Journal of Coastal Research	2	2	199-203	Fort Lauderdale	Spring 1986

Influence of Estuaries on Shelf Sediment Texture[1]

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ABSTRACT

NAIR, R.R. and HASHIMI, N.H., 1986. Influence of estuaries on shelf sediment texture. *Journal of Coastal Research*, 2(2), 199-203. Fort Lauderdale, ISSN 0749-0208.

Granulometric analyses of sediments on the western continental shelf of India demonstrate that the texture of inner continental shelf sediments (10 to 60 m water depth) appears to be determined by the size and number of estuaries present on the coast. Offshore from regions where there are a large number of estuaries, the inner shelf sediments are fine grained (average mean size 5.02 ϕ, 0.03 mm), rich in organic matter (>2%) and low in calcium carbonate (<25%). In contrast, in regions with relatively fewer estuaries, the shelf sediments are of sand size (average mean size 1.53 ϕ, 0.35 mm), poor in organic matter (<1%) and rich in calcium carbonate (>30%). Echo profiles of the sea floor are characterized by sub-bottom reflections in the former and their absence in the latter. These differences are attributed to the fact that the estuaries act as regional filters which permit deposition of only fine-grained sediments on the inner shelf while trapping the coarse-grained material in the estuarine basin. An example of this filtering effect is discussed from the sediment texture distribution on the south-western shelf of India (Kerala) where it is particularly well displayed.

ADDITIONAL INDEX WORDS: *Continental shelf, estuary, sediment texture.*

INTRODUCTION

Detailed sedimentologic investigations of the western continental margin of India have been conducted by the National Institute of Oceanograpny, as part of Geological and Geophysical studies on board RV GAVESHANI. Some reconnaissance work in this area was carried out on INS KISTNA and INS DARSHAK in the late 1960s and early 1970s. Based on the granulometric analyses of samples, a map of the surface sediment texture on the western continental shelf was prepared. In this paper the influence of estuaries on shelf sediment texture is discussed using an example from the south-western (Kerala) shelf of India. The sediment texture has been singled out for discussion because it is the sediment size that determines many other properties such as, organic carbon, calcium carbonate, benthic population, and nutrient regeneration from the sediment. For the purposes of this paper, these properties are considered as 'derived properties' and their relationship as a function of sediment size has been so well established for shelf sediment that no further elaboration seems needed. The fact that estuaries act as filters between land and the oceans has been recognized of late and the filtering effect from the viewpoint of physical, chemical, biological, and geological processes has been documented in KENNEDY (1984). While the emphasis of the papers in the Kennedy book is on the filtering processes prevailing within estuaries, our stress is on the effect of this filtering on the adjoining continental shelf.

The details of sample collection and analyses have been described by HASHIMI *et al.* 1978; NAIR *et al.*, 1978; NAIR and HASHIMI, 1980, and HASHIMI *et al.*, 1981.

TOPOGRAPHY AND SEDIMENTS OF THE WESTERN CONTINENTAL SHELF

The following account is a summary of the above mentioned comprehensive reports. As background information we provide a general summary of the topography and surface sediment texture on the western continental shelf of India.

The western continental shelf of India covers an area of about 310,000 km^2. The shelf is widest off Bombay, extending up to about 300 km and narrowest (about 60 km) off Cochin. The topography of the shelf is even with very gentle gradients to about

[1]*84-036 received 30 July, 1985; accepted in revision 11 November 1985.*

60 m water depth from the coast. The outer shelf (beyond 60 m to the shelf edge) which ranges from 90 to 120 m water depth, has uneven topography and is sometimes rugged, with local undulations of more than 5 m.

Sands of the shore zone occur within a few kilometers of the coast to about 10 m water depth. These sands are composed of quartz with varying proportions of heavy minerals. Modern muds occur deeper than 10-20 m. They are terrigenous clastics, texturally silts and clays with low carbonate content (<10%); they extend 160 km offshore from Bombay (water depth of about 60 m). Towards the south, these muds extend 25 km offshore (water depth of 40 m) near Cochin but disappear near Quilon. This facies is replaced by relict carbonate on the outer shelf which have been radiocarbon dated at 9,000 to 11,000 BP.

