

Journal of
The Indian Association of
Sedimentologists

Proceedings of the 5th Convention

1985

Editors

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Department of Geology
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HYDERABAD.

Volume 8

1989

THE INDIAN ASSOCIATION OF SEDIMENTOLOGISTS
ALIGARH.

CLAY MINERAL DISTRIBUTION ON TROPICAL SHELF : AN EXAMPLE FROM THE WESTERN SHELF OF INDIA

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Abstract

Clay mineral determinations have been made on the less than 2 μm fraction of 67 surficial sediment samples from the inner shelf consisting of six depositional environments along the west coast of India. Montmorillonite is the most dominant clay mineral in all the depositional environments. This is due to the coverage of a vast area by the Deccan Trap Basalts and the laterite along the coast. Hence, the other clay minerals are used here to retrace the signatures of the different environmental/lithological zones occurring on the west coast. The area of Gulf of Kachchh and the area north of it show relatively higher abundance of chlorite and illite which is due to the influence of Indus river. Towards the southern part of western coast, the relative percentage of montmorillonite decreases, whereas towards the shield rocks area (south of 15° N lat.) the relative percentage of kaolinite shows an increasing trend along with the appearance of gibbsite mineral. The mineralogy and the geographic distribution of the clays in these samples reflect the source lithologies.

INTRODUCTION

Clay mineralogy of the surficial sediments has been used widely as a first order guide to the source, environment and transport paths of fine grained sediments (Grim, 1959; Biscaye 1965; Griffin et al., 1968). During the studies of the sediment samples of the western continental margin of India from the Indus Canyon in the north to the Cape Comorin in the south, the need for a regional reconnaissance clay minerals investigation was realised. The major purpose is to evaluate the type and amount of the clay minerals present in the different sedimentary environments present in the western continental shelf of India and their relationship with the provenance.

MATERIAL AND METHODS

The samples used in the present study (Fig.1) were selected from the National Institute of Oceanography's collection of the samples from the west coast of India, collected during the different cruises of INS DARSHAK and RV GAVESHANI by using the La Fond Dietz snapper and Van Veen grab.

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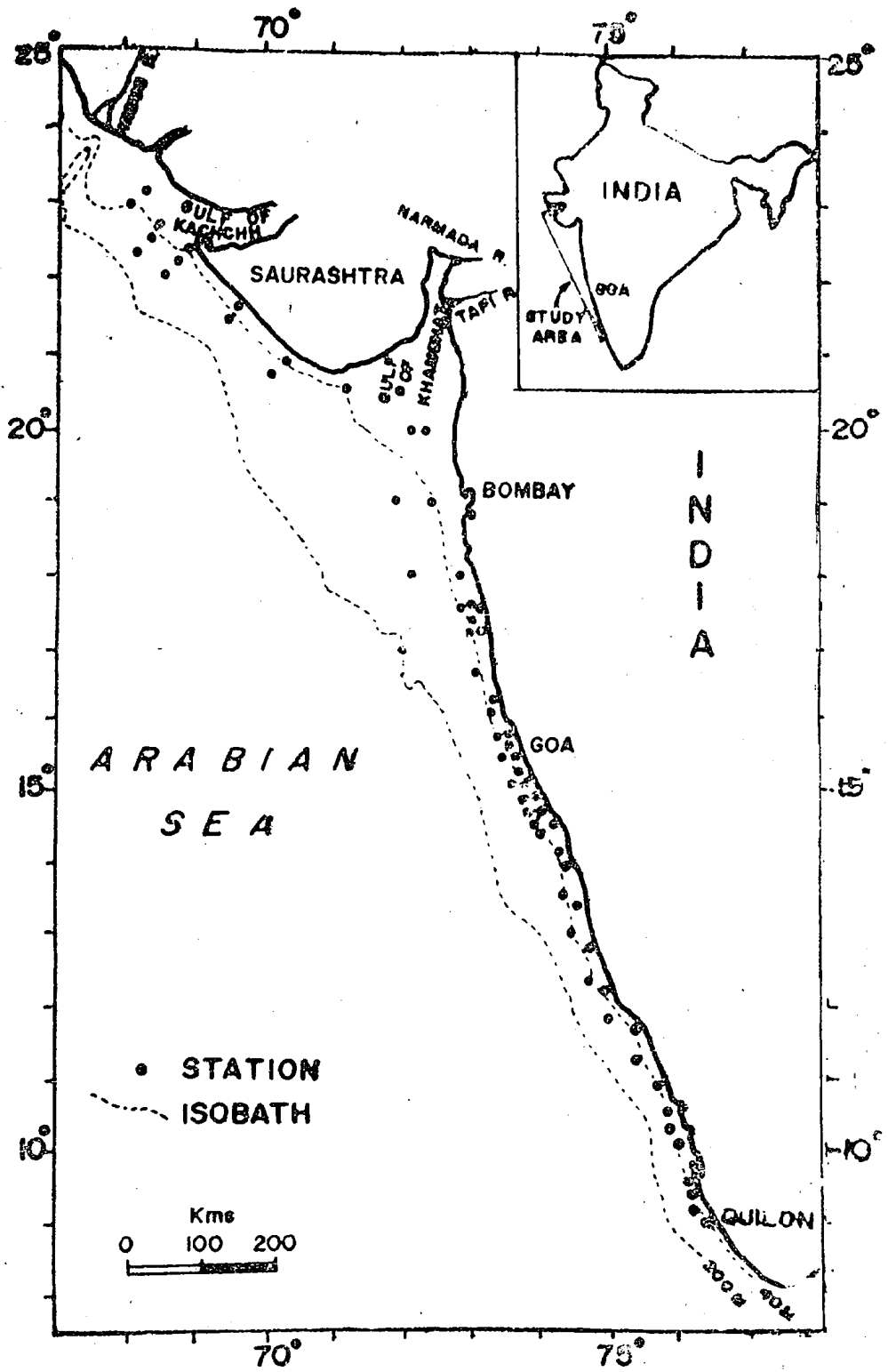


