CHAPTER - IX

TRACE FOSSILS, DEPOSITIONAL ENVIRONMENTS AND SEDIMENTATION MODEL.

As viewed earlier in Chapters V, VI and VII several characteristics of the eastern Kutch sedimentary deposits including their trace fossil diversities indicate deposition within a deltaic setting. There is a marked heterogenity with shales, burrowed and laminated siltstones, burrowed sandstones, and trough cross-bedded, channel fill sandstones occurring within 15-20 m, thick sequences. The diversity of rock types and their abrupt vertical and lateral transitions between them reflect a mosaic of shifting depositional regimes which typifies deltaic environments. Deltas, however, are stressful environments due to fluctuations in salinity and current energy and the trace making communities which inhabit these zones thus have to be tolerant to a wider range of conditions than their normal shallower water and deep water counterparts These animals further be able to relocate themselves readily following outset of unfavourable conditions.

Recently, Rhoads (1975), worked out general gradations of trace fossil assemblages in relation to increasing water depths. As claimed by him the nearshore environmental conditions are generally highly variable than deeper water and are subjected to more rapid and more regular changes. Consequently, animals which inhabit these shallow water zones are tolerant to a wider range of conditions than their deeper water counterparts and are able to relocate readily following outset of unfavourable conditions.

Environmental zonations, entirely based on the trace fossil distributions on the above aspects as suggested by Rhoads (1975), the author feels may not be a very straightforward task when applied to the sedimentary rocks having a complex deltaic pattern. Despite some of these difficulties an attempt has been made here to use trace fossil evidences to reconstruct the possible Mesozoic depositional environments prevailing in eastern Kutch. This task looks quite attractive as there are already two depositional models explaining the nature of the sediments which can also be tested for their validity. These models are by Deshpande (1972), and Biswas (1981). Both these models are summarised and reproduced in the following tables 15 and 16.

The recognition and interpretation of the eastern Kutch environments in the present studies are mainly based upon analogy with two deltaic sedimentation models which have been developed as the result of recent studies of modern

TABLE - 15 : DEPOSITIONAL ENVIRONMENT IN WAGAD (after DESHPANDE,1972)

Formation	Nature of Sediments; Tectonic Setting of the basin	Depositional Environments
Washatwa Formation	Sandstone, quartzwacke to quartz arenite. Occasionally micaceous : 75% to 30%. Shales grey to khaki, silty, constitute rest of the percentage. Stable to unstable shelf conditions Mild Subsidence in the north while moderate Subsidence in the south.	Deposition during a marine regressive cycle representing shallow marine environment in the SW and delta mouth bar in the NE. Rapar Mewasa axis forming lobate shore line in relation to delta.
Lower Kanthkot Formation	Sandstones, quartz arenite varying from 90% to 60%. Shales grey to brownish, Khaki constitute rest of of the amount. Stable to unstable shelf conditions. Mild Subsidence of the northern part while mild to moderate subsidence of the southern parts of the area.	Shallow marine in northern half and delta complex in the eastern half. Strand line Rapar-Chitrod axis. Delta complex differentiated into channels and flood plain deposits occupying the interdistributory area of the eastern part. The region close to the shoreline to its immediate east probably represents the distributory mouth bar sub-environment. The western has of the area experienced Pro-delta or shallow marine environments associated with delta. During the entire course of Lw. Kanthkot deposition the western half of the area experienced a continuous marine regressive cycle, while the eastern half experienced initially a marine regression followed by a deltaic environment.

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TABLE - 15 : contd..

Formation	Nature of Sediments; Tectonic Setting of the basin	Depositional Environments
Kanthkot Formation	Sandstones calcareous, quartz arenite. Occasional micaceous. Constitute about 90% to 60%. Rest are Shales and Siltstones. Northwest part represents stable shelf as compared to south western part which is unstable shelf. Mild to moderate subsidence only in the western half of the Wagad area. Mild uplift in the north and moderate uplift of the Southern part (Uplift post-Kanthkot and Pre-Gamdau).	The eastermost part (east of Hamirpur and Bhimsar) was the area of non-deposition as the start of the Upper Kanthkot deposition - The area between this and Narada-Chitrod in the central part, possibly experienced a deltaic environment. Western part deposits under transgressions.
Gamdau Formation	Sandstone over 90%, mainly quartz arenite to quartz wacke types. Rest Shales and Clays. Mild Subsidence. Little or no uplift.	Rocks devoid of fossils. Possibly fluvial or Valley fill environments of deposition. The fining upward pattern confirms its fluvial nature.

