

Carbonate Components in the Coarse Fraction of Western Continental Shelf (Northern Part) of India

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Study of nature and distribution of skeletal and non-skeletal components in the coarse fraction of the western shelf of India (northern part) reveals that skeletal components (bivalves and foraminifers) are abundant in the inner shelf sediments, classified as detrital; whereas the outer shelf sediments, classified as relict, are characterized by non-skeletal components (ooids, lithoclasts etc.). Roundness of the skeletal component is independent of depth and is confined to class 0 (complete shells) and class 1 (first stage of breakage with no evidence of roundness). The inner shelf is a zone of accumulation in contrast to the outer shelf. Sedimentary and topographic data suggest the presence of onshore sediment transportation and the influence of bottom current on the outer shelf.

CARBONATE and non-carbonate fractions of the sediments of the continental shelf have different origins and have different ages of deposition. Carbonate components are products of the environment. Non-carbonate fraction is normally terrigenous and may be considered as a dilutant of the carbonate fraction¹. In view of the fact that carbonate fraction is a product of the environment and is expected to reflect the conditions prevailing in the depositional basin, its study has frequently been found to be extremely useful. The extensive use of carbonate component in understanding the sedimentary and depositional processes has been reviewed by Bathurst² and Milliman³.

This study is an attempt to elucidate the sedimentary processes prevailing on the western continental shelf of India using skeletal and non-skeletal components of carbonate fraction of the shelf sediments.

Geological Setting of the Area

The area under investigation can be divided into 2 different regions. The division is arbitrary and is based on climatic conditions, shelf width and depth of the shelf break. The Saurashtra coast with its relatively hot and dry climate, has a shelf width of about 120 km (av.) and a shelf break in the range of 130-152 m. Southward from the head of the Gulf of Cambay down to Ratnagiri, the coast has hot, wet climate. Two major rivers, Narmada and Tapti, flow into the Gulf of Cambay in addition to several minor seasonal streams discharging into the many estuaries found on the coast. The shelf width off this coast is about 280 km and the shelf break occurs between 90 and 140 m.

In each of these 2 regions, the shelf can be further divided into inner shelf (0-60 m) and outer shelf (60 m to shelf break). The topography and sediments of each of these zones are very different. The inner shelf has smooth featureless topography

whereas the outer has a rugged topography consisting of prominences (1 to 10 m height)^{4,5}. The outer shelf topography off the Gulf of Cambay and southwards has been suggested by Nair^{6,7} to consist of algal and oolitic ridges originating during the Holocene transgression.

The sedimentary facies of the inner and outer shelves are also markedly different. The inner shelf is floored by terrigenous silt and clay, while the outer-shelf sediments are relict carbonate sands. The sediment zonation is more distinct on the shelf off Bombay than off the Saurashtra shelf. Siddique and Rajamanickam⁸ attribute the influx of sediments from the Indus river to the Saurashtra shelf for the intermingling of the 2 sediment types.

Differences in the nature of sediments also show up in the colour of the sediments. The inner shelf muds are various shades of grey (10Y 4/2, 5Y 4/1, 5Y 2/1, 5Y 3/2). Outer shelf carbonate sands have shades of brown (5Y 5/6, 5Y 4/4). Patches of brown coloured sediments also occur in the inner shelf off Bombay and Okha. With respect to the colour of the sediments also, the Saurashtra shelf sediments are different. Throughout the Saurashtra shelf, the common colour is olive grey (5Y 3/2) whereas brown coloured sediments are absent everywhere⁸.

Information on the regional structure of the continental shelf, and particularly of the top few 100 m is absent. Harbison and Bassinger^{9,10} report seaward dipping reflectors, which are probably the Deccan Traps and the overlying Tertiary formation. They have also suggested that the narrowing of the shelf of south-west Saurashtra may be due to a fault.

