

Late Quaternary sedimentation in the eastern Bay of Bengal

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Abstract - This study presents variations in various size measures, calcium carbonate, organic carbon, clay mineralogy and major and trace elements in a core (5.40 m long, 2713 m depth) from the eastern Bay of Bengal. Size characteristics reveal that these sediments, in general, fall in the medium silt - clay grade; they are poorly sorted with a variable skewness and most of the sediments show platykurtic to leptokurtic nature. The coarsening at three different intervals (60-95 cm, 240-320 cm and at 535 cm) together with an increase in sorting index have also been observed. The calcium carbonate in the core which varies from 4 to 27%, shows a clear decreasing trend from 0 to 40 cm below which values are rather low (<12%) with minor fluctuations. Organic carbon ranging from 0.24 to 1.13 per cent exhibits lower content in the top portion (0-40 cm) compared to the rest of the core. The correlation between organic carbon and calcium carbonate for the entire core is found to be negative ($r = -0.44$; $n = 47$).

On a CM diagram, the sediments of the core occupy the area designated for suspended sediments indicating that the entire sedimentary section was deposited under calm conditions. The sharp change in distribution of organic carbon and calcium carbonate at 40 cm suggests a change in the nature of sedimentation and perhaps represents the boundary between the Pleistocene and Holocene. The variations in relative abundance of clay minerals as well as the chemistry of the sediments above and below 40 cm lend support to the above inference.

INTRODUCTION

The Bay of Bengal which covers about 2.2 million sq. km (LA FOND, 1966; STOW *et al.*, 1989) is one of the highest terrigenous input sites of the world ocean. The bay is bounded on the north by the deltaic region of the Ganges and Brahmaputra having annual discharge $1003 \times m^3 10^9 yr^{-1}$, on the east by Andaman and Nicobar islands, on the west by the coast of India having some major rivers, *viz.* Godavari ($92 \times m^3 10^9 yr^{-1}$), Krishna ($32 \times m^3 10^9 yr^{-1}$), Cauvery ($21 \times m^3 10^9 yr^{-1}$) and on the south by the Indian Ocean. The Bengal fan together with its eastern lobe, *i.e.*, Nicobar Fan is world's largest fan (VON DER BORSH *et al.*, 1974; CURRAY and MOORE, 1974; EMMEL and CURRAY, 1984). The fan is reported to be about 2800-3000 km long, 830- 1430 km wide and over 16 km thick beneath the northern Bay of Bengal.

Various studies (SIDDIQUIE, 1967; GOLDBERG and GRIFFIN, 1970; KOLLA and RAO, 1990) have addressed to the source of the surficial sediments. They have suggested that river borne solids, sources of which lie in the Indian Peninsula, are the primary components of the Bay of Bengal. The work of SUBBA RAO (1964), RAMAMURTHY and SRIVASTAVA (1979), SUBRAMANIAN (1980), NAIDU *et al.* (1985), RAO *et al.* (1988) and KOLLA and RAO (1990), based on the clay mineralogical studies, has delineated the probable sources of the sediments. These studies are limited in the sense that they report the variations of the sediment distribution in space. To provide a time factor to this, ten cores from a transect along 15° latitude, from the east coast of India to the northern most portion of the Andaman islands, were collected during cruise SK 31 of the ORV *Sagar Kanya*. The present work discusses the results of the eastern most core (Fig. 1).

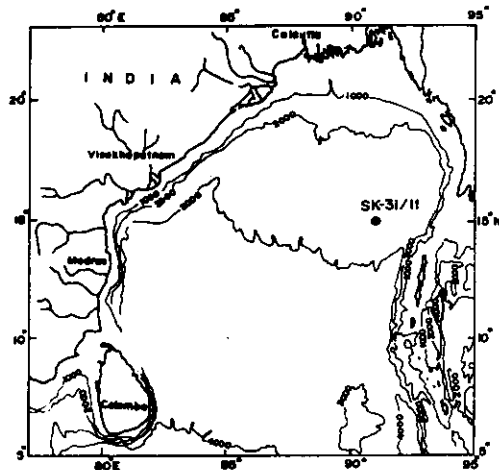


Fig. 1. Station location map.

