

Sediments of the Gulf of Kutch — A High Energy Tide Dominated Environment

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The Gulf of Kutch, one of the indentations on either side of the Saurashtra Peninsula, has an approximate area of 7350 sq km, a maximum water depth of 60 m and an average tidal range of 4 m. Except for an extensive area, extending from the mouth of the Gulf to the centre which consists of rocks (calcareous sandstones) the remainder consists of silts and clays with patches of fine sand. The coarse fraction of the sediments are predominantly quartz including frosted variety, feldspar and mica with minor amounts of carbonate. Sedimentary processes are influenced by high (2 to 5 knots) tidal velocities. The aridity of lands surrounding the Gulf precludes the possibility of their acting as major sources of sediments. Sources within the Gulf and from the river Indus are inferred. Reconstruction of past environment suggests that the Gulf was a desert during the Pleistocene.

RECONNAISSANCE survey of the Gulf of Kutch was carried out in Feb./March 1976 by *RV Gaveshani*. During the cruise 26 stations for snapper, 3 stations (G2/42, G2/45 & G2/47) for dredging were occupied along seven cross sections (Fig. 1). Out of 26 snapper stations there was practically no recovery of the sediments at 6 stations and at 5 stations small quantities of rock and coral fragments were obtained.

Sediments of the Gulf of Kutch have not been studied in detail so far. A limited collection of

samples was made in Jan. 1975 off Okha. Petrographic and foraminiferal studies of the rock samples indicate that they consist of calcareous sandstone which are formed in an intertidal zone.

This paper reports the sediment distribution and the sedimentary processes taking place in the Gulf of Kutch.

Methods

Samples used in the present study were collected using a La Fond Dietz snapper. The colour of the

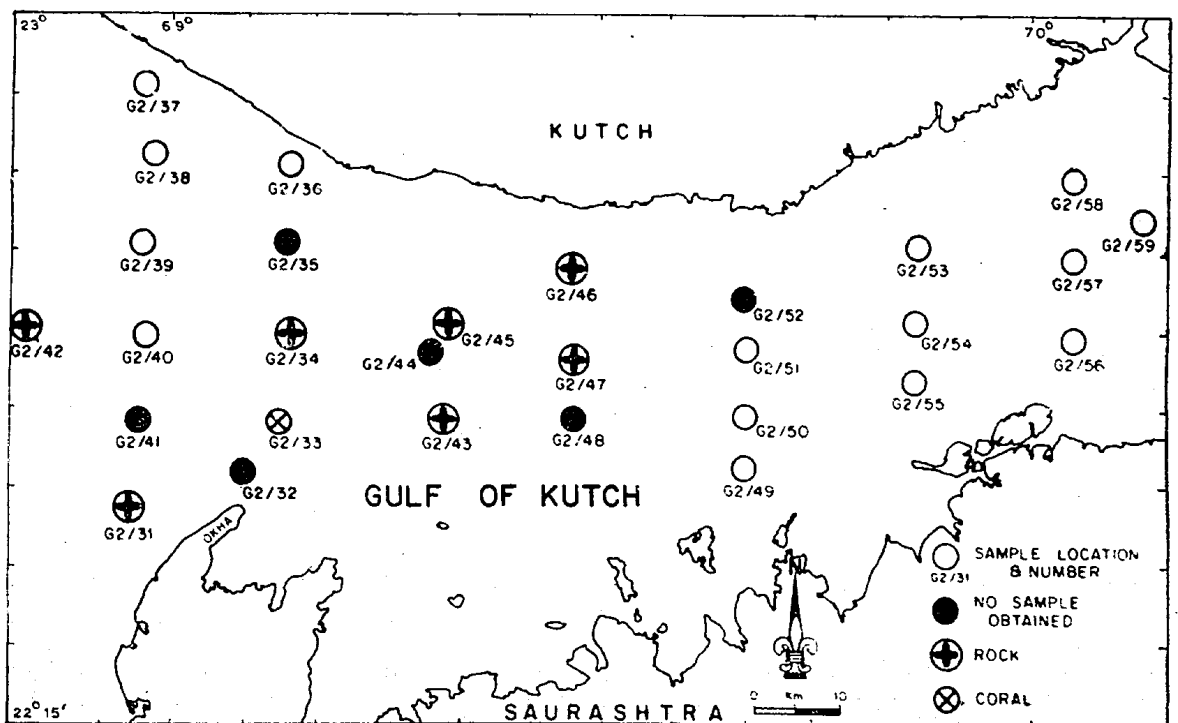


Fig. 1 — Station location

sediments was visually compared with the rock colour chart.

