

Fluctuation in Glacial & Interglacial Sediment Discharge of the River Indus as Seen in a Core from the Arabian Sea

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Sediment core from the upper continental slope off Saurashtra coast has been analysed for CaCO_3 and coarse fraction contents in addition to planktonic foraminifera and clay mineralogy. Based on CaCO_3 and planktonic foraminiferal data a boundary between glacial and interglacial is placed at 42 cm assuming the sedimentation rate as $4 \text{ cm } 1000 \text{ y}^{-1}$. Distribution of CaCO_3 clearly shows the sharp change in its abundance at the 42 cm boundary. Among planktonic foraminifera, *Globigerinoides sacculifer* and *G. ruber* are by far the most abundant. Variation in the planktonic foraminiferal fauna is not as sharp as CaCO_3 , because of the insignificant change in the temperature during glacial and interglacial periods of late Pleistocene. Some species of *Orbulina*, viz. *Orbulina bilobata* and *O. suturalis* are encountered and believed to be reworked ones. Distribution of clay minerals such as kaolinite, illite and chlorite along with quartz shows an increasing trend towards the bottom of the core in the glacial period. This may reflect the fluctuation in the sediment discharge from the river Indus, whereas, in the interglacial period this is not encountered and may be attributed to the existence of dynamic barrier in Holocene.

The single largest source of sediment for the Arabian Sea is the river Indus. It discharges at present about 450 million tons of sediment annually which results over the course of time, in the formation of Indus cone with as much as 2500 m of unconsolidated sediment at its proximal end¹. The present day pattern of the sediment discharge has however certain unusual features. It has been found from the sedimentological studies of the Gulf of Kutch, a macrotidal bay, that the high velocity tidal currents at the Gulf mouth act as a dynamic barrier to the transport of the Indus borne sediment across the Gulf mouth to the continental shelf and slope of the Saurashtra peninsula² (Fig.1). In other words, had it not been for the presence of tidal barrier, the continental shelf off the Saurashtra coast would have been covered by modern muds whereas relict calcareous sands are present on the outer shelf. A mineralogical aspect of the Indus sediment that is relevant here is the presence of chlorite in the sediments deposited in the Gulf and on the shelf north of the Gulf mouth. Chlorite³ is a mineral more common in sediments of northern latitude seas and in the present instance results from the fact that the Indus drains the high altitude regions of the Himalayas. Thus, chlorite being Indus specific in the Arabian Sea the possibility arises that the abundance of chlorite in the sediments can be used as an index of the variation of the past sediment input of the Indus to a first approximation in addition to the gross input of other clastic terrigenous components.

The phenomenon of the dynamic barrier and the presence of chlorite provide a method for determining although only qualitatively the variation in the nature

of sediment discharged by the Indus during glacial and interglacial times and in this study an attempt has been made in this direction by examining a core sample from the upper continental slope south of the Gulf of Kutch (Fig.1).

Materials and Methods

During the 98 cruise of *R V Gaveshani* in the northeastern Arabian Sea a sediment core (length 74 cm) was obtained from a water depth of 670 m on the continental slope at lat. $20^{\circ}30'N$ and long. $60^{\circ}19'E$ (Fig.1). In general, the core was mainly composed of fine clay/pteropod foraminifera ooze. The colour of the sediment (Fig.2) in the top 12 cm was pale greenish yellow (10Y 8/2), pale olive (10Y 6/2) further down and from 32-74 cm grayish olive (10Y 4/2).

The core was sub-sampled at intervals of 5 cm at the upper region and 10 cm at the middle and the lower regions. The sub-samples were dried in an oven maintained at $70^{\circ}C$ and later dispersed in distilled water and washed through a 230 mesh ($63 \mu\text{m}$) sieve to determine the coarse fraction ($> 63 \mu\text{m}$) content. Later this coarse fraction was sieved through a 100 mesh ($149 \mu\text{m}$) sieve and the $+149 \mu\text{m}$ fraction was scanned under stereo-binocular microscope for planktonic foraminiferal content and 30-300 tests were counted depending on the population of foraminifera in each sample. Grouping of foraminiferal assemblages was done following Be and Tolderlund⁴. CaCO_3 in the sediments was estimated by the titration method using EDTA⁵.