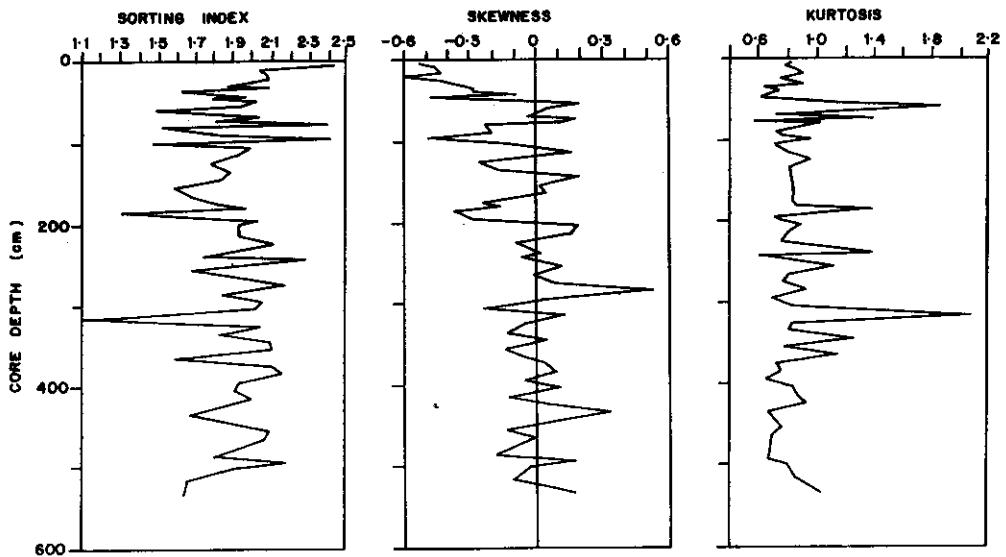


Fig. 2. Size measures on the sub-samples of the core.

METHODOLOGY

The core (5.40 m) was collected using a box corer and was sub-sampled at 5 cm intervals and preserved for further analysis. The sediments were washed salt free and dried at 70° C. About 20 g of the sample obtained through progressive splitting by coning and quartering method were subjected to grain size analysis at 1 ϕ intervals. The size fraction >4 ϕ (<63 μ m) were obtained using standard pipette method (FOLK, 1966). Due to high correlation between graphic and moment measures (SEVON, 1968; CHAUHAN and CHAUBEY, 1989), graphic measures were obtained on a Norsk Data 570 computer. In all 64 sub-samples were analysed.

The determination of calcium carbonate and organic carbon has been done following the standard methods (MULLER and GASTNER, 1971; EL WAKEEL and RILEY, 1957 respectively). The correlation coefficient (r) probability of r being accidental, \bar{X} and \bar{Y} and regression equations for organic carbon and calcium carbonate were obtained on the ND 570 computer using the methods described by KENNY and KEEPING (1964).

Clay mineralogical analysis of $< 2 \mu\text{m}$ fraction of the sediments was done on a Phillips X-ray diffractometer (Model PW 1840/11) following standard procedures for sample preparation, glycolation and weighted peak area percentage calculations (BIS-CAYE, 1965; CARROL, 1970).

The bulk samples from selected levels were analysed for their metal contents by using a X-ray fluorescence on board the Russian research vessel 'Akademik Mstislav Keldysh'. The precision of the analysis was checked by using the sediment standards SDO-2 and SDO-3 (USSR) and was found to be better than 5% for the elements analysed.

RESULTS AND DISCUSSION

The variations in the various size measures are presented in Figure 2. These results indicate that the analysed sediments in general fall in medium silt - clay range. However, between 60 - 95 cm, 240 - 320 cm and at 535 cm intervals coarsening of the sediment has been observed. The sorting of the sediments in general is poor and exhibits oscillatory trend. The sediments at 62-65 cm, 73-78 cm, 95-100 cm, 185-195 cm and 238-243 cm intervals, where mean size also shows coarsening, were found to be relatively better sorted. The skewness of the sediments is nearly symmetrical at 60-65 cm and 70-80 cm intervals in the samples which show coarser mean size and relatively better sorting. The variations in the kurtosis values at 60-65 cm, 73- 78 cm, 185-190 cm and 238-243 cm intervals show leptokurtic nature which otherwise remain platykurtic. The plots of coarse fraction (C) and median values (M) of different fractions of the core on a CM diagram (PASSEGA, 1964) is presented in Figure 3 which depicts that sediments of the entire core fall in the area designated for the sediments deposited under calm conditions through suspension.