Fig. 1. Samples locations map, and bathymetry of the area.

Calcium carbonate and organic matter free clay fraction of the sediments were obtained by standard sedimentation methods and the oriented samples of less than $2\ \mu\text{m}$ fraction were prepared by pipetting on the glass slides. The slides were scanned from 4° to $30^\circ\ 2\theta$ at 2° per minute, with slow scanning at 1° and 0.5° per minute for selected reflections on a Philips X-ray diffractometer using Nickel filtered, $\text{Cu K}\alpha$ radiations, proportional counter and pulse height analyser. The instrumental setting were 20 mA, 40 kV, 4 seconds time constant and range of 400 and 1000 counts per seconds. Standard tests were carried out for confirmation of montmorillonite by glycolation and for chlorite by acid treatment (1 N HCl at $80^\circ\ \text{C}$ for an hour; Carrol, 1970; Thorez, 1975). The relative proportions of the clay minerals were determined by measuring the area of their principal reflections, in many cases the average of replicate measurements, by a polar planimeter. The percentage of the major and minor clay minerals thus determined are shown in Figs. 3A-F. Duplicate analyses show that the results are accurate to within 10% for montmorillonite and about 5% for Kaolinite. All the identifications of the clay mineral in this paper are confined to group level of Brindley et al. (1968).

In addition to the continental shelf samples analyses were also carried out on a variety of other samples for comparison purposes. These consisted of (i) analyses of kaolinite (unoriented sample and cavity mount) occurring as pocket in the local coastal laterites, to compare their degree of crystallinity to that of kaolinites in the sediments (ii) whole rock laterite (ground to $63\ \mu\text{m}$ cavity mount) to ascertain whether or not montmorillonite content really exceeds the kaolinite content in these rocks. Cavity mounts do not lead to the possibility of enhancement of the montmorillonite reflection at the expense of the kaolinite reflection whereas, the possibility of such an occurrence has been reported by Gibbs (1965) in the case of samples prepared by the pipette-on-glass slide method. This artifact is due to the smaller grain size of the montmorillonite mineral which tends to segregate as the upper most layer on a glass slide sample, (iii) confirmation of the presence of gibbsite in the country rocks was obtained by analysing whole rock laterite samples, the diffractograms showed sharp peaks of gibbsite at 18.3° and 20.3° (iv) a few samples from the local estuary (the Mandovi) to ascertain qualitatively the estuarine clay contribution to inner shelf. All the estuarine samples showed that montmorillonite level exceeded those of kaolinite. The results of the above analyses being of a qualitative nature, are not shown in the Fig. 3.