South-Western Continental Shelf of India

The continental shelf of south-western India (offshore from Kerala) demonstrates the influence of estuaries on sediment textures of shelf areas. Between Cochin and Quilon, the estuarine area on the coastal plain is about 400 km^2 while south of Quilon it is only about 25 km^2. The surface sediment texture on the continental shelf to a depth of 50 m off these regions is shown in Figure 1. The most striking feature is the marked change in texture that occurs near Quilon: sedimentary textures between Cochin and Quilon are sand-silt-clay or clayey silt but south of Quilon the sediments are entirely calcareous sands. Echosounding profiles (Figure 2) also show differences. For example, the shelf off Cochin, which is covered with fine-grained sediments is characterized by echograms in which clear subbottom reflections are present (Figure 2A). Similar features are absent on the echogram from the shelf off Cape Comorin where the sediments are calcareous sand (Figure 2B). Another striking difference between the two regions is the presence of dense mud suspensions, termed mud banks, between Cochin and Quilon, and their total absence on the shelf south of Quilon. These mud banks (NAIR, 1976) are discontinuous suspensions having dimensions of the order of tens of square kilometers of highly turbid waters. These mud banks consist of 45 to 65 percent clay fraction with secondary amounts of silt and a very small sand size fraction. More importantly, the coarse fractions of these sediments contain muscovite, biotite, and much plant and wood material, all of which are usually transported as suspended load. The absence of terrigenous sand size material in the sediments suggests that they are trapped in the estuarine basin; this conclusion is supported by VEERAYYA and MURTY's (1974) data for the estuary (Vembanad Lake). Their report indicates that the percentage of coarse sand is on the order of 20 percent, the percentage of fine sand is relatively low. Differences in some other parameters for the two regions are summarized in Table 1.

The percentage of sand and carbonate increases towards the south, while clay minerals present between Cochin and Quilon, in order of their abundance, are montmorillonite, kaolinite, illite, chlorite, and gibbsite (NAIR *et al.*, 1982). South of Quilon, aragonite (33-93%), high-magnesium calcite (18-42%) and low-magnesium calcite (6-35%) constitute the mineralogy of the carbonate sediments (HASHIMI *et al.*, 1982).

DISCUSSION

The differences in the nature of the sediments between Cochin-Quilon and south of Quilon are attributed to the fact that the estuaries act as regional filters in the northern part of the region. These estuaries permit deposition of only fine-grained sediments on the inner shelf because coarse-grained sediments are trapped in the estuarine basin. Trapping may result from a sudden fall in the velocity of the transporting agent (the river) as it enters the estuarine basin. The estuaries in our region are strongly influenced by the annual monsoons. The cyclic variation in coastal water salinity may lead to flocculation which causes deposition of fine-grained sediments on the inner shelf. This is possible because the monsoon runoff has a salinity as low as 2‰ and is discharged as sediment-laden waters directly into the relatively higher salinity waters of the inner shelf. Deposition takes place within 15-20 km on the shelf between Cochin and Quilon (see Figure 1). South of Quilon, the scarcity of estuaries results in the deposition of coarse to medium calcareous sands over the same distance interval. Because the estuaries are stratified and also develop a salt water wedge during the monsoon, part of the sediment load that is transported seaward with fresh water flow will settle into the salt water wedge and be carried upstream back into the estuaries. For example, the vertical variation of the annual mean suspended sediment load at the mouth of the Vemvanad Lake has an annual mean value between 25 and 50 mg/l and during an average tidal