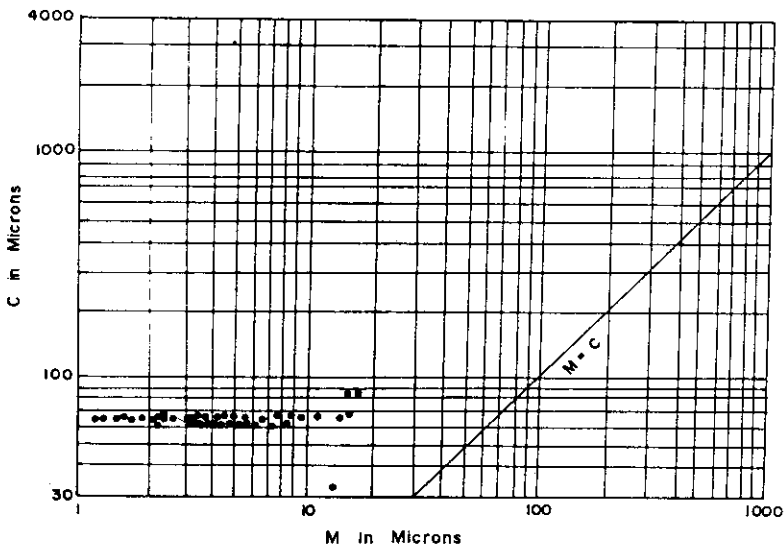


Fig. 3. C-M diagram for the sub-samples of the core. Note that the sub-samples of the core occupy the area designated for suspension.

Calcium carbonate shows considerable variations ranging from 4 to 27% for the entire core (Fig. 4). It is distinctly observed that higher concentrations (upto 27%) are seen in the top 40 cm as compared to the remaining part (40 cm downwards) where low values (<12%) are registered. Organic carbon content for the entire core varies from 0.24 to 1.13 per cent. It clearly shows lower concentrations (< 0.5%) in the top 40 cm, whereas higher values (> 0.5%) are observed below 40 cm. The variations of CaCO₃ and organic carbon along the core length show (Fig. 4) that below 40 cm organic carbon is relatively high, while CaCO₃ content is low. However, above 40 cm organic carbon shows a sharp decreasing trend, whereas CaCO₃ shows sharp increasing trend upwards. A correlation analysis (Fig. 5) reveals that the calcium carbonate and organic carbon are negatively correlated ($r = -0.44$; $n=47$). Thus, the negative interrelationship in CaCO₃ and organic carbon along the entire core suggests that the deposition of CaCO₃ and organic carbon was governed by two independent processes.

