Indian Journal of Marine Sciences
Vol. 20, March 1991, pp. 1-6

Clay mineral distribution in the continental shelf and slope off Saurashtra, west coast of India

V Purnachandra Rao
National Institute of Oceanography, Dona Paula, Goa 403 004, India
Received 6 March 1990, revised 27 November 1990

Clay mineral distribution in the sediments of the west coast of India indicates that the illite and chlorite-rich sediments, derived from the Indus, occupy the continental shelf of the northern part of the Gulf of Kutch. Montmorillonite derived from the Deccan trap coastal province is the predominant clay mineral in the sediments of the continental shelf south of the Gulf of Kutch. Lateral variations reveal that the montmorillonite contents are high in the innershelf and on the continental slope with relatively low values on the outershelf. Illite and chlorite contents are high on the outershelf. These variations are attributed to the influence of depositional environment and individual property of the clay minerals. Distinct differences in the nature of montmorillonite derived from basic and gneissic rocks are identified. Review of the clay mineralogy suggests that their distribution is related to the provenance, and the latitudinal zonation of clay minerals may not be valid in this part of the Arabian Sea.

Previous studies on clay mineralogy of the west coast of India are few and many of them are of regional interest[1-9]. Mattiat *et al.*[10] studied the clay mineralogy of the samples on a few widely spaced traverses of the continental shelf. A more detailed study was by Nair *et al.*[11] on the inner continental shelf. Clay mineralogy of the sediments of the Arabian Sea was also reported.[12-18] The objective of the present study is to provide the clay mineral distribution in the sediments of the continental shelf and slope off Saurashtra and also from the sediment samples of the southwestern part of the continental shelf.

Materials and Methods

Thirty five sediment samples were selected from the Saurashtra continental shelf and slope for the present study. In order to compare the clay minerals from Saurashtra shelf with those from the shelf to the far south, one sample from Goa and another sample from off Cochin (Fig. 1) have also been analysed for clay mineralogy. The procedure for texture of the sediments and identification and semi-quantitative determination of clay mineral abundance reported elsewhere[19] was followed.

Results and Discussion

Clay minerals in the sediment samples are montmorillonite, illite, kaolinite, chlorite and gibbsite. However, the relative abundance of clay minerals varied depending on the region. Sediment sample (st 31/01) of the northern part of the Gulf of Kutch (Fig. 2) shows that illite is the dominant mineral (45%) followed by kaolinite plus chlorite (32%) and montmorillonite (23%). The crystallinity value of montmorillonite is 0.3. Apparently, the clay mineral abundances in the south of the Gulf of Kutch are different from the north. Along the inner continental shelf of Saurashtra, montmorillonite dominates illite and progressively increases from 39% in the north (st 37/02) to 61% in the south (st 43/02) while the illite content decreases from 31 to 14%. Furthermore, the montmorillonite in this region has sharp reflections and has relatively higher crystallinity values (av. 0.65). Montmorillonite also dominates illite in the outer continental shelf and slope sediments in the northern part of the Saurashtra and there are not much variations with depth or with sediment texture. However, in the southern part of the Saurashtra, the relative percentage of montmorillonite is high (av. 52%) in the innershelf (about 50 m) and on continental slope (> 130 m) (av. 53%) sediments but, decreases to low (av. 35%) on the outershelf region (60-130 m). On the other hand, illite percentages are high (av. 30%) on the outershelf and low (20 %) on the inner continental shelf as well as on continental slope. The textural studies (Fig. 3) indicate that inner continental shelf and slope are silty clay/clayey silt while the outer shelf sediments are relict carbonate sands.