Methods

All samples used in the present study (Fig. 1), were grab samples collected during the oceanographic cruise in the northern Arabian Sea¹¹. In addition, sample-i collected during earlier cruises (1969-71) were also examined. Coarse fractions (greater than

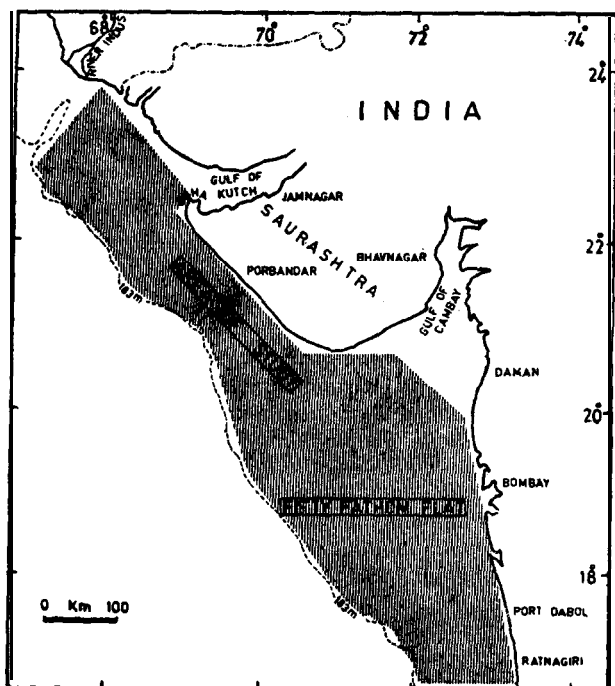


Fig. 1— Area of study

62 μm) of the samples were separated by conventional methods. The coarse fraction was further sieved and the +18 mesh (2 to 1 mm) and +35 mesh (0.5 to 1 mm) were used for the identification of carbonate components. These mesh sizes were selected because they permit optimum degree of recognition of the components¹². Approximately 300 grains in each fraction were counted by spreading the sample on a gridded tray and using a binocular microscope. In those samples, such as the +18 mesh fraction, where the grains were generally few, all were counted. All the values were expressed in number percentage.

The following skeletal and non-skeletal components were identified and counted: (1) bivalves (lamellibranchs and brachiopods), (2) gastropods, (3) pteropods, (4) foraminifers, (5) bryozoans, (6) corals and coralline algae, (7) worm (serpulid) tubes, (8) echinoderms, (9) calcareous pelletoids, (10) ostracods, (11) oolites, (12) grapestones and lithoclasts (Fig. 2).

Roundness of the skeletal components was estimated (Fig. 3), using the roundness chart for the visual classification of shelf carbonate used by Pilkey et al.¹³. In this classification complete shells constitute class 0, shells in the first stage of breakage with no evidence of roundness constitute class 1, and classes 2, 3 and 4 are stages showing increasing degree of roundness. To maintain consistency in the visual estimation, which is a highly subjective process, all estimates of roundness were made by (13) the same person.

Insoluble residue values were obtained¹⁴ by the method of Chester and Hughes¹⁵. This method is expected to give somewhat less weight percentage as compared to the conventional hydrochloric acid digestion because the ferromanganese minerals also

go into solution. However, for the purpose of the present study, the insoluble residue distribution as obtained by "the above method is adequate to show the regional trends.

Out of the total of 104 grab samples collected, 66 samples were analysed for carbonate components because they had sufficient (more than 5% by weight) coarse fraction and 90 samples were analysed for the insoluble residue.

Results and Discussion

Distribution of skeletal and non-skeletal components — Bivalves are one of the most abundant skeletal components. They are found throughout the depth range 10 to 139 m (Fig. 2). The relative abundance of bivalves varies with mesh size. For instance, the maximum found in the depth range 38 to 65 m is in the +18 mesh, while in the +35 mesh, the range of 20-50% is maintained throughout the depth. The above distribution suggests in a general manner that the bivalves in the shallower depths are larger than those in deeper waters.

Gastropods are found in far less numbers as compared to bivalves. They are fairly uniformly distributed between 10 and 20% throughout the depth range. The distribution in both the mesh sizes is also uniform.

The number of pteropods in both the size fractions is even less than that of gastropods. Sporadic occurrences take place in the depth range 10 to 80m but are more commonly found on the outer shelf between 80 and 139 m within a restricted percentage of 10-20.