Conventional sieve and pipette methods were used for the size analyses of the samples. Size parameters were calculated using the formulae of Folk and Ward². The texture of the sediment, was determined on the basis of sand, silt and clay ratios³. The study of the coarse fraction was carried out by spreading a part of the coarse fraction ($>62 \mu$) on gridded tray and the constituents were counted under the stereobinocular microscope. Percentages of the following constituents were estimated: (1) Terrigenous minerals (quartz, feldspar and other light coloured mineral except muscovite), (2) ferromagnesian minerals (except biotite), (3) mica, (4) rock fragment, (5) foraminifera, (6) molluscs, and (7) others (including bryozoans, spines of echinoids, ostracods, etc.).

Description of the Area

The Gulf of Kutch, one of the indentations found on either side of the Saurashtra Peninsula, has an area of approximately 7350 sq km and a maximum depth of 60 m. Its climate is semi-arid with the maximum rainfall of the order of 50 cm. It has, therefore, little run off from the land. The numerous rivers found on the northern and southern coasts are mostly estuarine.

The Gulf has an average tidal range of 4 m. It varies from 3.06 m at Okha to 5.89 m at Kandla⁴ (Fig. 2). Northern and southern shores of Gulf are bordered by tidal flats and have dead fringing coral reefs at places.

Bordering the Gulf at its head is the Rann of Kutch, a desiccated region, which during the south-west monsoon gets inundated. A part of the inundation, other than due to the rainfall, may be due to the piling up of water at the head of the Gulf because the SW monsoon winds acting in conjunction with the high tidal range. Evaporation of the water leaves behind salt encrustations and Ranns are considered to show similarities with the Sabkhas of the Persian Gulf⁵.

Bathymetry

The floor of the Gulf is highly variable. It consists of numerous topographic irregularities, like pinnacles, as much as 10 m high separated by flat topped features. The topography at the north and at the middle of the Gulf is relatively more rugged as compared to the head of the Gulf⁶.

A number of shoals (Ranwara shoals, Lushington shoals) are present in the Gulf. A depression demarcated by the 50 m isobath and located at the mouth of the Gulf is probably a tidal or scour channel. Numerous islands occur along the southern shores in water depths of 20 m or less but are absent along the northern shores.

Geology and Tectonics

The Gulf is bounded on the south by the Deccan Traps which are found in the Saurashtra Peninsula. On the northern side in the interior of Kutch area a complete series starting from Jurassic to Pleistocene is found. The Jurassic rocks occupy a large area and are bordered successively by Deccan

Traps and Tertiary rocks which extend to the coast and have dips towards the south and south-west⁷.

The region surrounding the Gulf was subjected to earthquakes. The great earthquake of Sind in 1819 is reported to have raised the central area of the Rann by several feet. An east-west fault along the northern border of the Rann of Kutch is reported⁸ and it is thought to be of lower or middle Pleistocene age.

Results and Discussion

Sediment characteristics — The colour of the sediments (Fig. 3) is throughout either medium light grey (N6) or light grey (N7) whereas on the adjacent shelf off Saurashtra the colour is dominantly olive grey (5Y 3/2)⁹. The light colour of the sediment is due to the predominance of terrigenous minerals (quartz, feldspar and mica).

Except for a large area, extending from the mouth of the Gulf to the centre, which consists of calcareous sandstones the remainder of the area consists of silts and clays with patches of fine sands. Mean sizes of the sand range from 2.4 ϕ and are found in the middle of the Gulf. Silt size materials (5-8 ϕ) are found at the mouth of the Gulf; fine silt (6-8 ϕ) and medium silt (5-6 ϕ) occur at the southern side of the Gulf towards its head (Fig. 4). The sediments throughout are poor to extremely poor sorted (Fig. 5). The skewness is highly variable (Fig. 6) and shows no relation to either the texture or mean size of the sediment. The interrelationship of the various parameters are shown in Fig. 7. The scatter in the relationship of the various parameters is large and is not helpful in discriminating the environment of deposition within the Gulf. The kurtosis (Fig. 8) does not show any particular variation in the Gulf except at 3 places (G2/53, G2/54 and G2/59) where it is leptokurtic. All the others are dominantly platykurtic. The sediments are polymodal (Fig. 9) indicating more than one source.

