

Clay mineral distribution in the shelf sediments off the northern part of the east coast of India

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Abstract—Forty-eight sediment samples from the continental shelf between Visakhapatnam and the Ganges were analysed by X-ray diffraction for the composition and distribution of clay minerals. Estuarine samples of the Hooghly are dominated by illite and chlorite with minor amounts of kaolinite and traces of montmorillonite. In the shelf sediments, the illite and chlorite concentrations decrease with increases in the concentrations of montmorillonite, kaolinite and gibbsite. The Ganges-derived sediment does not reach the shelf off the peninsular rivers. Sediment samples off the peninsular rivers show illite, kaolinite and montmorillonite with minor amounts of chlorite and gibbsite. Spatial variations in the distribution of clay minerals indicate that illite and kaolinite concentrations are higher in the clay fraction of the more sandy sediments and montmorillonite proportions are higher in the clays. The clay minerals present in the shelf sediments closely reflect their sources but their relative abundance depends largely on the energy conditions of the shelf environment and the properties of the individual clay minerals.

INTRODUCTION

THE continental shelf in the study area extends from Ganges in the north to Visakhapatnam in the south (Fig. 1). Many rivers empty their sediment load directly or via estuaries onto the continental shelf. In the north, the Ganges, the second major river of the world in terms of suspended load, discharges 1451×10^6 tons annually (LISITZEN, 1972) and it is the main contributor of sediments to the Bengal Fan which is the largest deep-sea fan in the world. Southwards, the Mahanadi, the third largest peninsular river together with smaller rivers such as Subernarekha, Brahmani, Devi, Vamsadhara and Nagavali contribute to the continental shelf sedimentation.

The width of the continental shelf in this study area varies from 210 km off the Ganges to less than 23 km off Puri and to about 40 km off Visakhapatnam. The shelf break ranges in depth from 200 m in the north to 43 m off Puri with a further increase to 200 m off Visakhapatnam (RAMA RAJU, 1973).

According to SUBBA RAO (1964) the surficial sediments off the Ganges and Mahanadi are silty clays/clayey silts. The continental shelf sediments between Santapilli and Visakhapatnam consist of sands down to the 27 m isobath below which are clays on the inner shelf, calcareous sands on the outer shelf and fine-grained clays on the continental slope (SUBBA RAO, 1964). Attention was also drawn to the absence of the clay zone on the inner shelf between Puri and Santapilli. Earlier studies on the clay mineralogy include those of SUBBA RAO (1963) on the shelf sediments off the east coast of India and