Foraminifers, quantitatively are significant carbonate contributors to the sediment. They are absent or rare in the +18 mesh size (Fig. 4A, B) and abundant in the +35 mesh (Fig. 5A-D) fraction and are distributed throughout the width of the shelf. Foraminifers are abundant, up to 90% in the depth range 10 to 50 m but decrease in waters deeper than 50 m.

Distribution of bryozoans is limited to a maximum of 10% in a few samples. These are rare or absent in most others. Off Saurashtra, however, in one sample (No. D/05 depth 113 m) bryozoans in both size fractions are found up to 20%.

In the category 'Others' (Fig. 2) are included corals, echinoderms, sponge spicules, pelletoids, ostracods, etc., which are absent in most of the samples and if present are quantitatively insignificant carbonate contributors. It should, however, be pointed out that though identifiable remnants of coralline algae are rare in various size fractions, substantial quantity of carbonate material is probably derived from coralline algae because the outcrops of algal limestone occur and have been obtained by dredging from the outer shelf. The difficulty in identifying algal fragments under the microscope stems from the fact that they are rapidly micritized to a featureless, opaque, brown mass¹⁶. In view of this drawback the algal components are, therefore, included in the category 'Lithoclasts'.

The unidentifiable remnants of one or more of the skeletal components other than algal are grouped together as 'Shell Fragments'. They are found

