) from the 20 samples were used to calculate the mean size of the tests. Stable isotope measurements were also made on *O. universa*. The stable isotopic measurements were carried out on a Finnigan MAT 251 mass spectrometer in conjunction with an automatic carbonate preparation device following the standard techniques (Hubberton and Meyer, 1989), with an overall precision of <0.09 per mil. The $\delta^{18}\text{O}$ values are reported relative to VPDB (Versus Pee Dee Belemnite). The percentage of clay minerals were determined by the weighted peak area method of Biscaye (1965).

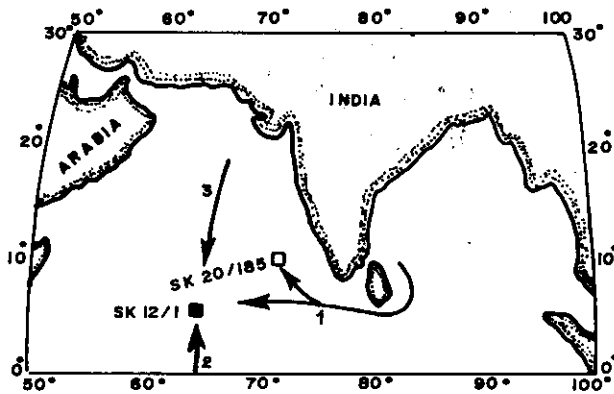


Fig. 1. Map of Northern Indian Ocean showing the core locations. Core SK 12/1, Core SK 20/185 of Sarkar *et al.* (1990) referred to in the text. Arrows show low salinity water from 1) Bay of Bengal due to northeast monsoons, 2) Antarctica due to melting of ice and 3) Indus due to melting of ice on the Himalayas.

To obtain the time standard, we have compared our results with another core from a nearby area (10°N , $71^{\circ}50'$ E, 2523 m water depth, core no. SK

20/185, fig. 1) for which ^{18}O variations of *O. universa* and ^{14}C dating are available (Sarker *et al.* 1990). It was observed in core SK 20/185 that after negative values of ^{18}O corresponding to intrusion of low salinity water from the Bay of Bengal to the Arabian Sea, caused by the winter monsoon during the last Glacial Maxima, there is a short positive excursion. The highest positive value of $\delta^{18}\text{O}$ was observed at 26 cm depth in the core which as per ^{14}C dating profile shows a time of 16,000 years B.P. Our core (SK/1) shows a similar pattern i.e. after negative values of $\delta^{18}\text{O}$ at the bottom of the core (fig. 2) there is a short positive excursion with a maxima at about 80 cm depth. By comparison one can estimate that 80 cm sediment in core SK 12/1 was deposited during last 16,000 years. Assuming uniform sedimentation, an accumulation rate of 5 cm/1000 years is inferred for this core. This inference is in agreement with the rate of sedimentation estimated by Nigam (1990), who has placed the Pleistocene/Holocene boundary (11,000 year B.P.) at 50 cm depth in the same core by using variation in the total number of planktic foraminifera and the abundance of *O. universa*.

RESULTS AND DISCUSSIONS

Figure 2a shows the down-core variation (0.47 to 0.63 mm) in the mean diameter of *O. universa*. However, the minimum diameter was 0.23 mm (at core depth 75-80 cm) and maximum diameter 1.19 mm (at core depth 20-25 cm). The mean diameter curve shows peaks at 10, 25, 40, 60 and 75 cm. As discussed earlier, since the mean diameter of *O. universa* is believed to be directly proportional to temperature, the peaks of the curve are considered as warm