Using the sand, silt and clay percentages and the bottom notations of the Admiralty chart, a sediment distribution map of the Gulf has been compiled (Fig. 10).

Coarse fraction composition — The composition of the coarse fraction in all the samples (Fig. 11) is dominated by terrigenous minerals (quartz and feldspar) and mica. Ferromagnesian minerals and rock fragments are locally abundant. Skeletal components are surprisingly little and non-skeletal components like ooids are absent. Distribution of mica in the coarse fraction is of special significance.

Mica is present in the coarse fraction of all the sediments (Fig. 11). It is highest (av. 55%) in the sediments of the northern part near the mouth of the Gulf. Information about the distribution of mica in the shelf sediments along the Saurashtra shelf to the Indus mouth¹⁰⁻¹², shows that the abundance of mica increases towards the mouth of the Indus river and south of Okha there occurs a sharp reduction in the mica content. An additional and important feature of the mica distribution is that the outer shelf is devoid of this mineral. The inferences that may be drawn from the distribution of mica are: (a) the source of the mica is apparent-

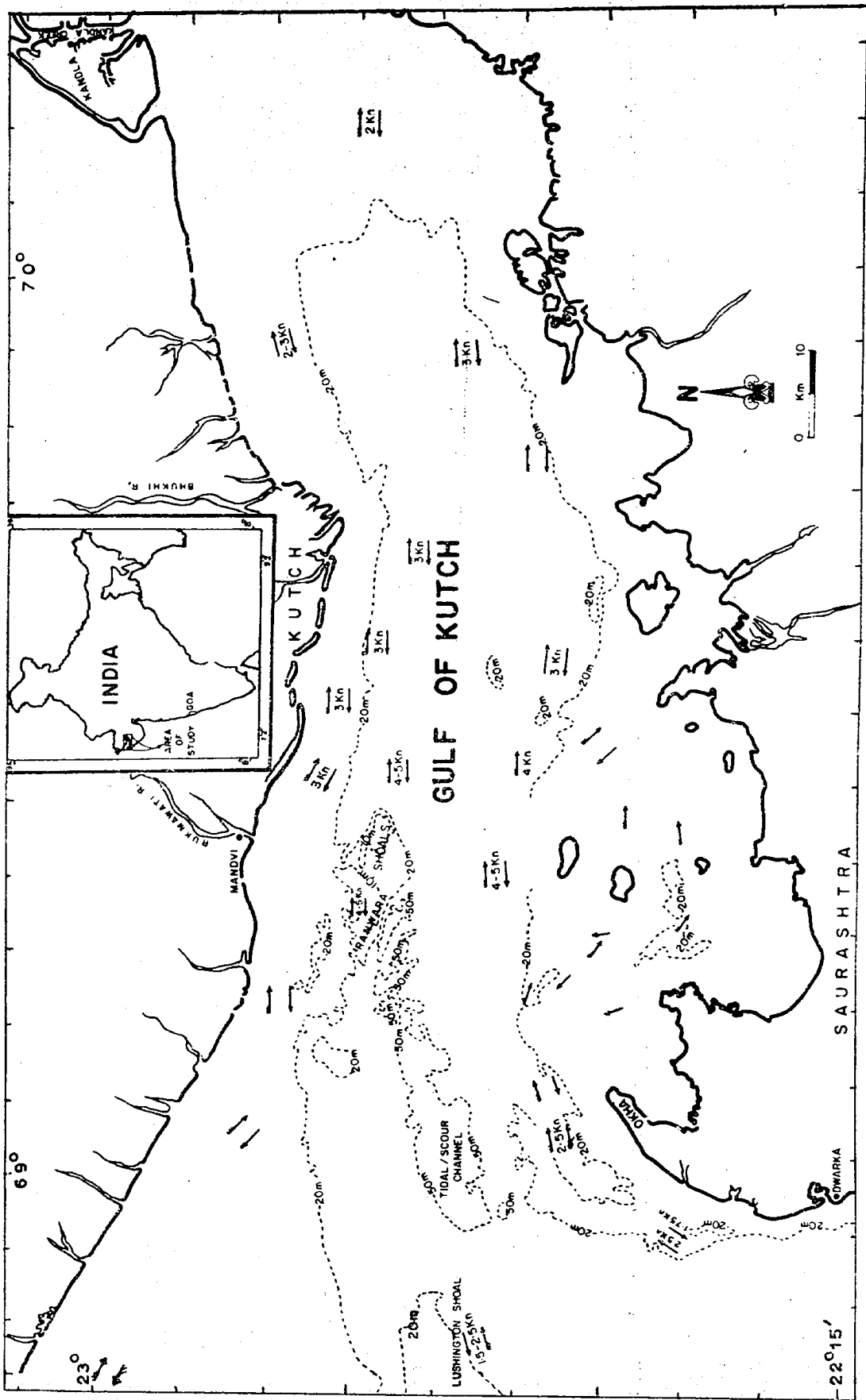


Fig. 2— General bathymetry and tidal current magnitudes and direction [From Admiralty Chart No. L (D₇)203]