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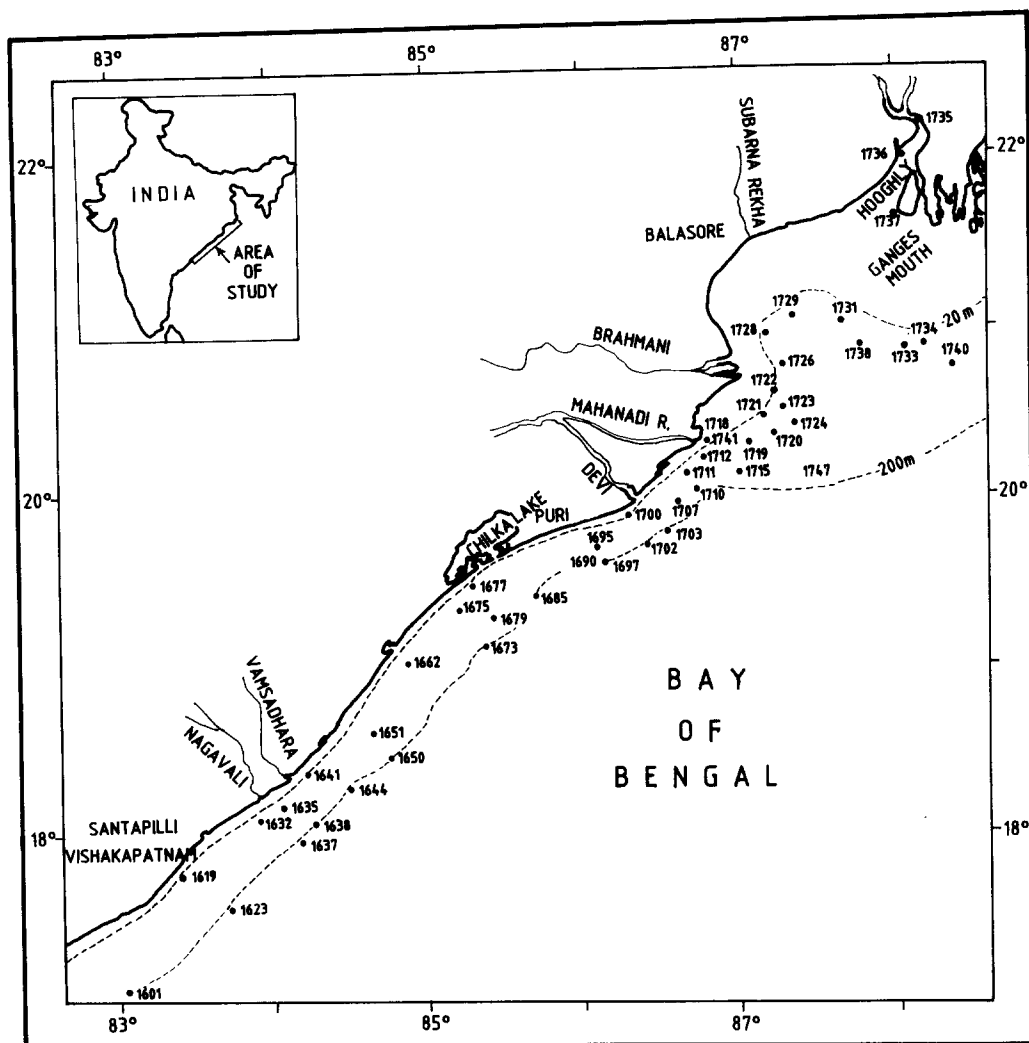


Fig. 1. Study area and sample location, eastern continental shelf of India.

RAMA MURTHY and SRIVASTAVA (1979) on the shelf sediments off the Ganges. Additionally, SUBRAMANIAN (1980) and NAIDU *et al.* (1985) have studied the clay mineralogy of the suspended and bed loads of various rivers, respectively. However, the above workers have analysed only a few samples and hence their conclusions are of no more than limited or local value.

The purpose of this paper is to semiquantitatively examine the clay minerals of the shelf sediments with a view to understanding their distribution and dispersal patterns.

MATERIALS AND METHODS

During the 77th cruise of *R.V. Gaveshani*, sediment samples were collected by Peterson grab from the continental shelf between Visakhapatnam and the Ganges. A

total of 48 samples were selected for the present study (Fig. 1). Following FOLK (1968), the less than 2 μm fraction of the sediment was separated from the total sample by settling and rendered free of calcium carbonate and organic matter by treating with acetic acid and hydrogen peroxide, respectively. Oriented clay samples were prepared by pipetting the clay solution onto glass slides and allowing them to dry in the air. The slides were scanned from 3° to 30° 2θ at 2° 20 min^{-1} on a Philips X-ray diffractometer using nickel filtered Cu K α radiation. These samples were also treated with ethylene glycol for 1 h at 100°C (CARROL, 1970) and rescanned with the same instrumental settings. Major clay minerals were identified following BRINDLEY and BROWN (1980). Abundance of clay minerals depends on variables such as X-ray machine conditions and sample mount techniques. Hence true quantitative evaluations of clay minerals are not yet possible. However, reasonably good approximations of clay minerals can be obtained for the comparison of different samples by the method of BISCAYE (1965) which has been followed here. The areas of the principal peaks of the clay minerals kaolinite and chlorite (7 A°), illite (10 A°) and montmorillonite (17 A°) were measured above the background response using glycolated sample X-ray diffractograms. The principal peak areas of the clay minerals kaolinite and chlorite, illite and montmorillonite were multiplied by the weighting factors 2, 4 and 1, respectively. The weighted peak area percentages of each clay mineral were calculated and are shown in Table 1. All the samples were scanned from 24 to 26° 2θ at $1/2^\circ$ 20 min^{-1} for the resolution of kaolinite and chlorite (BISCAYE, 1964). The areas under each peak were estimated and the ratio of kaolinite to chlorite was calculated. Chlorites with less than 30% of iron ions in the octahedral positions have medium to strong intensities for the first five order basal reflections whereas chlorites rich in iron give relatively weak (001) and (003) and strong (002) and (004) reflections which are due to the combined effect of climate, topography and weathering (GRIM, 1968). Accordingly, two types of chlorites, Fe-rich and Fe-poor are differentiated in the present study. Gibbsite has been identified from its 4.85 A° and 4.37 A° reflections and being a minor mineral only its presence or absence has been noted.

