Chapter - 9

STRATIGRAPHIC EVENTS, DEPOSITIONAL ENVIRONMENTS AND SEDIMENTATION MODEL

IX. 1. INTRODUCTION:

The main aim of the author to study the Mesozoic sequence in the area south and southeast of Bhuj is to reveal the ichnologic and the stratigraphic events documented in those rocks. The ichnological part has been fully discussed in the previous chapters VII & VIII. In this section the author attempts to delineate various events which he has foresighted. All these are categorized in the following broad divisions:

(1) Physical events; (2) Biological events; (3) Stratigraphic events; (4) Palaeo-climatic events; (5) Catastrophic events; (6) Cyclic events; and (7) Tectonic events.

The physical events traced by the author include transgression- regression cycles, depositional and erosional phases, major and minor breaks like unconformities or hiatuses evidenced through the omission surfaces or non-depositional episodes. The biological events consist of presence or absence of mega-, micro-, and trace- fossils and their relationships with the sediments and their sedimentary environments. The stratigraphic events constitute major and minor events that have taken place during the formation of individual stratigraphic units or noticed at their boundary levels. Cyclic events, on the other hand are repetition of these events for their predictable and non-predictable causes. While tectonic events cover faulting, folding, intrusive episodes etc.

Many of the above events are confirmed by the author during his field studies on the basis of direct evidences. While, some events are reconstructed based on the observations on lithological characters, structures, trace fossils, associated lithologies and contacts above and below the targeted units, (judging from the physical parameters of thicknesses, lateral and vertical extension and variations, geometry, grain size, packing etc., observed in individual beds), or according to the observations recorded for the entire stratigraphic sequence (coarsening or fining upward; thickening or thinning upward). While, certain of these are merely inferred from their direct evidences or negative evidences or on the basis of other supporting events, e.g. catastrophic or storm events. (These normally involve some type of climatic variations or tectonic episodes e.g. high velocity wind, typhoon or earthquake). The overall depositional environments have been deduced from the various long range events or short term episodes of environmental or climatic cycles. These often involve various types of conditions prevailed at the time of final deposition of the sediments. In case of normal depositional events, it is observed that slow but, more or less continuous vertical accumulation of fine grained sediment is often interrupted by erosion or scouring followed immediately by the succeeding depositional episodes.

Most event beds observed in the area investigated by the author show a kind of amalgamation and cannibalism, i.e. large events wipe out the record of earlier smaller ones, including part of their host sediment. As a result, one event bed is often found directly following another or several other ones, the top of which is seen truncated. This observation generally concludes that the thicker of event bed and the deeper it has eroded, the longer is the recurrence interval of the event. Such a sedimentological episode has normally to be a matter of hours or days, wherein the areal extent of the individual event bed is limited to parts of a sedimentary basin. However, their have been times in the studied sedimentary record in which allogenic processes such as global sea level falls, have triggered the generation of discyclic rhythmic bedding. Such episodes appear to be true in case of LM, DOM and BM event sequences.

As viewed earlier in chapter V, VI, VII several characteristics of the mainland Kutch sedimentary deposits including their trace fossil diversities indicate deposition within a linear clastic shoreline setting. Very often, lateral continuation of intercalated shale siltstone, and sandstone facies with gradual variation in lithology and related trace fossils are the characteristic indications of these environments. On the other hand, there is a marked heterogeneity with shales, burrowed and laminated siltstones, burrowed sandstones, and trough cross bedded, channel fill sandstones occurring within 15.0- 20.0 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 environment due to fluctuations in salinity and current energy and its effects are seen on the trace making communities. One more related environment which has been encountered in the uppermost part of the Mesozoic sequence investigated is the estuarine environment. The rocks are typified by coarse grained large scale cross stratified sandstones showing prominent bimodal palaeocurrent directions. Since, these zone contain variations in tidal energy and salinity levels, they are characterised by poor diversity of fauna, and in rare cases with dominance of individual opportunistic ichnofossil communities or ichnocoenoses.

Furthermore, as very well known, the near shore environmental conditions are generally highly variable than the deep water and are subjected to more rapid and more regular changes. Consequently, animals which inhabit shallow water zones are tolerant to a wider range of conditions than their deeper water counter parts and are able to relocate readily following out set of unfavourable conditions (Rhoads, 1975).

The recognization and interpretation of the environments in the present studies are therefore based upon analogy with work in other geographical areas with identical geological set ups. The references of which are sited at appropriate places in the description.

IX. 2. STRATIGRAPHIC EVENTS:

Considering all these criterias so far discussed, the author now attempts to analyse individual stratigraphic units and probes through various sequential events and episodes that are found characteristic and typical in their own.

IX.2.1. CHARI FORMATION:

The Formation contains four Members, each of which coincides with a transgressive-regressive phase and is bounded by physical breaks. The Chari Formation thus represents four main transgressive regressive cycles. Following Haq (1987, 1988) these could be considered as third or fourth order cycles. Details of the Chari Formation at its Member levels are discussed below:

IX.2.1.1. JAMAYWADI MEMBER:

The lowermost JWM has *Gyrochorte, Ophiomorpha, Thalassinoides, Rhizocorallium, Diplocraterion* ichnocoenoses which represents the earlier phase of marine influence in Jurassic section. It demonstrates an almost continuous depositional event with very few major gaps. The sequence is coarsening upward with increasing frequency and thickness of SS facies at decreasing interval to represent a regressive phase. The same is evident in the trace fossils record noted in the progressively higher up sequence of sediments.

The intermingling of thin SS, and LSS facies depicts rhythmic repetitions. Such fluctuations and temporary shallowing are further marked by slump structures, interference ripples and parting lineations, to indicate shallowing conditions in the basin. These could be termed as minor cyclic events. Reasons for this cyclicity are rather unknown. However, the gully structures, described earlier, on top of SS beds are indicative of erosional episodes in localised areas could have formed under barrier to tidal flat conditions. Again abrupt change in lithology and occurrence of DSSS facies show depositional events under changed shallow lagoonal to tidal conditions. Here, occurrence of Bivalve Sandstone facies is indicative of high energy possibly a storm event. The base of it is slightly uneven suggest scouring event. The bed also represents a biologic event when various genera of bivalves, brachiopods, gasteropods etc. were populated in the sea. It appears that there must be a high velocity wind action or typhoon in the atmosphere or a climatic event which is reflected in form of storm that has generated the BS facies. The DSSS sequence is followed by tidal flat - beach conditions recognised in form of SS facies beds, with slight erosion at its lower contact.

The JWM as a whole represents deposition under low energy conditions and more or less a stable substrate conditions, which favoured development of varied ichnogenera. Biologically, entire sequence reveals scattered *bivalves, brachiopods, gasteropods*, and spines of varied origin etc., in the sequence except some tidal lag fossiliferous deposits and small *gasteropods* in living conditions in the SS facies. The sequence also contains few (3-4), 2.0 to 4.0 cm thick ferruginous or calcareous bivalve beds probably representing mild effects of storm in the basin.

Several minor depositional hiatus or breaks can be recognised in the JWM sequence represented by omission surfaces which are marked by ripple marked-, parting lineated-, surfaces on the top of siltstones of LSS facies or sandstones of SS facies with ferruginous or white marly crust as well as ferruginous hardened layers (hardgrounds) and in the shales of LSS facies.

In its last depositional phase, the JWM in turn, is followed by an extensive erosional event, marked by an unconformity, and uneven junctions at the lower contact of the upper sequence and missing of several uppermost sandstone beds of JWM and the lower beds of overlying GM especially noted in areas around Gangeshwar. It most probably represents contact between Tewaria Kutchensis Partial Range zone and Proteonina difflugiformis Astacotus anceps - Assemblage zone of Pandey and Dave (1993). The unconformity represents contact between JWM and GM.

IX.2.1.2 GANGESHWAR MEMBER:

The large scale erosional event at the end of JWM is marked by an unconformity, and appears to be continued for a longer time. Thus, deposition of the lower beds of the GM in the distal parts of the basin and erosion of the upper beds of the JWM in the proximal part were going on simultaneously. This is evident by absence of upper beds of JWM and lower beds of GM within few hundred meter distance from exposures of almost complete sequences, tapering of some of the lower beds of GM, presence of prominent uneven erosional surface between the JWM and GM, as well as occurrence of large rounded sandstone boulders - an erosional product under semiarid-arid conditions - uneven in size and present at different level in the lower part of the lowermost sandstone bed of GM (plate-2). The boulders are erosional remnants of sandstone beds of JWM, which have entrapped in the lowermost sandstone bed of GM by little transportation or are dropped from a head land or caught in situ in the transgressing sea. The increase in thickness of the beds towards distal part suggest moderate to high gradient of the basin.

The marine influence in GM is depicted by the occurrence of sparse trace fossils and minute *bivalves, brachiopods, gasteropods* etc., alongwith some physical sedimentary structures in beds. All these features are variously discussed in the description of the Member and the concerned lithofacies. The depositional events in the GM are almost continuous with minor omission surfaces on the top of each bed. In the MS facies sequence of GM, seven beds have been recognized, each marked on the top by either ripple marks or parting lineations and ferruginous or marly crust and sparse dwelling burrows. The beds commonly shows complete or incomplete sequence of physical structures from bottom to top: massive, horizontally stratified, planar cross bedded, ripple marked or parting lineated with fine crust. These suggest seven shallowing upward cycles in the sequence and also indicates rate of sedimentation exceeding rate of subsidence, which bring water sediment interface almost near the water level. Each depositional event is followed by omission surface marked by crust, ripple marks and parting lineations. The ripple marks are big (W.L. 15.0-20.0 cm, Amp. 3.5 cm) suggest moderate to high energy conditions of the waves. Such a conclusion is also supported by the presence of gritty to fine gravelly grains on bed surfaces. Parting lineations indicates partial subaerial exposures in intertidal zone. They are usually perpendicular to the shore line extension. The above mentioned evidences suggests an initial transgressional phase with increased energy conditions and higher sand influx. This possibly indicate constant strand line conditions and can be interpreted following Gibling (1977) as recurring shallow subtidal to intertidal transitions resulting from progradation of tidal flats and beaches. This initial phase of transgression seem to have degraded the basinal slopes to low gradient, and in the upper part it seems to have covered entire basin as is observed by the presence of cross stratified sandstones of HS on all the exposures of the GM, to indicate high energy conditions and migrating sediments as reflected in the erosional and reactivation surfaces of the varied cross stratified beds and herringbone structures. The whole sequence thus depicts successive cycles of scouring of loose sediments and redeposition by shifting sand waves or big ripples, under highly agitating tide dominated sea with moderate to limited sand supply. This event, however, ceased against a major omission surface or hiatus or a hardground developed surface marked by scattered dwelling trace fossils, ferruginous crusts and sharp junction as well as change in lithology. This major hiatus marks the junction between GM and overlying LM, and suggest nondepositional event, and development of hardground as it is not affected by scouring during later events.

The high sand influx in the Member, in general, indicate large carrying capacity of the transporting agency, and higher distributing capacity of waves and currents as well as high rate of sediment production. The transgression event may be related to subsidence as it is of minor extent and the regression observed in the sedimentary depositional phase may have been caused during the upheaval. The topmost part of the sequence suggest that these horizons containing vertically oriented burrows represents periods in which the bedform caused to migrate and was colonized by suspension feeding infauna. Sellwood (1975), observed similar structures in Jurassic tidal flat deposits of Bornholm, Denmark.

IX.2.1.3. LER MEMBER:

In this sequence overlying the GM, a great number of interesting evidences related to event stratigraphy and episodic sedimentation are found. Here, the beds represent accumulation of several erosional and depositional events and as such can be interpreted as multiple event beds.

The deposition of LM in fact is the third transgressive event in the Chari Formation. The Ler Member commenced with a storm event represented by gritty pebbly coarse grained Bioclastic Sandstone (BS facies) with mega ripple marks on top. The beds also show planar cross stratification, and contain gritty to fine pebbly material in large proportion alongwith bioclasts of bivalves, belemnoids, ammonoids and small to large ferruginous red brown flat pebbles in a poorly graded manner. These are lag deposits, scoured, winnowed, much less transported and deposited under subsiding storm conditions (plate-10). Transportation, whenever occurred seems to have taken place as bed load as can be seen from cross stratification. Later, after deposition mega wave impressions on the sediments, were impregnated. Much amount of finer calcareous and ferruginous material seems to have accumulated from suspension at the time of deposition simultaneously to the lag material. In the eastern Kutch, in Washtava area similar sandstone beds below the lower astarte band, displays hummocky top where dense pelecypod trails perhaps dating an event of crises have been recognised (Shringarpure, 1985). These lag deposites are further followed by moderate to high energy condition depositional events with a cyclicity marked by repeated erosional and reactivation surfaces in 16-17 cross stratified units varying in thickness from 7.0 to 15.0 cm. Two more beds showing identical characters have been observed either amalgamated one over the other or found with a maximum spacing of 1.0 m of shales, in the middle part of the Ler sequence. These can be interpreted in the same way, the bed just described and discussed, and occurs on scoured surfaces on shales. The beds in the middle part of the LM sequence can be regarded as marker horizons below Dhosa Oolites as they show much lateral extension in the mainland and uniform characters and thickness. Such beds are approximately 20.0-22.0 m above the base of LM in the exposures north of Gangeshwar (plate-10).

Further evidence of episodic event by storm and crises comes from the Astarte beds. Two separate astarte beds have been recognised on the exposures two kilometer southwest of Gangeshwar, while one bed with three amalgamated sequences have been observed half kilometer north of Gangeshwar. Normally top part of the beds show mega wave ripples. The lower Astarte bed, is a bed of shell rich layer. Such shell layers alternating with barren interval, according to Dott (1983, p. 16) are evidences of some sort of episodicity. The possible origin of such layers as explained by him as due to violent disturbances of shells through bottom stirring by unusually large waves which disturb and concentrate the shells by winnowing away all fine sediments. Subsequent return to normal conditions as suggested by him would produce fine sediments containing scoured shells. In this last phase also, microlevel episodes have been observed in the exposure of the three tire amalgamation of Astarte beds north of Gangeshwar. Here the bivalves are found arranged parallel to the bedding plane. In its lower part, majority (up to 70%) of the bivalves are concave up with other convex upward and few inclined to vertical to the bedding plane. This appears to suggest receding energy conditions under which bivalve settled alongwith finer sediments from the suspension which kept them concave up. Weak bottom currents likely to exist, may have turned up, some settled bivalves to convex up or inclined to vertical position. Inclined or vertical position are directly produced at the time of settlement from the suspension in the cohesive unconsolidated sediments. This is followed by mild scouring and flattening which lead to the development of scoured erosional plane and next deposition started on such a reactivation surface.