Air dried oriented samples of $2 \mu\text{m}$ fraction were prepared by pipetting on glass slides. The slides were

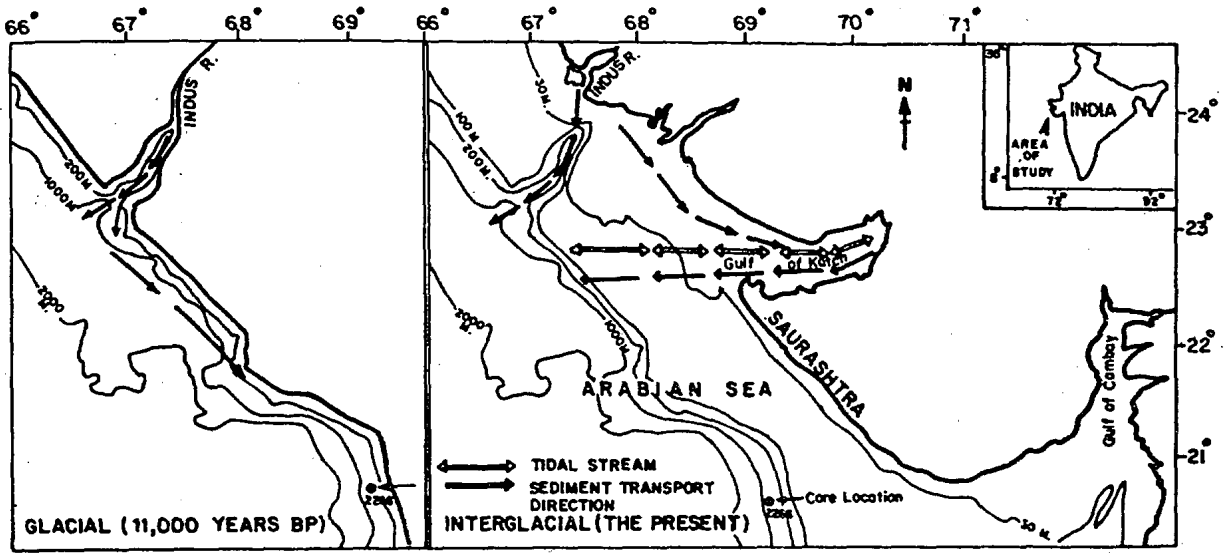


Fig. 1—Core location and inferred sediment transport direction during the Interglacial period (The Present) and Glacial (11,000 years B.P.) coastline and the inferred sediment transport direction

