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Clay minerals in identification of provenance of sediments of Mandovi estuary, Goa, west coast of india

S. S. Bukhari & G. N. Nayak
Department of Marine sciences & Marine Biotechnology, Goa University, Goa 403 205, India

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Relative abundance and spatial distribution of the clay minerals show considerable variation with changing seasons all along the length of the Mandovi estuary. Kaolinite, illite, montmorillonite and gibbsite have been identified as chief clay minerals in both the suspended sediments and the surface bed sediments. Of all the minerals, kaolinite is the most dominant. Kaolinite and gibbsite predominantly have their origin in the laterites and lateritic soil. Illite originates basically from the metasediments, while majority of montmorillonite is brought in from the offshore.

Clay minerals of surficial sediments have been used widely as a first order guide to the source, environment and the transport paths of fine grained sediments[1-4]. Lateral variations in the relative abundance and association of the clay minerals like kaolinite, montmorillonite, illite and their seasonal variations give a lead in deciphering the source of sediments. This is especially true of such complex environments as estuaries wherein sediments are contributed from various sources along their course.

Present study consists the use of certain clay minerals - their spatial and seasonal variations in the abundance and distribution as guide in deciphering the source of sediments in the Mandovi estuary and to understand the role of seasons in deciding the predominant source.

Materials and Methods

River Mandovi (length of 70 km) is joined by numerous tributaries. It flows across extensive open cast mining zones. Surface bed sediment samples, representing three seasons viz. premonsoon (May), monsoon (August) and postmonsoon (December), were collected during 1990 using a stainless steel Van veen grab from 7 stations (Fig. 1). Samples were desalinated and the $< 2m\mu$ fraction was separated[5] for clay mineral analysis. Fine fraction was then treated overnight with 5 ml of acetic acid and 30% hydrogen peroxide to remove calcium carbonate and organic matter. After washing the sample free of reagents, a small fraction of the clay suspension was pipetted out into a glass slide to obtain oriented slides which were further air dried.

About 40 litres of surface water was collected from each of the selected stations during premonsoon and monsoon seasons. Suspended sediments from these waters were separated by filtering each of the sample through 0.4 μ nuclepore membrane filter paper using a filtration unit under vacuum. Suspended sediments were treated as above to obtain oriented slides. Oriented clay slides were scanned on a Philips X-ray diffractometer using Ni filtered Cu $K\alpha$ radiation from 3° to 30° 2θ at 2° 2θ per minute. Scanning was done both prior to and after glycolation. For glycolation, the slides were treated with ethylene glycol and glycolated at 80°C for 1 hour. Chief clay minerals like kaolinite + chlorite (K+C), illite, montmorillonite and gibbsite were identified from reflection peaks. Principal peak areas of these minerals were estimated using polar planimeter and following Biscay,[2] multiplied by weighing factors 2,4 and 1 for K+C, illite and montmorillonite respectively. Weighted peak area percentages were then calculated for all the minerals mentioned.

Results and Discussion

Clay minerals that are identified in this work are kaolinite + chlorite, illite, montmorillonite and gibbsite (Fig. 2). Semiquantitative analysis giving the relative abundance of these minerals is presented in Table 1. Distribution and seasonal variations of the minerals is presented in Figs. 3 and 4.

