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# Topography & Sediments of the Western Continental Shelf of India—Vengurla to Mangalore

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**Survey of the western continental margin of India between Vengurla and Mangalore shows that the shelf has an average width of about 80 km. The most common shelf break in the region belongs to the gentle break type of Wear [*Mar. Technol. Soc. J.*, 8 (1974), 37] and for this reason the depth of the shelf break varies between 90 and 120 m. A less common variety of the shelf break is one where a terrace is present at the shelf break as off Bhatkal. Surficial sediments consist of silts and clays on the inner shelf (50 m), calcareous sand on the outer shelf (50 to 100 m) and silty sands on the upper continental slope (100 m). Carbonate content in the coarse fraction is low in the inner shelf (< 30%), intermediate on the outer shelf (30 to 90%), and high (> 90%) on the upper continental slope. On a carbonate free basis the change in texture of the sediments is least on the inner shelf and greatest on the outer shelf and upper continental slope. Outer shelf sands contain iron-stained quartz (recent and relict) to the extent of 20% whereas the inner shelf sediments contain only unstained quartz. Distribution of mud on the continental shelf has been explained using the conceptual models of McCave [*Shelf sediment transport process and pattern* (Dowden Hutchinson & Ross, Inc., Stroudsburg), 1972, 225].**

As part of the programme of the International Indian Ocean Expedition *INS Kistna*, in 1965, carried out reconnaissance sampling along 5 traverses across the western continental margin of India. Two of these sampling traverses were located off Karwar and Mangalore. A generalized sediment distribution map based on the reconnaissance sampling was prepared[3]. Since the samples were widely spaced many of the details of the sediment distribution were obscure. The continental shelf between Vengurla and Mangalore was resurveyed in relatively greater detail by *RV Gaveshani* during her 17th and 18th cruises in March and April 1977.

Results on the nature of the bottom topography, the distribution of sediments and some of the depositional processes prevailing on the continental shelf between Vengurla and Mangalore are reported in this communication.

## Materials and Methods

Sediment (129) and rock (5) samples were collected by grab and dredge respectively (Fig. 1). Grab samples were spaced at approximately 10 km along traverses spaced at 20 km. Continuous echosounding was carried out with a Kelvin and Hughes MS 45 echosounder and intermittently by Simrad EQ echosounder. Navigation during the 17th cruise was based on shore and radar fixes and on satellite navigation during the 18th cruise.

## Physiographic Setting

The continental shelf between Vengurla and Mangalore is bordered by the Western Ghats. In this region they consist of gneisses, schists and granites of Dharwarian age and form part of the south Indian shield. Extensive laterite formation and the presence of rich iron deposits (banded ferruginous quartzites) are characteristic features[4,5].