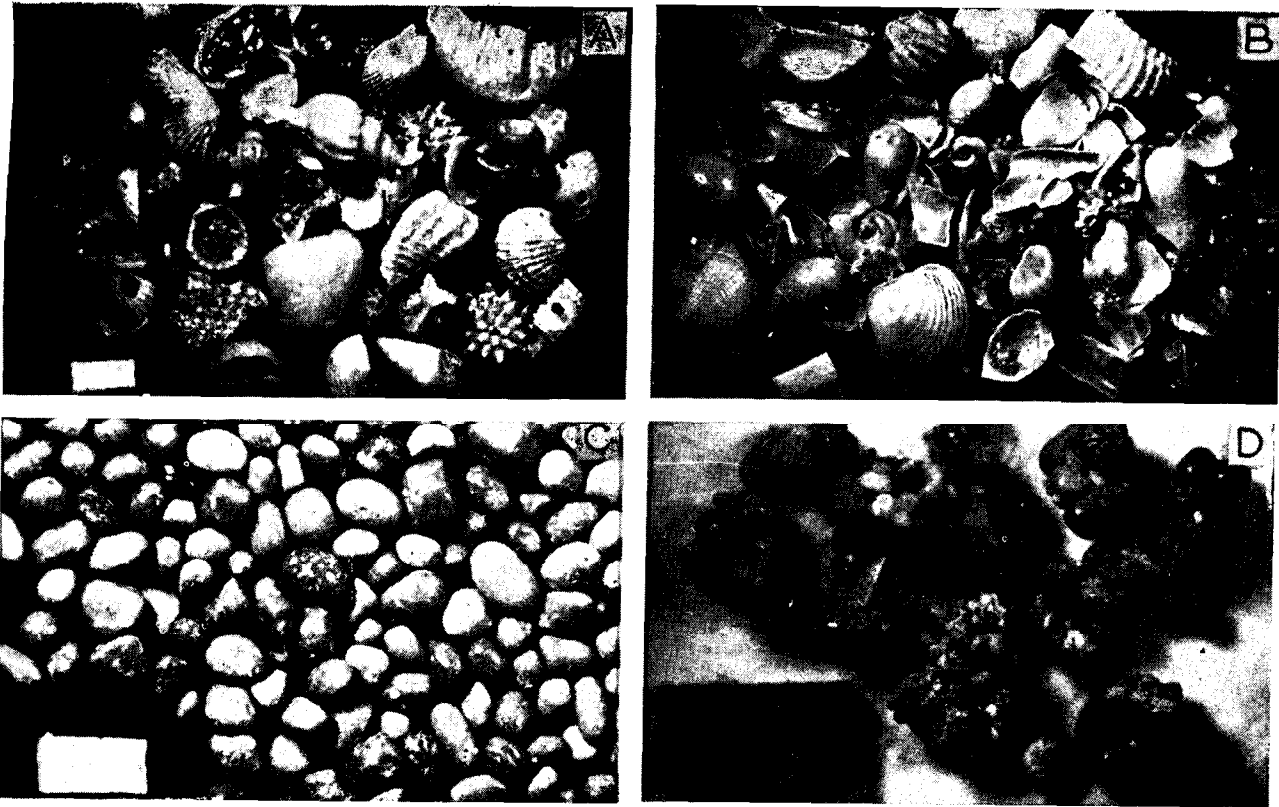


Fig. 4 — Skeletal components of sample (A) 0/04 (+18 mesh) and (B) F/05 (+18 mesh); (C) oolite concentrated from sample S/06 (+35 mesh) ; and (D) grapestone concentrated from sample S/06 (+ 18 mesh). [Scale bar is 2 mm]

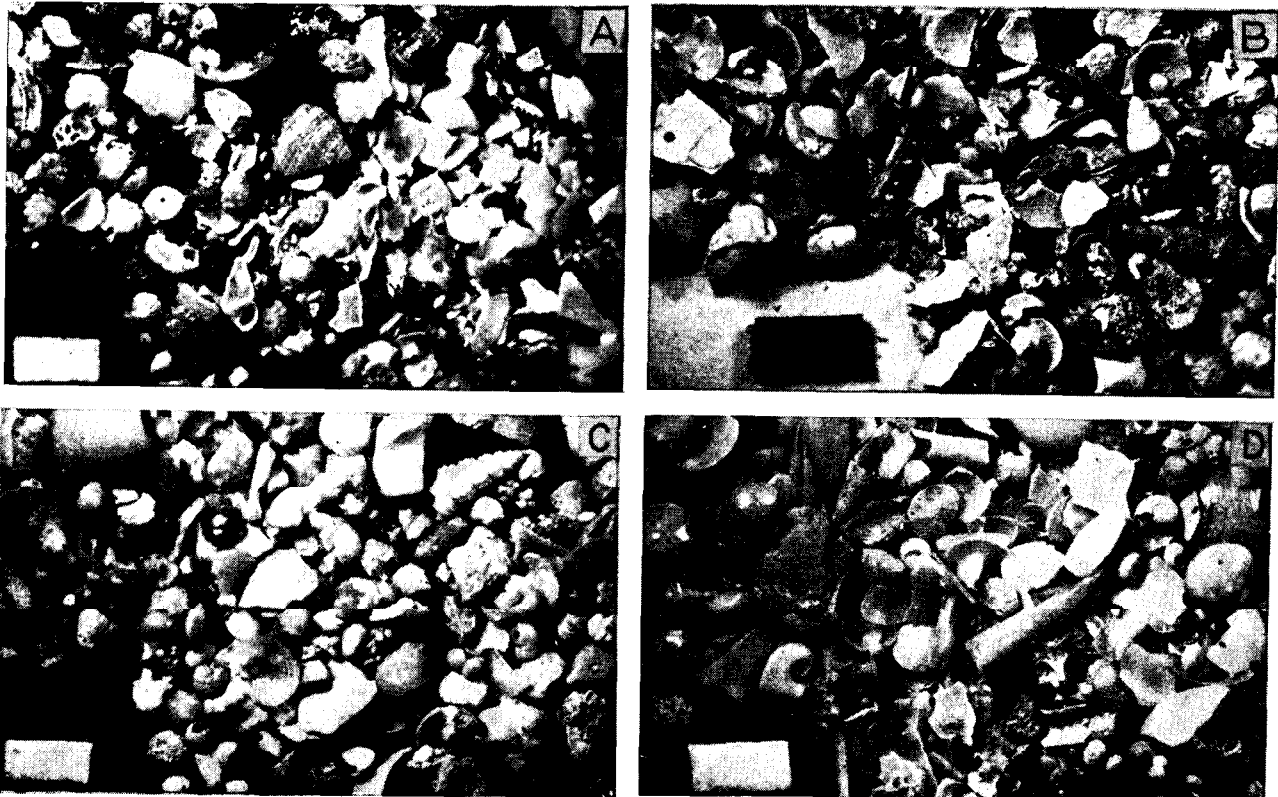


Fig. 5 — Skeletal components of sample (A) T/0C (+35 mesh), (B) S/04 (+35 mesh), (C) H/04 (+35 mesh), and (D) F/05 (+35 mesh) [Note the difference in the composition from + 18 mesh components (Scale bar is 2 mm)]

in both the size fractions and do not show any control of the distribution by depth of water. They are, however, found in the greatest abundance along the 50 fm Flat.