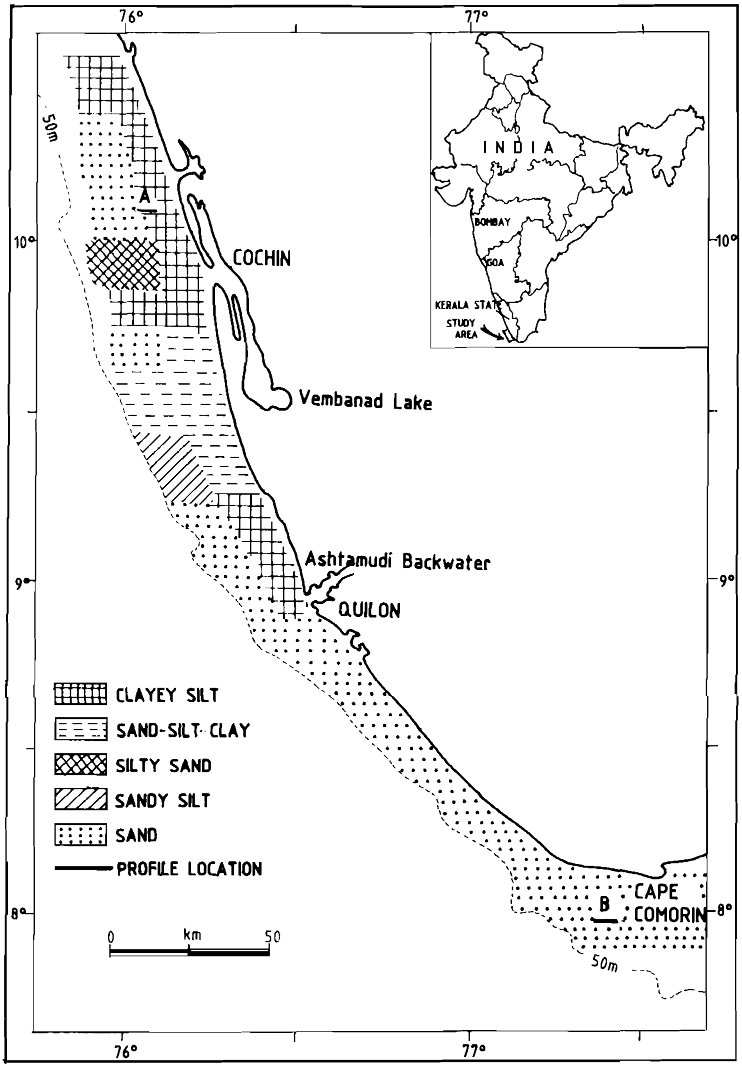

Figure 1. Surface sediment texture. Note the distinct difference in texture, north and south of Quilon.

period of equal flood and ebb, more suspended sediment moves into the harbor with the flood current (RAMA RAJU *et al.*, 1979). This fractionation results in only a part of the original river sediment load accumulating on the inner continental shelf. Previous experimental studies (KRONE, 1962; KUENEN, 1965; POSTMA, 1967) have shown that the velocities required to erode fine sediments, once they have been deposited, are greater than the velocity which transported them. This is due to the cohesive nature of the muds. Consequently, the fine-grained sediments that are deposited during the monsoon are unlikely to be eroded during fair weather pre-monsoon or post-monsoon seasons. This results in a net accumulation of muds on the inner continental shelf offshore from estuarine coasts. The facts that the muds do not significantly dilute the sands south of Quilon (clay fraction 0.0 to 1.5 percent, Table 1) and the absence of mud banks in this region support our reasoning.

Thus, the estuaries act as filters that trap coarser-grained sediments and allow only the finer