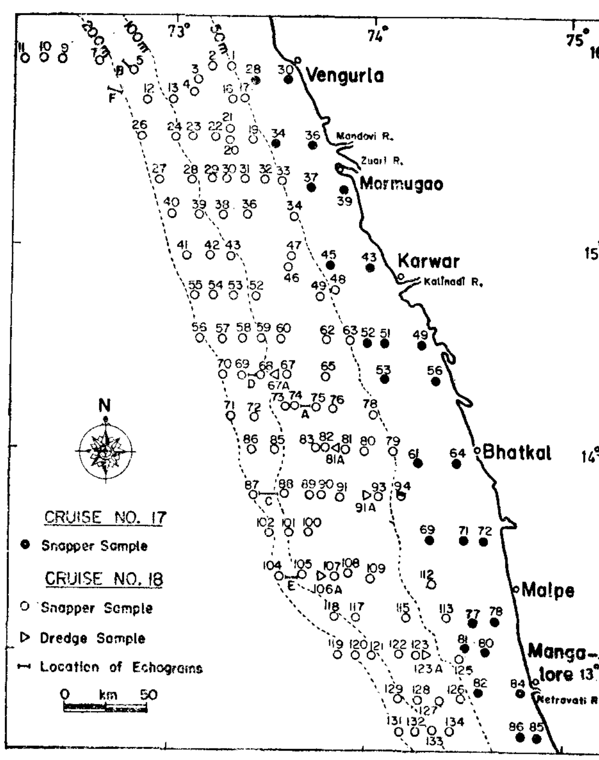


Fig. 1 — Location map of samples and echograms

The climate is tropical with maximum precipitation during the monsoon. The coastal plain increases in width from about 24 km at Vengurla to about 78 km towards the south at Mangalore. Many short rivers flow across the coastal plain. They are the Mandovi and Zuari in Goa, the Kalinadi in north Kanara, the Netravati in south Kanara (Fig. 1). Most of them are estuarine for the greater part of their length. The Mandovi in Goa can be considered as typical of the estuaries of the region. The characteristics of the Mandovi are described in detail because the primary pathways of the sediments enroute from their source in the coastal formations to the continental shelf are through these estuaries. The Mandovi waters[6] attain their maximum temperature of 31·5°C during premonsoon and a minimum of 25·5°C during postmonsoon season. Salinity during the premonsoon ranged from 29·5 to 36‰ and during monsoon from 2 to 35‰. Maximum salinity gradient of 2·0‰/km is also found during monsoon. The estuary changes from a stratified type during the wet season to a well mixed type during premonsoon. Suspended load increases from $<50$ mg/litre during premonsoon to $>100$ mg/litre during monsoon. The salt water boundary is located 36 km upstream during premonsoon, $<25$ km from the mouth during monsoon and migrates gradually upstream reaching a distance of 31 km during postmonsoon season. It is evident from the descriptions that radical changes in the characteristics of the estuaries of the region take place during monsoon. From the viewpoint of sediment contribution, increase in suspended load in monsoon to twice the value suggests that much of the sediment is likely to be carried to the inner continental shelf during monsoon season. The reduction in salinity of the estuarine waters during monsoon leads to the possibility of the flocculation of fine grained sediments when the sediment laden estuarine waters discharge their load into the sea. One may further surmise that during postmonsoon and premonsoon months no net contribution of sediments to the continental shelf occurs. On the other hand suggestions of the onshore transport of sediments into the estuaries have been obtained from the study of the Aguada Bar located at the mouth of the Mandovi[7].

## Results and Discussion

*Continental shelf topography and shelf break* — The continental shelf in the study area has an average width of 80 km. The mud covered inner shelf to a depth of 40 to 50 m is generally smooth and featureless. Beyond 50 m numerous small scale (maximum relief of 5 m) prominences and undulations appear (Fig. 2A). Off Karwar, some of these prominences at 70 m are seen as continuous features extending for about 60 km and may be algal ridges. Other prominences occur as isolated pinnacles 6 m in height in a water depth of 111 m (Fig. 2B). A prominent scarp with a height of 4 m is seen at 98 m off Bhatkal (Fig. 2C).

The shelf break takes various forms. One definition is that the shelf edge (shelf break) is the point of the first major change in gradient at the outermost edge of the continental shelf[1]. According to Wear *et al.*[1] the most common is the sharp break type where the change in gradient is abrupt. A gradual shelf break is one which is arcuate and generally broader than the abrupt type. The gentle break type is one in which the change in gradients is only slight. There is yet another type where terraces are present at the shelf break.

The shelf breaks between Vengurla and Mangalore belong to the gentle break type (Fig. 2A-E). Since the change in gradient is gradual the depth of the shelf break varies between 90 and 120 m. Fig. 2C is an example of a shelf break with a terrace. The first change in gradient is abrupt and takes place at 94 m and seaward of 98 m the change in gradient is gradual up to 137 m. We believe that the first change in gradient is the seaward edge of the 90 m terrace. This terrace may be the southward extension of the 50 fm flat which is very prominent on the outer continental shelf off Bombay[8]. About 40 km south of profile C (Fig. 2), the scarp is absent and a gentle shelf is found (Fig. 2E). We do not know why the 94 m scarp is not seen on all the profiles. It could, for example, be masked by sediment deposition or other forms of constructional (algal?) feature.