The term lithoclasts is applied to fragments of rocks, largely those of limestones of various kinds and in the same sense as that of Folk¹⁷. With a few exceptions, lithoclasts are absent in the shallow water samples and increase from 80 m to the shelf edge. The lithoclasts are mostly oolitic and algal limestone fragments derived from the late Pleistocene algal and oolitic limestones outcropping on the outer shelf. Lithoclasts contribute carbonate material to the extent of 50% in some of the outer shelf samples and are more in the coarser size fraction.

Oolites (Ooids) constitute a significant proportion of the outer-shelf sediments. Their occurrence in the western shelf has been recorded¹⁸⁻²⁰. Oolites and grapestones (Fig. 4C, D) are dull lustrated, bored, brown and black in colour on the middle shelf and highly polished, tan and cream coloured on the outer shelf. Many of the oolites are of the superficial type with smaller amounts of true, mature, ones. Some of them are probably derived by erosion from the shelf oolitic limestones, which has been radiocarbon dated to be 9200±135 yr in age. The percentage of oolites, skeletal components and lithoclasts in each sample is shown in Fig. 6. It is clear from both the figures that lithoclasts and oolites (non-skeletal components) are less on the inner and middle shelf (0-60 m) and become important on the outer shelf (60 m to shelf break). The skeletal components on the other hand show an opposite distribution. It is further observed that as much as 80-90% of the carbonate fraction is composed of oolites on the 50 fm Flat and that with a few exceptions oolites are absent on the outer shelf off Saurashtra. A noteworthy finding is the occurrence of grapestone in the near shore mud samples at Ratnagiri (Fig. 5A).

Roundness of carbonate components — The degree of roundness and sphericity of non-carbonate grains, particularly quartz, reflects the abrasional history of the grains. Complicating the interpretation of the roundness of non-carbonate grains are factors such as selective sorting in the sedimentary environment. Carbonate components, on the other hand, being products of the environment should reflect the immediate abrasional history of the particle¹³.

Roundness determinations were made on the skeletal components only. Oolites were excluded from the determination because of their inherent roundness and abundance both of which tend to yield misleading results if grouped with the skeletal components. The bulk of the samples have carbonate components with roundness in class 0 and class 1. Samples with components having degree of roundness greater than 1 are rare or absent (Fig. 3). The larger number of whole shells (class 0) found in the +35 mesh fraction is due to the dominance of foraminiferal tests in that fraction (Fig. 2). Degree of roundness in class 2 are confined to the +18 mesh size fraction of the shelf edge samples. Relationship of degree of roundness with increasing

water depth as also with increasing distance from shore is not clearly discernible. From Fig. 7 it is, however, seen that the percentage of shells in class 1 to 4 in the +35 mesh fraction shows a decrease to 50 m, increase to 70 m, remains constant at 90 m, and thereafter decreases to 120 m depth. The significance of such a distribution is not known.

Insoluble residue — The amount of insoluble residue can be taken as a qualitative measure of the amount of influx of terrigenous material into the sedimentary environment. Fig. 8 shows the percentage of insoluble residue in the shelf sediments. The 80% contour is close to the coast all along from Ratnagiri to the Saurashtra coast indicating greater influx of sediments in the near shore areas. The same contour protrudes into the Gulf of Cambay due to the sediment discharge of the Narmada and the Tapti which flow into the Gulf. In addition to the river discharge, the 10 m tidal range in the Gulf and the associated tidal currents, which are of the order of 10 knot²¹ result in highly turbid waters and the formation of linear sand bars at the head of the gulf.