The middle unit contains most of the convex up shells with few concave up oriented shells, depicting prevalent strong bottom currents working simultaneously to the settling of the shells.

In the upper part of the sequence alternate layers containing convex up and concave up shells respectively show some kind of cyclicity of the episodes. Top part with mega ripples depict continuation of retreating storm conditions, and omission surfaces, with beds showing weak gradation.

In the southwestern exposures to Gangeshwar the most prominent feature of event stratigraphy is displayed by the shell coquinas forming the upper *Astarte* bed. The concentration of the bivalvia Astarte shell as shell coquinas can be interpreted as under:

During peak storm conditions the shallow sea floor was subjected to scouring. The coarser material including the Astarte shells formed winnowed layer. While the finer material was held in to suspension. As the storm was over, the finer material dropped rapidly from suspension, some intermixed the coarser grained winnowed lag deposits including the shells and formed weakly graded beds with distinctive wave generated structures including the infiltration fabrics, shelter porosity and micrograded sediment perched on the individual shells etc. Shell beds formed in this way have contained reworked but untransported fossils.

Four more beds with almost similar characters are recognised in the higher up sequence in the Member in Ler section. These beds are included under bivalve limestone facies. They show much less thickness, compactly packed nature with bioclasts of bivalves, cephalopods, brachiopods, bryozoans, corals, foraminifers, echinoderms, gasteropods etc., and gritty material, fine quartz pebbles, red brown ferruginous to white marly flat pebbles in a scattered manner with fossils and much less amount of finer material. These beds are also interpreted as products of storm episodes where water probably has agitated for a longer time, not allowing the finer particles to deposit in large quantity as in Astarte beds. Upper two storm generated Bivalve Limestone beds are found amalgamated on each other. Normally these beds show mega ripples on top surfaces only, and harmony of top and bottom in a mega rippled manner suggesting presence of unconsolidated but cohesive sediments on the shallow subtidal part of the sea floor above storm wave base. Stormy wave has carved top of these sediment layers in a mega rippled manner alongwith deposition of bioclasts on it producing mega rippled BL facies showing harmony of top and bottom.

Thus, all these sediment layers indicate episode that suddenly changed the depositional style. The bioclastic beds represent reworked, disturbed material winnowed in place rather than having been transported long distances although affected by storm.

Other type of extraordinarily high energy episodes are represented by Intraformational Polymictic and Oligomictic Conglomerate beds. The lowermost of these episodic bed is found

30.0 cm above upper Astarte bed in Gangeshwar section and approximately 3.0 m above the same in section exposed 2.0 km south of Jamaywadi. It contains compactly packed clasts of ferruginous and micritic claystones alongwith bioclasts of bivalves, cephalopods, bryozoans, foraminifers etc. These are framework supported with fine micritic material and peloids as interstitial material. It seems, exhumation has taken place in shallowed subtidal part where upper regimes of storm might have scoured the sea floor and carried away finer material, leaving behind concretions, clasts, fossils, etc. Less amount of finer material appears to be deposited in the shallower part with thin pile of water after catastrophic episode as texture of the rock is frame work supported.

In the upper part of the LM sequence other six intraformational oligomictic conglomeratic layers are observed especially in Ler section. These storm generated beds show presence of small to very large gravels to cobbles of micritic mudstones with few ferruginous claystone and few bioclasts. Normally they form a single or hardly double layer of evacuated clasts where clasts hardly touch each other and are fixed in yellow to white micritic or reddish brown ferruginous or mixed cementing material. Top of such beds never show mega ripples. Base is uneven. These IC beds show similar type of conditions which have produced intraformational polymictic conglomerates. The finer material in this case also seems to be not deposited immediately after ceasing of stormy conditions, because, many of the clasts are bored on top and bottom. Such clasts seems to be overturned after development of borings on one side due to succeeding higher energy conditions to the one during which the clasts were accumulated. Many larger clasts are bored only on upper surfaces. These appear to be not overturned due to their larger size. All these characters suggest that the clasts are in situ deposited from where they have been exhumed and little or not transported. Visual density of the clasts is only three to four times higher in conglomerate bed than the concretion layers present in shale sequence exposed below, from where concretions are exhumed and reset in the conglomerates in form of clasts or pebbles. Normally concretion layers occur at an interval of 5.0 to 20.0 cm. That means, only three to four concretion layers exhumed during an episode which have scoured, on an average, 30.0 to 50.0 cm or maximum 1.0 m of predeposited sediments. The presence of fragmented *Thalassinoides* burrows signifies moderate to low energy conditions of deposition below normal wave base but above storm wave base, prior to the catastrophic event.

Each storm generated strata like BS, BL, IC, records following sequence of episodic events: scouring of sea floor sediments and exhumation of concretions and epi- and infauna; deposition of clasts and bioclasts with negligible to appreciable finer sediments; nondepositional event with slow sedimentation of finer crust; early diagenesis and in several cases development of hardgrounds, which have protected the strata from evacuation during next similar episode and generated amalgamated episodic beds. In this way, in all, total sixteen episode generated beds have been recognised in the LM sequence within thickness of about 57.0 m, every episode suddenly changing the depositional style to represent a sum of erosional and depositional multiple events.

Normal depositional events that took place under intertidal to subtidal beach, lagoonal, bar barrier to shallow subtidal conditions, thus are disturbed and intersected by catastrophic episodes in regressive sea. Last phase of depositional event ended in an erosional event under subaerial condition as evidenced from a erosional contact and EOC at the base of overlying DOM, which eroded almost entire upper sequence of LM up to uppermost BS in the middle part of the sequence in Gangeshwar and Fakirwadi areas.

Some of the clasts in the IC further displays formation of 'hiatus concretions', a phenomena referred by Voigt (1968), due to interplay of deposition, scouring and lithification. The sequence of events are explained as under. The lag intraclasts bored and encrusted by organisms or in some cases not bored and encrusted, is reburied and grew by further aceretion. This growth was interrupted by reexhumation through scouring and new surfaces once again encrusted and bored by organisms. The cycle of events appears to be repeated, each instance producing a micro-omission surface within the intraclasts, may be heterogeneous in composition.

The entire sequence therefore depicts rhythmic depositional events: normal deposition; scouring during storm event; deposition during storm event; nondepositional episodes after storm; and normal deposition. Such cycles repeat several times as can be seen from the vertical section (fig. 17). The LM depositional event in possibilities seems to be representing equivalent universal transgressive event during Callovian time, which may be of third to fourth order cycle (Haq, 1987,1988).

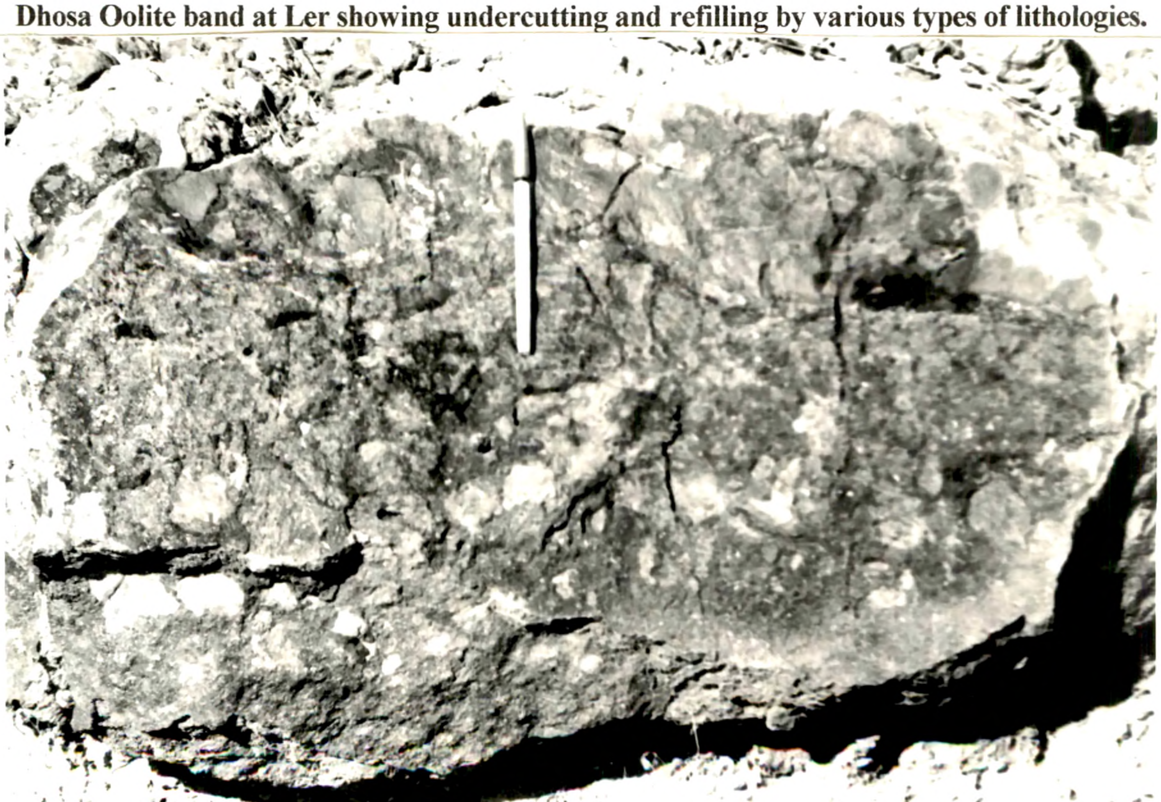
IX.2.1.4. DHOSA OOLITE MEMBER:

It appears from the field record that erosional event at the end of Callovian ceased as the transgression and depositional cycle of DOM of Oxfordian age commenced. This event appears to have continued uninterrupted till first sandy oolitic limestone band (D.O.) appeared in the sequence. The bands intercalated with shales suggest minor fluctuating energy and relative depth conditions and indicate cyclicity of events. Normally, minimum three such beds appear in the sequence but five and seven bands are not uncommon in the study area (e.g. at Fakirwadi - Mundra road and Gangeshwar)

The uppermost Dhosa Oolite band shows complex nature of its origin. At Ler and Fakirwadi, undercuts are developed by erosional event which later on is filled by oolitic micritic material different than the first one. It is seen in a lower continuous bed followed by another bed in patchy form with different type of lithology and third bed identical to the first one (plate-72 a & b). This suggest that roofs of undercuts are older than the material filled in it. The undercuts indicate early diagenesis followed by large scale erosion and subsequent deposition. On this the development of a thin veneer of fossiliferous lag deposit indicate storm event. This is followed by a thin to thick ferruginous crust of a prolonged nondepositional event. The ferruginous crust is cut across by polygonal fissures, which are filled by slightly light or dark ferruginous material. These must have formed when material was in a plastic condition on top before complete lithification or hardening and filled by similar type of unconsolidated to semiliquid material from within. Such rupturing and refilling could be the result of some disturbing episode, most probably an earthquake.

Intraformational conglomerate present on top of Dhosa Oolite Member indicates a strong storm event. The clasts present in the conglomerate are of varied origin. Some of the clasts are similar to the underlying Dhosa Oolite bands and presumed to be eroded and exhumed pebbles of those bands. Large number of pebbles are of micritic limestones or marls which are dirty white to pale

Dhosa Oolite band at Ler showing undercutting and refilling by various types of lithologies.



Dhosa Oolite band at Ler showing undercutting and refilling by various types of lithologies.

yellow in colour and different than any of the Dhosa Oolite bands. From this it appears that most deposition of thin sequence of sediments occurred with formation of concretions after the nondepositional episode on topmost D.O. band. The fact is evident by the occurrence of about 50.0 cm of shales overlained by approximately 30.0 cm thick micritic limestone band similar in composition to the pebbles present in the intraformational conglomerate, above top of most Dhosa Oolite beds and below Katrol sequence at Ler. These deposits seems to have exhumed during storm event and concretions remained in situ to form IC, where as at Ler the deposits skipped the exhumation due to development of continuous hard layer in place of concretions. The clasts are embedded in dirty white micritic material to ferruginous material and the conglomerate shows almost similar characters to the intraformational conglomerate present in LM. Fursich et al. (1992) have observed east- west alignment of pebbles in Habo dome in Intraformational Conglomerate suggesting prominent direction of strong currents during storm. The event seems to have followed by erosional event as is observed in uneven surfaces on top of conglomerate at different places. The top of the DOM marks junction between Chari and Katrol Formation, DOM and GRM as well as Chari and Katrol series. It represents junction between Oxfordian and Kimmeridgian stages of chronostratigraphic classification. In the study area the DOM sequence *represents Epistomina majungaensis Range zone* and *Epistomina majungaensis - Lenticulina bulla Interbiohorizon (poorly fossiliferous) zone* of Oxfordian age, when compared to the observation by Pandey and Dave (1993).

The depositional event of DOM is also followed by tectonic event responsible for folding in the area. It is very clear from the variation in dip of DOM and immediately succeeding rocks of GRM.

IX.2.2. KATROL FORMATION:

The Katrol Formation contains three main transgressive regressive cycles, which are accordingly considered as three main Members demarcated by lithological variations or physical breaks. The events and episodes are confined within the three Members viz. Gunawari River Member, Marutonk-Dungar Member; and Jadura Member, are described below:

IX.2.2.1. GUNAWARI RIVER MEMBER:

Deposition of GRM most probably took place in a regressive cycle after the peak marine transgression. Here, transgressive deposits are not observed in the lower part. The beds in the Member represent progradation of delta and development of delta slope, prodelta, and delta front conditions under a regressive cycle.