Beyond the shelf edge the sea floor falls sharply to 1000 m. Many topographic prominences and terraces are present between 210 and 275 m, and from 275 to 1000 m the upper continental slope has smooth topography (Fig. 2F).

An interesting feature on the outer continental shelf off Malpe (north of Mangalore) is the occurrence of two 'seamount' shaped features, one of which is 14 m in height and the other 38 m in height. The latter is capped by living hermatypic corals and has been named Gaveshani Bank[9].

*Sediments* — Fig. 3 shows distribution of surficial sediments. Areally the 3 most abundant sediment types are clayey silt, silty sand and sand. The clayey silts form a relatively narrow band confined to $<50$ m water depth and within a distance of 25 to 35 km from the coast. Between 50 and 100 m the sediments are sands. Off Goa and north of Mangalore these sands extend to 200 m. The silty sands do not show any relation to water depth and are found from 40 to 200 m. In contrast to the generally uniform distribution of clayey silt present on the inner shelf, the inner shelf off Bhatkal has silt sized material. Few samples obtained from the upper continental slope off Vengurla indicate the sediment to be clayey silt grading with depth to silty clay (Fig. 3).

*Carbonate content of sand fraction* — Since the majority of samples (103 out of 129) are sands, the estimation of carbonate content (by the conventional 10% HCl digestion) is confined to that fraction (Fig. 4). Some amount of carbonate is doubtless associated with the fine ($<63$ μm) fraction of the sediments but is of little significance to their relative abundance on a regional scale.

The amount of calcium carbonate is low ($<30\%$) in the inner shelf clayey silts, intermediate in the outer shelf sands (50 to 70%) and high ($>90\%$)