Higher concentrations of illite and chlorite in the sediments of the northern part of the Gulf of Kutch

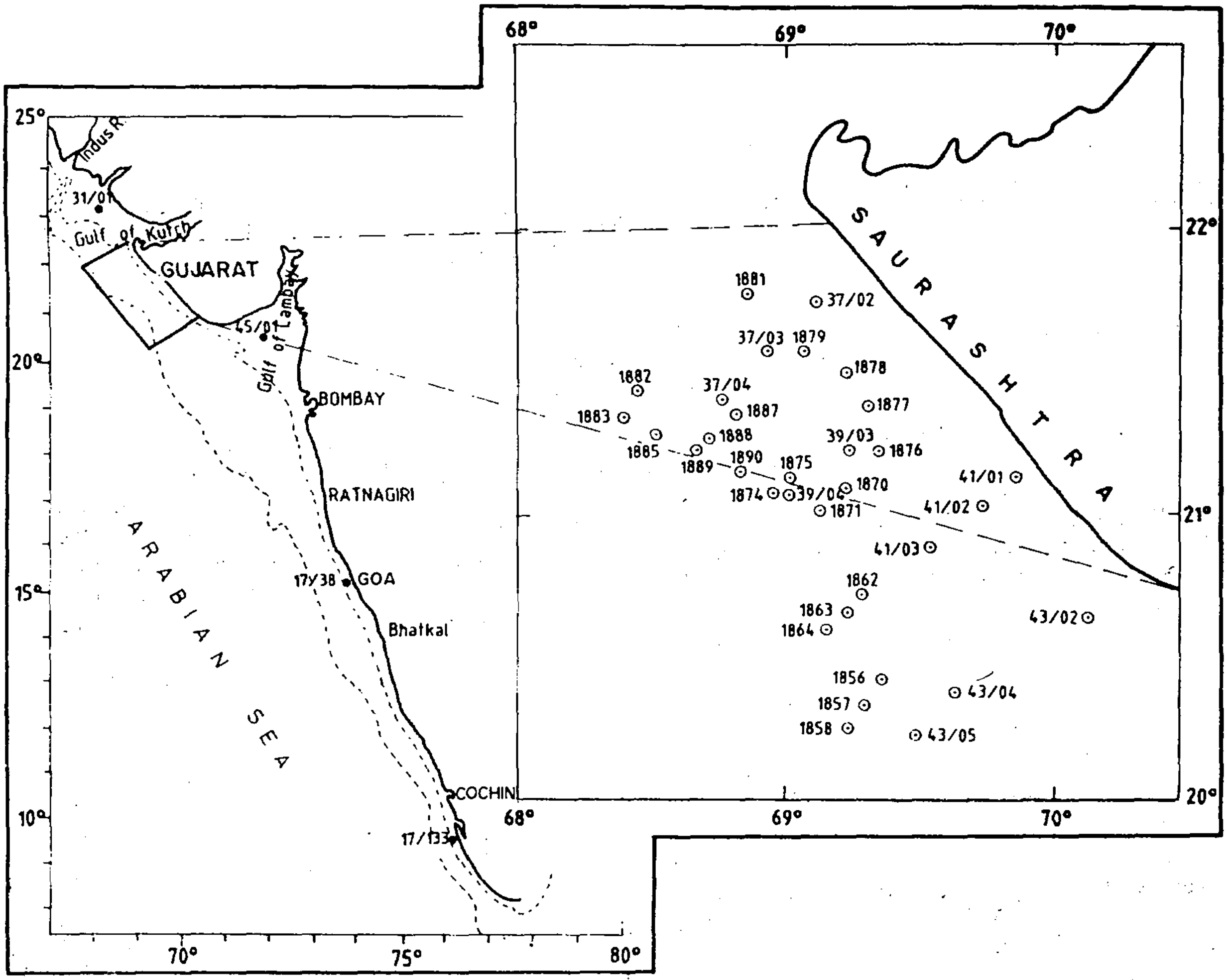

Fig. 1—Sample location

and their reduced values with a corresponding increase in montmorillonite and kaolinite in the south of the Gulf indicate that the sediments on either side of the Gulf are derived from two different sources. The river Indus located about 100 km northwest of the Gulf of Kutch, originates in Himalayas and carries sediment load, resulted from the glacial weathering of the rocks. Hence, illite and chlorite are the dominant clay minerals in the Indus discharge[20] and with the longshore transport these sediments are accumulated on the continental shelf in the northern part of the Gulf of Kutch. The sediments on the south of the Gulf of Kutch are enriched with higher concentrations of montmorillonite and kaolinite because, the onshore rocks in the Saurashtra peninsula are predominantly the Deccan traps. Deccan traps contain[21] significant amounts of Mg, Na and a low content of K. The weathering under conditions of semi-arid, moderate rainfall (50 $cm.y^{-1}$) leads to poor drainage and thus permits magnesium to remain in the weathering zone after it is released from the parent rocks. Therefore the montmorillonite would form as an abundant clay mineral in the semi-arid climate. The two different types of sediments enriched with different abundance of clay minerals resulted because, the macrotides operating at the Gulf of Kutch, to some extent, act as barriers to the longshore sediment transport. Nair *et al.*[4] and Hashimi *et al.*[22] studied textural distribution, mica content and clay minerals of the sediments and topography on either side of the Gulf and attributed the differences due to the tidal effect.

Illite concentrations are relatively high in the northern part of the continental shelf (inner and outer) off Saurashtra and reduce southwards suggesting that the illite that escaped from barrier effect of tides may be depositing in the northern part of the shelf. Very high concentrations of montmorillonite on the innershelf off Saurashtra indicate that source rocks in the onshore influences more on the clay mineral composition as compared to the longshore transport from Indus.