In the GRM sedimentary sequence, prominent scouring and erosional events have been recorded at the base of OBS facies which represents prograded submarine part of delta structure. Below this delta front deposits are present, representing first formed marine sediments in rejuvenated basin after brief erosional event following end of DOM. Prolonged omission surfaces and hardgrounds developed in form of red brown ammonoid bearing hard ferruginous layers known as Katrol ammonoid beds. Maximum seven such layers have been observed in lowest two meter sequence which are rich in ammonoid fossils These represent nondepositional time spans. Scouring is also recorded in form of pebbles containing ammonoids and wood fossils which are embedded within OBC facies sequence represented by fine sandstone. These are exhumed pebbles scoured from underneath during long term scouring event in some nearby area and settled in the above mensioned rock. Top of each such sandstone contains micritic crust showing minor omission surfaces. Two to three thin Intraformational Conglomerates and fossiliferous lag deposits suggest effect of storm event in the basin. Storm conditions are also depicted by mega wave ripple marks on the top of OBS with scattered ferruginous claystone pebbles. While high energy conditions with unidirectional currents have been observed in the trough to planar cross stratified OBS facies which contains coarse gritty to fine pebbly material with large number of bioclasts of *oysters*. Prominent standstill conditions can be marked on the top of mega ripple marked coarse OBS facies with a ferruginous crust, which is followed by rejuvenated transgressive event during which deposition of MDM occurred.

The top of the Member marks the nondepositional boundary between GRM and MDM. The GRM sequence probably represents part of *Lenticulina Bulla partial - Range zone* of lower Kimmeridgian stage as postulated by Pandey and Dave (1993), based on foraminiferal zonation.

Here, repetition and cyclicity of proximal & distal OBS and LSS seems to have occurred as a result of autocyclic nature of deltas. There are two coarsening upward cycles of the sequence which demonstrates the cyclicity. The thick occurrence of coarse grained clastics in the sequence show sufficient precipitation and transporting capacity of rivers to feed delta development, alongwith concentrated pouring and accumulation of sediments and inefficient marine waves and current energy leading to delta development.

IX.2.2.2. <u>MARUTONK DUNGAR MEMBER</u>:

The rocks of the Member exhibit almost continuous depositional event primarily under transgressive phase followed by regressive phase in the later part of the sediment deposition.

The only somewhat high energy event represented in this Member is in the form of fine to medium grained sandstone in its lower middle part with wave ripple marks on its top. The ripples could be the result of migration of sand waves under moderate to high agitating water conditions or it may be the result of imprints of storm waves during such an event. The sandstone demonstrates minor scouring at its base and short lived omission surface at its top represented by thin marly crust.

The upper part of the sequence is coarsening upward suggest regressive phase of transgression-regression cycle and progradation of beach, barrier, bar system. Here, rhythmic sequence of SS & LSS with progressively decreasing interval of SS in the higher up sections and thickening suggest fluctuating sea level or detrital supply conditions or both. Fluctuations might be due to sudden episodic elevation and slow subsidence.

Less amount of detrital material supply in the lower part of the Member is represented by finer clastics, may be due to occupation of source areas by transgression, supply increases towards the top represented by sandstones, for which shallowing due to regression and increased carrying capacity of distributing agencies may be responsible.

The upper boundary of the Member is uneven and some what denuded suggest appreciable to substantial erosional event in some part of the area at the end of the depositional event; while in the distal part of the basin deposition remained continued.

Some what angular nature of the unconformity below JM suggests tilting of the older beds and hence apparent angular relationship of rocks is exhibited at the contact.

The transgression which is responsible for the deposition of MDM appears to be very slow with low energy condition, is represented in uniform sequence of DSSS, SS and LSS lithofacies in the Member. This conclusion is further supported by the large amount of feeding, grazing, crawling and dwelling traces.

IX.2.2.3. <u>JADURA MEMBER</u>:

The rocks of the JM exhibits last phase of third to fourth order transgressive cycle (Haq, 1987, 1988) in the Katrol formation. In its lower part EOC, SS, DSSS, SS and LSS facies represent depositional event in a transgressive phase in various parts of the basin. The upper sequence represented by LSS, SS, DSSS, SS facies exhibits regressive phase of a transgression regression cycle in form of coarsening upward sequence.

Cyclicity in form of repeated sandstone beds of SS facies can be observed in the upper part of the sequence. It results from the development of similar type of bar, barrier, beach conditions repeatedly in the regressive event. This could be as a result of repeated minor fluctuating water level conditions associated with episodic subsidence alongwith sedimentation and filling of the basin. It, thus, seems that sedimentation may have been faster than the subsidence with almost stranded water level, which has produced thick sequence of identical beds. Minor omission surfaces in form of thin crust can be seen on various SS beds. Big symmetrical pointed crested ripples are found on SS in the upper part represent moderately high energy connditions than the normal.

The entire sequence shows overlapping relationship with the underlying MDM. The upper boundary of the Member represents contact between JM and TM, Katrol Formation and Umia

Formation and also Katrol series and Umia series. The sequence represents Tithonian sediments, which is specified to be part of *Lenticulina Bulla - Epistomina ventricosa interbiohorizon (Barren) zone* on the basis of foraminiferal zonation by Pandey and Dave (1993).

The top of the Member has preserved evidences of prolonged erosional event in form of undulating erosional surfaces, formation of under cuts and low lying cliffs, and apparent angular relationship with overlying TM sequence registering upheaval and tilting of beds before next depositional cycle. The TM shows overlapping relationship with the JM rocks.

IX.2.3. UMIA FORMATION:

The Umia Formation has been considered on the basis of recognisation of two transgressive regressive cycles. The initial transgressive event appears to be of appreciable magnitude. The next transgressive event recognised in the Formation is seemingly of much less magnitude in comparison to the first one. The deposit resulted due to both of these transgressive events have been included by the author under Tapkeshwari Member of Umia Formation. The details of various events have been dealt with in the following paragraphs.

IX.2.3.1. TAPKESHWARI MEMBER:

The transgressive event in the beginning of the Member is represented by EOC facies on erosional uneven surfaces of Jadura Member. The rocks of TM show overlapping relationship with the JM, and unconformable contact with the underlying rocks. The erosional event at the end of JM seems to be much prolonged, as uneven surfaces, under cuts and cliffs have been developed in the sandstone of JM, and the same was most probably continued almost upto the end of first transgressive event in high altitude areas and may be in some nearshore islands which is clearly exhibited in the Sanatorium area where JM rocks are directly found overlying RFSSS facies of TM.

The depositional event during transgression has developed thick sequences of shales. The regressive event can be marked by development of barrier beach deposited SS facies and tidal flat deposits of RFSSS facies.

Three storm events have been observed in the tidal flat deposits of RFSSS facies. These are represented by gritty to pebbly sandstones with mega ripple marks. Two such events are observed in the bottom part of RFSSS facies sequence and one at the topmost part. The topmost bed shows harmony of such mega ripple marks on top as well as bottom of the thin (10.0 to 25.0 cm) bed. The mega ripple marks are best developed in the Observatory section. In Sanatorium and Bharapar area hummocks are developed. This is followed by omission period, during which at some places flat erosional surfaces are developed. In a nala section north of Bharapar village, three beds with big ripple marks have been encountered suggesting higher wave energy conditions. While hummocks depicts storm conditions. Two to three, 3.0 to 5.0 cm thick, ferruginous fossiliferous bands alongwith the RFSSS depicts their origin as tidal lag deposit.

The next transgressive event for the Member seems to be a minor one during which sub-tidal to tidal conditions were developed as evidenced in the MS and HS litho-facies.

In the HS facies sequence in the upper part of the TM, prominence of cross stratified units producing herringbone structures are suggestive of higher wave energy conditions under tidal setup. Further, large ripple marks, hummocky cross stratification, flaser bedding etc., associated with the sequence are very significant. Large ripple marks confirm higher energy conditions. Hummocky beddıng depicts stormy events. Flaser bedding suggest somewhat calm condition and lateral transport during which finer sediments were deposited in the form of lenses or disconnected ripples. Coarse grain size of the rocks, gravely layer and reactivation surfaces also supports higher energy conditions and episodic scouring and deposition. This sequence, in turn, is followed by nondepositional surfaces to little erosional to flat surfaces, which in fact indicates boundary between Umia and Bhuj Formation as well as between TM and BM. It also represents lower boundary of Bhuj stage. As per Pandey and Dave (1993), the sequence represents *Epistomına ventrıcosa Range zone* of Tithonian age and the boundary represents the junction between Tithonian and Neocomian.

The two minor transgressive regressive cycles that the sequence exhibits could be of fourth order and corresponding subsidence and upheaval events.

RFSSS and HS litho-facies in the sequence depict a number of minute cyclic repetitions of ripple marked partings and cross stratified beds respectively.

The abundance of arenaceous material in the sequence demonstrates much sand influx at the time of depositional events.

Micro omissions surfaces are abundant in the sequence on almost all the tops of the ripple marked surfaces, algal mates or stromatolite structures support this fact along with thin fine crust. While scouring event are abundant in form of reactivation surfaces in cross stratified beds.

Depositional events in the sequence are also associated with the formation of sandstone dykes and mud to sand volcanoes. It signifies much fast rate of sedimentation on unconsolidated water worn sediments below, in almost semiliquid or plastic conditions. This can be explained in the following way. The larger volcanic structures possibly may have been produced due to hydro-thermal activity. Such structures are present in RFSSS sub-facies and HS sub-facies. It could have some tectonic significance also, i.e. triggering of injection and formation of fissures - fractures may be directly or indirectly related to the tectonic activity, which could be generally an earthquake.

IX.2.4. BHUJ FORMATION:

In the Bhuj Formation, two main transgressive regressive cycles have been recognised. These main cycles show number of other stratigraphic events and episodes like deposition, scouring, storm, flood, omission etc. and here, quite a considerable thickness of sequence appears to be deposited under episodic conditions like storm in tidal regime to spring tide to flood in estuarine conditions rather than normal deposition under calm or quiet time spans. Hence almost entire sequence of BF represents cyclic and event stratifications. The details are discussed under the Bharapar Member below:

IX.2.4.1. BHARAPAR MEMBER:

The beginning of the Member is marked by storm generated Bioturbated Sandstones in tidal - shallow sub-tidal conditions. It represents commencement of transgressive phase in the initial stage. The rocks are coarse grained gritty to small gravelly sandstones with moderate to high amount of bioturbation and with mega to large scale ripple marks on top. The rocks show horizontal stratification to planar cross stratification and uneven erosional-scoured bottom parts. Top parts are uneven erosional or even scoured in case of occurrence of similar type of lithology on top in amalgamated sequence, to ripple marked showing omission surfaces. Gradation is seen in few cases only. These characters individually do not signify much, but as these are collected together in same litho units, depict high energy storm event deposition. Occurrence of flat clay pebbles in some cases also supports such a cause. Further development of opportunistic biogenic sedimentary structures like the *Diplocraterion*, and *Skolithos* ichnocoenoses depict the post-depositional moderate to high energy conditions. It seems that typical storm generated characters like mega ripple marks, cross-stratification, gradation etc. have been preserved only in few cases, and in majority of the cases it is reworked by physical and biogenic processes. Still the coarser grain size and uniform lateral extension of beds along with characteristic trace fossils suggest overall higher energy conditions. Hence, beds of Bioturbated Sandstone facies have been considered to be of storm generated origin which are reworked later on. The beds show much vertical repetitions in the sequence of BM and also producing amalgamated sequence of the same. Such repeated occurrence or amalgamated sequence shows cyclicity of events.

The flood events in the sequence are preserved in form of torrential bedding and large scale planar cross stratification, which shows slumping of cross-strata, contortion, micro-faulting and penetration of dykes. All these suggest episodic sedimentation. Normally thickness of single units containing such structures is more than 1.0 m in CBCGS facies and prominent south and south-east palaeo-current direction suggests flood events. Their site of deposition in estuaries can be confirmed by presence of almost monodominant *Ophiomorpha* and occasionally *Skolithos* burrows as well as by creation of herringbone structures due to alternate opposite directions of cross stratified units at several places. The opposite cross-stratified unit pointing north-northeast palaeocurrent direction may be the result of spring tide or storm event. Such beds are prominent in the middle and topmost part of the sequence.

Deposition of quiet conditions are represented by thin shales- siltstones or fine sandstones containing small scale trough cross stratification, and minor channel cut and fill structures within the planar cross stratified sandstones of CBCGS facies. Omission surfaces are represented on majority of sandstone beds in form of fine ferruginous or marly crust. This later part shows regressive phase. Two such cycles have been recognised showing identical characters - storm dominated in the lower part and flood dominated in its upper part of a single cycle. It thus indicates two transgressive regressive events.

Rootlets etc. in the rocks represent prominence of terrestrial conditions. The prominent south southwest variations in the cross stratification depicts prominence of fluvial processes. The last depositional phase of sediments is followed by prolonged erosional or denudational phase during larger part of the Cretaceous time which subsequently appears to have ceased by commencement of the volcanic activity.

The upper boundary of BM represent junction between Bhuj Formation and Deccan Trap. It is as well the marker of the last depositional phase of sediments in the Mesozoics of Kutch. The depositional events as a whole show much sand influx indicative of increased denudation and enhanced transporting capacity of the transporting agency.

IX. 3. DEPOSITIONAL ENVIRONMENT:

The various studies carried out by the author involving stratigraphic units, lithofacies, ichnocoenoses, etc. accord a generalised shallow siliciclastic shelf sea environment to the depositional basin in the area of his study. Many good examples of clastic shore line and shallow shelf deposits comparable to the author's observation have been reported in the literature. These include Johnson (1919), Shepard (1963), Inman and Nordstrom (1971), Emery (1952, 1968), and Reineck (1963). The commonly accepted definition of shallow siliciclastic sea (according to Davies, 1964) is that the transgression and encroachment of a sea on peneplained continental shelf with ample supply of siliciclast material. Shallow siliciclastic shelf sea sequences are widespread in the geological record, and their facies, execute broad spectrum of primary structures and bed forms. Varied biogenic sedimentary structures are reported in various shelf sea sequences, many of these display trace fossil structures by the dwelling organisms. Main reason for the availability of biogenic structures in these sequences is that such a system of depositional environments consist mainly of slowly settling argillaceous and arenaceous sediments alternately resulting in suitable substrates for most burrowers and trace makers. The author's study area seems one such an exceptional locality where marine shelf sequence containing large amount of finer siliciclastic sediments and a remarkably diverse and well displayed trace fossil assemblages representing several ichnocoenoses, each characteristic of a particular marine shelf sequence, is observed.