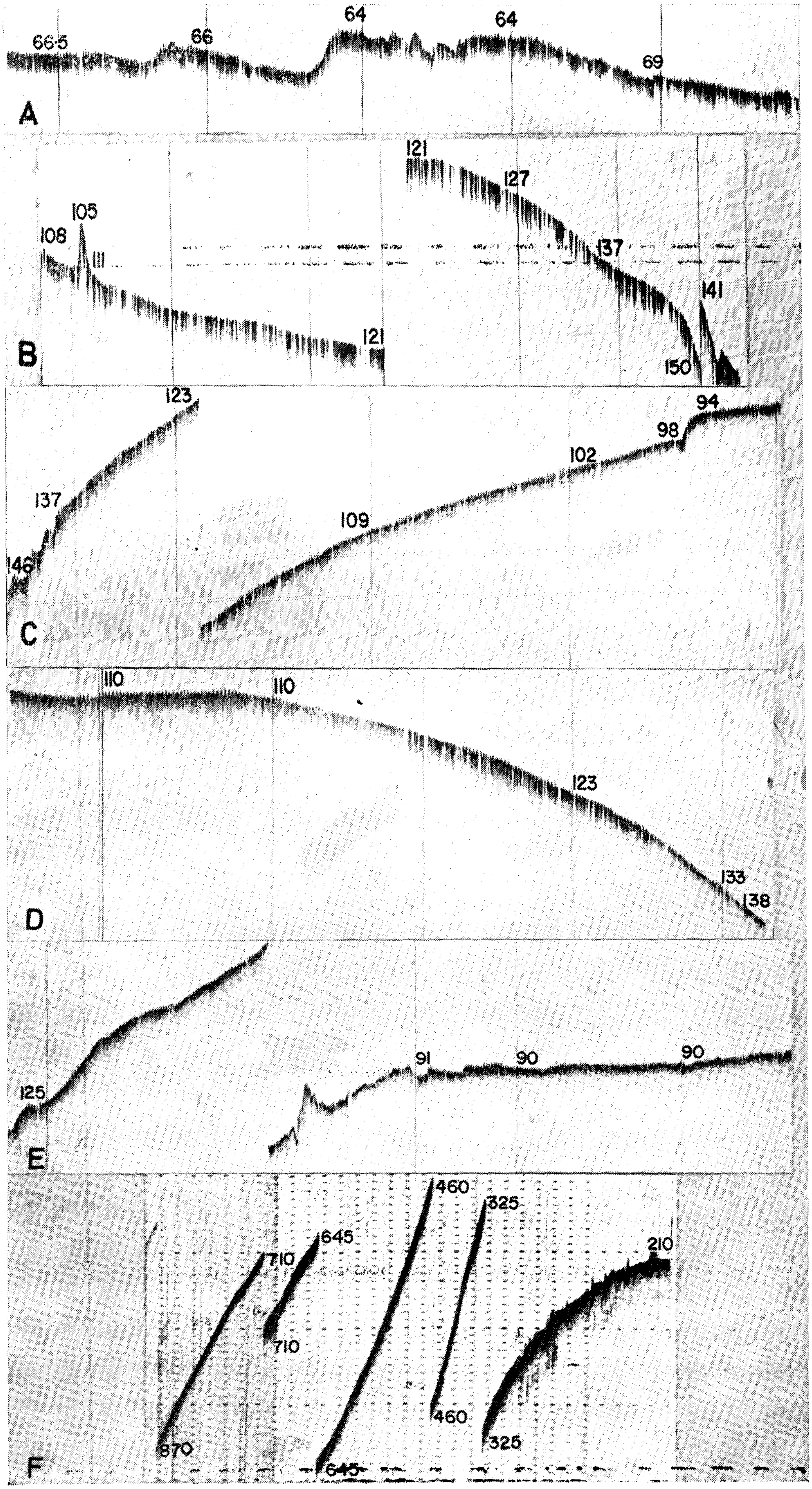


Fig. 2 — Bottom profiles, depth in metres (locations in Fig. 1)

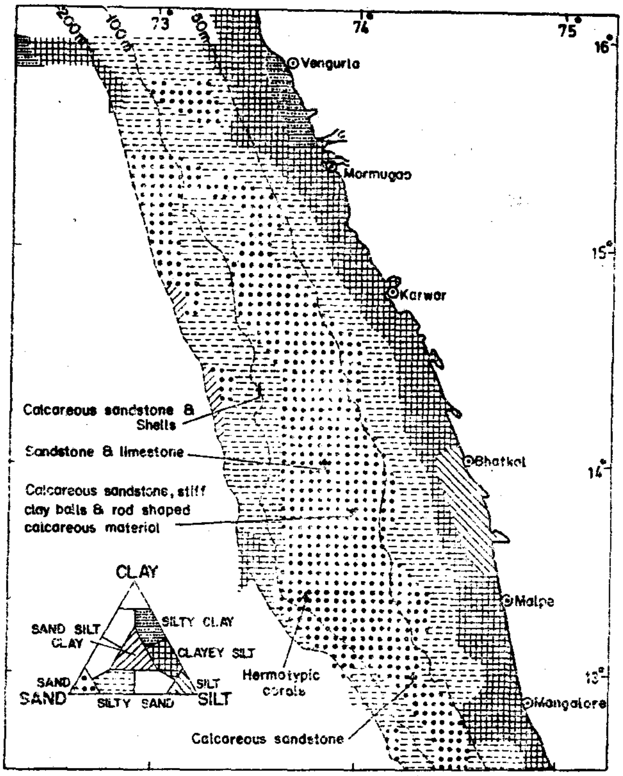


Fig. 3 — Surface sediment distribution [Also shown are the composition of the dredge samples]

in the shelf edge sediments. Exceptions to this distribution are the zones of 50 to 90% carbonate found on the middle and outer shelf between Vengurla and Karwar, on the middle and outer shelf off Bhatkal, and on the outer shelf off Mangalore (Fig. 4). General distribution of carbonate content is similar to the distribution on the northern part of the western shelf.