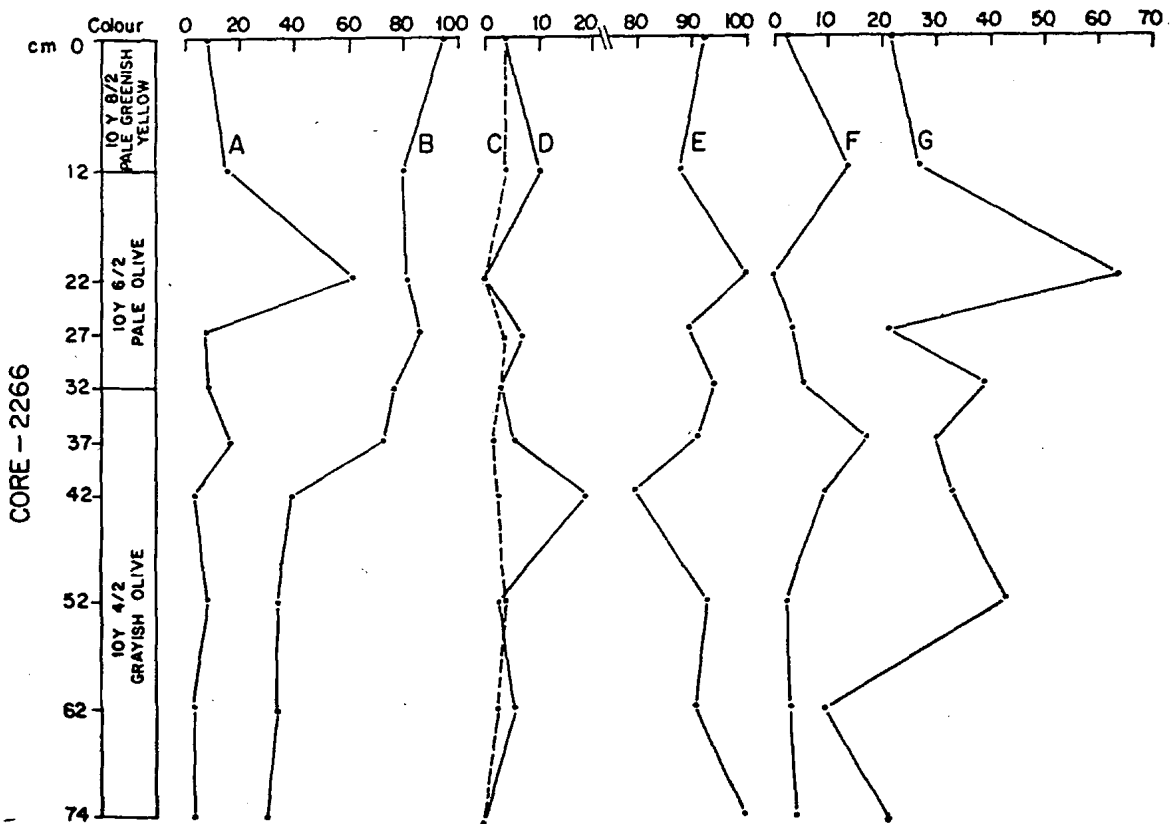


Fig. 2—Down core variation (in %) of (A) Coarse fraction, (B) Calcium carbonate, (C) Polar planktonic foraminifera, (D) Sub-polar planktonic foraminifera, (E) Tropical planktonic foraminifera, (F) *Globigerina bulloides* and (g) *Globigerinoides sacculifer*

scanned from 4-30° 2θ at 2° min⁻¹ on a Philips X-ray diffractometer using Ni filter Cu Kα radiation, proportional counter and pulse height analyser. The relative proportion of the clay minerals were determined by measuring the peak height.

Results and Discussion

Although the coarse fraction content shows a solitary high of 63% (Fig.2), it exclusively comprises pteropod foraminifera ooze and there is hardly any terrigenous input to the sediment. From the top to 74 cm the coarse fraction (10-15%) is biogenic, a product of warm water conditions during the interglacial periods. Ruddiman and Mc Intyre⁶ based on the study of northeast Atlantic deep sea cores have concluded that the biogenous input is greatest during the interglacial climate, while the terrigenous input is greatest during the glacial periods.

Calcium carbonate content—CaCO₃ in the core ranges from 93% in the top region to 33% in the bottom region. From top to a depth of 37 cm down core it progressively decreases from 93 to 73% and further down from 42 cm it diminishes to as low as 33%. The clastic fraction decreases from top to 22 cm and further down it increases towards the bottom of the core.

Arrhenius⁷ suggests that the variation in CaCO₃ in down core is directly responsible to the change in climate. Subsequent workers have been treating the variation in CaCO₃ as a function of fluctuation in Quaternary climate. The bundance of CaCO₃ is attributed to the high productivity in the interglacial periods. Thus, there exists a close correspondence between the fauna and CaCO₃ (Fig.2).

Clay mineralogy—The clay minerals present in the core are kaolinite, illite, chlorite along with quartz. There exists a distinct increase in abundance of these minerals from top to bottom. Peak heights for example at the 3 intervals (32-37; 37-42; and 62-72 cm) for illite, chlorite and quartz are shown in Fig. 3.

Planktonic foraminifera—Although the planktonic foraminiferal population is poor, it shows good diversity representing 28 species. In view of the fact that the core under investigation was obtained from a tropical region, the mid and high latitude species of planktonic foraminifera constitute a minor element.

In the present instance, the cold water assemblage is composed of only 5 species (*Globoquadrina pachyderma*, *Globigerina bulloides*, *G. quinqueloba*, *Globorotalia inflata* and *G. truncatulinoides*) where as warm water group is represented by 23 species (*Globigerinoides sacculifer*, *G. ruber*, *G. tenellus*, *G. conglobans*, *Globigerinella aequilateralis*, *Globigerina*

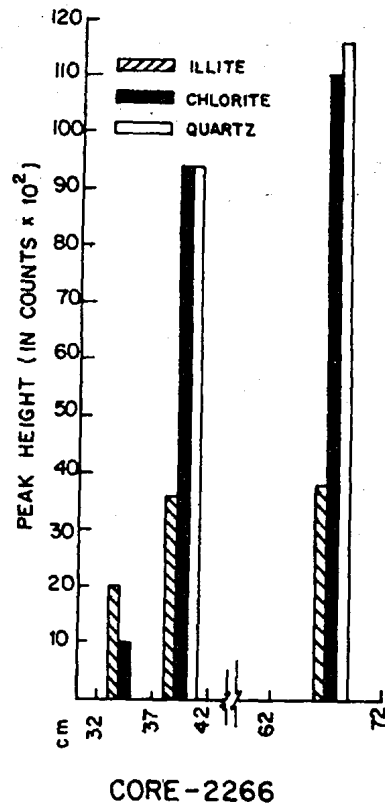


Fig. 3—Down core variation of illite, chlorite and quartz (Note the abrupt increase of all components at 42 cm)

calida, *G. falconensis*, *G. digitata*, *G. rubescens*, *G. hexagona*, *Globoquadrina dutertrei*, *G. conglomerata*, *Orbulina universa*, *O. suturalis*, *O. bilobata*, *Sphaeroidinella dehiscens*, *Pulleniatina obliquiloculata*, *Globigerinita humilis*, *G. glutinata*, *Globorotalia menardii*, *G. tumida*, *Candeina nitida*, *Globorotalia crassaformis*) of which the surface dwelling *Globigerinoides sacculifer* and *G. ruber* are by far the most abundant.