Numerous attempts have also been made to classify the wide range of present day non-deltaic shorelines using one or more of the main controls on coastal development such as sediment supply, hydrodynamic setting, climate, sea level history, tectonic setting and the pre- existing structure of the depositional area to categorize the shore line types. A scheme which is currently gaining acceptance as a sedimentological classification of shore line stresses the importance of tidal range and proposes three divisions: microtidal, < 2.0 m; mesotidal, 2.0 - 4.0 m; and macrotidal, > 4.0 m (Davies, 1964; Hayes, 1975; Hayes and Kana, 1976). The significant fact is that the development of shorelines can be considered in terms of these ranges. Shallow shelfs are of two main types (1) marginal or pericratonic seas, and (2) epeiric or epicontinental seas (Shaw, 1964; Heckel, 1972); sediments in the study area are considered to be deposited on second type of set up.

In the successive paragraphs, in light of the above concepts and the various facies association established in the central mainland Kutch shallow shelf sequence, the author attempts to discuss and interpret the process of emplacement of the sediment sequences and their environments of deposition.

As could be recalled, there are in all nine Members and ten lithofacies fully described and interpreted by the author in chapter nos. V and VI. Each of this facies appears to have deposited in a unique set of physical parameters that has left its imprints on the sediments. All these can now be taken in to consideration according to their associations or mutual relationships with each other and the interplay of the total depositional environments could be postulated.

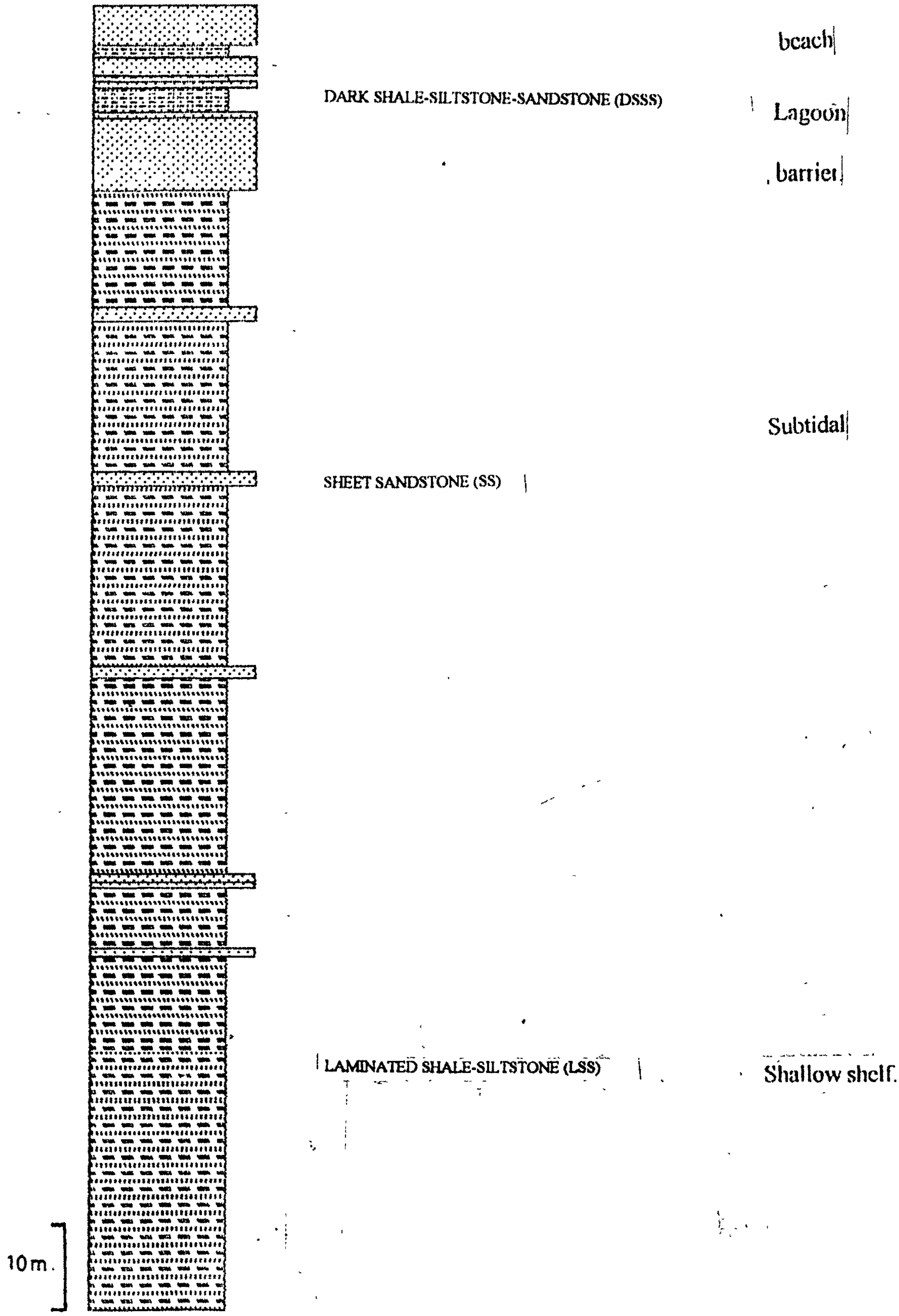


FIGURE – 17a.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF JAMAYWADI MEMBER

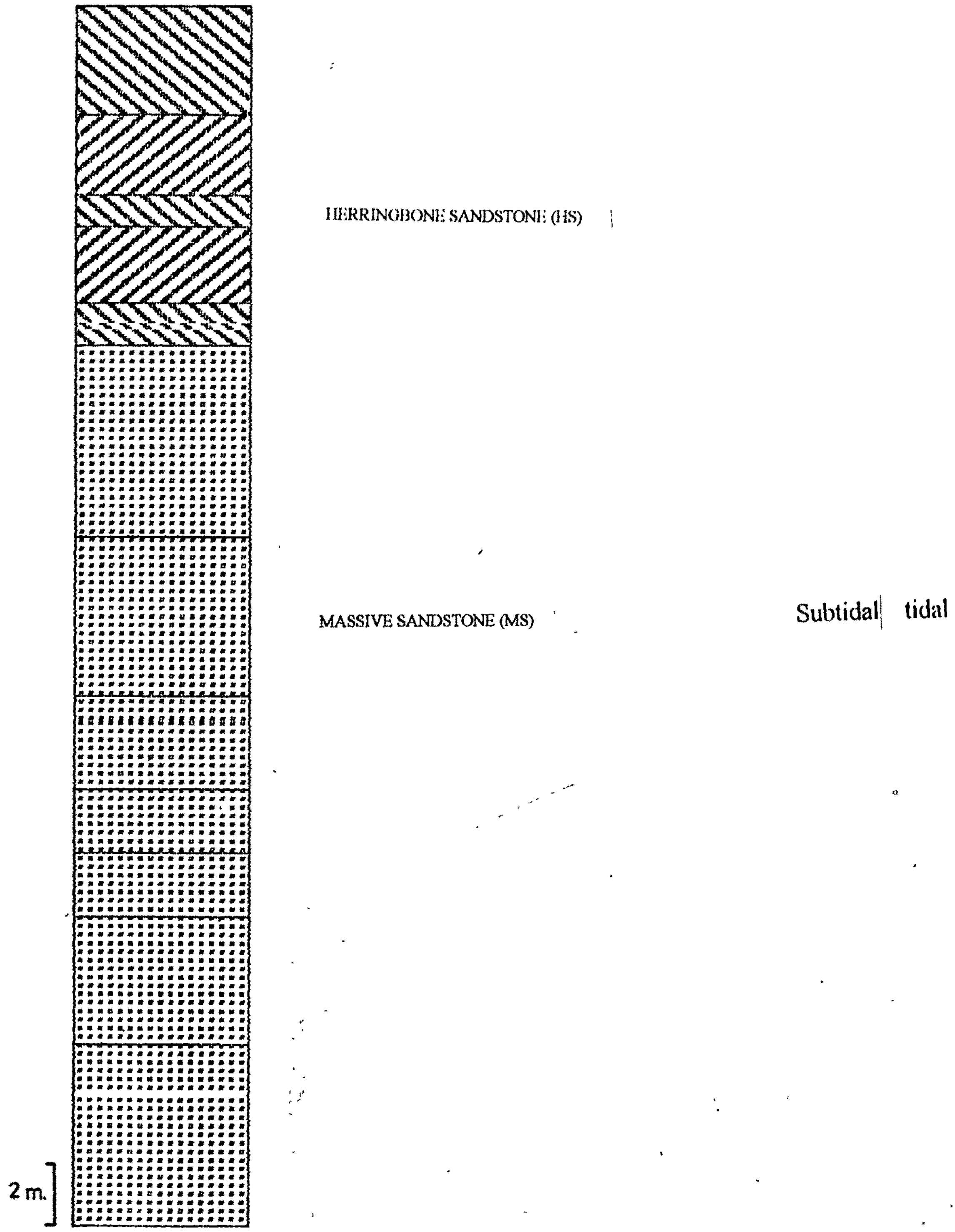


FIGURE – 17b.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF GANGESHWAR MEMBER.

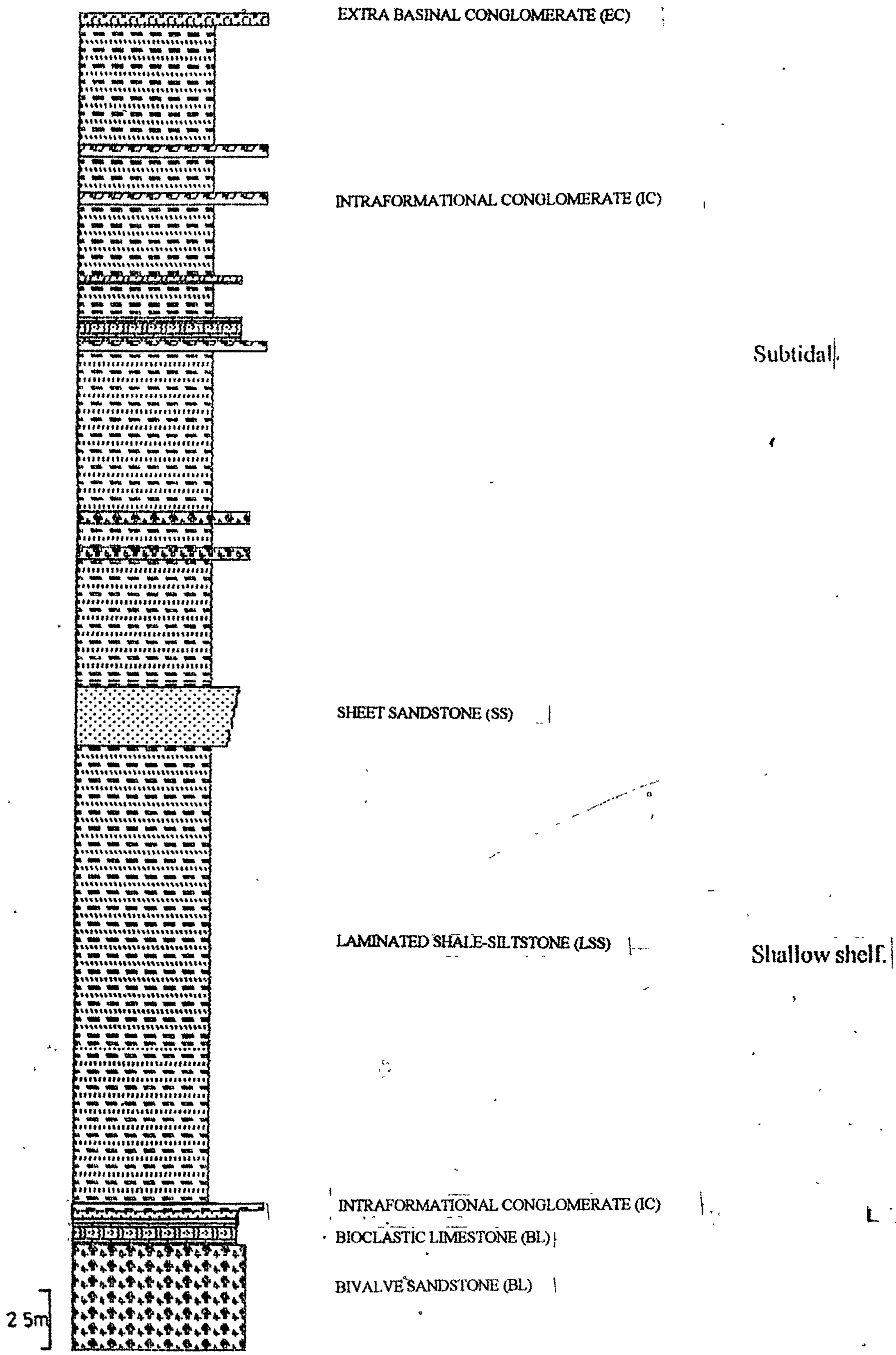


FIGURE – 17c.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF LER MEMBER.