CLIMATE AND GEOLOGY OF THE WEST COAST OF INDIA

Climate : The west coast of India extends from $8^\circ\ \text{N}$ to about $24^\circ\ \text{N}$. Within this domain are present a variety of climatic conditions. The northern part borders the Tropic of Cancer and is a region of semi-arid climate having high temperature

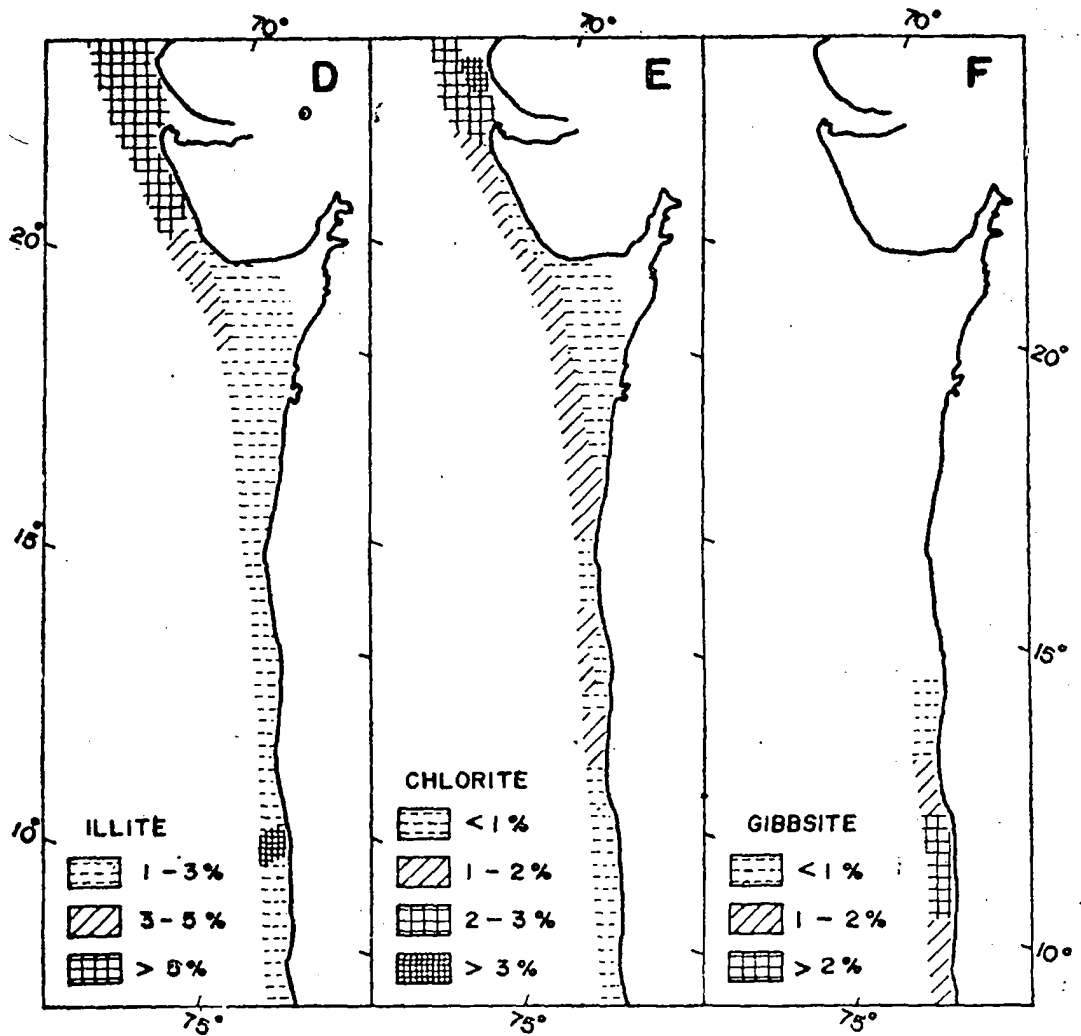


Fig 3. Distribution of (A) clay size fraction (B) montmorillonite (C) kaolinite ; (D) illite (E) chlorite (F) gibbsite in the shelf sediment samples.