TABLE - 16: DEPOSITIONAL ENVIRONMENTS IN EASTERN KUTCH
(after Biswas, 1981)

	Formation	Sedimentary Characteristics	Depositional Environments
	Washatwa Formation 675 ft.(+) (Argovian)	Interbedded Shales and sandstones, Shales grey gypsus with ferruginous bands. Fissile sandstones, and fossiliferous limestones. Sandstones red and yellow, medium to fine grained feldspathic waeke, crossbedded (Planar). Ferruginuous bands, ripple marked. Shales fossiliferous in the west becoming unfossiliferous towards east. Topmost bands in the west are highly fossiliferous containing ammonites, belmnites, Pelecypods, gastropods and single corals.	Lagoonal or Restricted Bay
WAGAD SANDSTONE	Kanthkot Member (Developed only in Western Wagad) 650 ft. Kimmeridgian to Neocomian	<u>Sandstone/Shale alternation:</u> Interbedded sandstone and gypseus shales with fossiliferous bands containing mostly pelecypods, ammonites, gastropods, belemnites, also fossil wood	Delta Fringe
		<u>Kanthkot Sandstone:</u> Buff, massive, firiable cross-bedded sandstone. <u>Lower Shale Bed:</u> Gray silty gypseous shales with ammonotes.	Delta Front Sand
	Gamdau Member 550 ft (+)	Deeply coloured sandstones: Coarse grained poorly sorted arenites and fine to medium grained well sorted ferruginous feldspathic wackes. Red ironstone bands, felspathic and carbonaceous shales, lenses of conglomerates in rhythmic sequence with sandstones. Cross-bedded, tabular, topped with feston, carbonised plant fragments, wood & occasional leaf impressions. Lower part intertongues with Kanthkot Member.	Delta Plain

deltas. These include Mississippi delta (Fisk et al. 1954; Shepard, 1960; Coleman and Gagliano, 1965; Gould, 1970); and Nigar delta (Allen, 1965, 1970). Based on their comparison the eastern Kutch Mesozoic sediments are interpreted as representing the following deltaic subenvironments:

I - DELTA PLAIN
II - DELTA FRONT
III - PRODELTA

DELTA PLAIN

The "delta plain" is the principal subaerial part of a delta and includes minor subaqueous environments such as distributory and tidal channels, natural levees, and flood basins (Swamps, marshes, lakes, bays and gathering streams). It is usually observed that following delta lobe abandonment, a series of arcuate barriers or delta margin islands are thrown up by reworking of underlying sandy delta front deposits. These in turn transgress landward as the delta founders.

The most common rock type in the delta plain environment is the dark brown to medium brown siltstone that is extensively mottled leaving only crude remnants of the original primary horizontal stratification. The red colour of the sediments is the characteristic which also suggest a terrestrial origin of this subenvironment.

(i) Distributory Channels:

Evidences for distributory channels can be found in parts of Washatwa, Nara, Kanthkot, Adhoi, Halre, Ramwao, and Tramau sections. Such evidences include sandstone-filled channels having their flat tops at various positions within the delta plain environments and their concave upward bases extending down to various levels, even well down into the delta front facies (Figure 39). Furthermore, these channels appear as cross-sections of sandstones that are elongated approximately in the east-west direction. Some of these channel cross-sections are relatively narrow and symmetrical while others are broader and less symmetrical (Figure 40). Trough cross-lamination is by far the most common sedimentary structure in all channels. It occurs from, or near the base to within a few meters to the top, where it is replaced by ripple laminations.