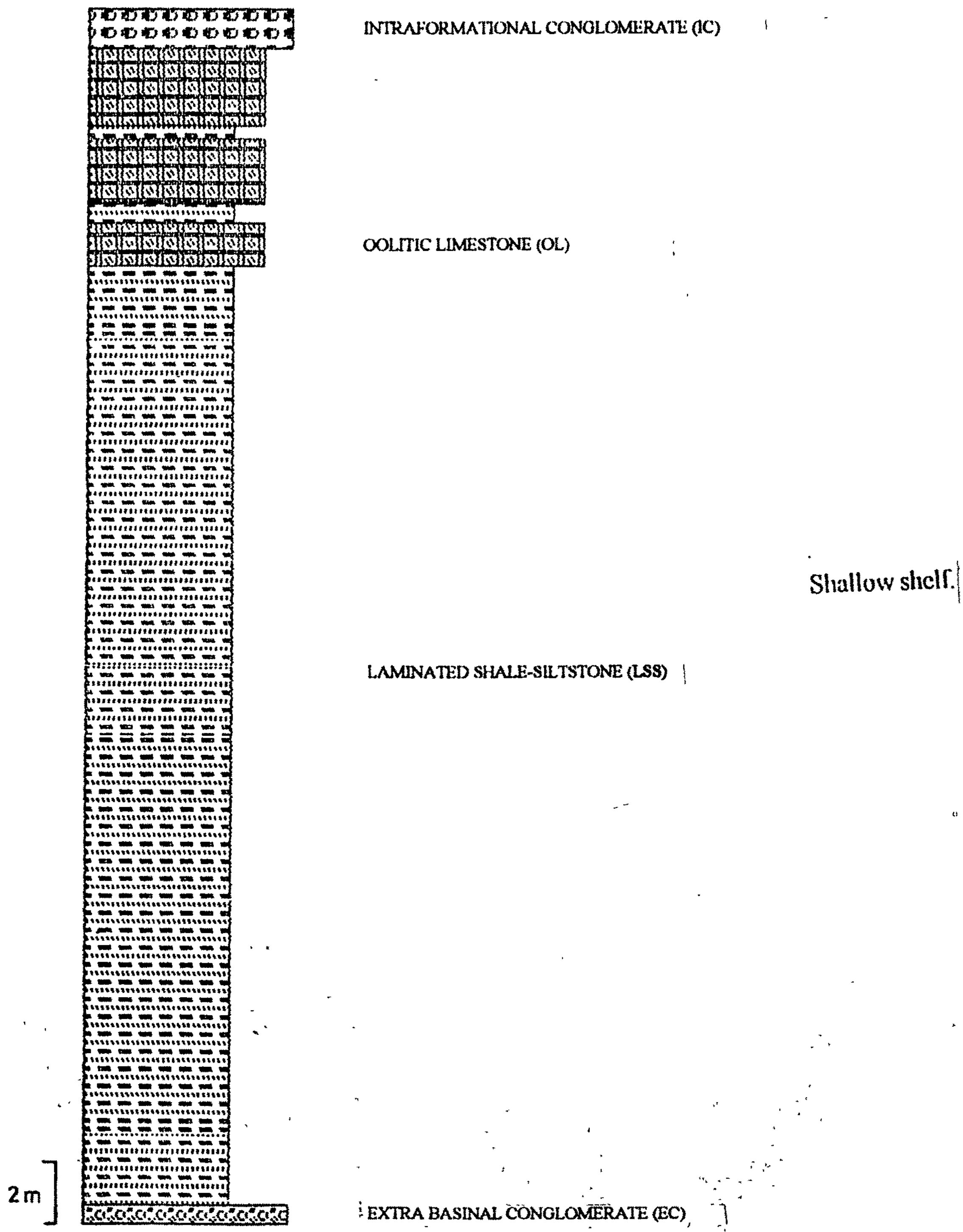


FIGURE – 17d.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF DHOSA OOLITE MEMBER.

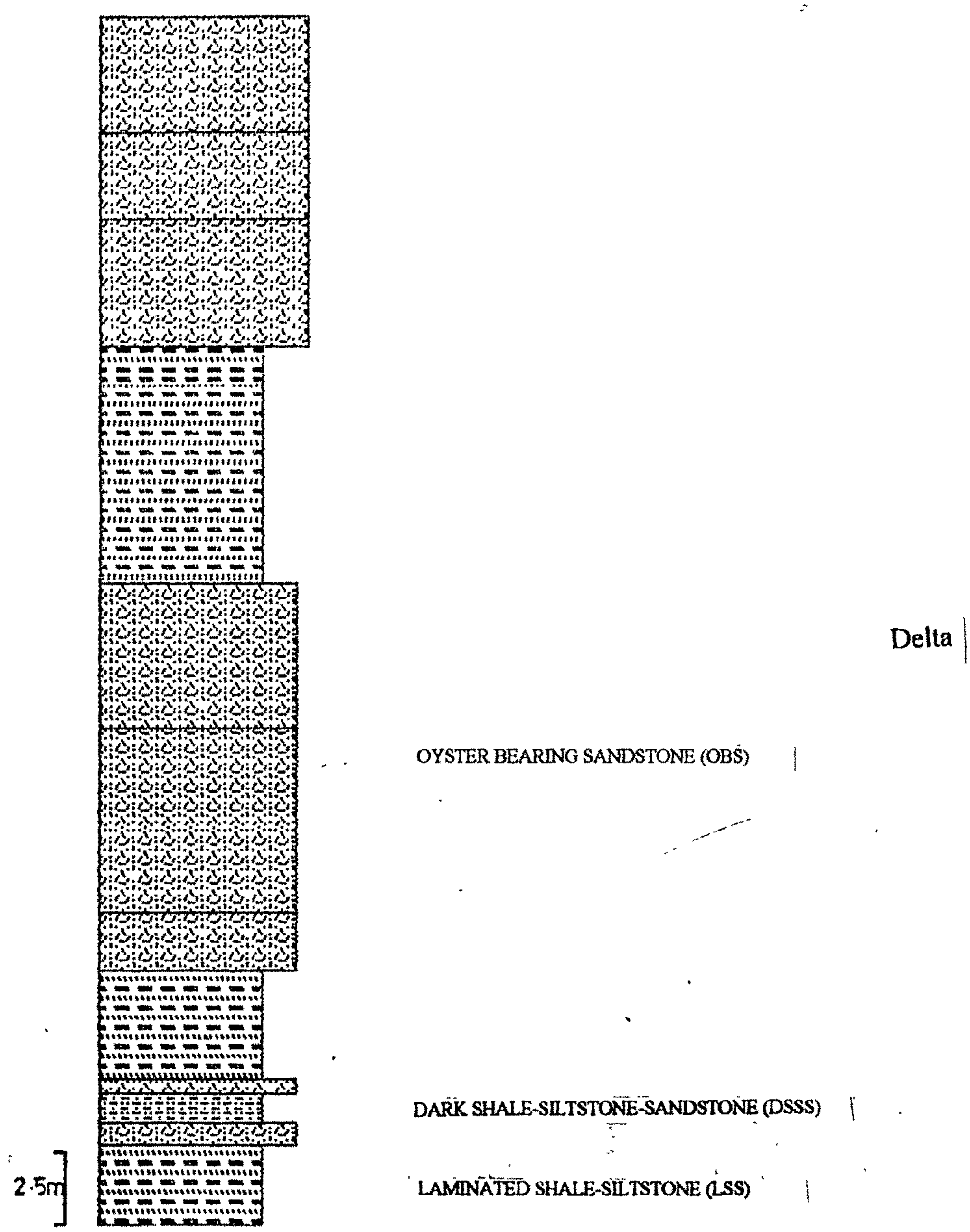


FIGURE – 17e.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF GUNAWARI RIVER MEMBER.

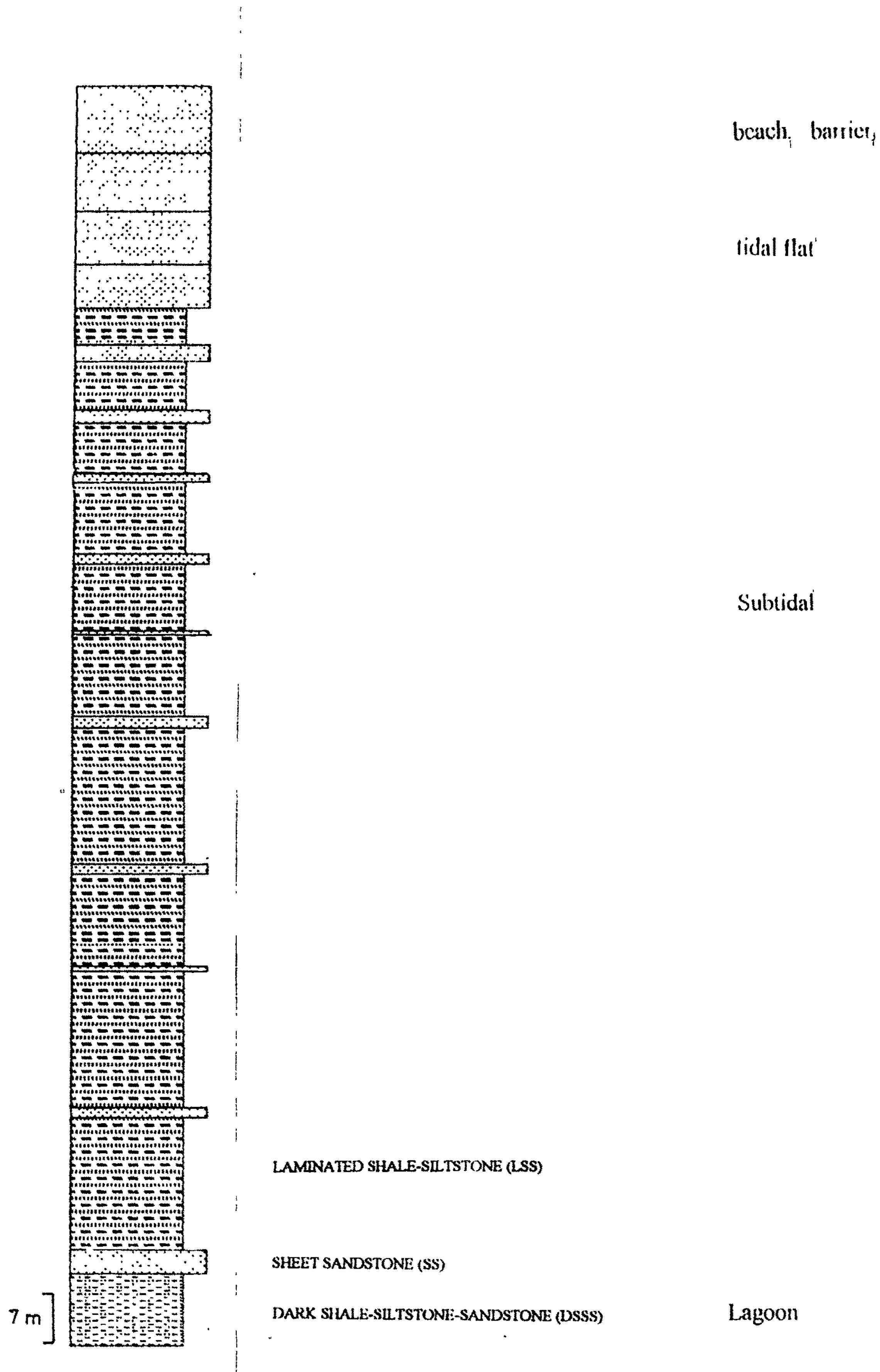


FIGURE - 17f.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF MARUTONK DUNGAR MEMBER.

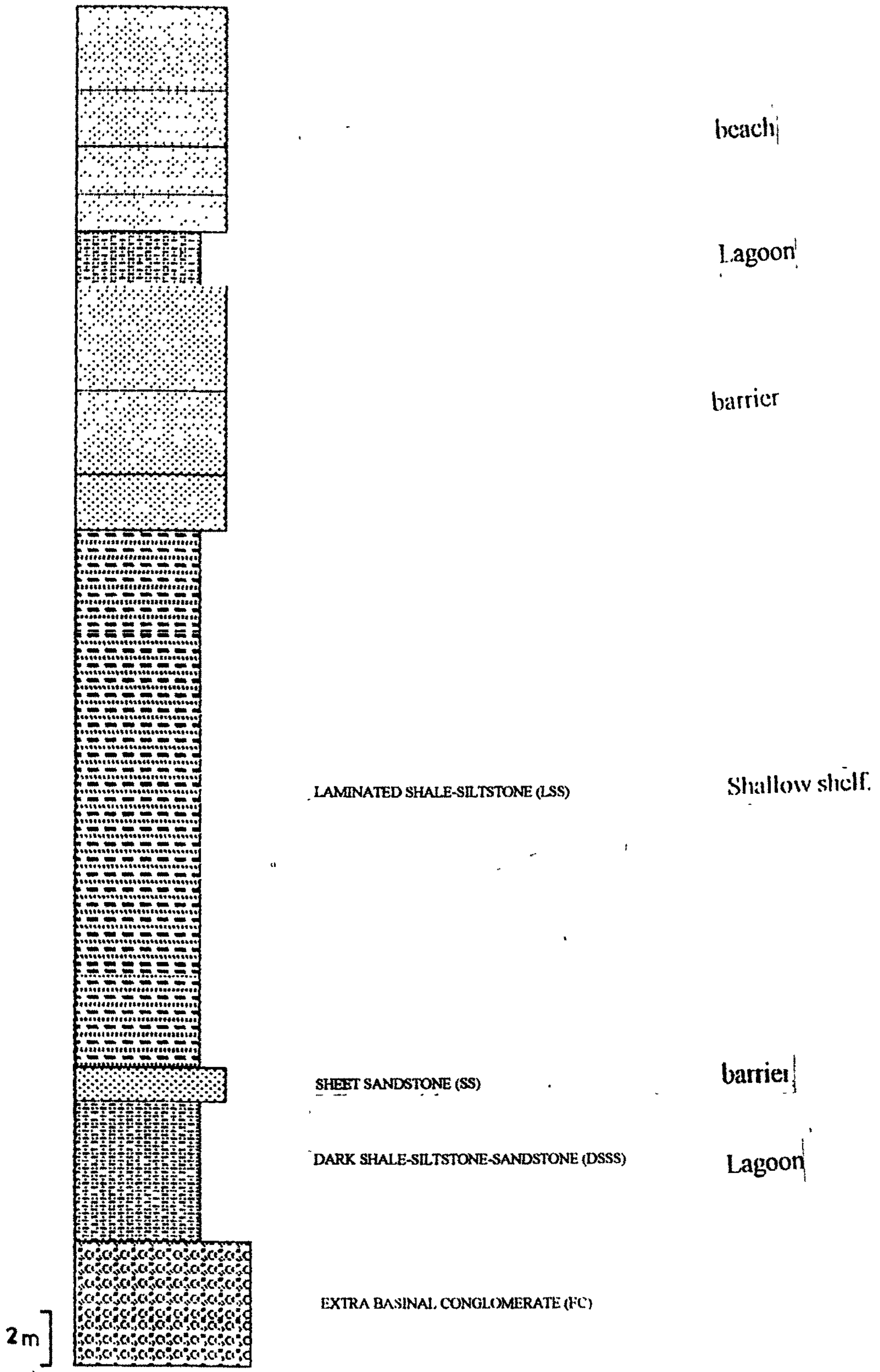


FIGURE – 17g.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF JADURA MEMBER.