(>40°C) and low rainfall (300 mm/Year). In this region lies the Gulf of Kachchh which receives little run off from land. It is a macrotidal (range of tide 3 to 6 m) bay and has high tidal velocities which act as a dynamic barrier to longshore sediment transport (Nair et al., 1982 a). South of this indentation is the semi-arid Saurashtra peninsula having the exposures of Deccan Traps and Recent alluvium. The other Gulf viz. Gulf of Khambhat has a large quantity of sediment supply through the rivers Sabarmati, Mahi Sagar, Narmada, Tapi, and is also macrotidal (range of tide 4 to 10m). To the south of Gulf of Khambhat is the region of the open ocean coast the dominant climatic feature of which is the tropical monsoon regime (rainfall 3000 mm/Year) where about 97% of the total rainfall during the three months, i.e. from June to August, the remaining months being by and large dry.

During the monsoon a few important changes take place in the waters of the shelf. They are (1) the shelf waters receive the maximum input of terrigenous sediment, (ii) a south flowing monsoon current is generated in response to the south-west monsoon wind system, (iii) upwelling of bottom water take place. Of these, the first two processes are involved in the transport and deposition of fine grained sediments whereas the role of the later is unknown, except that upwelling may be a process involved in the transfer and recycling of suspended clay minerals to the estuary and shelf.

Geology : Areally the two most extensive rock types significant to the generation of clay minerals are the basalts of the Deccan Traps which occur over an area of 500,000 km² and the Pre-Cambrian granites, schists and gneisses of the southern part of the peninsular India (Fig. 2). The approximate boundary on the coast of these rock types is at the latitude of Goa (15° N). Relative to the above two rock types, quantitatively insignificant outcrops of Tertiary rocks occur at certain coastal localities. The hot and wet climatic regime acting on the various rocks results in a variety of deep soil profile (chernozeamic soils and latosols) with extensive development of high aluminous (bauxite) or highly ferruginous (laterites) deposits.

The following depositional/environmental zones are demarcated to identify the types and extent of the clay minerals and their relationship with the provenance and the climate (i) Gulf of Kachchh (ii) Saurashtra coastal zone (iii) Gulf of Khambhat (iv) Deccan trap dominated coastal zone (v) Transitional zone and (vi) Shield rock dominated coastal zone (Fig. 2).

SEDIMENTARY FRAMEWORK OF THE WESTERN SHELF

Two principal types of sediment facies are present (i) the relatively shallow water modern terrigenous facies and (ii) the deep water relict calcareous sand facies. The modern terrigenous facies extends as a prominent band from the proximity of the river Indus in the north to Quilon in the south, a distance of about 1700 km. They extend seaward in water which varies from 40 to 60m depth and to a maximum distance from the shore of about 160 km off the Gulf of Khambhat. On the central and the south western parts of the shelf the width of the terrigenous facies zone is reduced and it is confined to within 35 km from the shore. South of the latitude of Quilon this facies ends and calcareous sand facies starts (Nair and Pylee, 1968; Nair, 1971; Nair et. al., 1978; Hashimi et. al., 1981). The amount of clay size fraction in the sediment samples of the inner shelf along the west coast of India is shown in Fig. 3A.

RESULTS AND DISCUSSIONS

The nature of clay minerals depend upon the (a) climate, (b) lithology, (c) weathering processes and (d) diagenesis. The clay minerals distribution pattern in the different sedimentary environments of the continental shelf is in turn a function of the oceanographic processes prevailing in the shelf waters. Further, complicating

the results is the fact that the same mineral can result from a variety of rocks under different weathering conditions. For example, the coastal laterites contain both montmorillonite and kaolinite, but the former exceeds the later. The bulk of the sediment input to the western shelf occurs during the south west monsoon rainy season and dispersal takes place in all probability, during when the clay minerals are deposited on the seabed, their cohesive nature due to their fine grain size and high organic carbon content may prevent their erosion and transportation. In the light of these facts the distribution of the clay mineral will be discussed in the various sedimentary environments. The following clay minerals (Figs 3B-F, Table-I) are identified in these sediments (i) montmorillonite, (ii) kaolinite, (iii) illite, (iv) chlorite and (v) gibbsite. Non-clay minerals are quartz and feldspars and they occur in minor quantities in the fraction of less than $2 \mu\text{m}$. Montmorillonite is the most dominant mineral in the sediment samples (Stewart et al., 1965; Nair et al., 1982; Bhattacharya, 1984) of all the different depositional environments of the study area (Fig. 3, Table-I).