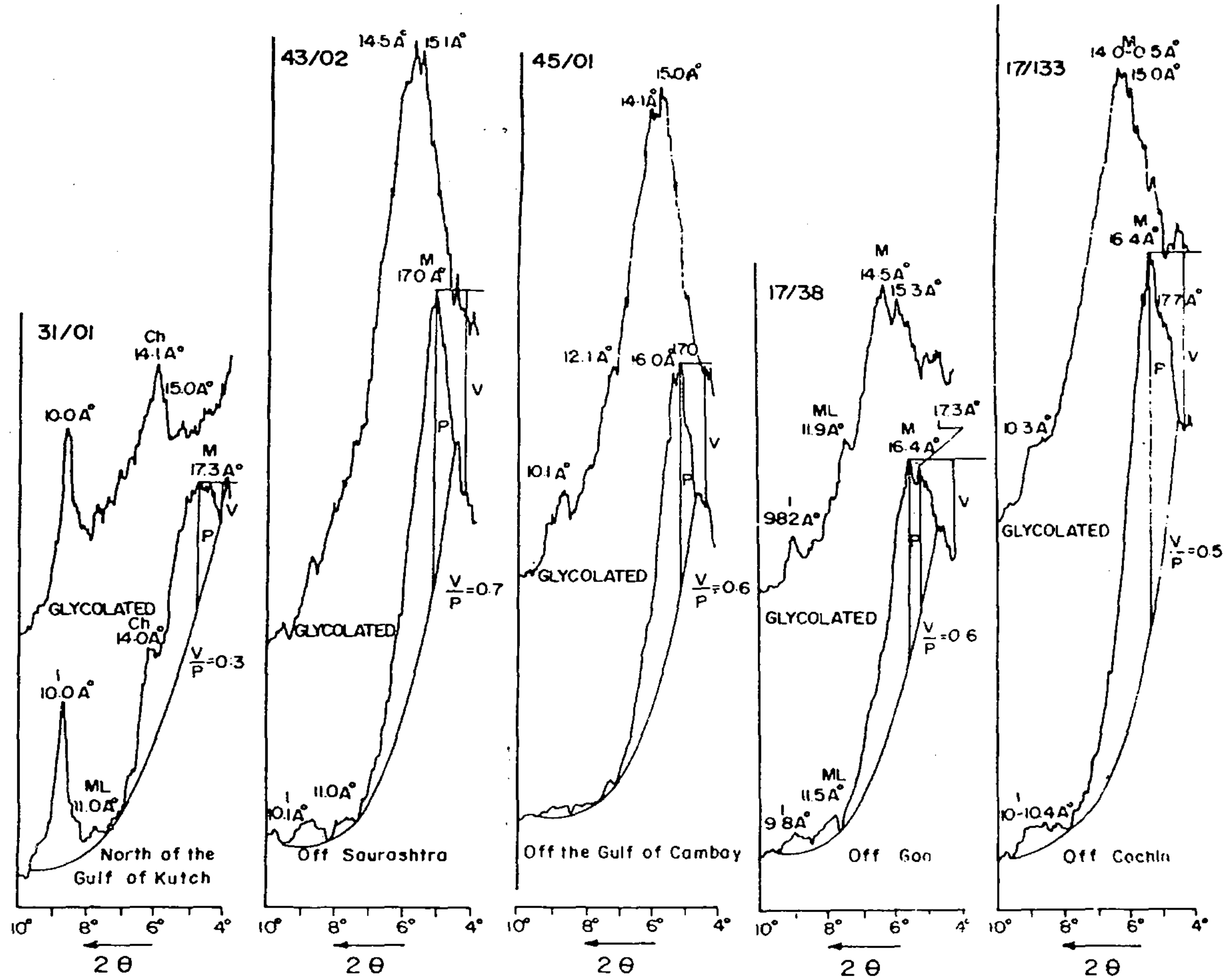

Fig. 2—Unglycolated and glycolated X-ray patterns showing montmorillonite (M) and illite (I) in the innershelf sediments. (V/P is the crystallinity of montmorillonite)

The clay minerals in the southern part of the Saurashtra shelf showed significant variation in their distribution from inner and outer continental shelf and on the continental slope and varied with sediment type (Fig. 3). Clayey sediments characteristic of higher organic matter (about 3%) and higher montmorillonite content are associated with the innershelf and on continental slope. On the other hand, the outershelf consists of relict sandy sediments ($< 10\%$ clay) with poor organic matter ($< 1\%$) and relatively less montmorillonite content. Hence the clay minerals present in these sediments are attributed to the influence of depositional environment and their affinity with the organic matter. Montmorillonite exhibits preferential settling, aggregates and settle more in the low energy environment.