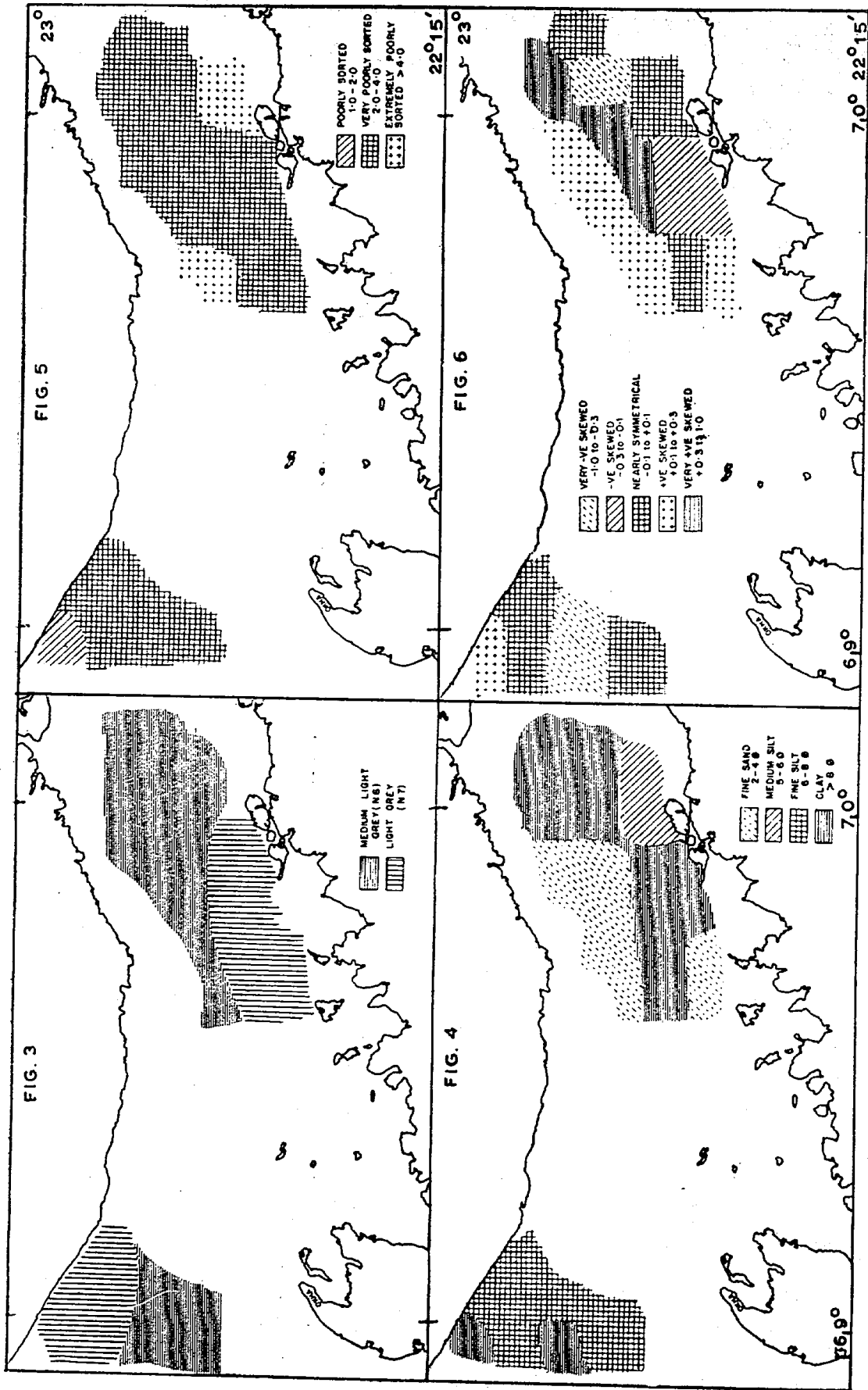


Fig. 3 — Colour of the sediment Fig. 4 — Variation of mean size Fig. 5 — Variation of sorting Fig. 6 — Variation of skewness

ly the Indus river, (b) mica is transported into the Gulf of Kutch and (c) reduction in the mica content south of Okha on the Saurashtra shelf is caused by a physical process which prevents the transport of mica across the mouth of the Gulf towards southern parts. One possible mechanism that could give rise to this effect is tidal current. These tidal currents are of high velocities (2 to 5 knots) and during the course of their movements into and out of the Gulf may act as a hydraulic barrier. It is also possible that this hydraulic (tidal) barrier is more effective against platy minerals, which tend to be transported in suspension as against the equidimensional minerals like quartz and feldspar which are transported as bed load material. Possibly the tidal currents act as filter allowing certain minerals to pass through and preventing others.

Within the Gulf proper, variation in the mica content is of interest. It has been suggested¹³ that the relative abundance of mica may be used as an indicator of the energy of the sedimentary processes. Areas of low energy are characterized by high mica content and conversely. Sample No. G2/40 is located in a trough-like feature which probably is a tidal or scour channel. Absence of mica in the coarse fraction of this particular sample is probably due to high current velocities in the tidal channels where only the coarsest material gets accumulated. The interaction of tidal currents with irregular topography of the Gulf floor can also result in zones of variable turbulence because of which local

accumulation or removal of mica can take place. Thus considering the Gulf of Kutch as a whole, despite being a high energy environment, it has abundant mica essentially because of the availability of high input.

Terrigenous components, quartz and feldspar are present in all the samples. Their percentage ranges from 20 to 75%. Quartz occurs in 2 types, clear, angular to subangular, with inclusions and the sub-angular frosted variety. The frosted quartz may be wind-borne and could possibly be transported from the inland sources by winds during the north-east monsoon and deposited in the Gulf. These wind-borne quartz will also contribute to the polymodality of the sediments.

Ferromagnesian minerals and rock fragments form a minor proportion of the coarse fraction. Rock fragments in the samples from the northern half of the Gulf are phyllites whereas those present in the centre of the Gulf are the calcareous sandstone outcropping on the floor of the Gulf. Sample No. G2/49 which contains the largest proportion of rock fragments (35%) are probably derived from the islands found along the southern side of the Gulf.

Carbonate material represented by shells of foraminifera and molluscs are uniformly low (16-20%).