Preliminary examination of coarse fraction (>63 μm) indicates the presence of 'foramol'[10]. Non-skeletal components are ooids and grapestones. The most striking difference between the sediments of this area and those of the northern part[11] in so far as the carbonate components are concerned is the paucity of ooids[12].

*Carbonate free sediment texture* — Carbonate components are products of the environment and they act as dilutant to the terrigenous sediments. Therefore, when one views the sediment distribution on a carbonate free basis, one enhances the clarity of the distribution of the terrigenous components.

In the present instance distribution of the terrigenous components is obtained by recalculating the percentage of sand, silt and clay on a carbonate free basis. This has been possible because the carbonate content is predominantly in the sand fraction and because 103 out of 129 samples fall into the category of sands according to Shepard's classification. This method will not be applicable to sediments like carbonate muds which have a substantial amount of carbonates in the finer fractions.

The carbonate free sediment distribution is shown in Fig. 5. The sediments fall into 9 textural classes as against the 6 textural classes when the carbonates

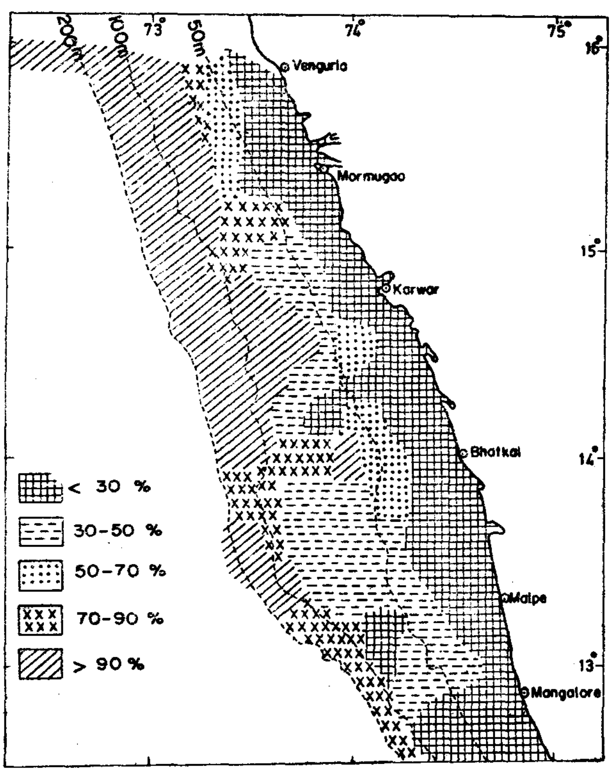


Fig. 4 — Carbonate content in sand size fraction

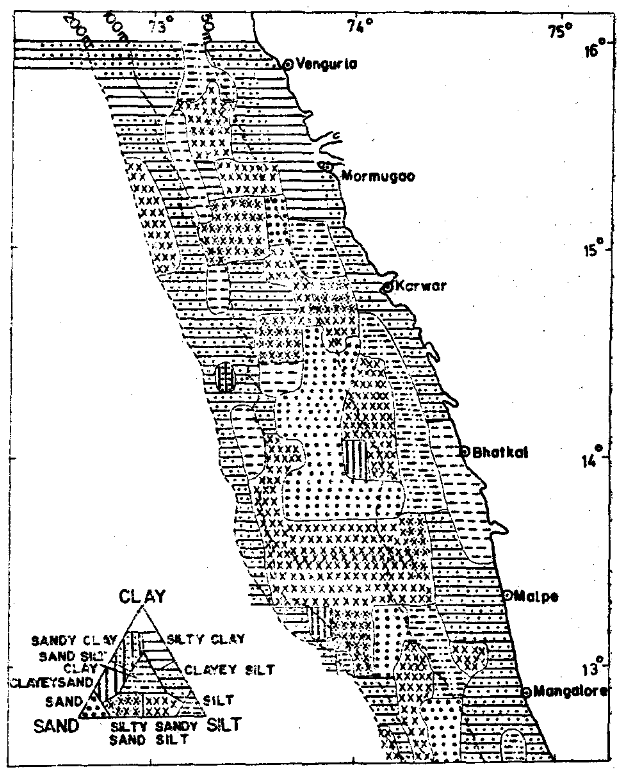


Fig. 5 — Carbonate-free sediment distribution [Note difference in the number of textural classes from Fig. 3]