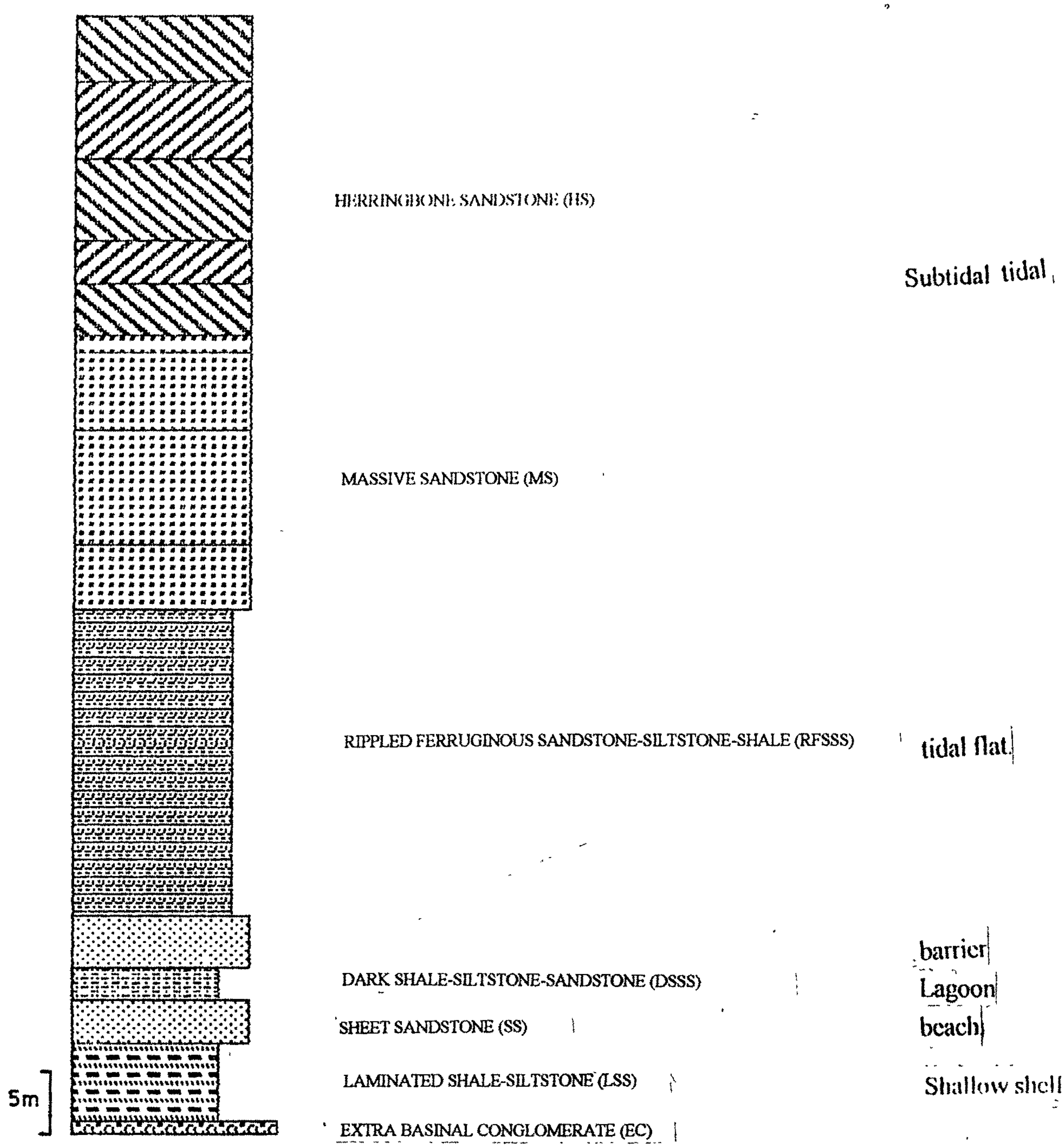


FIGURE – 17h.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF TAPKESHWARI MEMBER.

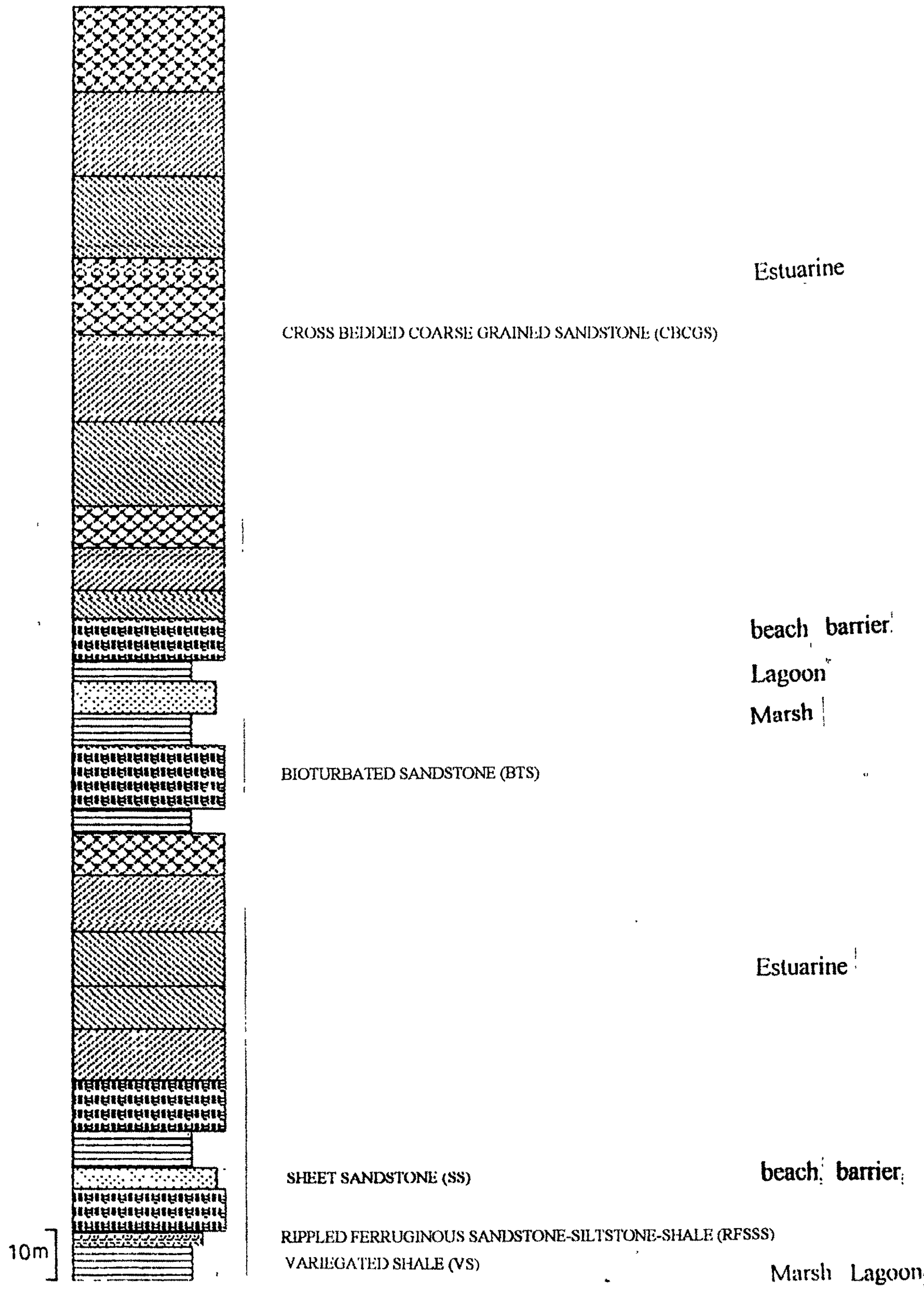


FIGURE – 17i.STRATIGRAPHIC SECTIONS, LITHOFACIES AND DEPOSITIONA ENVIRONMENT OF BHARAPAR MEMBER

IX.3.1. FACIES ASSOCIATION AND DEPOSITIONAL ENVIRONMENTS:

In all, seven main depositional environments are identified for the entire depositional setup in the area of study. These include:

1. Estuarine

2. Marsh

3. Delta

4. Linear Clastic Shoreline Setup:

Intertidal - beach, barrier, tidal flat.

5. Lagoonal

6. Subtidal, and

7. Shallow shelf.

IX.3.1.1. <u>ESTUARY</u>: An estuary is a physically complex environment defined by Pritchard (1967) as `a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.' Present day examples occur in association with tidal flats, barrier islands and river deltas, and fall in to two distinct categories: those which are simply the tidally influenced lower stretches of rivers, and those formed by the drowning of river or glacial valleys during the Holocene transgression. Tidal processes are important, and two points concerning physical processes in estuaries deserve emphasis. Firstly, as fresh water and salt water are of differing density, a variety of circulation patterns develop depending on the manner in which the water bodies mix (Pritchard, 1955; Cameron and Pritchard, 1963). Secondly, the properties of the tidal regime and the manner in which these properties change along the estuary are crucial to sediment transport and ultimate facies characteristics (Postma, 1967; Write, Coleman and Thom, 1973, 1975; Boothroyd and Hubbard, 1975).

Hayes (1975) distinguished microtidal, mesotidal and macrotidal estuaries but he used extremely broad definitions which were not in accord with Pritchard's definition of an estuary except the macrotidal estuaries.

In the area investigated by the author the BM exposed south of Bhuj, and its thick sequence of CBCGS facies is accorded to be deposited under estuarine environment. In this facies, coarse grained sandstones with opposed sets of large scale planar and trough cross stratification forming herringbone structures indicating bidirectional flow, are present in the nala exposures near Chakar. It represents cosets relevant to flood- and ebb-tide in an estuarine set up. An interesting feature which is observed near Kera in the river section is an amalgamated sequence of cross stratified cosets with reactivation surfaces (plate-13). On this exposure, BM rocks exposed on western bank show northwardly dipping cosets, while rocks exposed on eastern bank - only few tens of meters away from first exposure - point in southernly direction. This has been interpreted as closely spaced but separate courses of flood-tide and ebb-tide dominated bed forms in a macrotidal estuary. All these bed forms are medium scale, and generally northerly dipping flood tide forms are slightly thicker than the adjacent, overlying or underlying southerly dipping ebb-tide generated forms. Mud and siltstone drapes are common in entire sequence of CBCGS facies on foresets as well as on bedding planes depicting standstill conditions. The reactivation surfaces are the result of erosion during maximum tide flow before depositional phase. Small asymmetric to linguoid ripple marks alongwith siltstones and shales as well as minute trough cross lamination alongwith microripples, and small scale trough cross stratification, most of them showing southeast to southwest (southerly) palaeocurrent directions, considered to represent weaker ebb tide flows or fluviatile flow in between two flood tides in estuarine set up. Large scale planar cross stratification units normally more than 1.0-1.5 m in thickness with associated features like slumping, contorted bedding, sandstone dykes, microfaulting, drapes etc. and torrential bedded units, both showing southernly palaeocurrent direction, have been inferred as fluviatile flood deposits, of course, in estuarine environment but at the time of much precipitation in rainy season.

Marked lateral and vertical facies changes characterise the facies pattern and reflect the variable conditions imparted by tidal processes. Directional bimodality and repeated small scale changes from bed load transport to deposition of fine sediment from suspension are the most diagnostic features to emerge from the present studies, though the former is not an ubiquitous features.

Cross bedded foresets draped by clay laminae and interlaminated clay- silts, suggesting that bed form migration was intermittent in response to tidal current fluctuations. Here, discrimination of estuarine facies over tidal inlet is tentatively interpreted based on the consideration of large scale planar cross stratification and torrential bedding showing a possible palaeo-seaward directed palaeocurrent mode, which is being attributed to fluvial flood out flow rather than ebb tide flow, and is supported by close association of small scale channel structures containing multidirectional fluviatile facies found cutting bimodal planar and trough cross bedded rocks near Chakar. Similar observations were made by de Raaf and Boersma (1971) for Pleistocene estuarine facies in Holland.

Massive to large scale cross stratified sandstone with monodominent *Ophiomorpha nodosa* ichnocoenoses are considered to indicate inshore marine conditions to relatively deeper parts of estuarine channels. This could be a tidal ridge to accreting point bars in a macrotidal estuary. Such observations have also been regarded for Tertiary lower Bagshot beds of southern England by Bosence (1976).

The alternations of thick sequences of CBCGS facies with thin intercalations of BTS, VS, CBCGS and SS in BM represents development of estuarine and linear clastic shore line conditions and related facies adjacent to each other in a tidal to lagoonal or subtidal set ups. Here, marsh, tidal flat, beach and lagoonal environments were prominent. This is evident by VS, SS, and CBCGS facies. As BTS facies indicates, the shoreline was frequently affected by storm events. This could be the result of development of erosional surfaces in the estuarine cross stratified units below reactivation surfaces, the tides may be associated with such higher energy events to become responsible for drastic erosional and depositional episodes. The above mentioned alternation in turn could be the result of the shifting of estuary and related facies on a regional scale, while depositional environment was more or less constant and stable during the deposition of BM consisting above mentioned facies.

IX.3.1.2. MARSH: The marshes are the low lying saline wet lands, which lie above the reach of the highest normal spring tides, may be many kilometers in width with a gently undulating topography. They occur in supratidal zone and are strongly influenced by climate and particularly by rain fall. These are frequently flushed by fresh water while hollows on the marsh surface may remain as temporary pools of fresh or brackish water. Marshes frequently contain certain amount of silts. These are deposited during wind tide and storm inundations of the supratidal area. Their sediments are normally accompanied by grasses and mangrove vegetation. Burrows are scarce or absent. Their parts are characterise by carbonaceous shales or peat (in regions with high rain fall) and sticky lime mud (in arid regions). Gypsum and anhydrite is developed by dry seasonal evaporation.

In the area studied Carbonaceous shales and peat occurs in BM on several exposures, on the other hand sticky calcareous shales also occurs in the same manner in BM. Such occurrence are found in localised exposures showing much less vertical and lateral extension. The presence of these characters demonstrate development of marshy conditions, and the varied nature of rocks along with these depict fluctuating climatic conditions - humid (with vegetation) to arid in various parts during deposition of BM. In the area of study the marshy condition appears to be a part of regional estuarine - linear clastic shore line during the time span of BM.