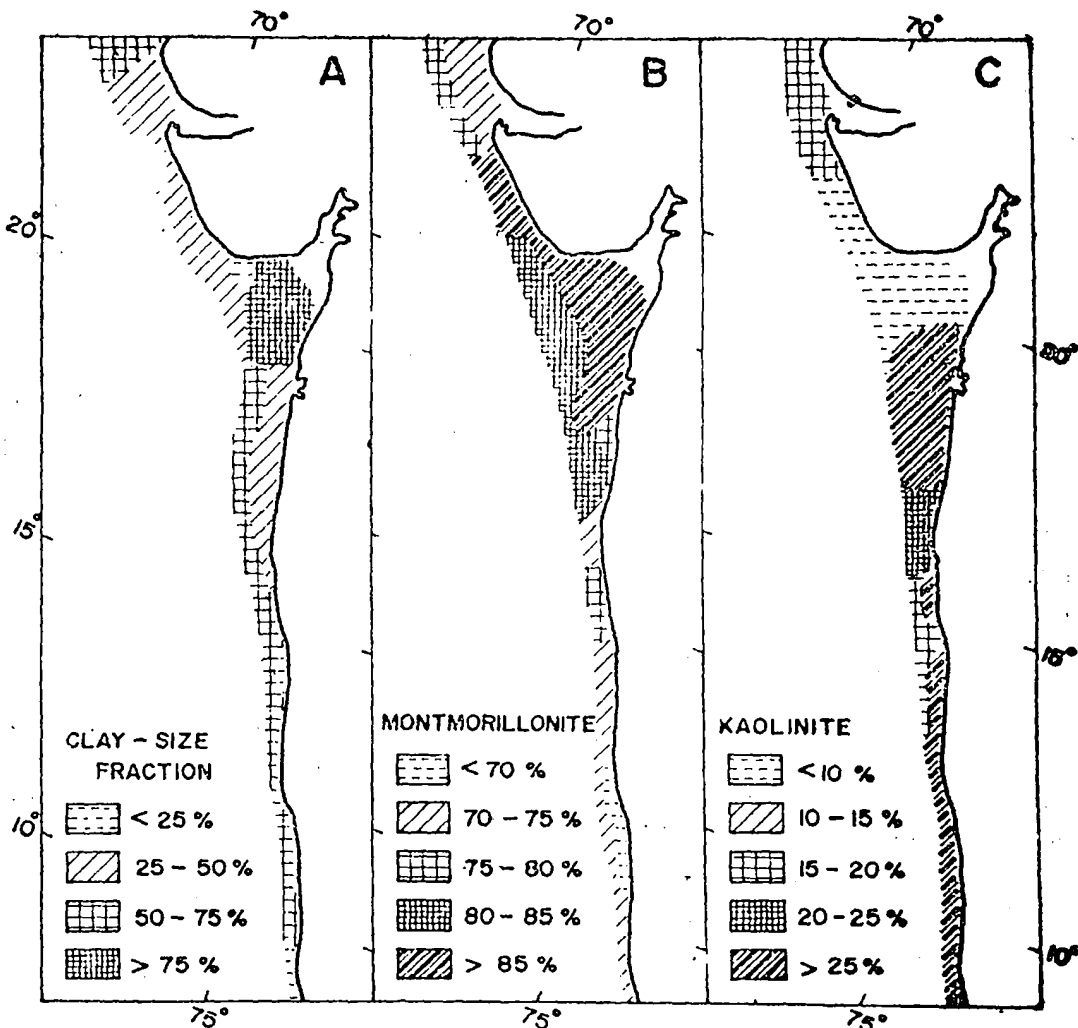


Fig. 3. Distribution of (A) Clay size fraction (B) montmorillonite (C) Kaolinite (D) Illite (E) chlorite (F) gibbsite in the inner shelf sediment samples.