The trace fossils of the channel fill deposits are represented by the highest energy assemblage similar to those of the marginal marine facies. Reinforced wall structures and or vertical burrow orientations are exhibited by the majority of the trace fossils within the sandstones. With the exception of Thalassinoides the trace fossil assemblage of the eastern Kutch channel fill sandstones closely resembles the trace fossil assemblages found in modern high-energy marine environments (Figure 41). This include Ophiomorpha which is the most prevalent trace in both modern and ancient upper shore face sequences (Howard, 1973; Howard and Scott, 1983; Howard and Frey, 1984). Skolithos and collapse structures (vertical succession of down-bent laminae on account of collapsed vacant burrows, (Plate 63) are also extremely common in upper shoreface environments as suggested by these authors.

(ii) Flood Basins:

Varieties of these water bodies are not consistently named. Among them are bays, lagoons, sounds, and lakes. They are either partly or completely open to the sea, or are inland and more restricted. Also, included in this category are the marshes and swamps which are periodically inundated and can be quite extensive, covering upto 90 percent of delta plain (Fisher, 1968).

(a) Marsh environments:- Evidences of marsh conditions are found in the rocks around Hamirpur and Bhutakia in the north-east of Chitrod-Rapar axis and around south and south-east of Chitrod proper (Figure 8). These rocks are characterised by layers of poorly sorted cross-bedded and laminated red and grey coloured sandstones intercalated with thinner

PLATE : 75 - Desiccation cracks indicating delta plain environment.

PLATE - 76 : Columnar structures indicating delta plain environment.

PLATE - 77 : Large Oysters - Protected bay or lagoon environments in parts of Chitrod and Washatwa.

layers of finely bedded dark grey to red clayey siltstones, ferruginous and calcitic concretions, sandstone and shale clasts, decisication cracks, columnar structures (Plates 75,76), rain imprints and penecontemporaneous slump structures are the common features that suggest their marshy origin. The typical trace fossils are Scoyenia, Chodrites, Skolithos, and Crustacean Thalassinoides burrows. Plant strands and rootlets also dominate the sediments.

(b) Protected Bay or Lagoon:- The rocks, south of Chitrod and Washatwa were the bay or lagoonal environments are predicted are grey to brown in colour, fine-grained and bioturbated with low diversity of trace fossil content. The traces include Rhizocorallium, Pelecypodichnus, Planolites, Paleophycos, Zoophycos, Chondrites and intercalated Thalassinoides in fine-grain sandstone layers. The sediments also contain large sized oysters (Plate 77).

The overall nature of the trace fossils indicate marine realm. The lack of sedimentary structures and the autochthnous nature of faunal elements indicate protected environments such as enclosed bays and lagoons.

Modern analogues for the lagoon trace fossils include callianassa burrows (Ophiomorpha nodosa); Upogebia burrows (Planolites montanus); Pelecypod resting traces (Pelecypodichnus)

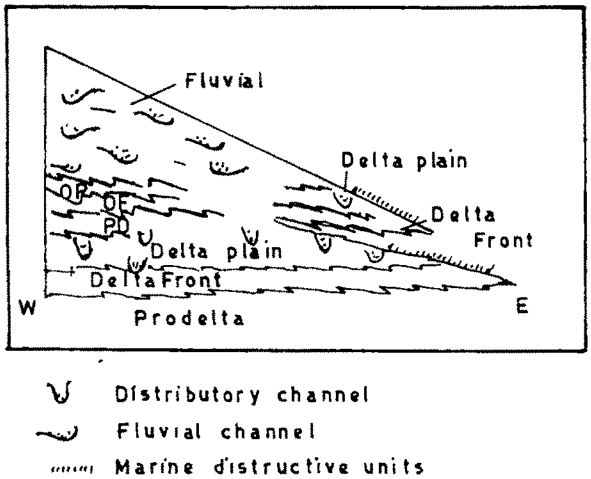

FIG. 39 - Diagrammatic facies profile - Eastern Kutch delta system.

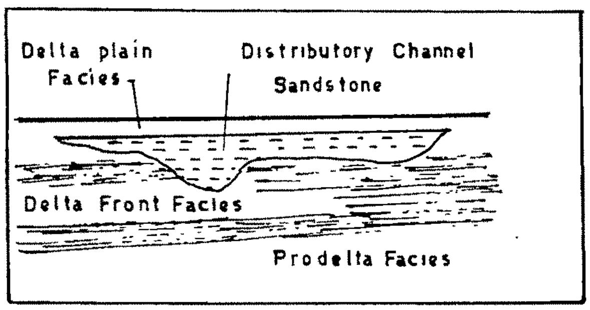

FIG. 40- Diagrammatic cross-section of distributory channel.