IX.3.1.3. DELTA: The commonly accepted definition of delta is that "An alluvial fan prograding into a standing body of water". The deltaic sequences are wide spread in the geological record and their facies execute broad spectrum of primary structures and bed forms. Although biogenic sedimentary structures have been reported in only a very few delta complexes. The main reason for the scarcity of fossils in delta is that, such a system consist mainly of rapidly deposited gravels and coarse grained sediments resulting in unsuitable substrate for most burrowers and trace makers. Deltaic sequences in the GRM, in the study area show similar type of characters except large amount of sediments which are fine to medium sandstones and medium to coarse sand to fine gravelly sediments.

Recently many good examples of delta deposits have been reported. Some of these are by Holmes (1965), McGowen (1970), Syrlyk (1978, 1984), McPherson et al. (1987) etc.

The delta front to prodeltaic environments recognised on various characters are discussed below:

Delta Front: The delta front is a transitional zone which incorporates a part of delta which withstands with the subaerial and subaqueous units. This is the area in which sediment laden fluvial currents enter the basin and are dispersed whilst interacting with the basinal processes. Basinal processes either assist in the dispersion and eventual deposition of sediment, or rework and redistribute sediment deposited directly as a result of flow dispersion.

The delta front facies associated in study area are generally represented by large scale coarsening and thickening upward sequences - (facies OS). This records a passage from prodelta facies upwards into a delta front facies which is usually gritty conglomeratic. All these sequences appear to have resulted from progradation of the delta front. Consideration of the processes operating in this subenvironment is usually crucial to a complete understanding of the ancient deltas as the interaction between sediment laden fluvial processes and basinal processes take place in the delta front. Furthermore, fluvial dominated delta front sequences according to T. Elliott (1986) have been widely recognised in the geological record and exhibit considerable variety. Most older delta front sequences as postulated by him are mud-silt-sand system developed at the margins of the marine sedimentary basins. In general they commence with a thick uniform interval of mudstones-siltstones deposited from suspension at the base of delta front. Such facies in the study area are massive siltstone- fine sandstone to coarse sandstones in a thickening and coarsening upward sequence. The rocks are found in form of pockets and are most probably around opening of transporting agencies in the seas, to be laterally merge into shale-siltstone alternations of prodelta facies. Such a condition indicates inefficiency of distributing agencies of waves and currents of the sea to spread the influx material finally resulting into a delta sequence. Marine fauna, although noted the faunal density and diversity, are generally low, which is mainly represented by *cephalopods* in the lower finer sediments. This may be due to the fallout of sediments from suspension, but in the upper gritty to pebbly rocks, abundant *oysters* and *cephalopods* have been observed, the first group suggests development of firm grounds and nondepositional periods. Plant debris found in the delta front facies are presumably an additional consequence of sediment input being directly supplied by the distributaries. The intermediate parts of sequences comprise shale siltstone background sediments in which coarser gritty pebbly sandstones and sandstone-siltstone beds are repeated and in lower finer sequence intercalated. The coarser beds have planer erosive bases which exhibit waning flow sequences.

In light of the above discussion it will now be appropriate to assign and workout GRM and their facies to the delta front sequence in the study area. In the GRM, the shale-siltstone intercalations which are followed by siltstone to coarse sandstone sequence with very thin shale lenses in between, in the lower (initial) part of the sequence, are quite significant. In the upper part the gritty, pebbly, coarse grained sandstones are trough to planar cross bedded and closely match the description of the delta front environment and hence finer and coarser sandstone repetition in the GRM can safely be assigned to such an environment.

The coarse grained calcareous sandstones containing *oyster* shells need explanation. The beds are containing intraclasts and many a times have shells aligned parallel to the bedding and show infiltration structures such as cement filled shell voids. These beds vary in thickness and are found laterally pinching out. These *oyster* bearing beds could be recognised as the features indicating periods of emergence and seems to be deposited under higher flow regimes. Other indications are the big cross stratified units and presence of polymictic intraclastic pebbles. Upper part of these beds seem to be worked out by storm - as could be seen from mega wave ripples.

All these characteristics point that the coarse grained gritty pebbly sandstones in the second cycle of delta sequence most probably developed on slopes, associated with delta front. Similar observations have been made by Stanley and Unrug (1972) in modern and ancient marine basins and by Vaishnav (1991) in the Khadir island of Kutch. In such a physiographic province, erosional and depositional accretion are in delicate balance. Further, as suggested by Stanley and Unrug (1972) the degree of crustal mobility, eustatic sea level changes and relative transgression and regression, rate of sedimentation, gradient, morphological relations to the shelf and break, sediment transport processes and resulting bioturbation are the critical controlling factors to be recognised.

The local fining upward sequence can be interpreted as described below. The sands were apparently susceptible to liquefaction within steep slopes promoting evolution of liquefied flows and development of turbulence. Rapid sedimentation of the coarse liquefied detritus left coarse grained, relatively clay free deposits followed by slow sedimentation at the top or in lateral parts, which can be marked by the presence of small scale cross stratification in fine sandstones, especially in facies OS.

The deltas in the study area were autocyclic in nature due to shifting of channel in adjacent parts through shortest route and hence coarsening upward deltaic sequences have occured repeatedly. This has been very well exhibited in the GRM sequence.

IX.3.1.4. LINEAR CLASTIC SHORELINE SETUP:

Deltas only form where rivers bring more sediments into the sea than can be reworked by marine current. Where marine currents are strong enough to redistribute land derived sediments, linear shorelines are formed alongwith shallow siliciclastic shelf. The linear shorelines are formed with bars, barriers and beaches running parallel to the coast. Wide tidal flats develop when tidal range is meso (2.0-4.0 m) and macro tidal (>4.0 m) (Davies,1964).

The linear clastic shorelines deposit sediment in a wide range of sedimentary environments range from continental to marine. Studies of Recent sediments show that both linear and lobate (deltaic) shorelines can form upward coarsening regressive sequences. Since, their sand body geometries are quite different, the two types can be distinguished and their distinction is much significant. The wide range of present day nondeltaic shorelines have been classified using one or more of the main controlling parameters on coastal development such as sediment supply, hydrodynamic setting, climate, sea level history, tectonic setting and the preexisting structure of the depositional area to categorise shoreline type (Johnson, 1978; Shepard, 1963; Cotton, 1952; Armstrong-Price, 1955; Davis, 1964; Inman and Nordstorm, 1971). In the Recent clastic shoreline, following major sedimentary environment are recognised. These are fluviatile coastal plane, intertidal complex with barriers and bars, lagoon, sub-tidal, and shallow shelf. Each of these environments deposit facies which can be distinguished from one another by their lithological characters, sedimentary structures, and biota and their activity.

In contrast to the above facts, the regression of the sea from a low lying land surface with no detritus leaves no mark in the geological record other than an unconformity. The actual shoreline may consist of a beach, barrier and lagoonal complex. As the sea retreats it leaves the old beach ridges stranded inland These are eroded and sediment are carried back to the sea to be redeposited on the beach face. Or in a cyclic transgressive regressive sequence sediments are reworked and deposited in form of subtidal sediments. Thus net sedimentation above the unconformity is generally zero. Hence in a quick cyclic transgressive regressive sequence as observed by the author in the area of his study, fluvial or terrestrial sediments, normally do not occur in between except during final retreat of the sea. Or are found in form of relict or palimpset sediments under subtidal conditions in a transgressing sequence.

INTERTIDAL - BEACH, BARRIER, TIDAL FLAT:

The intertidal environments are divided into beach barrier complex and tidal flat complex.

(a) BEACH: The area is aligned parallel to the shoreline and superimposed on a general seaward fining of sediment. It contains supratidal part which is only inundated during storms upto intertidal areas which terminate against low water level. Sediment emplaced on the supratidal part during storms is partly reworked by wind action during fair weather periods. Intertidal areas are generally characterised by swash to surf zone processes where sediments transported landward - coarse in form of bed load and finer in suspension forming suspension clouds or sand fountains (Ingle, 1966; Fig. 7.5; Brenninkmeyer, 1976).

In the study area beach facies are represented by the sheet sandstone facies that repeatedly occurs in the sequence. It is observed capping DSSS facies in vertical section in regressive - progradational sequences, and in transgressing system below DSSS or LSS facies. In both the cases junction is gradational. The Members, which contain beach rocks are JWM, LM, MDM, JM, and BM. The beds show typical horizontal stratification with flat truncation planes reflecting brief periods of erosion that divide the lamination into discrete sets.

Also observed are the local planar and trough cross stratifications reflecting migration of ridges or antidunes. Tidal pools and swells occurring in BM depicts development of 'ridge and runnel topography' on the intertidal beach environment.

The rocks of MS facies in GM, JM and TM show massive to horizontal stratification with local cross stratification, which are considered as drowned remnants of beaches under subtidal conditions.

In CBCGS facies in BM, which is associated with intercalated sequence of BTS, VS and SS, cross stratification are indicative of migration of sand ridges on beaches.

(b) BARRIER: The barriers are no more than an offshore bar exposed at low tide, or it can form an island with aeolian dunes on the crest. Intermittently along its length the barrier are cut by tidal channels or gullies in which cross bedded sands are deposited (Armstrong Price, 1955; Hoyt and Henry, 1967).

In the study area, the rocks which are interpreted as barrier bar sandstones are included under the Sheet Sandstone facies. The rock shows almost flat to low angle stratification with local planar-trough cross stratified units. This differs from beach sandstones in consisting small tidal gully structures on top which host some what coarser gritty sandstones which some times shows cross stratification. Further, sandstones are moderate to well sorted and reflect winnowing and grain attrition by wave action.

Laterally the sandstones are extended for larger distances with more or less uniformity in thickness and occur below lagoonal DSSS facies and overlying marine LSS facies in a progradational system, and above DSSS facies & below LSS facies in a transgressive system. In both the cases, gradational contact with LSS and sharp erosional contact with DSSS facies are conspicuous. It occurs in JWM, LM, MDM, JM, TM and BM.

The thick sequence of SS in regression phase of MDM and JM as well as on some exposures in TM represents still stand conditions of shore line for a longer time span with a balanced sand influx and subsidence.

As per Elliott (1978) the first criteria used in recognising ancient beach and barrier bar deposits concerns the shape, orientation and stratigraphic relationships of sandstone bodies. Such laterally extensive sandstone bodies are found aligned parallel to the inferred palaeo-shoreline. Further, he points that facies deposited in these systems are petrographically distinctive in comprising well sorted orthoquartzites which reflect intense winnowing and grain attrition by wave action (Ferm, 1962). From the bed forms and the internal structures of modern systems, this information was applied to ancient analogs (Berg and Davies, 1968; Davies, Ethridge and Berg, 1971). All these lines of evidences are currently in use for identifying beach-barrier-bar depositional environment, and it is now possible to distinguish progradational sequences produced by beach faces of differing wave energy and transgressive sequences.

The overall facies pattern of a beach or barrier island is determined by its long term response to sea level fluctuations, subsidence/emergence rates of the depositional area, and variation in sediment supply (Dickinson, Berryhill and Holmes, 1972). Under conditions of continued sediment supply, stable sea level and low to moderate subsidence rates, facies prograde offshore, where as a reduction in sediment supply, a rise in sea level or a high rate of subsidence induces landward migration of the facies. Alternatively, the system may remain stationary, as argued for Padre Island, Texas, which is considered to be thickening in place (K.A.Dickinson, 1971).

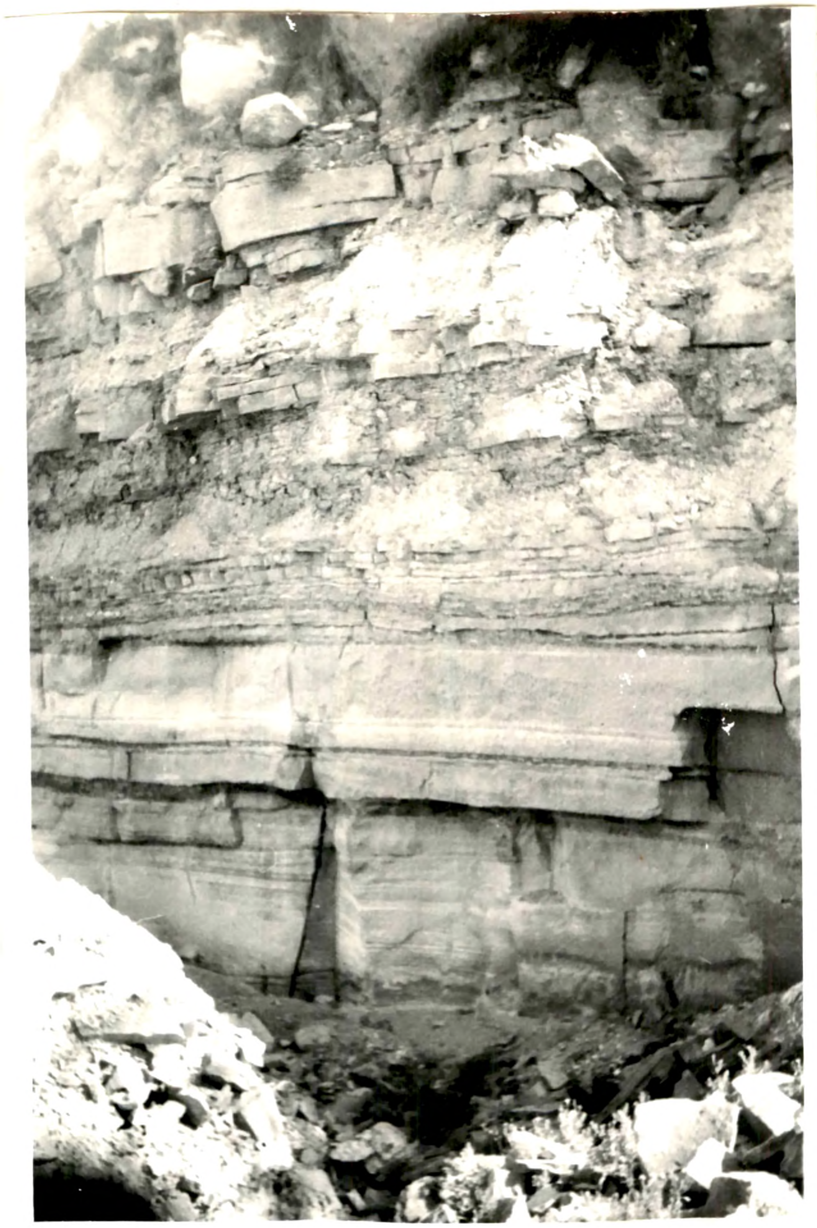
Very few transgressive barriers have been recognised in the geological records so far, possibly because they tend to produce relatively thin sequences. However, several examples occur in the lower Silurian of southwest Wales which was deposited in eustatic rise in sea level (Bridges, 1976).