are included. Inner shelf silts and clays show the least amount of textural difference because they have the least amount of carbonate. The greatest variation is shown by the sediments occurring in water depths >40 m because they have the maximum carbonate content. The overall distribution of non-carbonate sediments appear to be patchy. However, a critical examination of Fig. 5 reveals a generally consistent though poorly defined pattern. At depths <50 m from Vengurla to Karwar and <40 m from Karwar to Mangalore, and beyond 100 m on the outer continental shelf the sediment texture is silt and clay. In between the 2 zones of silt and clay, lies the zone where sands with varying proportion of silt predominate. Within this zone the abundance of sand increases to the south. The explanation for the similarity in texture of sediments on a carbonate free basis on the inner continental shelf and beyond the shelf break is probably due to the fact that during the course of their transportation from the coast some of the fine sediments are deposited on the inner shelf and the balance bypasses the outer shelf and gets deposited on the shelf edge and on the upper continental slope. This view is in agreement with the observation that the bottom sediments on the outer shelf (between 50 and 100 m) are largely free of clay fraction (Fig. 5).

The carbonate free sediment distribution does not show any relationship to present day river mouths (Fig. 5). No regular trend of the sediment texture is aligned, for example, across the shelf from the river mouths. This lack of relationship or patchy distribution may be a reflection of the dispersal or reworking of the shelf sediments. During periods of lowered Pleistocene sea level rivers would have discharged their sediment load further seaward from their present day mouths. The subsequent Holocene trend of rising sea level would result in progressive displacement of the shore line to the coast and in this process dispersal of sediment may result. We also do not rule out the possibility of the reworking of the sediments in response to the present day hydraulic regime of the shelf waters.

*Mud deposition on the continental shelf* — The possibility of the deposition of fine sediments by flocculation arises from the fact that during monsoon the estuarine waters have salinities as low as 2‰ and when these low salinity sediment laden waters are discharged into the relatively higher salinity waters of the inner shelf the sediments get flocculated and are deposited. This deposition takes place as mentioned earlier within 25 to 35 km from the coast. The deposition of river discharged mud within close proximity to the coast is apparently not an uncommon feature. For example, the study of Drake[13] on the shelf off Southern California shows that 80% of the sediment discharged during a flood could be accounted for on the shelf at depths <50 m and distances <20 km from the river mouth. He attributes the deposition largely due to physicochemical flocculation.

Whereas Drake's study is concerned with the sediments discharged by a flood which is sporadic in occurrence the estuaries in our region are markedly influenced by the monsoon which is an annually recurring feature. The cyclic variation in salinity of the estuarine waters operating over a long period leads one to infer that flocculation may be a dominant process causing mud deposition on the inner shelf.

Since the estuaries during the monsoon are stratified and also develop a salt water wedge[6] a part of the sediment that is transported seaward with the fresh water flow will settle into the salt water wedge and be carried upstream back into the estuaries. There is thus a tendency for only a part of the sediment that is discharged by the rivers to accumulate on the inner continental shelf.

Experimental studies[14-16] have shown that the velocities required to erode mud which has once been deposited are greater than the velocity which transported them. This is due to the cohesive nature of the fine grained sediments. Thus, fine sediments that are able to settle in areas where average tidal velocities are reduced will accumulate unless much higher current velocities are reached later. Therefore, in qualitative terms the fine sediments that are deposited during monsoon are unlikely to be eroded during premonsoon or postmonsoon seasons.