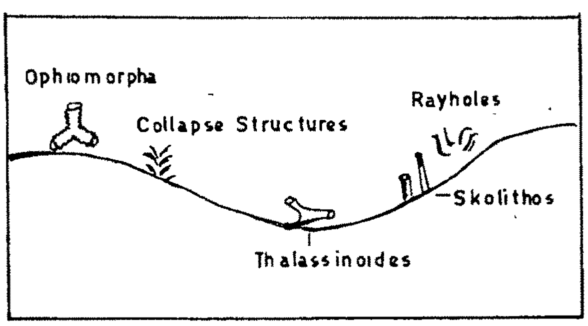

FIG. 41 -Common trace fossils of channel fill asseblage in modern high energy environments.

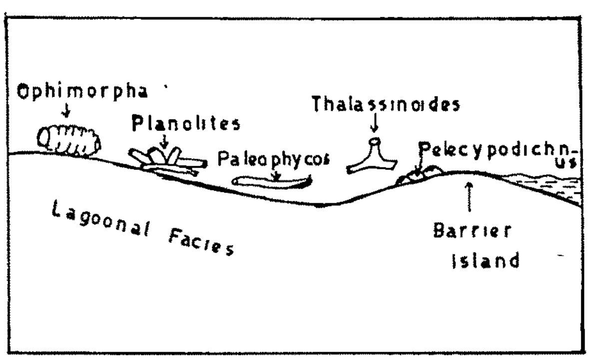

FIG. 42- Common trace fossils in modern lagoonal environments.

Polychaete burrows (Palaeophycos) ? shrimp burrows (Horizontal sand filled tubes). (Figure 42).

Thalassinoides shrimps are thought to be responsible for the mottled bedding found in the lagoonal environments as suggested by Curren and Frey, (1977).

(c) Destructive Delta Margin Sands :- These are usually well-sorted sands that have the even parallel or low-angle cross-lamination typical of beach shoreface deposits.

Beach :- Evidences of beach are once again located in the Chitrod and Washatwa sections (Figure 29 & 30). The rocks here are well sorted but unconsolidated, medium bedded, lenticular or tabular cross-bedded red and grey sandstones. Paucity of mud and lack of autochthnous marine invertebrate fossils are the characteristics of these rocks. The trace fossils include - Arenicolites, Diplocratarion, Spirophyton, Rosselia, Ophiomorpha, and Thalassinoides burrows indicating the Arenicolites and Diplocraterion ichnocoenoses. These ichnococoenoses as seen earlier are typical of an unstable substrate that is subjected to high rates of sedimentation and erosion, thus indicating a high energy environment. Similar traces have been reported by Fursich, (1974) from the Corallian (Middle and Upper Oxfordian) rocks of England and Normandy.

The most important evidence towards beach developments however, is provided by the Ophiomorpha burrows in the Lower

Kanthkot Formation in Chitrod and Washatwa sections. The *Ophiomorpha* as mentioned earlier with their vertical branches that terminate at progressively higher (younger) bedding planes indicate positions of erosional bedding plane surfaces. Such structures as claimed by Howard (1975) are indicative of rapid beach progradation with each termination or bypass structure of *Ophiomorpha* burrow marking the former position of a beach surface (Plate 64).

DELTA FRONT

The delta front environment is the shallower, coarser, and in part, steeper subaqueous part of a delta, extending from delta plain seaward to the transition with prodelta environment. There are two subenvironments of the delta front. Major sand deposition occurs on the "distal bar", which is away from channel currents and deeper than normal wave influence. Sand is also deposited in the upper part of delta front on the "distributory mouth bar crest" which is scoured and winnowed by channel currents and/or by waves tidal action.