[23] Montmorillonites have relatively high surface area and thus adsorb more dissolved organic substances and as a consequence optimum aggregation occurs with this mineral. Results based on laboratory experiments[24] indicate that the organic compounds such as sugars and amino acids readily form polymers known as melanoidins whose formation is highly favoured in the marine environment. The montmorillonite bonds with melanoidins with greater intensity than the other clay minerals. Degens and Ittekot[25] studied trap samples and found that the peaks of high terrigenous flux are in accord with the high productivity in the surface layers and suggested that the organic matter acts as an agent to carry the terrigenous flux to the sediments. Therefore it is suggested that high montmorillonites in the innershelf and on continental slope are due to the effect of depositional environment and organic productivity which leads to the removal of high montmorillonite content from the surface layers and transport to the underlying sediments.

Montmorillonite grain size is smaller than

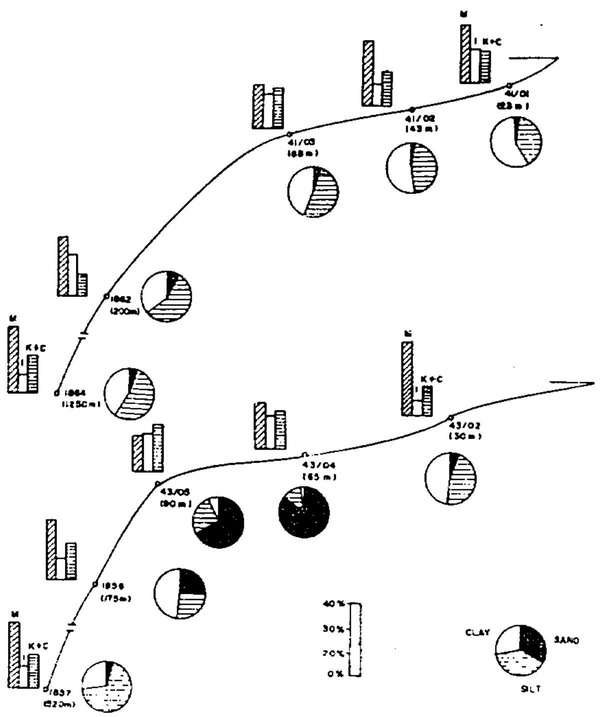

Fig. 3—Profiles showing clay mineral distribution in the continental shelf and slope sediments off Saurashtra