The conceptual models of McCave[2] reproduced in Fig. 6 are helpful in explaining the mud deposits on the shelf. The diagram emphasizes the fact that the location and rate of mud accumulation are controlled by the balance between supply (concentration in the shelf nepheloid layer) and the marine transport ability (the sum of tidal, wave, wind and density currents near the sea floor). Permanent mud accumulation at any shelf position will occur if sediment supply is sufficient to form a cohesive bed that will withstand the disturbing effects of benthic organisms and storm current erosion[2].

Mud on the inner shelf between Vengurla and Mangalore is an example of Case 1 since the mud occurs immediately adjacent to the narrow strip of sand that borders the coast. Its presence implies that the amount of fine sediment discharged by the rivers exceeds the capacity of the marine transport processes and results in mud accumulation. The

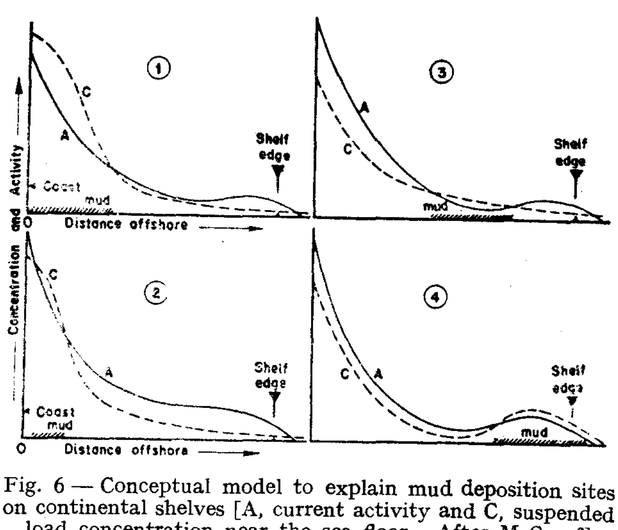


Fig. 6 — Conceptual model to explain mud deposition sites on continental shelves [A, current activity and C, suspended load concentration near the sea floor. After McCave[2]]

absence of fine sediments on the outer shelf means that the marine transport activity (wave action or by current activity or both) prevents mud deposition. Indirect evidence of the absence of turbid waters is the presence on the outer shelf of living corals on Gaveshani Bank. It is well known that corals do not survive in turbid waters and their presence therefore, indicates the waters remain clear over extended periods of time.

Shelf edge muds that occur at depths >90 m in the study area is an example of Case 4 in which the concentration of mud exceeds the amount that can be removed by currents. The presence of shelf edge muds is, however, contrary to the generally held notion that the shelf edge is the locus of high energy conditions (stronger turbulence, stronger currents). Southard and Stanley[17] in their review of shelf edge physical processes identify a variety of currents that may prevent deposition or resuspension of sediments already deposited. Since no observational data on the shelf edge currents in the study area are available, we conclude from the circumstantial evidence of the presence of fine sediments on the shelf edge that it is a locus of low energy conditions.

How does the mud reach the shelf edge ? Some general possibilities are presented here. Cross-shelf mud transport can take place by the processes of convective diffusion and advection[2]. When a concentration gradient is established near the coast by the discharge of river-borne sediments, as is the case between Vengurla and Mangalore, the mud diffuses across the shelf in response to the gradient. Advective transport involves the movement of suspended material resulting from net horizontal water movement under action of semi-permanent currents caused by wind, density or inertia.

*Iron-stained quartz and authigenic limonite* — Samples (130) were examined for the presence of iron-stained quartz and their abundance estimated by the method of Terry and Chilinger[18]. In addition a few samples of modern sediments collected from the estuary of the Netravati and from the beach at Mangalore were also examined. Iron-stained terrigenous sediments are generally assumed to reflect deposition in an oxidizing sub-aerial environment but may also reflect sediment source[19]. The iron-stain usually is yellow to dark brown depending on the intensity of the stain and takes the form of hematite. The critical factors in the formation of hematite[20] are (1) presence of iron bearing source minerals (2) post depositional conditions favouring intrastratal solution of the iron bearing grains (3) Eh-ph conditions favouring $Fe_2O_3$ formation and (4) absence of subsequent reducing conditions.