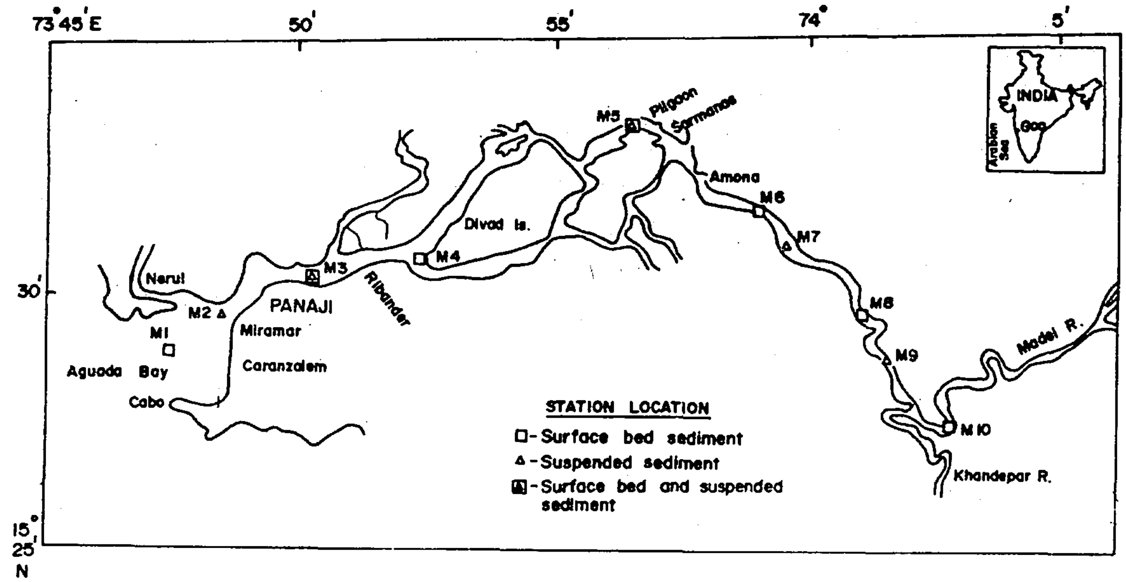

Fig. 1—Station Location in Mandovi estuary.

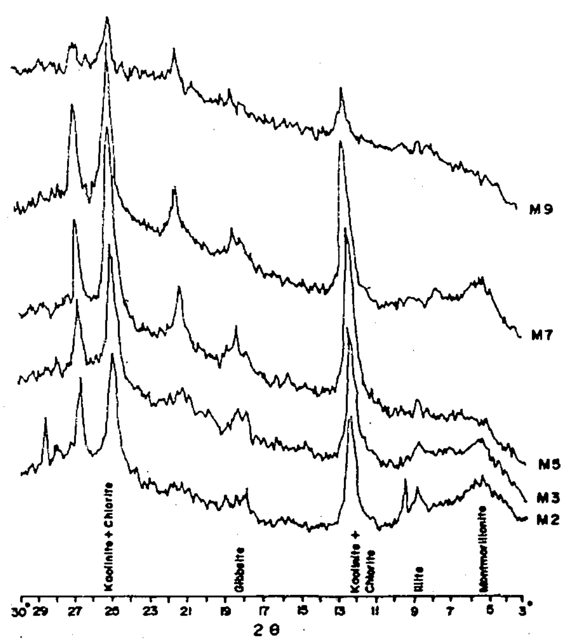

Fig. 2—X-ray difractograms of representative samples along the length of the estuary during premonsoon.

Kaolinite + chlorite (K+C)—The peak reflecting K+C is the most predominant indicating its dominance and abundance over other minerals. During premonsoon K+C in bed sediment, ranges from 44.01% to 73.39%. Highest content is recorded at station M4 but on either side, it decreases both towards downstream and upstream (Figs.3, 4). In monsoon K+C content varies from 64.35% to 77.73% with an average abundance higher than in premonsoon. There is no marked variation in the trend along the length of the estuary. Postmonsoon trend is quite irregular as K+C does not show a definite trend. Relative abundance ranges from 50.94% to 85.71%.

In the suspended sediments, the premonsoon season shows a gradual decrease of the mineral in downstream direction. It ranges from 63.7% to 84.66%. In monsoon K+C makes for the bulk of the composition, varying from 85.51% to 93.22% and shows a general decrease towards downstream.

Illite—Illite varies from 9.79% to 46.33% within the bed sediments during premonsoon season (Figs. 3, 4). It shows a decreasing trend from stations M1 to M4 but increases gradually further upstream. In monsoon, the sediments show general increase in illite towards upstream, with an exception of station M10. The range in abundance of illite during monsoon is 5.88% to 20.79%. Illite content in sediments was low in postmonsoon.

In the suspended sediments, during premonsoon, illite shows two peak values - one at station M2 (14.75%) and other at M7 (16.83%). Rest of the stations it varies over a small range of 7.25% to 8.46%. During monsoon, the mineral abundance increases towards upstream ranging from 5.24% to 10.47%.

Montmorillonite—In the bed sediments, montmorillonite shows on an average, a higher

Table 1—A Relative percentage abundance of clay minerals and amount of clay fraction * in bedload.