kaolinite and illite as demonstrated by settling velocity study of the minerals[26], tends to remain in suspension longer, settles relatively less in the non-depositional environment. Since outershelf is a non-depositional environment as evidenced by the occurrence of Late Pleistocene relict sandy sediments (< 10% clay) and less organic matter, montmorillonite thus selectively winnows to the slope region. Ramaswamy and Nair[7] also reported low montmorillonite and relatively high concentrations of illite and kaolinite + chlorite in the outershelf region extending from Saurashtra in the north to Cochin in the south and in the sediment trap samples and interpreted the outershelf clays to be the Indus derived. If this interpretation is correct, the adjacent continental slope sediments are also expected to have high concentrations of illite and, kaolinite and chlorite but, montmorillonite is the dominant mineral in the slope sediments (Fig. 3, Table 1). Kolla *et al.*[18] also reported smectite-rich zone all along the continental margin. Furthermore, the ^{210}Pb excess dating of the core sediments[27] suggests that modern clays are accumulating on the continental slope. In view of the above it is suggested that the cross shelf variations in the distribution of clay minerals are due to the influence of depositional processes and individual property of clay minerals; this results bypassing of clay minerals on the outershelf and deposit on the continental slope.

The sediment sample off the Gulf of Cambay (st 45/01) consists of highest concentrations of montmorillonite (74%) followed by kaolinite + chlorite (18%) and illite (18%). The crystallinity value of montmorillonite is 0.6 (Fig. 2). Mixed layer reflections occur in the glycolated X-ray patterns. Illite reflections are broad and diffuse, and appear to be a degraded variety. High montmorillonite may reflect the weathering products of Deccan trap basalts carried by rivers Narmada and Tapti. Suspended and bed loads collected from the estuaries of these rivers revealed abundant montmorillo-

Table 1—Distribution of major clay minerals (2 μm fraction) and texture of the sediments of the western continental shelf and slope of India

Sample No	Depth (m)	Texture of the sediment	Weighted peak area % of			M/I
			M	I	K+C	
31/01	20	Silty clay	23	45	32	0.5
37/02	35	Clayey silt	39	31	30	1.2
41/01	23	Silty clay	47	27	26	1.7
41/02	42	Silty clay	54	18	28	3.0
43/03	40	Silty clay	61	14	25	4.3
45/01	25	Silty clay	74	8	18	9.2
17/38	38	Silty clay	51	9	40	5.7
17/133	35	Silty clay	55	6	39	9.1
1879	56	Silty sand	49	29	22	1.7
37/03	50	Clayey silt	46	30	23	1.5
1881	65	Sand	35	24	41	1.5
37/04	90	Clayey silt	46	29	25	1.6
1882	215	Sand silt clay	43	24	33	1.8
1883	310	Silty sand	42	31	27	1.4
1885	285	Silty sand	6	53	41	0.1
1889	110	Clayey silt	35	28	37	1.3
1890	200	Clayey silt	43	34	23	1.3
1888	210	Clayey silt	51	22	27	2.3
1887	750	Clayey silt	32	32	36	1.0
1877	53	Silty clay	45	35	20	1.3
1878	54	Silty clay	49	24	27	2.0
39/03	70	Silty sand	42	30	28	1.4
39/04	120	Clayey sand	41	28	31	1.5
1875	130	Sand	28	41	31	0.7
1874	900	Clayey silt	17	48	35	0.4
1876	63	Silty sand	45	28	27	1.6
1870	85	Sandy silt	50	22	28	2.3
1871	165	Clayey silt	51	23	26	2.2
41/03	65	Clayey silt	37	29	34	1.3
1867	1205	Clayey silt	54	16	30	3.4
1862	200	Clayey silt	48	34	18	1.4
1863	765	Clayey silt	38	36	26	1.1
1864	1250	Clayey silt	58	16	26	3.6
43/04	65	Sand	39	29	32	1.3
43/05	90	Silty sand	30	31	39	1.0
1856	175	Sandy silt	51	18	31	2.8
1857	520	Clayey silt	55	17	28	3.2
1858	970	Silt	9	43	48	0.2