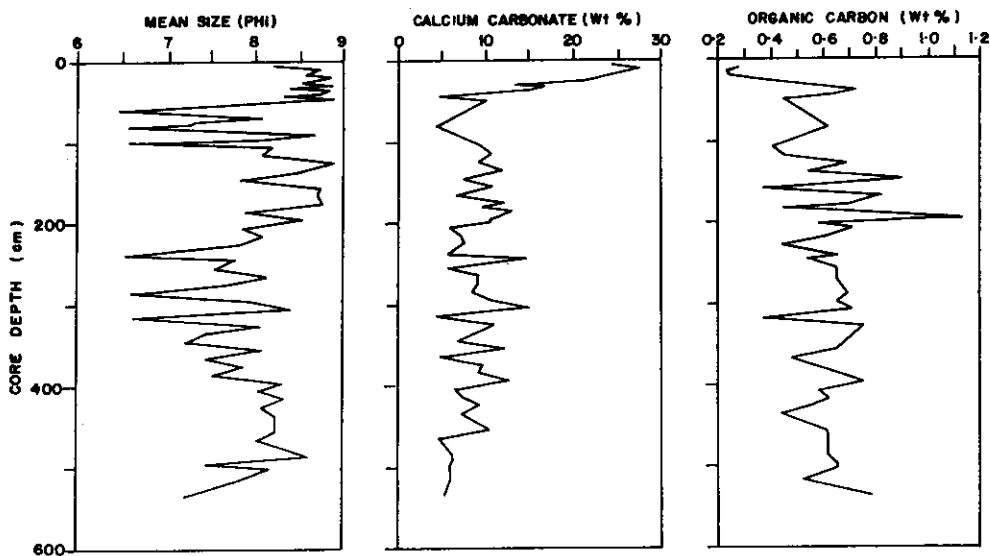


Fig. 4. Variations of calcium carbonate, organic carbon and mean size (M_z) with depth in the core.

The studies of coarse fraction ($> 63 \mu\text{m}$) show that the CaCO₃ content of these sediments is entirely biogenic and its upward increasing trend above 40 cm is due to an increase in skeletal components. It is well established that in marine sediments, calcium carbonate being biogenic/autogenic shows an inverse relationship with terrigenous material (HAYS and PERRUZZA, 1972; SHEU and HUANG, 1989). Thus, the low content of CaCO₃ below 40 cm clearly suggests that there had been a continuous and large supply of terrigenous material diluting the biogenic carbonate component. The relatively higher organic carbon content ($>0.5\%$) is observed in the core below 40 cm level. Since higher terrigenous influx based on low CaCO₃ is envisaged below this level, it is inferred that the organic carbon in this core reflects terrigenous contribution. Based on low $\delta^{13}\text{C}$ values, FONTUGNE and DUPLESSY (1986) also concluded that organic matter in the eastern Bay of Bengal, especially the area under study, is mainly of terrigenous nature. Mechanism of the terrigenous sediment transport, based on C-M diagram (Fig. 3), appears to be through suspension and not through turbidity as suggested by KOLLA and RAO (1990) for surficial sediments. It would thus appear that the present core is located in the levee rather in the channel.

Above 40 cm, following the above analogy, the decrease in organic carbon content suggests a decrease in the terrigenous contribution while increase in CaCO_3 indicates enhanced biogenic contribution. The geochemical investigation have shown a significant upward decrease in the elemental concentrations characteristic of terrigenous material (Al, Fe, Ti, Cr and V) and increase in elemental concentrations characteristic of authigenic (Mn) and biogenic material (Ca, Sr and Ba) (Table 1) above 40 cm portion in the core and lends credence to the above observation. The investigation by SARIN *et al.* (1979) in a nearby core which showed flattening of slope of 'Th-230 excess' at 40 cm, together with a similar change in elemental concentrations are supportive of our conclusion.

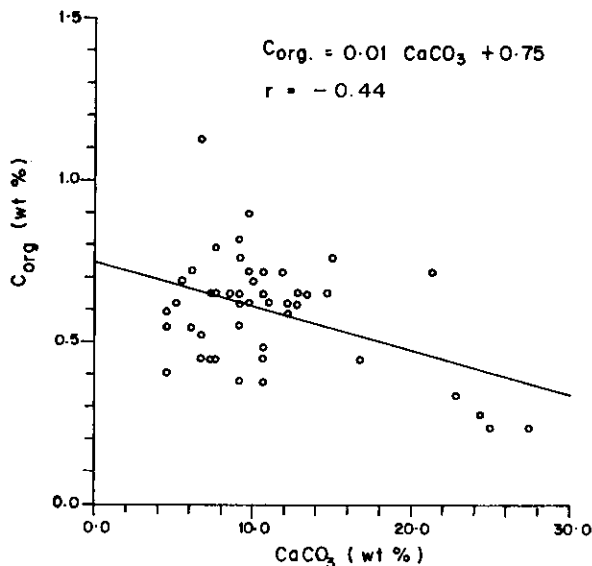


Fig. 5. Correlation between organic carbon and calcium carbonate for the sub-samples of the core. Correlation coefficient (r) and equations of the regression are also shown.