Station	Premonsoon					Monsoon					Postmonsoon				
	K+C	I	M	G	CLAY%	K+C	I	M	G	CLAY%	K+C	I	M	G	CLAY%
M1	48.11	20.25	22.78	8.86	41.46	--	--	--	--	--	50.94	13.58	28.86	6.62	43.88
M3	54.05	16.22	21.62	8.11	36.73	77.73	5.88	10.51	5.88	18.83	80.77	10.00	3.65	5.58	25.96
M4	73.39	9.79	10.70	6.12	15.45	71.19	12.53	7.93	8.35	16.70	72.11	13.66	4.74	9.49	19.41
M5	68.21	18.47	10.74	2.56	31.50	73.96	11.84	5.92	8.25	4.16	73.47	12.24	6.12	8.17	10.65
M6	56.55	30.85	5.14	7.46	2.30	64.35	20.79	6.19	8.67	2.20	61.85	24.75	5.15	8.25	2.70
M8	44.01	46.33	5.80	3.86	2.00	69.20	15.22	1.74	13.84	0.31	85.71	9.52	4.70	0.00	4.19
M10	--	--	--	--	--	74.79	12.82	4.91	7.48	17.80	79.69	11.72	3.90	4.69	3.65

B: Relative percentage abundance of clay minerals in suspended sediment.

Station	Premonsoon				Monsoon			
	K+C	I	M	G	K+C	I	M	G
M2	65.58	14.75	16.39	3.28	85.90	7.56	3.09	3.43
M3	71.01	7.25	15.94	5.80	85.70	5.24	3.47	6.55
M5	80.20	7.29	3.74	8.68	88.81	5.92	0.24	5.03
M7	63.70	16.83	13.22	6.25	85.51	10.47	1.40	2.62
M9	84.66	8.46	3.19	3.70	93.22	4.52	0.28	1.98

K+C - Kaolinite +chlorite ; I- Illite ; M - Montmorillonite ; G - Gibbsite.
* Bukhari (ref. 15).

abundance during premonsoon, ranging from 5.14% to 22.78% (Figs. 3, 4). It shows a distinct and systematic decrease towards upstream. Highest percentage is recorded at station M1. During monsoon, there is a general decrease in the mineral abundance towards upstream. Ranging from 1.74% to 10.51%, the average content is the lowest of the three seasons. Sediments show a high percentage (28.86%) at station M1 but for rest of the stretch the values fluctuate between 3.65% and 6.12% during postmonsoon season.

In suspended sediments this mineral decreases from mouth to upstream. It is highest at station M2 (16.39%) and lowest at station M9 (3.19%). Station M5, however deviates from the trend by showing a low value. Sediments in suspension during monsoon are distinctly impoverished in montmorillonite.

Gibbsite—During premonsoon gibbsite in bed sediments varies over a range of 3.80% at M8 to 8.86% at M1 showing a general decrease towards upstream. In monsoon, the sediment shows a gradual increase in gibbsite content towards upstream. The range in variation observed is 5.88% at station M3 to 13.84% at M8. During the postmonsoon season the stretch between M4 and M6 shows a high percentage of gibbsite. Mineral is not detected at station M8 and the content is quite low at M10. The range is from 0.0% to 9.49%.

Within the suspended sediments gibbsite shows high concentrations in mid reaches between stations M5 and M7, but decreases on either sides of this stretch. Its range in abundance is 3.28% to 8.68%. Monsoon sediments show a wide range from 1.98% to 6.55%. Highest value is at station M3 and lowest at M9.

In the present study, montmorillonite and kaolinite + chlorite are observed to be predominantly characteristic minerals in the mouth region and upstream end respectively although kaolinite + chlorite is quite high. The peaks reflecting the presence of kaolinite + chlorite could rather be considered as representation of kaolinite than chlorite since the former is more likely to prevail under the conditions typical of the study area.