The lone polar species *Globoquadrina pachyderma* (dextral) is present in very insignificant proportion along with the other cold water species like *Globigerina bulloides*, *G. quinqueloba*, *Globorotalia inflata* and *G. truncatulinoides*.

Globigerinoides sacculifer is widely distributed and is the most abundant species (9.4 to 63.6%) followed by *G. ruber* (2.4 to 41%) in both the glacial and interglacial periods (Fig.2). Be et al.⁸ have also reported the persistent abundance of *G. sacculifer* and *G. ruber* during the glacial and interglacial periods in the equatorial Atlantic and attributed it to the relatively slight environmental contrast (0.1 to 3.6°C) between glacial and interglacial epochs. Although *Globorotalis menardii* is an excellent indicator of tropical marine

environment, it is very scarce and may be attributed to upwelling in the study area⁹. The remaining cold and warm water species are represented in smaller quantities.

One of the striking features noticed in the fauna is the occurrence of *Orbulina suturalis* and *O. bilobata* in addition to the commonly occurring species *O. universa*. The former 2 species are most uncommon in the Quaternary sediment of the Arabian Sea. However, *O. bilobata* has been reported as *Biorbulina bilobata* in traces from the slope region off Bombay¹⁰. All the *Orbulina* spp show stratigraphic distribution from the base of the *Globorotalia peripherorunda* Zone (Middle Miocene) to Recent.

According to Blow¹¹, *O. suturalis* probably became extinct in late Miocene or Basal Pliocene. While *O. bilobata* continued till recent, it never became abundant as *O. universa*. Therefore, it is presumed that these species may be derived from the outcrops of Mio-Pliocene beds off Saurashtra coast of the Indus drainage basin.

Apart from the planktonic foraminifera, pteropods are quite common throughout the core. Pteropods usually found only on shallow parts of submarine banks, rises, seamounts, marginal seas on the submerged slopes, oceanic islands and occasionally on continental slopes where terrigenous and benthic biogenic production is limited¹². According to Chen¹³ pteropods are most abundant in the cold glacial periods and are less abundant or absent in warm periods. Although the pteropod outnumber the foraminifera, it has been observed that the ratio between foraminifera and pteropod is less in the lower parts of the core under investigation. It is possible that these components may have been transported and deposited by currents from the carbonate dissolution minimum zone where the aragonite tests are preserved. Bein and Futterer¹⁴ are of the opinion that the maxima in pteropods content can be explained by lateral supply of particle by particle transport.

Age of sediment—According to Heye¹⁵ the sedimentation rates in the middle of the Arabian Sea is about 0.32 cm. 1000 y⁻¹ and on the continental slopes off Africa and India the rate increases to 2 cm. 1000 y⁻¹. In a core at 2042 m depth, close to the present core location, the average sedimentation rate has been estimated¹⁵ to be 2.62 cm. 1000 y⁻¹. Based on the sharp change in the percentage of CaCO₃ in the core under study, the boundary between Holocene and Pleistocene is placed at 42 cm and the approximate sedimentation rate for the core is 4 cm. 1000 y⁻¹ for the Holocene period. From the study of a 65 cm core from the Carlsberg ridge, Peng *et al.*¹⁶ have reported a

conspicuous change in sedimentation rate from 3.46 to 2.26 cm. 1000 y⁻¹ around 10,200 years before present. This date marks the glacial and interglacial boundary in the Arabian Sea and return the age of the 42 cm boundary in the present core.

From 42 cm downwards, the coarse fraction and CaCO₃ show a sharp decreasing trend, where as the terrigenous components (clay and quartz) show an increasing trend. Therefore, the terrigenous sedimentation must have been high and this depth interval represents the glacial conditions. The terrigenous detritus comprising especially kaolinite, illite, chlorite, and quartz, deposited during the glacial period, must have been obviously supplied by the Indus river. On the basis of radiocarbon dates on oolites, oolitic limestones and shells, a low stand of sea level at 90 m between 11,000 and 10,000 years ago on the western continental shelf has been reported¹⁷. At the time of this low sea level the shelf was very narrow and the Indus must have flowed into the sea directly into the canyon head located at present at 50 m depth. Given a low stand of sea level at 90 m the Gulf of Kutch would have become dry land and consequently the tidal barrier which is present today would have been absent (Fig.1). This would therefore, allow the Indus sediments to be transported southwards to the continental shelf and slope and result in the deposition of higher quantities of kaolinite, illite, chlorite and quartz seen in the glacial interlude at the lower part of the core. In order to confirm these results further studies on cores from off the Saurashtra coast with better radiometric time control are required.

Acknowledgement

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