Evidences of delta front environments are found in Washatwa, Adhoi, Nara, Kanthkot, Ramwao and Tramau sections. Along the entire outcrop belt the delta front deposits are continuous and are marked with sandstones and occasional thin interbeds of siltstones. Changes upward from the basal transition with prodelta include (i) increase in grain size of the sandstone from very fine to fine and, in some places medium, (ii) including thickness of individual sandstone beds, (iii) Siltstone beds become thinner and less numerous and (iv) dominant sedimentary structures changed from even parallel lamination to trough cross lamination.

Most of these changes indicate high energy environments where the trace fossil occurrence is rather rare and sporadic. It is possible that this coarsening upward delta front sequence occurred as a series of coalesced distributary mouth bar crests and associated distal bars.

PRODELTA :

The prodelta is the most distal subaqueous part of a delta it lies seaward of the delta front and landward of the shelf and is where fine terrigenous sediments is deposited principally from suspension as the first record of an advancing delta (Figure 43).

Such evidences of prodelta environments can be located in parts of Washatwa, Nara, Adhoi, Halre, Mae and Manfara sections (Figures 30, 37, 32, 31, 36 and 38). The rocks include repeated parallel and lenticular laminated silt with occassional cross laminations and current ripples, alternating with dark coloured highly burrowed mud dominations. Ferruginuous concretions and extensive churning of the substratum by organisms, was presumably associated with slow rates of deposition in a low energy, deeper water environment. The absence of cross-bedding in the siltstones and the general lack of storm initiated sedimentary structures in its major portion indicates that current action was not effective in reworking the sediments. It is, therefore, possible to conclude that the prodelta sediment of the eastern Kutch were in the most of their time were deposited below wave base in water perhaps deeper than 100 m. This is particularly supported from the Scolicia type large sized trails that look so similar to those reported by Ekdale and Berger (1978) from their DSDP investigations in the equatorial pacific ocean.

The prodelta biogenic sedimentary structures on the whole show more diversity and less density of individual genera and species. The common traces are - Scolicia, Bolonia, Gyrophyllites, Halminothopsis, Paleodicton, Taenidium, Chondrites, Scalarituba, Taichichnus, Zoophycos, Rhizocorallium, Muensteria, Gyrochorta, Paleocypodichnus, Planolites Paleophycus, Walcottia, Crossopodia, Cylindrichnus, Spongeliomorpha etc.

SEDIMENTATION MODEL

The prograding deltaic evolutionary model of the Mesozoic rocks of the eastern Kutch can be appreciated if one follows the sequence of events in the formation of a modern delta. As often inferred, deltas are the products of rapid deposition of stream-borne sediments into relatively still-standing bodies of water. Their presence represent the continuing ability of a river to supply and deposit sand, silt and other detrital materials more rapidly than they can be removed by currents. A major phenomena in deltaic evolution is the shifting of river courses into successive distributaries. As a delta progrades further and further into the sea, the gradient and carrying capacity of the river gradually decrease, and much shorter routes to the sea are being found in adjacent areas. Furthermore, when active progradation ceases delta lobes that are developed earlier are foundered and destructive processes of marine origin rework the delta sands into destructive delta margin sands that veneered back over the delta plain sediments to develop features like protected bays or lagoons and barrier beaches (Coleman, 1968, p. 260).

As previously discussed the deltaic deposition in the eastern Kutch is comparable to modern deltas which are ephemeral (short lived, or transitory) due to changes in the balance between progradation and destruction by marine processes. Such a setting is characterized by a complex of mosaic of environments with salinity and sedimentation characteristics that are directly reflected in their trace fossil contents.

The sequential deltaic evolution in the eastern Kutch can now be explained as under:

(1) The deltaic evolution probably started with the characteristic epehmeral changes (short lived, or transitory changes), a delta would undergo during its development.

In all possibilities an abandoned delta lobe having delta front sands existed in the south and southeastern parts of the eastern Kutch, especially around Chitrod and Washatwa. As a result of likely shift in the distributory channels the delta lobe appears to have collapsed and marine destructive delta margin sands veneered back over the delta plain sediments to form the features of the protected bays or lagoons and barrier beaches in this region. The existence of such bays or lagoons and beaches is very well documented in the earliest trace fossil records in Washatwa Formation.

(2) Active progradation is thought to have continued through different distributory channels in parts of Washatwa, Nara, Kanthkot, Adhoi, Harira, Ramwao, and Tramau.