RESULTS

Illite, kaolinite, chlorite and montmorillonite are the major clay minerals in the study area and their relative abundances are shown in Table 1.

The estuarine samples of the Hooghly River contain the highest percentage of illite (70–80%), and Fe-poor chlorite/kaolinite (20–30%). Of the latter there appear to be only minor amounts of kaolinite ($\text{Av. K/C} = 0.3$) (Fig. 2a). Only about 2% of montmorillonite was found in sample no. 1737 from this area (Table 1). Shelf sediments towards the south differ and are characterized by the much higher contents of: montmorillonite (up to 19%), and kaolinite (as evidenced by a mean K/C ratio of 0.6), with corresponding decreases in the content of illite and chlorite (Table 1). Gibbsite is also seen in these sediments.

The order of abundance of the clay minerals in all the shelf sediments off the peninsular rivers, is illite, kaolinite/chlorite and montmorillonite. Moreover, they are characterized by the presence of gibbsite and the dominance of kaolinite over chlorite. The ratio of kaolinite to chlorite increases southwards and the samples off Vamsadhara showed only kaolinite peaks. This trend is illustrated in Fig. 2. Chlorites everywhere appear to be an Fe-rich variety. The content of illite, which is always more abundant than

Table 1. *Distribution of major clay minerals in the less than 2 μm fraction of the sediments*

Place	S. no.	Sample no.	Depth (m)	Type of sediment	Weighted peak area % of			
					M	I	K+C	K/C
Hooghly	1	1735	–	Sand	–	74	26	0.30
	2	1736	–	Sand	–	73	27	0.30
	3	1737	–	Sand	2	80	18	0.40
	4	1740	50	Sand	–	74	26	0.60
	5	1734	38	Clay	15	59	26	0.60
	6	1733	49	Clay	19	58	22	0.50
	7	1738	55	Sand	8	71	21	0.70
	8	1731	41	Clay	13	71	16	0.80
Brahmani	9	1729	23	Clayey sand	8	71	21	1.80
	10	1728	21	Clayey sand	16	49	39	1.30
	11	1726	29	Sand	25	41	34	1.30
	12	1722	19	Sand	14	59	27	1.80
	13	1723	29	Clay	17	45	38	1.30
	14	1724	52	Sand	7	71	22	1.10
Mahanadi	15	1741	10	Sand	12	57	31	1.70
	16	1712	20	Clay	20	42	38	1.30
	17	1718	20	Clay	18	50	32	1.50
	18	1721	20	Clay	16	43	41	1.70
	19	1720	45	Clay	15	69	16	1.60
	20	1719	36	Clay	12	69	19	2.70
	21	1747	100	Sand	7	76	17	0.80
	22	1715	125	Sandy clay	24	56	20	1.60
	23	1711	18	Clay	20	51	29	2.70
	24	1700	16	Clay	24	30	43	2.70
Devi	25	1702	150	Clay	23	32	45	1.40
	26	1703	170	Clay	36	41	23	1.30
	27	1707	33	Clay	25	45	22	2.30
	28	1710	35	Clayey sand	21	42	37	1.30
	29	1695	32	Sandy clay	26	44	31	1.10
	30	1696	215	Clay	22	39	39	1.20
	31	1697	220	Clay	39	48	14	1.20
	32	1686	55	Clay	24	50	26	1.70
Puri-Kalingapatnam	33	1677	29	Sand	11	63	27	1.70
	34	1675	58	Clay	34	34	29	2.50
	35	1679	120	Clay	30	43	28	1.80
	36	1673	205	Clay	39	35	26	1.60
	37	1662	54	Sandy clay	43	31	26	1.80
	38	1651	60	Clayey sand	24	52	24	1.40
	39	1651	170	Clayey sand	17	66	17	2.50
	40	1641	35	Silty sand	19	44	38	1.20
	41	1635	37	Clay	32	27	41	1.80
	42	1644	218	Clay	54	21	25	1.70
	43	1638	94	Sandy clay	19	58	23	2.00
	44	1637	193	Clay	35	44	21	1.30
	45	1632	31	Clay	23	46	31	2.30
	Visakapatnam	46	1619	32	Sand	24	42	34
47		1623	180	Clay	32	48	20	1.50
48		1601	94	Clayey sand	26	54	20	1.50