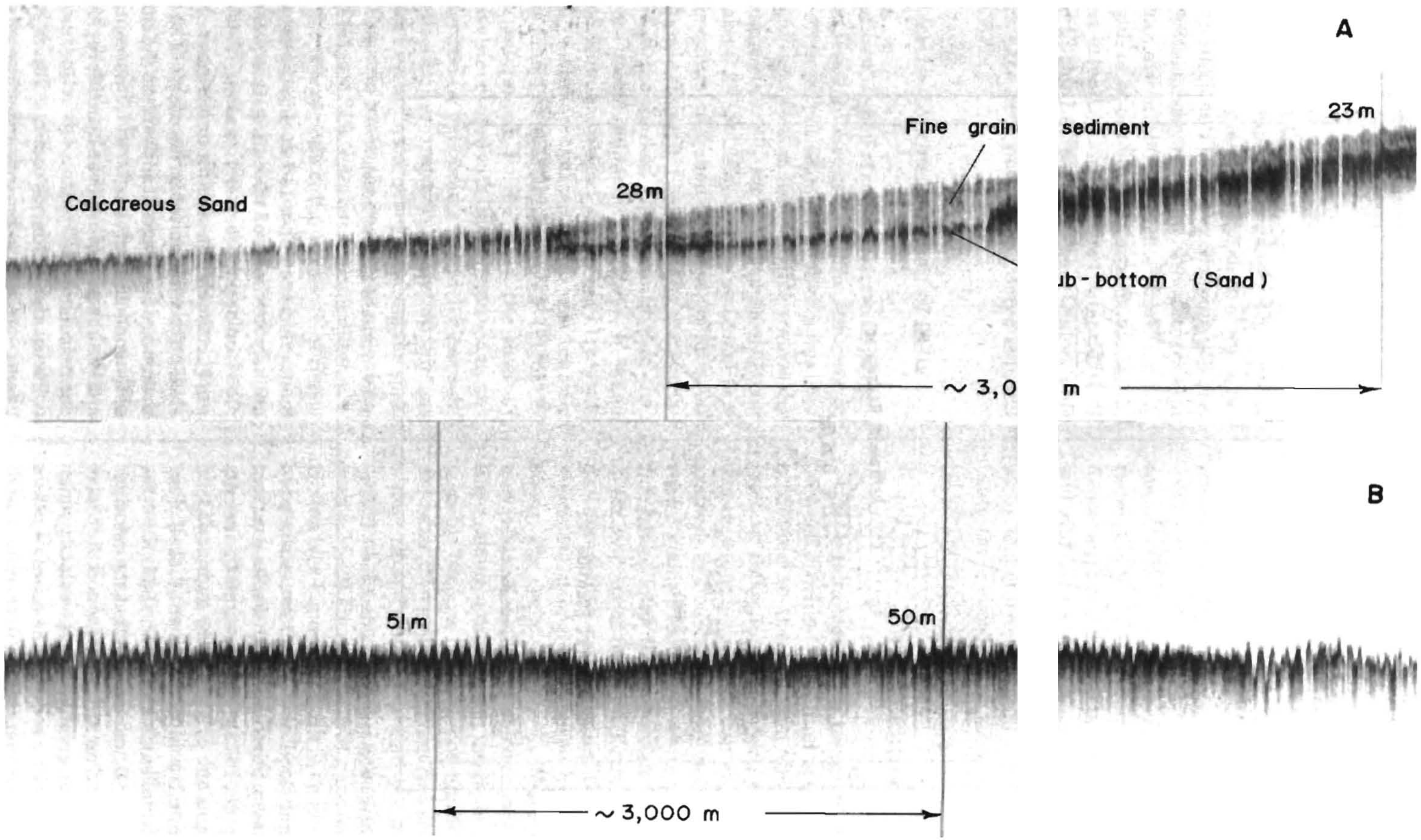

Figure 2. A. Echogram off Cochin showing clear sub-bottom, calcareous sand overlain by fine-grained sediments. :hogram off Cape Comorin showing absence of fine-grained sediments.

Table 1. Characteristics of the topography and the sediments on the continental shelf along estuarine and non-estuarine coasts.

Parameters	Cochin to Quilon		Quilon to Comorin	
	Range	Average	Range	Average
1. Sand %	0.2-93.8	36.9	91.4-98.3	93.2
2. Silt %	5.0-70.4	41.2	1.3-8.6	4.0
3. Clay %	1.4-49.7	21.2	0.0-1.5	0.3
4. Mean size (ϕ)	0.8-7.9	5.02	0.3-2.5	1.5
5. Sorting (ϕ)	1.1-3.5	2.23	0.9-1.7	1.3
6. Skewness	−0.2-0.5	0.25	−0.2-0.3	0.001
7. Kurtosis	0.6-1.6	1.09	0.9-1.4	0.98
8. Carbonate in sand % fraction (>62.5 μm)	1.3-50.6	26.9	4.7-75.0	37.4
9. Organic matter %	—	>2	—	<1
10. Dominant sedimentary environment	Terrigenous		Carbonate	
11. Mud bank	Present		Absent	
12. Bottom topography	Smooth with sub-bottom reflections		Uneven, sub-bottom reflections absent	
13. Estimated estuarine area	∿400 km²		∿25 km²	

material to be deposited on the inner shelf. The area occupied by estuaries between Cochin and Quilon is of the order of 400 km^2, whereas south of Quilon it is only about 25 km^2. Although other oceanographic processes such as the differences in the wave and current regime can exert strong influence on shelf sediment textures, these appear subordinate in the areas under discussion.

ACKNOWLEDGMENTS

The authors are grateful to Dr. H.N. Siddiquie, Director for his interest and encouragement. Abstract of this paper was presented in the Seminar on "Estuaries — Their Physics, Chemistry, Biology, Geology, and Engineering Aspects," held at Goa during December, 1981.

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