(3) The generally east-west orientations of the distributory channels produced a sequential westward displacement of deltaic tracts which are once again very well revealed by the trace fossil changes observed in different stratigraphic sections.

(4) At essentially all the exposures along the east-west outcrop belt, the sedimentary sequence from base to top developed three major deltaic subenvironments: Prodelta, delta front, and the delta plain (Figure 39).

(5) The delta plain environment by far was such that it showed greater variety of rock types and facies geometry than its underlying delta front and pro-delta counterparts.

(6) The delta front sandstone dominated environments continuously evolved laterally, is indicated by their down depositional dips due west.

The sand rich delta front facies of western Kutch and its cyclic nature of Progradation probably resulted from the variations in the style of delta front sand accumulation. Such a change could be predicted in the presence of a broad, fanshaped complex of delta front sands comprising numerous coaleseing and overlapping delta lobes.

As indicated by the great lateral continuity of the delta front, the deltaic deposition must have continued under the influence of wave action and the long shore currents.

(8) During delta advancements, sediments comprising principally suspended fine terrigenous material deposited near the seaward parts of the delta to form the prodelta deposits. Such deposits are located in Washatwa, Nara, Adhoi, Halre, Mae and Manfara regions. The biogenic sedimentary structures clearly indicate these features.

(9) The deltaic deposition appears to have been controlled by the balance between subsidence and sediment supply to the depositional basin. However, at broad intervals this balance was being disturbed and sequences recording alternations between marine and nonmarine depositional conditions were introduced in the system. This fact is reflected in the paucity of

biogenic sedimentary structures in the Fort Sandstone Member which normally should have a high trace fossil preservation potentials, instead of lower faunal diversity and abundance. This happened perhaps on account of its possible association with fresh water and fluctuating salinity conditions within a coastal low salinity stream systems. The burrowed zones in Fort Sandstones thus represent establishment of euryhyaline species or localized incursions of water of high salinity.

(10) The depositional basin in the eastern Kutch is further claimed to have witnessed shorter cycles in which transgressive episodes (subsidence rate $>$ sedimentation rate), altered with progradational episodes (subsidence rate $<$ sedimentation rate). Such repetative patterns are said to be "autocyclic"- produced by shifting patterns of sedimentation in a continuously subsiding basin or "allocyclic" - resulting from external events like relative sea level fluctuations, tectonic events, compaction of underlying sediments, eustatic sea-level changes or any combination of these.

The overall sedimentological and ichnological evidences at various localities of eastern Kutch support possibilities of both the autocyclic and allocyclic nature of deposition.

(11) In conclusion, the deltaic sedimentary record of eastern Kutch shows a diachornous pattern of deposition that is typical of a regressive megasequence. This essentially corresponded to the building up of a deltaic complex which filled a slowly subsiding basin during the Callovian-Oxfordian time. Development of omission, and hardground surfaces and episodic sedimentation all indicate slower deposition, depositional breaks without much erosion and event stratifications.

(12) Neocomian time saw the final shift in the deltaic environments in eastern Kutch giving way to the fluvial deposition of the Gamdau sediments.

Finally, the three depositional models by Deshpande (1972), Biswas (1981) and by the author show comparable inferences and could be used in combinations for more accurate and useful information. (Scematic diagrams; Figure 44).