M, montmorillonite; I, illite; K, kaolinite; C, chlorite.

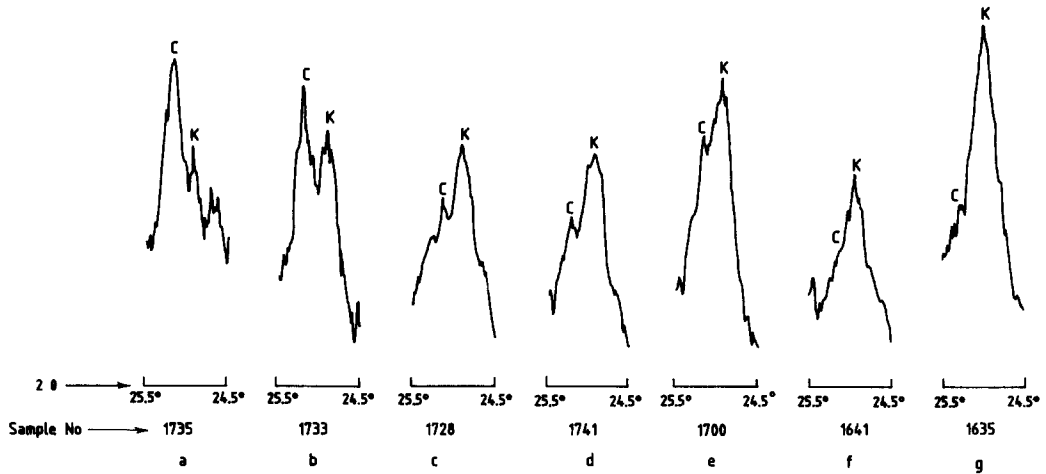


Fig. 2. Slow scan X-ray diffractograms of a representative sample showing kaolinite (K) and chlorite (C).

montmorillonite, progressively decreases from 60% in the shelf samples off Brahmani to 44% in the samples off Visakhapatnam. Montmorillonite shows a corresponding increase from 14 to 32%.

Spatial variations in the distribution of clay minerals with sediment type on the shelf have also been observed. Illite and kaolinite plus chlorite contents are higher in the sandy zones that occur nearshore and on the outer shelf, and lower in clayey zones on the inner continental shelf and on the continental slope. On the other hand, montmorillonite percentages are greater in clay zones and comparatively lower in the sandy zones (Table 1). These variations are best observed in samples between Puri and Visakhapatnam, where gradations from nearshore sands to continental slope clays are best displayed. High contents of illite and kaolinite occur in the nearshore sands off the Mahanadi, whereas Hooghly estuarine samples only display illite.