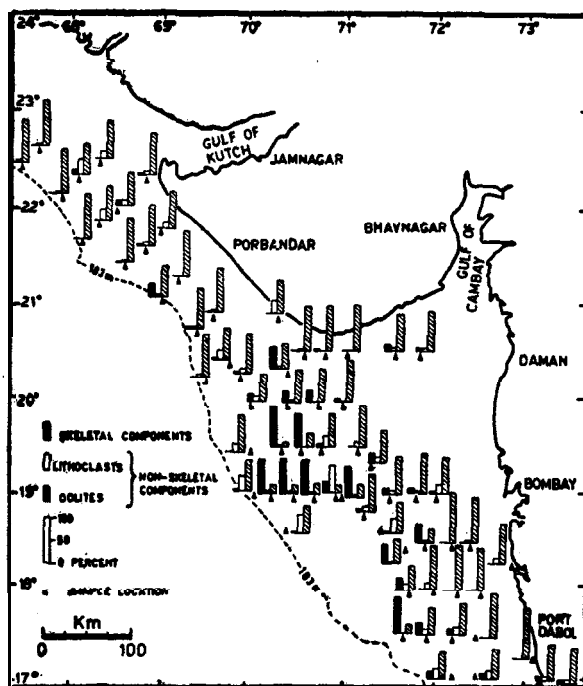


Fig. 6 — Relative distribution of skeletal components lithoclasts and oolites in each sample (+35 mesh) [Note the abundance of oolites and lithoclasts on the outer shelf off Bombay and their rarity or absence on the shelf off Saurashtra]

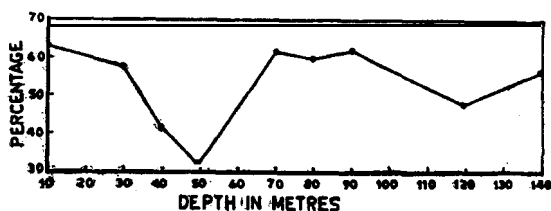


Fig. 7 — Relationship of roundness with water depth of the components (+35 mesh) [Values averaged over 10 m depth interval]

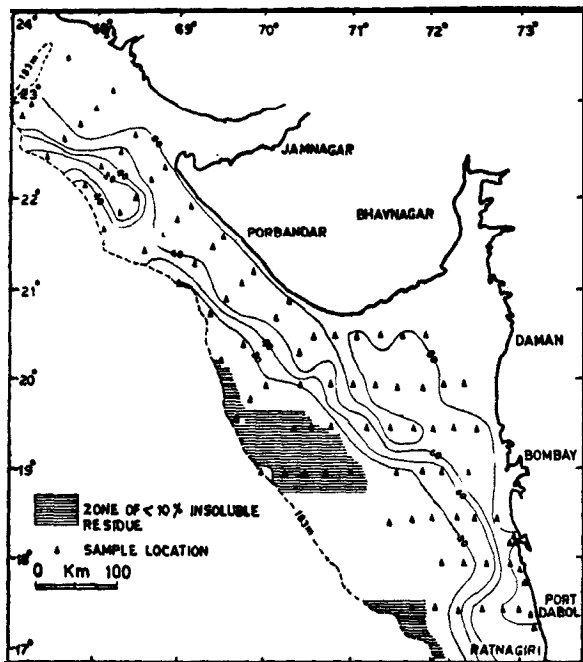


Fig. 8 — Percentage of insoluble residue in the shelf sediments [Note the zone of less than 10% on the outer shelf]

The percentage of insoluble residue decreases rapidly on the shelf off Bombay to the extent that the outer shelf areas have 10% or less (Fig. 8). This is due to the fact that the bulk of the terrigenous material is confined to the inner and middle shelf, leaving the outer shelf free from sediment accumulation. In contrast to the shelf off Bombay, the Saurashtra shelf shows a different distribution. The rate of decrease of insoluble residue across the shelf is gradual. This distribution reflects the influence of the Indus sediments which the Saurashtra shelf receives from the north-west. The Saurashtra coast is generally arid with relatively little rainfall and has no major rivers. It is, therefore, not likely to contribute much sediments to the adjacent shelf. The increase in percentage of the insoluble residue towards the mouth of the Indus (Fig. 8) supports the inference that the river is the source of some of the sediments on the Saurashtra shelf.