In present study the estuarine sediments of Mandovi are rich in kaolinite, both in suspension and bed load. It should be noted that though montmorillonite has been found to be the most dominant mineral in tropical river sediments Irion[6], drew conclusion that in the fine grained, poorly drained sediments, predominantly montmorillonite is formed, while in coarsely crystalline rocks and coarse to medium grained sediments with high permeability and good drainage kaolinite is formed. This is well elucidated in Deccan Traps, along west coast of India, wherein the soils developed therein are supposed to be the source of montmorillonite

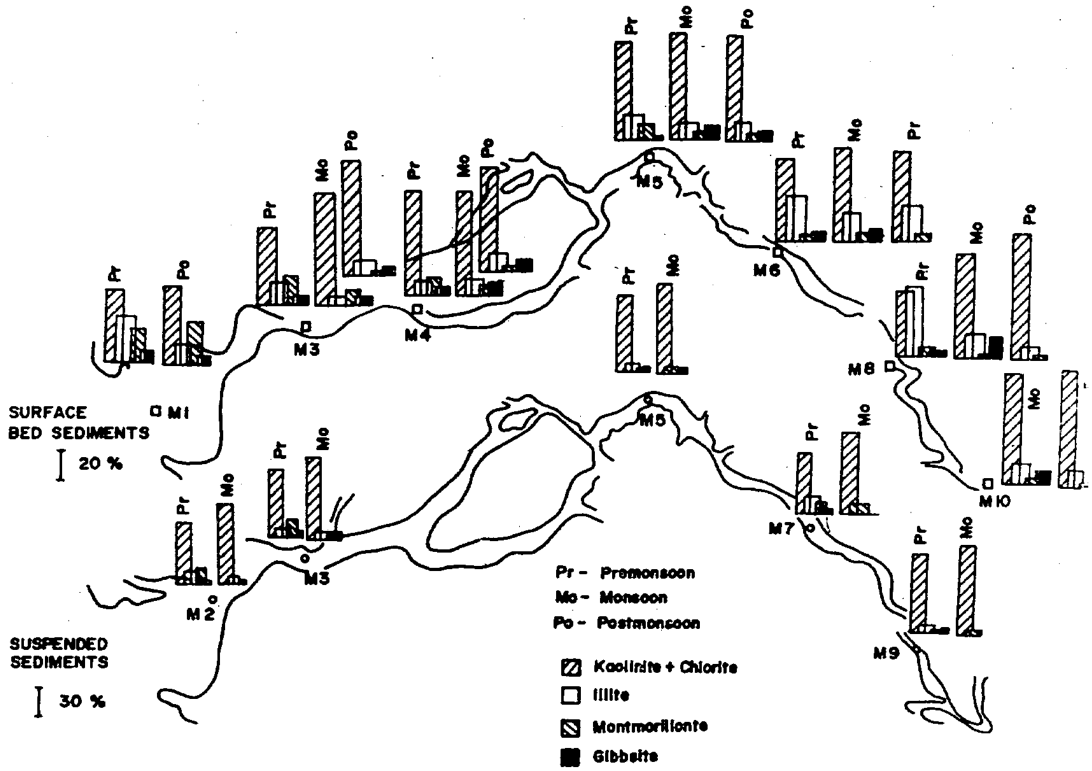

Fig. 3—Longitudinal variation in clay minerals.