DISCUSSION

The results above illustrate that the clay mineral suite of the Hooghly Estuary is different from that found in sediments of the eastern shelf of India which have been contributed by the peninsular rivers. This is due to differences in drainage and climatic conditions of the two river systems. The Hooghly River is a distributory of the Ganges which originates in the Himalayas and drains under cold climatic conditions. It erodes precambrian formations in its upper reaches and Rajmahal Traps, and recent alluvium in its lower reaches. It is presumed that the occurrence of illite and chlorite as major mineral phases is a result of the glacial weathering, while kaolinite and montmorillonite are formed as a result of chemical weathering under warmer low latitude/altitude conditions. The earlier findings on the dominance of illite in the Ganges monsoon silt by SEN and CHATTERJEE (1960) and kaolinite in the premonsoon silt by SEN *et al.* (1961), are in agreement with the present observations. Furthermore, illite kaolinite and chlorite have been reported in the suspended load, and illite and chlorite in the bed loads of the Ganges by SUBRAMANIAN (1980) and NAIDU *et al.* (1985), respectively. SUBBA RAO (1963)

found illite and chlorite with minor amounts of montmorillonite and traces of kaolinite while RAMA MURTHY and SRIVASTAVA (1979) reported illite with minor amounts of kaolinite and montmorillonite in the sediments off the Ganges.

In contrast the peninsular rivers drain Precambrian and Quaternary sediment terrains under humid tropical conditions. Under these conditions, chemical weathering products such as kaolinite and montmorillonite, are likely. Since Precambrian khondalites in the eastern ghats are capped by laterites (KRISHNAN, 1967), gibbsite is also likely to be carried by certain peninsular rivers and should be seen in neighbouring shelf sediments. SUBRAMANIAN (1980) reported the absence of chlorite in the suspended loads of the Mahanadi, but we have confirmed the observations of NAIDU *et al.* (1985) that it is present in the bed loads (Fig. 2). This discrepancy may be because the (003) reflection of chlorite was taken into account for its abundance by SUBRAMANIAN (1980) but the intensity of this reflection is likely to vary based on the iron enrichment in the chlorites (GRIM, 1968). Chlorites coming from the Mahanadi are the Fe-rich variety and have very weak (001) and (003) reflections and as a consequence SUBRAMANIAN (1980) might not have detected their presence. The occurrence of Fe-rich chlorites also reflects poor drainage conditions compared to the Ganges.

Lower contents of illite and chlorite and more of montmorillonite, kaolinite and gibbsite in the shelf sediment samples off the Hooghly compared with the estuarine sediments indicates that the clay mineral suite of the peninsular rivers is mixing with the clay mineral suite of the Hooghly River. This is due to the offshore drift over the shelf area under the influence of anticlockwise gyral flows which are likely to be intensified at the head of the bay during the Southwest monsoon (LA FOND, 1957). At such times, peninsular rivers discharge most of their sediment load onto the shelf and some of this is transported towards the northeast and mixes with the Ganges clay mineral suite. Since the southerly current during the northeast monsoon is very weak, the clay mineral suite is not contaminated by the Ganges clay mineral suite. From a study of the heavy mineral assemblage in the shelf samples off the northern part of the Bay of Bengal, MALLIK (1976) reported the probable current direction here is towards the east. These observations infer that the Ganges-derived sediment is deposited either on the continental shelf or in the deeper parts of the bay but does not reach the southern part of the shelf off the peninsular rivers.

Occurrence of clays and sands in the shelf sediments are related to the energy conditions of the environment. Hence, the clay minerals associated with them could also be explained as due to the influence of the depositional environment and the propensity of the individual clay minerals for transport. Montmorillonites, because of their fine grain size, are deposited more in low energy environments while illite and kaolinite do not show such preferential settling and hence deposit even in high energy conditions. Montmorillonite might also form aggregates in the low energy environment and settle in clayey sediments. The much higher concentrations of illite and kaolinite in the nearshore sands may be due to the early flocculation of these minerals in response to saline conditions. Such arguments are supported by WHITEHOUSE *et al.* (1960), who found that illite and kaolinite particle sizes are larger compared to montmorillonite and the settling velocity of illite and kaolinite increases with increasing salinity, whereas montmorillonite is relatively less influenced by salinity. STANLEY and LIYANAGE (1986) reported the clay mineral variations in the Nile delta and attributed these to the influence of depositional and settling processes. Therefore, it is concluded that climatic conditions leave an

imprint only on the characterization of the clay minerals, whereas their distribution on the continental shelf depends partly upon current patterns and partly upon the energy of the depositional environment.

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