Sediment Types

The most frequently used system of classification of continental shelf sediments is that of Emery^{22,23}. Emery's classification is genetic, yet is simple and practical. It is, therefore, followed in this study. The classification consists of detrital, biogenic, residual, authigenic, volcanic and relict.

Detrital sediments are those deposited by water (most common agent), ice (in the northern latitudes) and wind, which are of local importance on continental shelves off deserts at middle latitudes. Biogenic sediments are usually the remains of calcareous skeleton secreting organism of various kinds and predominate on tropical and sub-tropical shelves. Residual sediments are those produced by weathering of bed rock outcropping on the shelf.

Authigenic sediments are products of precipitation in the marine environment. Volcanic sediments are products of volcanic eruption such as pumice and ash which are deposited on the continental shelf. Relict sediments are those that were deposited in the geologic past in equilibrium with the environment and which are not in equilibrium with the present.

The sediments of the western continental shelf, in general and in the study area in particular can be classified on the basis of earlier published data^{24,25} and the results of the present study into detrital and relict types. Biogenic, residual and authigenic sediments are no doubt present on the shelf but are quantitatively less. Volcanic sediments are absent on the shelf.

Detrital sediments are those found in the numerous estuaries which act as settling basins for river-borne sediments, and the near shore quartz and heavy mineral sands. On the shelf proper, the detrital component is the terrigenous silts and clays found to a depth which locally varies between 55 and 65 m. Relict sediments are the calcareous sands found seaward from 65 m to the shelf edge. These relict sediments have been identified earlier by their typical characteristics like grain size, iron staining, presence of oolites, submerged terraces and radiocarbon dating'. Most of the relict sediments on the western shelf are not yet buried under the newer sediments, except those of the Saurashtra shelf.

Sedimentary Processes on the Shelf

The amount of sediment accumulation in a given basin of deposition is the result of the balance between the processes of production, destruction and dilution. Where the production of sediment is relatively high and destruction or dilution is low, as on the coast from Ratnagiri to the head of the Gulf of Cambay, the sediments accumulate in estuaries, beaches, near shore area and the inner continental shelf. In contrast, the Saurashtra Coast contributes little sediment to the shelf. Compensating the absence of sediment contribution from the coast is the contribution from the river Indus, which tends to bury the relict sediment on that shelf.

Evidence in favour of onshore transport, reported to occur on the US Atlantic coast^{26,27}, is also present on the western shelf of India. The evidence takes the form of grapestone occurrence in the shallow water (10 m) samples near Ratnagiri. Grapestones (and oolites) are found in abundance on the outer shelf. Their presence in the inner shelf sediment therefore, implies that they may have undergone landward transport from their original site of deposition, on the outer shelf. In the absence of the occurrence of grapestones and oolites in the samples elsewhere in the nearshore region, the process of onshore transport remains unconfirmed.

Other processes operating in the depositional environment and bringing about a redistribution of bottom sediments are bottom currents. These currents can be a combination of tide and or wave generated. No direct measurement of bottom

currents are available on the western shelf. Indirect evidence of the role of currents can be inferred from the bottom topography obtained from echograms. Echograms of the outer shelf show extensive irregular or rugged topography with a relief of the order of 10 m consisting of pinnacles like features, moundshaped protuberances separated by V-shaped depressions^{5,7}. Of interest and relevant to the present discussion is the fact that many of these depressions are not filled up by sediments. The insoluble residue data presented earlier have already showed that the outer shelf does not receive much sediment. Absence of sediment in the depressions can be taken to imply (a) that no sediment reaches the outer shelf or (b) that sediment is deposited but does not accumulate because of removal by resuspension by bottom currents. The sediments so removed are then redeposited on the continental slope, Stackelberg²⁰ reports possible winnowing of sediments from the shelf edge and their deposition as finely laminated sediments on the upper continental slope.

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