In the area under study stained quartz content ranges from 5 to 20% and is confined to the sediments occurring between 50 and 100 m. The inner shelf sediments and those beyond the shelf edge in general are devoid of stained quartz (Fig. 7) even though quartz grains are present particularly in the inner shelf muds. Stained quartz is present to the extent of 5% in the shelf edge sediment off Mangalore. High values of iron-stained quartz between Karwar and Bhatkal (Fig. 7) may be due to the presence of extensive ferruginous laterite and iron-rich coastal rocks in the area. The few samples examined from the beaches and estuaries also show the presence of stained quartz.

In contrast to the iron-stained quartz which is found mainly on the outer shelf, authigenic limonite occurring as infillings (moulds) of the recent shells of foraminifera, pteropod and gastropod are found mainly in sediments on and seaward of the shelf edge. These shells are assumed to be recent because of their fresh (shining, unbroken) appearance in contrast to the relict shells which have a worn and dull appearance.

We believe that since the authigenic limonite is found in the recent shells the formation of limonite is a modern feature. The origin of the iron stain on the other hand may be partly relict and partly modern. Because of the high iron content of the rocks of the hinterland and of the prevailing tropical climate in the area iron is mobilised either in the colloidal or soluble form. It is contributed to all the marine environments such as estuaries, beaches and the continental shelf. For example the iron content in the inner shelf muds (silt and clay) is 3·8% and decreases to 1·3% on the outer shelf sands[21] demonstrating a decrease in iron content with increase in distance from the coast. The iron is retained in part as iron oxide stain on quartz grains of the beaches and estuaries, and as stain on the quartz and as limonite infillings in the shells of the outer shelf sediments. The staining on the quartz grains does not take place in the inner shelf muds (the iron forms iron sulphide within the rapidly deposited muds) because of the interstitial reducing conditions associated with them. The occurrence of authigenic

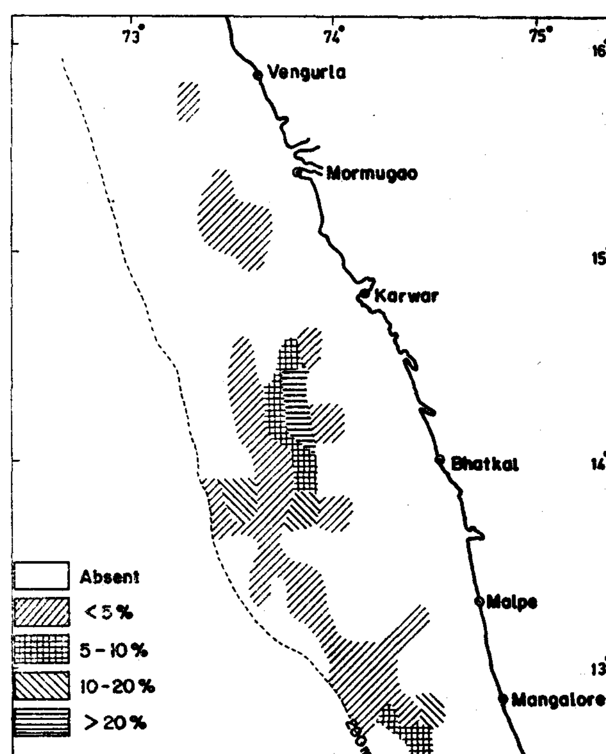


Fig. 7—Distribution of iron-stained quartz

pyrite in the inner shelf sediments off Mangalore[22] lends support to the reasoning for the absence of stained quartz in the muds. The presence of stained quartz in the modern sediments however, indicates that a certain proportion is also a direct reflection of the contribution of source rocks. This source may have also contributed during times of lowered sea level. Therefore, distribution of stained quartz in the shelf sediments portrays the combined influence of the contribution during the time of lowered sea level as well as present day contribution from coastal rocks.

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