M = montmorillonite; I = illite; K + C = kaolinite + chlorite.

nite.[28-30] Bhattacharya[8] reported that montmorillonite is the dominant clay mineral everywhere on the continental shelf (between Bombay and Saurashtra) followed by expandable mixed layers and minor amounts of kaolinite and traces of degraded illite. Relative amounts of mixed layers and kaolinite vary in the samples off Maharashtra and Saurashtra. He further reported the close similarity in the mineral composition in all varieties of samples and concluded that diagenesis has insignificant effect on clay mineral alteration.

In the sediments off Goa and Cochin, the relative percentage of montmorillonite is low (av. 53%) and kaolinite + chlorite is high (av. 40%). Crystallinity values of montmorillonites are about 0.6 (Fig. 2). Illite content is lowest (av. 8%) in this region. The increase in kaolinite and chlorite content is mainly due to the increase of kaolinite content. Kaolinite is a typical product of chemical weathering of continental rocks under humid tropical conditions. This change (i.e. the increase of kaolinite) has taken place because the onshore rocks that is the Deccan traps, in the north change to Precambrian acidic rocks in the south. This changeover in geology occurs around Goa and is reflected in the offshore sediments of that region. The transition region off Goa is also evidenced by two types of montmorillonite. For example, glycolated X-ray diffractograms showed principal peak positions of montmorillonite at 17 A° in the northern part (Saurashtra and Gulf of Cambay), while in the southern part (off Cochin) (Fig. 2) it occurs at 16.4 A°. The sediments off Goa which represent a transition region contain both 17 A° and 16.4 A° reflecting the transition in the onshore region. Gibbsite occurs as a minor mineral in the sediments off Kerala and was also reported earlier.[5,11]

Mattiat *et al.*[10] have studied the clay minerals in the sediment samples of the western continental margin and indicated that illite, illite-montmorillonite, montmorillonite and montmorillonite mixed layers are important in the sediments off Karachi, Saurashtra, Bombay and between Vengurla and Cochin respectively. Nair *et al.*[11] studied sediment samples of the inner continental shelf and based on the ratio of montmorillonite (M) to kaolinite (K), they divided the entire shelf into 4 regions—(1) montmorillonite, illite, kaolinite and chlorite zone in the northern part of the Gulf of Kutch; (2) montmorillonite-rich zone ($M/K = 3.5$) with minor amounts of kaolinite and illite extending from Saurashtra to Ratnagiri; (3) a transition zone consisting of montmorillonite, kaolinite and illite with M/K ratio of 1.5 to 2 between Ratnagiri and Bhatkal; and (4) montmorillonite poor zone (av. $M/K = 1.3$) from south of Bhatkal to Cochin. Highest concentrations of kaolinite in the mud banks which occur at 10 m depth off Cochin are attributed to the extensive kaolin deposits on the Kerala coast.[2,3]

Gorbunova[13] and Rateev *et al.*[14] reported 80% illite, 20% chlorite in the Arabian Sea sediments and suggested that the clay minerals follow a latitudinal zonation. Goldberg and Griffin[16] and Kolla *et al.*[17,18] reported illite-rich sediments (40-50%) in the Indus fan and smectite-rich zone all along the indian margin and believed that the former are supplied by the Indus and latter by Narmada and Tapti rivers and have been subsequently dispersed by prevailing southerly and to some extent by northerly surface currents. These workers have suggested the detrital nature of clay minerals and their distribution in the ocean is being controlled by the oceanic circulation and concluded that the near perfect latitudinal localisation of clay minerals as suggested[13,14] is not valid in certain parts of the Indian ocean.