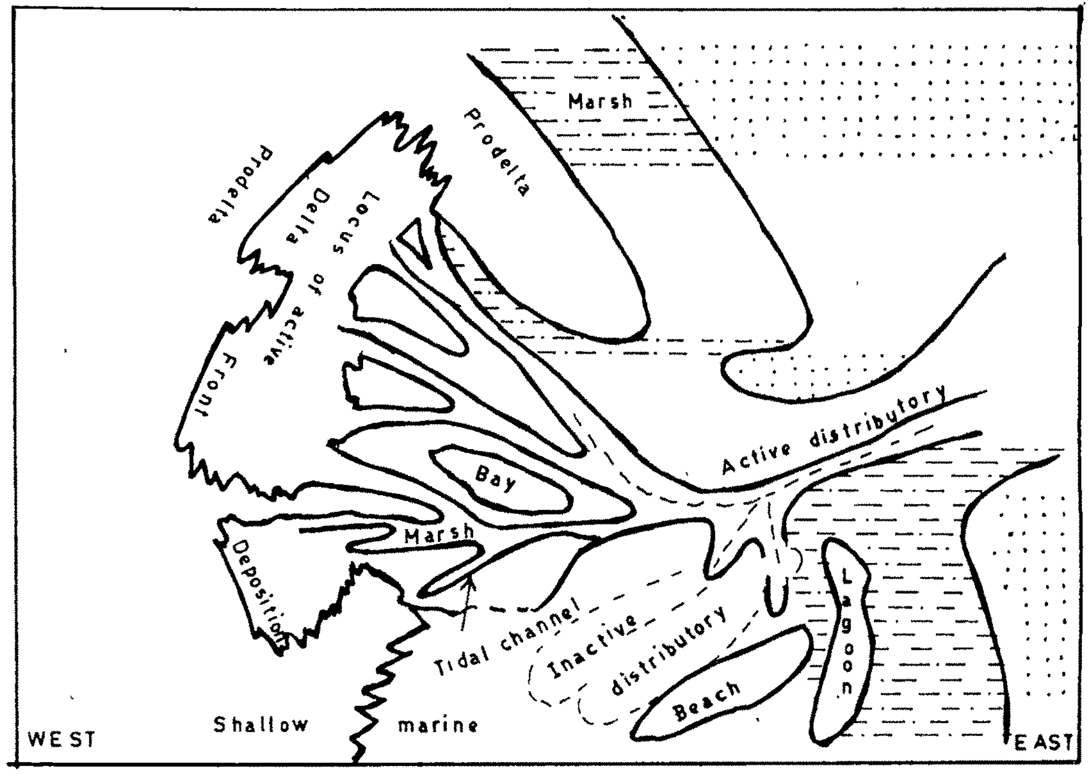

FIG. 43 .

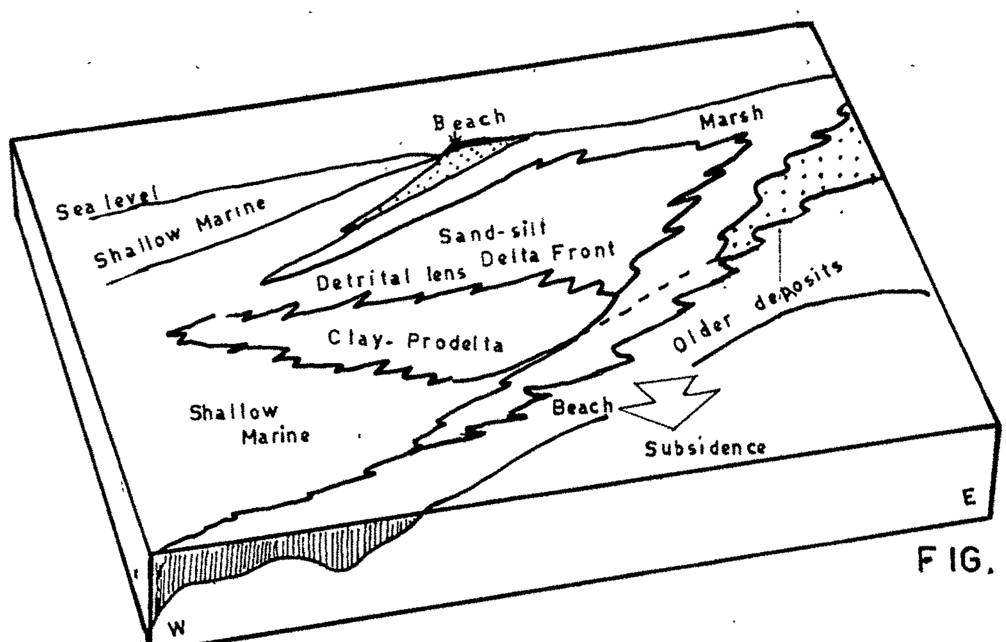

FIG. 44.

FIG. 43, 44 : Schematic diagram illustrating depositinal environments as revealed by trace fossil occurrences in eastern Kutch.