The variations in the abundances of clay minerals (Fig. 6) further indicate that above 40 cm, the montmorillonite content increases with corresponding decrease in illite and chlorite and there is no significant change in the content of kaolinite. Earlier clay mineralogical studies (SIDDIQUIE, 1967; VENKATARATHNAM and BISCAYE, 1973; KOLLA and RAO, 1990) have clearly indicated that illite and chlorite are characteristic clay minerals derived from the Himalayan source and is mainly supplied to the Bay of Bengal by the Ganges and Brahmaputra and to some extent by Irrawadi rivers. Therefore, the decrease in illite and chlorite content observed by us above 40 cm level indicates reduction in the supply of terrigenous material from Himalayan sources to the core site. It is well established that montmorillonite is a characteristic mineral derived from the Deccan Traps (GOLDBERG and GRIFFIN, 1970; VENKATRATHNAM and BISCAYE, 1973; KOLLA and RAO, 1990). Further, it is reported that montmorillonite derived from the Deccan Traps is enriched in Mn content (MURTY *et al.*, 1978; MASCARENHAS *et al.*, 1985). An increase in montmorillonite content as well as in Mn above 40 cm, thus clearly implies a relative increase in terrestrial contribution from southern India through the peninsular rivers (e.g. Godavari and Krishna) with simultaneous decrease in contribution from Himalayan sources.

The present day circulation patterns (LAFOND and LAFOND, 1968, Fig. 7) also clearly indicate that such a transport mechanism of montmorillonite to the core site is possible. This inference is also supported by work of FONTUGNE and DUPLESSY

Table 1. Averages of major and minor elements in sediments of the core SK 31/11, above and below 40 cm (major elements are in weight percentage and minor elements in ppm).

Elements	Al (----- values in wt per cent -----)	Fe (----- values in wt per cent -----)	Ti (----- values in wt per cent -----)	Ca (----- values in wt per cent -----)	Mg (----- values in wt per cent -----)	Mn (----- values in ppm -----)	Cr (----- values in ppm -----)	V (----- values in ppm -----)	Sr (----- values in ppm -----)	Ba (----- values in ppm -----)
Above 40 cm	7.85	3.91	0.38	8.11	1.51	6718	84	96	444	848
Below 40 cm	9.51	5.81	0.55	3.21	2.01	1179	119	130	122	425

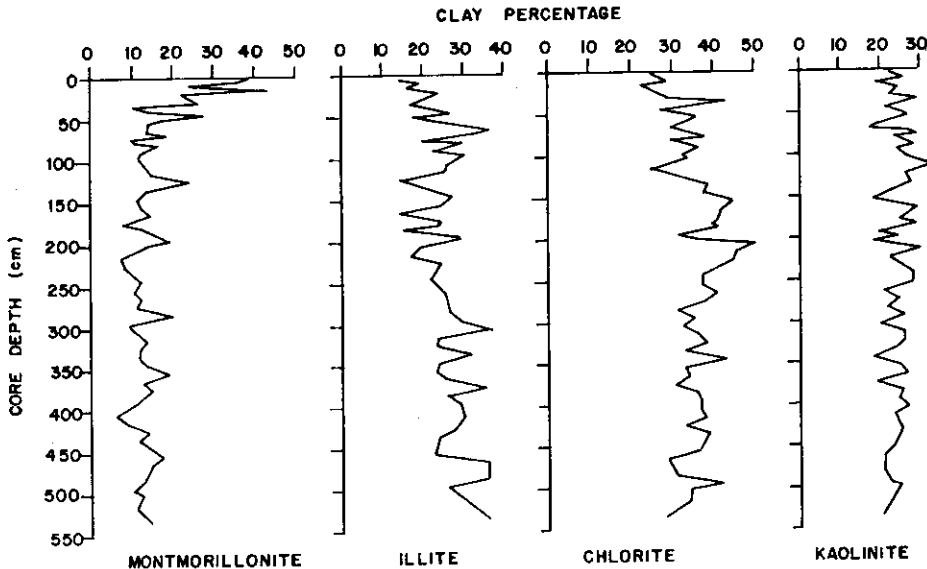


Fig. 6. Variations in montmorillonite, chlorite, illite and kaolinite with depth in the core. Note almost uniform distribution of kaolinite in the entire core and higher contents of montmorillonite in top 40 cm portion of the core.