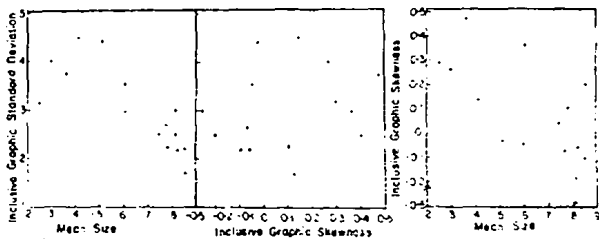


Fig. 7 — Scatter diagram of various textural parameters

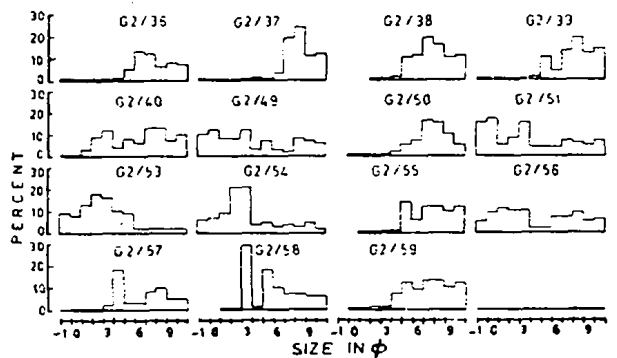


Fig. 9 — Grain-size variation

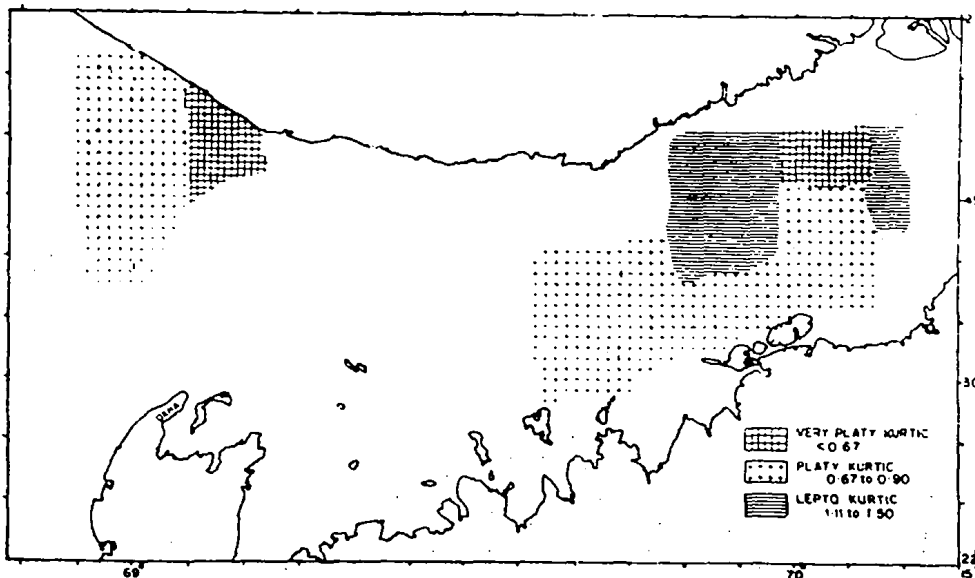


Fig. 8 — Variation of kurtosis

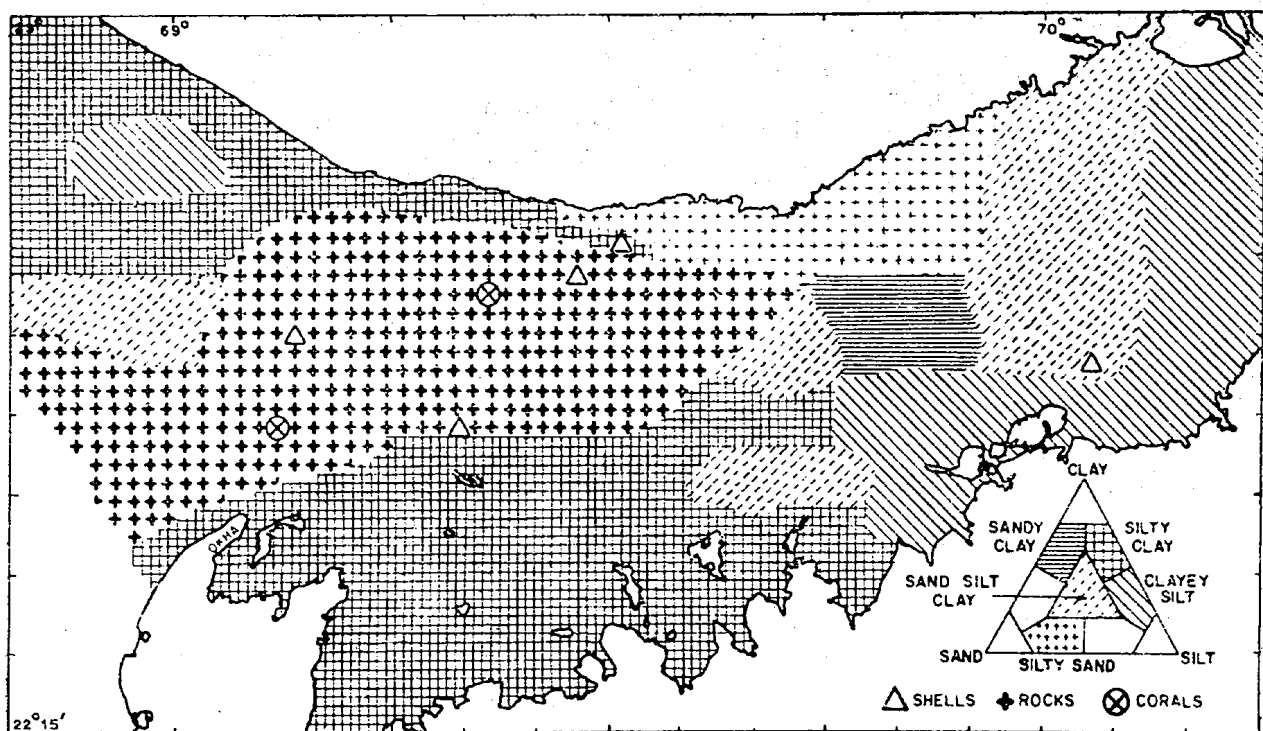


Fig. 10 — Generalized surface sediment distribution

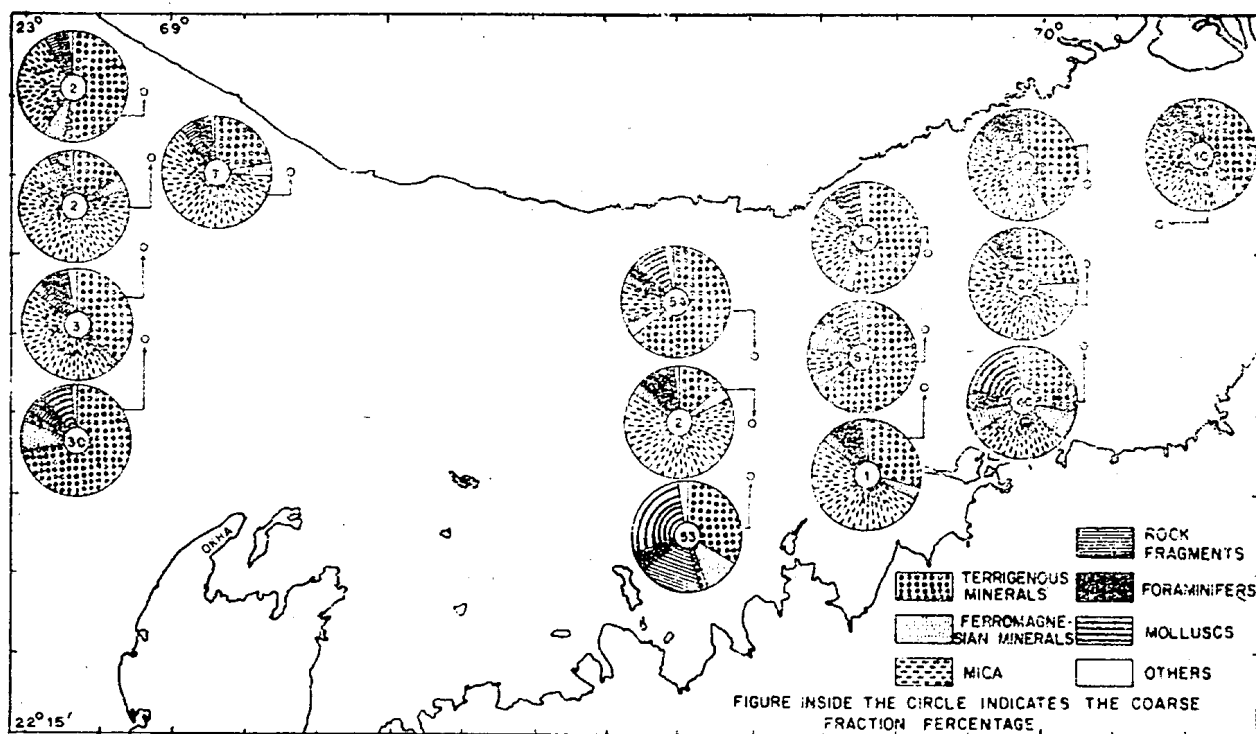


Fig. 11 — Abundance and distribution of coarse fraction constituents

This is in contrast to the shelf sediments which are dominated by carbonate material of late Pleistocene age¹⁴. Paucity of skeletal carbonates in the Gulf may be either due to the inherently low biological productivity of the waters or account of high turbidity or due to destruction of biogenic carbonates by the high tidal velocities. High tidal

velocities also lead to high substratal mobility and may be responsible for the impoverished bottom fauna. Skeletal components, except those of foraminifera and molluscs, are grouped in the category "others". The fragments found are too small to allow identification but these appear to be coral and coralline (?) algal fragments.