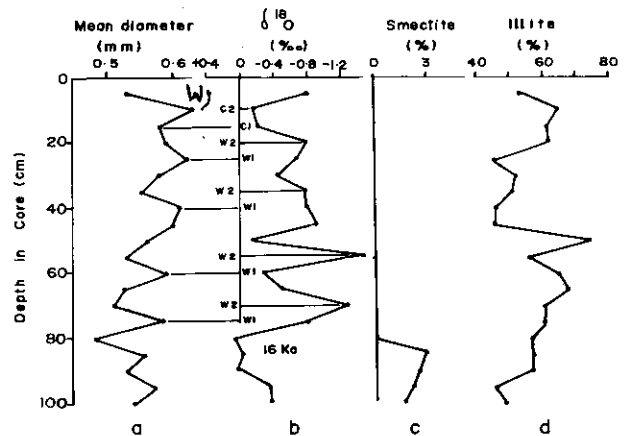


Fig. 2. Down-core variations in (a) Mean diameter of *Orbulina universa* (b) $\delta^{18}\text{O}$ (per mil.) of *Orbulina universa* (c) Percentage of smectite and (d) Percentage of illite. For symbols W1, W2, C1 and C2, see the section of Results and Discussions.

(marked as W1) and the troughs as cold (marked as C1) periods.

Figure 2b shows the down-core variation in $\delta^{18}\text{O}$ of *O. universa*. The values vary from -1.29 to 0.13 per mil. Since decreases in $\delta^{18}\text{O}$ values indicate warm periods, they are marked W2, and positive peaks (troughs in curve) are marked C2 indicating relatively cooler periods.

A comparison of events (warm and cold) in both the curves (fig. 2, columns a and b) shows that the peak of diameter curve of *O. universa* precedes corresponding peak of the isotopic curve by some 5 cm. This represents ~1000 years based on the accumulation rate noted earlier in previous section.

In view of the above, it may be concluded that changes in test morphology (mainly caused by temperature) are followed 1000 years later by changes in the isotopic composition of shells caused mainly by reduction in salinity. This lag may reflect the time required to melt the continental ice during warm episodes and to affect isotopic composition of shells in the Carlsberg Ridge area.

There seem to be three possible sources of isotopically light water in the Carlsberg Ridge area. (1) melting ice in Antarctica, (2) water transferred from Bay of Bengal by the north-east monsoon; (3) water from melting ice over the Himalayan region (Khule, 1987) brought down by the Indus river.

Sarkar *et al.* (1990) provided evidence for the transport of low salinity water from the Bay of Bengal to a site relatively very close to ours (fig. 1) and postulated that winter monsoon was intense during the Last Glacial Maxima (LGM). To check the possibility that a low salinity intrusion from the Bay of Bengal continued even after the LGM, we have studied the clay mineralogy of the sediments. A number of workers have studied the mineralogy and origin of clays in the Bay of Bengal and the Arabian Sea (Kolla and Biscaye, 1973; Kolla *et al.*, 1981; Bhaskaran and Somayajulu, 1986; Sarin *et al.*, 1989). These studies established that the southwestern part of the Ganges cone, i.e. coastal areas of eastern Indian is characterised by smectite-rich sediments derived from Traps. However, the Arabian Sea shows a dominance of illite, which is principally generated by the weathering of granite, and brought down by the Indus river. Therefore, if low salinity water is considered as an agency transporting the sediments to the core site, smectite should be the dominant clay mineral. But, in our core, illite is dominant (fig. 2,

column d and smectite shows its presence only between 85 to 100 cm depth in core with a maximum value of 3% (fig. 2, column C). Therefore, it is possible that during the LGM low salinity water brought by the north-east monsoons might have played a dominant role (Sarker *et al.*, 1990) but its effect then declined rapidly.

Since Antarctica is far distant from the Carlsberg Ridge area and Hays *et al.* (1976) have observed a 1500 years lag of $\delta^{18}\text{O}$ changes and records of palaeotemperatures in the temperate southern Indian Ocean through the last 300,000 years, it is obvious that this lag should increase towards the north if same conditions prevailed in the two areas. We have, however, found evidence for a reduced lag i.e. 1000 years. Therefore, in view of the clay mineral distributions in the core and the relative proximity of the core site to the mouth of the Indus, it is suggested that melting water from the Himalayan region discharged by this river could have played the dominant role in reducing $\delta^{18}\text{O}$ levels. This suggestion indirectly draws support from the study of snow line depression over Tibet during last Ice age by Gupta and Sharma (1992) who concluded "...a fairly extensive but thin Ice sheet over the Plateau that would be sensitive to small, short duration (~1000 years) regional temperature fluctuations".

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