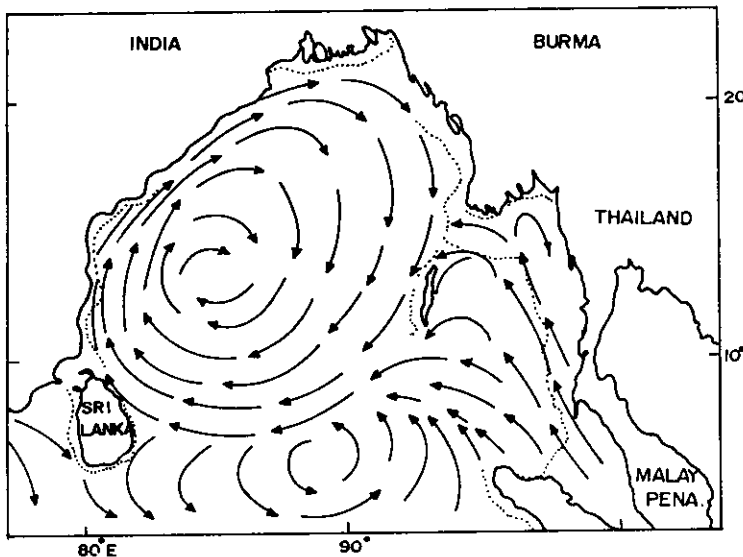


Fig. 7. Current pattern in the Bay of Bengal (modified from LAFOND and LAFOND, 1968).

(1986) who concluded that during Holocene period the terrestrial contribution is higher in the eastern part of the basin due to eastward flowing currents which prevail during SW monsoon when river sediment discharge from peninsular river is at its peak, depriving the central and western basin of terrigenous material.

It is well established that the sea level was almost 120 m below the present level during Pleistocene, i.e. during Last Glacial Maxima (LGM) at about 18 kyr B.P. and has risen rapidly from about 10 kyr B.P. (FAIRBRIDGE, 1962; CURRAY and MOORE, 1974; STODDART, 1971) during Flandrian transgression. Such a rise in the sea level in the Bay of Bengal must have been responsible for recession of the mouths of all the rivers, thus affecting the current and dispersion pattern of the sediments discharged in the bay. The significant reduction in the rate of terrigenous input with relative decrease of terrigenous supply from Ganges-Brahmaputra and Irrawadi rivers and a relative increase in terrigenous supply by peninsular rivers above 40 cm is, thus, suggestive of onset of Flandrian transgression. In addition to overall decrease of terrigenous input, the low organic carbon content above 40 cm also suggests weak productivity in overlying waters. It is well established that the productivity in the Bay of Bengal has decreased since the beginning of Holocene (FONTUGNE and DUPLESSY, 1986). Therefore, the decrease in organic carbon content above 40 cm appears to suggest the beginning of Holocene. Based on these observations, the level of 40 cm is identified as the boundary between Pleistocene and Holocene; the inferred rate of sedimentation being about 4 cm kyr⁻¹ during Holocene.

The proposed rate of sedimentation and the time boundaries mentioned in the text are only an approximation based on the data available with us. A detailed geochronological study for the entire core is needed to supplement our data to further refine the above inferences.

CONCLUSION

1. The variations and inter-relationship among calcium carbonate, organic carbon and elemental concentrations suggest 40 cm level in the present core as the boundary between the Holocene and Pleistocene. The average rate of sedimentation is proposed to be 4 cm kyr⁻¹.

2. The recession of the mouth of the rivers due to rise in the sea level since LGM and resulting reduction in the supply of the terrigenous sediments in the Bay of Bengal as reflected by the CaCO₃ contents above 40 cm level appears to be the controlling mechanism for reduced terrigenous input to the site of the core.

3. Relative increase in the abundance of montmorillonite and Mn contents in the upper 40 cm portion of the core suggest higher contribution of sediments through peninsular rivers to the core site since Holocene.

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