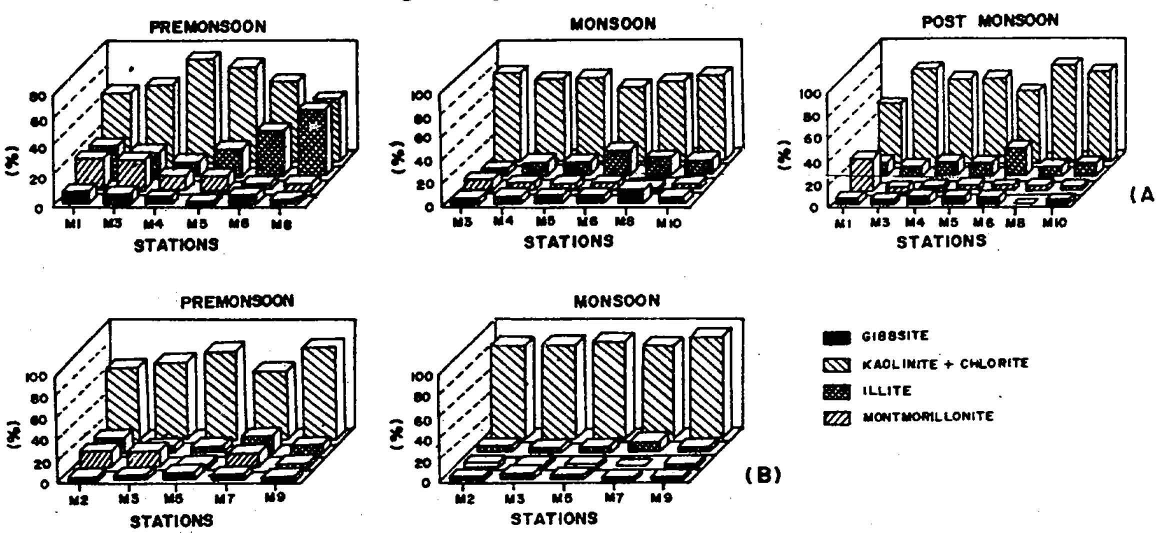

Fig. 4—Seasonal variations in relative abundance of clay minerals in bedload (A) and suspended load (B).

rich sediments[7-9] and subordinate kaolinite[10], found in the shelf. Here, limited leaching and moderate rainfall with restricted circulation has led to the development of montmorillonite. In the south, however extensive leaching aided by high rainfall and good drainage over porphyritic basalt has resulted in the origin of kaolinite[11]. Further south, there is a gradual decrease in montmorillonite as the lithology changes to crystalline metamorphics and phyllitic rocks. It should be noted here that geologically the Mandovi basin comprises of metamorphosed crystalline rocks, pink phyllites intercalated with ferrugenous bands, Greywackes, etc. and traversed by basic dykes, all weathered to varying degrees[12]. The type of hot and wet climate regimes acting on various rocks result in a variety of deep soil profiles (Chernozen soils and latisols) with extreme development of high alumina bauxite and highly ferrugenous laterite[4]. It is mentioned earlier that kaolinite as predominant mineral in Mandovi sediments with relatively high concentration in the upstream. Gibbsite and kaolinite are most important products of silicate alteration in laterites and lateritic soils wherein strong leaching produces moderate dislocation and results in the formation of kaolinite. While intense leaching results in complete dislocation so that octahedral layer remains free eventually crystallising to gibbsite[11]. It is clear from this study that large quantity of kaolinite is being released from the catchment area to the Mandovi.

The fact that illite decreases in down stream direction indicates that mineral is not influxed any where except at the upstream end. Here it seems to have been brought in by the two important tributaries, the Madei and the Khandepar. Illite, therefore must have originated from the metamorphosed crystalline rocks and argillites (phyllite) in the catchment area. It is clear from the earlier studies[1,13] that the illite is the most dominant mineral species of clay mineral in the argillaceous sedimentary rocks.

Higher concentration of illite observed at the mouth region may be attributed to the formation of this mineral from montmorillonite. It is observed that salinity is highest at this place. Montmorillonite converts to illite by absorbing more potassium ions from saline waters[14].

High abundance of montmorillonite is associated with highest salinity values and the fraction of the clay sediments[15], wherein it shows good correlation with clay fraction ($r = 0.858$), which is particularly dominant in lower estuary since a significant amount of this clay is supposed to have been brought in from the sea side, it could be assumed that an equally significant amount of clay minerals are brought in, too. Hence, montmorillonite shows a gradual but distinct decrease towards upstream, owing perhaps, to progressive settling and impoverishment.

In case of substantial amounts of montmorillonite being brought into the estuary from the hinterland, there should have been a higher accumulation of it in the vicinity of the confluence of the two main feeding tributaries, the Madei and the Khandepar in the upstream, especially in the premonsoon. During the season the flow velocity and corresponding currents are very weak in the upper reaches of the estuary[15] and montmorillonite owing to its small size forms aggregates and settles in high proportions at places where bottom currents are weak[14]. Thus one could expect higher concentrations at upstream end if a sufficient amount of the mineral is brought by the tributaries.

Correlation of montmorillonite with other minerals show $r = -0.577$ (kaolinite), -0.004 (gibbsite) and -0.068 (illite). This shows that the relative abundance of montmorillonite and its decreasing trend towards upstream does not acutally affect the overall profiles of other minerals and that it is less dependent on these.

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