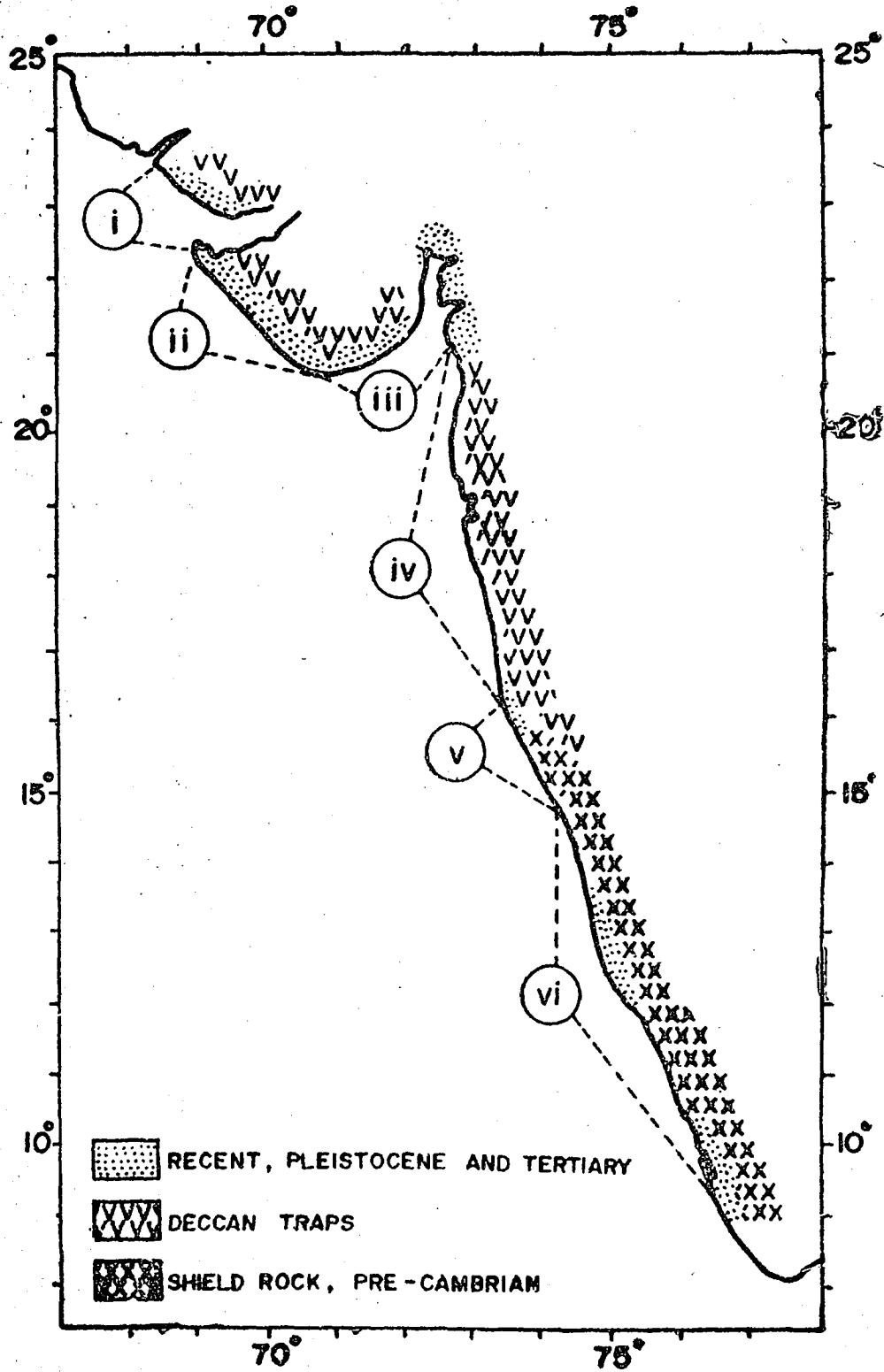


Fig. 2 Coastal Geology and the demarcation of zones i) Gulf of Kachchh ii) Saurashtra Coastal Zone iii) Gulf of Khambhat iv) Deccan Trap Dominated coastal zone v) Transitional zone vi) Shield rock dominated coastal zone