Acknowledgement

Author thanks Dr B N Desai, Director, Mr P S N Murty, Head, GOD and Mr R R Nair, Project leader, for the encouragement.

References

1 Stewart R A, Pilkey O H & Nelson B W, *Mar Geol*, 3 (1965) 413.
2 Nair R R & Murty P S N, *Curr Sci*, 37 (1968) 589.
3 Nair R R, *American Ass Petrol Geol Bull*, 60 (1975) 616.
4 Nair R R, Hashimi N H & Rao V P, *Mar Geol*, 47 (1982a) 77.
5 Rao V P, Nair R R & Hashimi N H, *J Geol Soc India*, 24 (1983) 540.
6 Ramaswamy V, in *Particulate flux in the ocean*, edited by E T Degens, E Izdar & S Honjo (Selbstverlag des Geologisch Paleontologichen Institute Univ. Hamburg) 1987, 232.
7 Ramaswamy V & Nair R R, *J Coastal Res*, 5 (1989) 541.
8 Bhattacharya N, *J Geol Soc India*, 25 (1984) 427.
9 Srivastava N K, *Proc Indian Acad Sci*, 58 (1970) 6.
10 Mattiat B, Peters J & Eckhardt F J, *Meteor Forsch-Ergebrisse*, 14 (1973) 1.
11 Nair R R, Hashimi N H & Rao V P, *Mar Geol*, 50 (1982b) M 1.
12 Biscaye P E, *Geol Soc America Bull*, 76 (1965) 803.
13 Gorbunova Z N, *Oceanology*, 6 (1966) 215.
14 Rateev M A, Gorbunova Z N, Lisitzin A P & Nosov G L, *Sediment*, 13 (1969) 21.
15 Griffin J J, Windson H & Goldberg E D, *Deep-Sea Res*, 15 (1968) 433.
16 Goldberg E D & Griffin J J, *Deep-Sea Res*, 17 (1970) 513.
17 Kolla V, Henderson L & Biscaye P E, *Deep-Sea Res*, 23 (1976) 949.
18 Kolla V, Kostecki J E, Robinson F & Biscaye P E, *J Sediment Petrol*, 51 (1981) 563.
19 Rao V P, Reddy N P C & Rao Ch M, *Continental Shelf Res*, 8 (1988) 145.

20 Konta J, *Transport of carbon and minerals in major world rivers*, edited by E T Degens & S Kempe (Milleiumgen aus dem geologischen Paleontologichen Institute Univ. Hamburg) 1985, 569.
21 Karkare S G, *Geochemical studies of the Deccan traps*, Ph D thesis, Banaras Hindu University, 1965.
22 Hashimi N H, Nair R R & Kidwai R M, *Indian J Mar Sci*, 7 (1978) 1.
23 Stanley D J & Liyanage A N, *Mar Geol*, 73 (1986) 263.
24 Hedges J I, *Geochim Cosmochim Acta*, 42 (1978) 69.
25 Degens E T & Ittekkot V, in *Nord - Sud Profile: Zentraleuropa-Millelmeerraum - Afrika*, edited by G Knitsch (Im Selbstverlag des Geologisch - Paleontologischen Institutes der Univ. Hamburg) 1984, 229.
26 Whitehouse G, Jefferies L M & Debbercht J D, *Clays Clay Minerals*, 7(1960) 1.
27 Borole D V, *Mar Geol*, 82 (1988) 285.
28 Subramanian V, *Mar Geol*, 36 (1980) M 29.
29 Bhaskaran M, Sarin M M & Somayajulu B L K, *Chem Geol*, 45 (1984) 33.
30 Naidu A S, Mowatt T C, Somayajulu B L K & Rao K S, in *Transport of carbon and minerals in major world rivers*, edited by E T Degens & S Kempe (Milleiumgen aus dem geologischen Paleontologischen Institute Univ. Hamburg) 1985, 559.