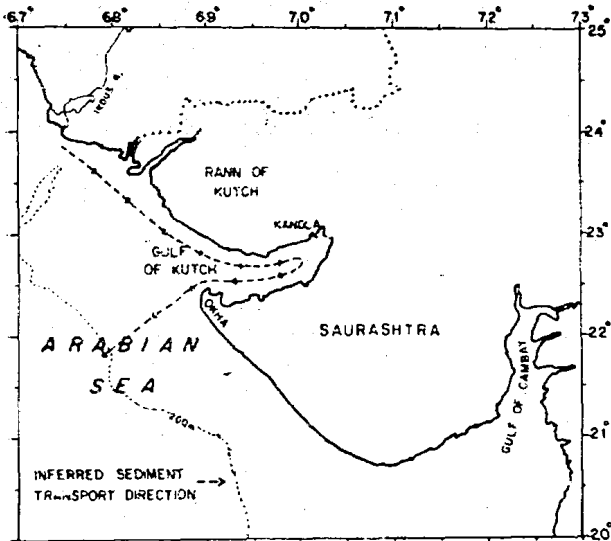


Fig. 12 — Inferred transport direction of sediments.

Sedimentary Processes

The nature and distribution of sediments point to the overriding influence of the high velocity tidal currents of the Gulf. As a sedimentary environment the Gulf may be said to be tide dominated. The principal tidal influence appears to be its role in transporting sediments from adjoining shelf into the Gulf. Redistribution of the sediments results from the interaction of the tidal current with irregular topography of the Gulf. Turbulence over irregular topography prevents accumulation of sediments in the middle of the Gulf (Fig. 10).

The sediment transported into the Gulf admixed with those derived from its shores and with wind borne sands give rise to polymodal character of the sediments. The proportion of sediments derived from the lands bordering the Gulf is likely to be little because the region as a whole is arid and has little run off. Wave erosion of Tertiary rocks outcropping on the shores of the Gulf and in the numerous islands in the Gulf is probably a greater source of sediment than that derived from the land. Numerous streams which discharge into the Gulf especially those at the head of the Gulf are short, <20 km, in length, and are estuarine. A net contribution of sediments from such sources is also not expected. An unusual feature of the Gulf is the inundation of large parts of the Rann of Kutch during the south-west monsoon. Whether any sediment contribution takes place to the Gulf due to this process is not known.

Inferred transport direction of sediments into and out of the Gulf are shown in Fig. 12. The shoals at the entrance to the Gulf probably splits the flood currents into 2 branches, one proceeding along the northern part and the other along the southern parts. The ebb current presumably is strong enough to transport the sediments out of the Gulf and deposits them on the slope bypassing the outer shelf. This is suggested by the absence of mica

on the outer shelf and its presence on the slope adjacent to the outer shelf¹⁰. Transport to the southerly direction is restricted by the tidal currents of the Gulf which act as a hydraulic or tidal barrier.

Reconstruction of past sedimentary environment and sedimentary processes is possible to a limited extent. Relict sediments are present on the western continental shelf between 60 and 90 m. These have a radiocarbon age ranging from 9000 to 11000 yr and suggest a low stand of sea level during that period¹⁵. Since the Gulf has a maximum depth of 60 m, a sea level lowering to that depth would result in the Gulf becoming an extremely shallow water region, analogous to the present day Rann of Kutch, and during maximum sea level lowering (120 m) even becoming dry land. The possibility of shallow water conditions in the past is also indicated by the presence of calcareous sandstones at a depth of 60 m which on the basis of petrographic and faunal studies¹ have been concluded to have originated in the inter-tidal zone.

Since the Pleistocene climate has generally been concluded to be more arid¹⁶, the Gulf region would have been subjected to even greater aridity than what is found at present. In brief, the area would approximate desert conditions. Under such conditions wind borne sediments like frosted quartz would be the principal sediment type. The subsequent rise of sea level (Holocene transgression) would have resulted in progressive transport of sediments from the adjacent shelf into the Gulf and their redistribution by the tidal currents.

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