(i) **GULF OF KACHCHH** : Barring montmorillonite, illite and chlorite are showing relatively higher percentage compared to the other areas. The range for illite (Fig. 3D) is between 5 and 9% (average 7%) and for chlorite (Fig. 3E) 1 and 4% (average 3%). Kaolinite (Fig. 3C) ranges from 17 to 22% (average 18%). It is a well known fact that chlorite occurs in greater concentration generally in the intermediate stages of leaching in temperature soils. It also occurs in the arid regions both high and low latitudes, or the distribution reflects the abundance of chlorite in mechanically weathered rocks of the colder parts of the continent where the soil processes do not result in the chemical alteration of chlorite into other minerals. Most of the clay minerals on this part of the shelf is brought by the river Indus having its origin in the higher altitudes of the Himalayas. This reason, together with the fact that the Gulf receives no significant sediment contribution from the surrounding land makes the clay minerals association unusual.

(ii) **SAURASHTRA COASTAL ZONE** : In this depositional environment montmorillonite is present in the highest percentage i.e. 87 to 94% (average 90%) followed by the kaolinite which ranges between 4 and 8% (average 6%). This dominance is attributed to the effect of limited leaching under moderate rainfall. Chlorite and illite are sharply reduced in quantity because of the tidal barrier (Nair et al., 1982 a).

(iii) **GULF OF KHAMBHAT** : This is the region where two major rivers Narmada and Tapi bring their sediment load from different provinces. Nevertheless no marked mineral change is found and very little differences are noticed in the average values in the distribution of montmorillonite, illite and chlorite.

(iv) **DECCAN TRAP DOMINATED COASTAL ZONE** : The major difference from the Saurashtra area is that this area receives much higher rainfall but has comparatively low temperature. These parameters provide the variation in the distribution of clay minerals. The average amount of montmorillonite is 81% within the range of 71-86%. Kaolinite percentage increases ranging between 10 to 25% with an average of 14%. Illite and chlorite abundance is not very significant. This region is on the whole comparable to that of Gulf of Khambhat, despite the fact that there are no rivers comparable to Narmada and Tapi flowing into the sea in this region.

(v) **TRANSITIONAL ZONE** : This is the area where the two main rock types of the west coast of India come in contact with each other. The change in the lithology is reflected in the clay mineral distribution. The kaolinite's relative percentage increases (average 22%) while the montmorillonite percentage decreases (average 75%).

(vi) **SHEILD ROCK DOMINATED COASTAL ZONE** : In this zone completely different type of rocks are exposed compared to the previously described. These rocks are granites, gneisses and schists. The presence of these rocks are reflected in the distribution of the clay minerals of the shelf in the form of high percentage of

TABLE - 1

Area	Montmorillonite %	Kaolinite %	Illite %	Chlorite %	Gibbsite %
1. Gulf of Kachchh	69-74 (74)	17-22 (18)	5-9 (7)	1-4 (3)	—
2. Saurashtra	87-94 (90)	4-8 (6)	1-7 (4)	5-1.5 (15)	—
3. Gulf of Khambhat	81-92 (87)	7-15 (10)	0.7-3 (1.5)	0-1.2 (.8)	—
4. Deccan Trap	71-86 (81)	10-25 (14)	1-3 (2)	0-2 (1)	—
5. Transitional	71-81 (75)	18-28 (22)	1-3 (1.7)	0-2 (0.7)	—
6. Shield rock	67-75 (70)	23-29 (25)	0.7-5.5 (2.3)	0-2 (0.6)	0-2 (1.6)
Range %	(Average %)				

kaolinite (Fig. 3C) which ranges from 23 to 29% and the average 25%. One of the notable feature is the sudden appearance of the gibbsite mineral (Fig. 3F) in this zone with an average abundance of 1.6%. Gibbsite forms either directly from the parent rock or indirectly from kaolinite by removal of silica. In the present instance it is more likely to be derived from the aluminous laterites on the coast.

From the above description of the clay mineral distribution in the various sedimentary environments, it is obvious that no direct correlation is present with clay minerals and climate, lithology and weathering. Caution should, therefore, be exercised in reconstructing paleo-environments solely from clay mineral data.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. H.N. Siddiquie, Director, for his interest and encouragement.

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