(c) TIDAL FLATS: In general, tidal flats are defined as featureless plains dissected by a net work of tidal channels and creeks and occurs in low wave energy mesotidal and macrotidal settings where they dominate extensive stretches of shoreline, or form within coastal embayments, lagoons, estuaries and tidally influenced deltas (Elliott, 1978). Intensively studied examples occur in north Germany and Holland, the Wash (eastern England), the Bay of Fundy and the Gulf of California (Van Straaten, 1954, 1961; Klein, 1963, 1967b; Evans, 1965, 1975; Reineck, 1963, 1967; Thompson, 1968, 1975). Normally during flood period, tidal water enter the channels, overtop the channel banks and inundate the adjacent flats. Following a period of still stand the tidal waters drain and re-expose the flats. Intertidal zone comprises smooth seaward dipping flats dissected by large and small scale tidal channels.

In the study area, tidal flat sequences are found associated with extensive stretches of shoreline with a low gradient within the intertidal zone and somewhat extending on subtidal environment and hence tide waters were directly able to cover the flats even though small and large channels and gullies have been observed with channel floor lag gritty conglomerates and autoclastic pebbles, may have been formed at the time of receding tide. Such deposits occur in form of topmost SS beds intercalated with shales (plate-73) in JWM and as RFSSS in TM. Here, the tidal flats deposits are delicately interlaminated muds, silts and fine sands, often rippled and extensively disrupted by bioturbation.

Various examples of tidal flat facies association have been recognised in succession ranging in age from Precambrian to recent (Klein, 1970a, 1971; Kuipers, 1971; Mackenzie, 1972, 1975; Sellwood, 1972b, 1975; Johnson, 1975; Rust, 1977; Tankard and Hobday, 1977). In the majority of the examples, recognition is based on an assemblage of structures and facies considered to indicate tidal processes.

Plate - 73



Tidal flat sandstone deposits near Gangeshwar.

The varied bioturbation in the study area and moderate to high level intensity depicts slow rate of deposition. Algal mat structures - stromatolites, further support this observation and provides evidence of the intertidal environment.

IX.3.1.5. <u>LAGOON</u>: Lagoons are extremely variable shallow water environments located behind barrier islands. The variability is in part attributed to the prevailing climate, and also depends on micro- or mesotidal settings. In general, lagoons accumulate fine grained sediment deposited from suspension, but depending on their size and depth and setup of minor depositional systems in to this background, e.g. washover fans, intertidal flats, tidal channels, flood tide deltas and small scale river deltas, range of lagoonal facies extends, and it may deposit sediment ranging from sand to mud. Evaporites are formed in hypersaline lagoons. In regions of low sediment influx carbonate mud can be deposited. The fauna of lagoon is similarly variable depending on the salinity. It ranges from fresh water, through brackish (with shell banks) to normal marine or, if restricted and of high salinity, a fauna may be absent. Bioturbation is common. Sedimentary structures of lagoons are similar to those of tidal flats with delicately laminated muds and interlaminated and rippled sand, silt and mud (Selley, 1970).

In the area investigated by the author the rocks of the lagoonal environment are represented by the DSSS facies, RFSSS facies on Tapkeshwari and in nala section exposures north of Bharapar, and in some instances by VS facies, and occurs in JWM, LM, GRM, MDM, JM, TM and BM.

In the DSSS facies, rocks are characterised by intercalation of shales, siltstones and sandstones. The shales and siltstones are delicately laminated with interlaminated rippled sandstones and siltstones. In many cases, as in DSSS facies associated with JWM, LM, GRM, MDM, and JM, the rocks show no physical structures except lamination entirely or within specific thicknesses depicting its deposition in quiet water areas. Bioturbation is moderate to intense and varied in DSSS and RFSSS facies exposures relevant to lagoonal environment in JWM, MDM, TM and BM, depicts normal salinity levels in the lagoons. It is represented by crawling trails and feeding, grazing structures with few dwelling burrows. It also indicates calm water conditions with much organic material deposited with sediment present in some amount in suspension form. This is also evident by the shales of the DSSS facies which are darker in colour which may be due to presence of organic matter. Shales in the GRM, MDM, JM, TM and BM are carbonaceous in nature and exhibit accumulation of plant debris in the lagoon. Very few well preserved leaf impressions and that too, not in the shales but in the siltstones or sandstones, and non-occurrence of insitu root portion depicts transported nature of such material.

Very thin lagoonal sequences are found to have developed in transgressive sequences (i.e., 30.0 cm to 1.0-1.5 m) or not at all developed (e.g. GRM, LM, DOM, JM, TM) except in MDM where DSSS sequence is more than 15.0 m thick. The first condition suggest quick encroachment and invasion of sea generating thin veneer of the facies or omitting it, while second depicts still stand conditions allowing accumulation of thick sequence.

The regressive sequences are commonly 2.0-5.0 m thick and observed in JWM, LM, GRM, MDM, JM and TM.

The DSSS facies either found enveloped within SS facies representing beach-bar-barrier environment or bounding on upper or lower side by unconformity. Further, the geometry of the rocks deposited in this environment is elongated in length parallel to the strike but width is less and mostly shows lensoid outlines.

The RFSSS facies in Tapkadevi area and north of Bharapar, contains 10.0 to 15.0 cm carbonaceous shales in between rippled sandstones- siltstones which are 0.5 to 1.5 m thick. The increased thickness of the sandstones in the facies (normally it is 5.0 to 30.0 cm) and occurrence of carbonaceous shales in the facies suggest that it was deposited in the lagoonal part of tidal flat.

In the same way, the ferruginous silty shales of VS facies showing bioturbation and biogenically disturbed but delicate lamination, associated with SS and BTS facies and with much less lateral extension, depicts its deposition under lagoonal environment in quickly varying depositional conditions.

All these characteristics confirm lagoonal depositional environments for the DSSS, and the specific RFSSS and VS facies exposures.

IX.3.1.6. SUB-TIDAL: The sub-tidal part occupies subaqueous beach face (shore face), commencing at mean low tide level and terminating at the fair weather wave base. The near shore part is relatively steep (1:10), but the slope decreases off shore until at the sea ward extremity in water depth of 12.0-20.0 m to maximum 40.0 m, where it has a value of 1:200 (Swift, 1976). In physical terms, it is an area of transition between shelf processes and near shore processes such as the breaking of waves. Bars and shoals may found in this part (e.g. east coast, USA and Cape Code; Nilsson, 1973), where as other examples have no major topographic features but are ornamented by a fluctuating assemblage of bed forms (e.g. the Oregon coast; Clifton, Hunter and Phillips, 1971).

The characteristic sediments are progressively sea ward fining which is attributed primarily to sorting in plumes of suspended sediment supplied to this part by rip currents, with other factors such as the land ward increase in wave induced shear stress supporting the trend (Cook, 1970; Cook and Gorsline, 1972; Swift, 1976a). Departures from this trend is not uncommon in several present day sub-tidal areas.

Facies details across the sub-tidal part are determined largely by the prevailing hydrodynamic regime in which wave action is pre-eminent, though biogenic processes are also important, and the facies often reflect an interplay between these processes. In high wave energy settings primary structures predominate as biogenic structures are not developed or have a low preservational potential, where as in low wave energy settings biogenic reworking may be so thorough that the sediment becomes homogeneous, poorly sorted and virtually structure less. Hence, normally intermediate to low wave energy regimes record an alternation between physical and biogenic structures. The wave regime controls the structural configuration and facies characteristics of the sub-tidal part. In high wave energy setting, sediment are coarse to fine sandy with asymmetric and symmetric ripples, symmetrical pointed straight crested large ripples (Clifton et al., 1971). In intermediate to low wave energy shorelines barrier islands are produced which composed mainly of fine sand merge in to seaward slopes to form sub-tidal parts. These are characterised by ripple lamination interbedded with parallel lamination and sediments are composed of fine sands, silts and shales (Howard, Frey and Reineck, 1972; Elliott, 1978).

In macrotidal areas bidirectional planar and trough cross stratification may produce herringbone structures in subtidal tidal setup.

When compared to the study area, higher wave energy subtidal deposits are recognised in form of medium to fine grained sandstones with negligible presence to absence of biogenic structures and massive to parallel stratification, symmetric to asymmetric and large pointed crested ripple marks and local cross stratification in GM, JM and TM. Larger topographic features seems to be absent in these cases. The local cross stratification is produced due to migration of lunate to straight crested mega ripples. The facies are represented by massive sandstones. These sediments many a times show palimpset to relict nature (e.g. GM, JM), and do not exhibit any kind of fining or coarsening upward sequences of beds. These characters are produced due to the initial transgression to a limited extent followed by a balance of sediment supply and subsidence which have maintained identical subtidal conditions for a longer time span to give rise to thick sequences. Minor fluctuations are recorded in form of bedding planes resulted due to brief omission & hardening, surface exposures in intertidal conditions (documented in form of parting lineations, interference ripples), local burrowing etc. Lagoonal or barrier sequences are not represented in the above cited examples, which depicts their absence.

Macrotidal setting in subtidal to tidal part has been recognised in form of HS facies showing bidirectional planar and trough cross stratification producing herringbone structures. It occurs in GM and TM and shows significant seaward and upward fining of the sediments. Hummocky stratification has also been observed in such sequence depicting stormy conditions. In such sequences, large number of other related physical structures like various types of ripple marks, climbing ripple cross stratification, flaser beddings etc., are also present.

In JWM, MDM, JM, and BM, intermediate to low wave energy regimes were produced in the subtidal part which are coarsening upward regressive sequences recognised in form of alternate LSS and SS facies with decreasing intervals of sandstone beds. These are produced on sea ward slopes on subtidal parts to the lagoons and barriers, and characterised by intercalated parallel and ripple laminated shales, siltstones and sandstones as well as interplay of physical and biogenic structures. Straight crested and large symmetrical ripples to asymmetrical ripples are common characters of such facies.

IX.3.1.7. SHALLOW SHELF: The shallow shelf are distinct marginal marine areas on continental shelf. The portion are subaqueous, dominated by marine processes and deposition of finer clastics and non-clastic, and subordinately influenced by shallow turbidity currents and debris flows that are triggered by sudden discharge of fluvial agencies. In the study area normal marine processes and deposition of finer clastic predominates. The sequence is shallowing upward and is marked by coarsening upward sediments, where sandstone partings increases towards top in a laminated shale siltstone sequence.In this regard the shale dominated sequences of LSS with subordinate sandstone partings or slabs can be compared with the somewhat deeper parts in the inner shelf, while sandstones and siltstone dominated sequences of LSS which alternates with SS facies can be labeled for the near shore shelf in much shallowed conditions on inner shelf. In the field the latter sequences are found above former one in a continuous manner and changes are gradual.

Finer grain size, predominance of argillaceous material, absence of ripple marks, presence of thin lamination in shales and siltstones and occurrence of ichnocoenoses like *Chondrites, Rhizocorallium, Gyrochorte,* etc. show characteristics of shelf sedimentation under calm conditions mostly from suspended finer particles. Predominance of finer clastic and negligible presence to complete absence of calcareous sediments support the above inference (observation).

In the second case where silty and finer arenaceous material is abundant with ripple marks, and presence of *Thalassinoides, Rhizocorallium, Diplocraterion, Skolithos* etc. Ichnocoenoses depicts near shore shelf characteristics above normal wave base under moderate energy conditions and some reworking and shifting of sediments.

The coarsening upward sequences of LSS depicts deposition in regressive phase in a shallow marine shelf environment.

IX. 4. SEDIMENTATION MODEL:

The overall data synthesized by the author can very well be compared with a transgressive and prograding linear clastic shoreline and shallow shelf sedimentation model which can be appreciated if one follows the sequence of events in the formation of a modern linear clastic shoreline sequence. As often inferred, the linear clastic shorelines are the products of moderate to slow deposition and winnowing to relatively agitating bodies of water. Their presence represent the continuing ability of marine waves, currents and tides as well as frequent storms to disperse and deposit sand, silt and other detrital material. Here, river and other agencies distributing detrital or clastic material, supply it less rapidly than they can be removed by marine processes. In such a case, normally estuaries are produced. A major phenomena in evolution of linear clastic shorelines is the transgression-regression sequences (the former is fining upward and latter is coarsening upward sequence) both being mirror images of each other. In such environments, shifting of major facies and environment is perpendicular to the elongation of shoreline, and is more or less opposite in case of a deltaic sequence where shifting of river courses in to successive distributaries is taking place more or less parallel to the shoreline. The carrying capacity of currents, waves and tides differ according to seasonal variations. The typical environments resulting from such interaction are estuarine, marsh, beach, tidalflat, lagoon, barrier, subtidal, shallow shelf and locally deltaic setups in the depositional regime. Majority of the facies repeat as in the Mesozoic sequence studied by the author. Such settings are characterised by a complex of environments with salinity and sedimentation characteristics that are directly reflected in their physical structures and trace fossil contents.

The schematic evolution of linear clastic shoreline and shallow shelf sequence of Mesozoic age in mainland Kutch can now be explained as under:-

As evidenced from the earlier studies the active sedimentation in the area studied by the author commenced from Middle Callovian time and continued to Oxfordian - Kimmeridgian - Tithonian - Neocomian - Post Aptian - Albian, of the Middle Jurassic and Cretaceous period depositing a total thickness of sediments of around 1000 m. This has been classified under four major stratigraphic units viz., Chari Formation, Katrol Formation, Umia Formation and Bhuj

Formation comprising 250 m, 350 m, 85 m, and 310 m of stratified deposits. The entire Mesozoic depositional phase is marked by eight major and four minor transgression regression episodes (three major and one minor episodes in Chari Formation, two major and two minor episodes in Katrol Formation, one major and one minor episodes in Umia Formation and two major episodes in Bhuj Formation); ten coarseningup and one finingup sequences (three coarseningup and one finingup sequences in Chari Formation, four coarseningup sequences in Katrol Formationn, one coarseningup sequence in Umia Formation, and two coarseningup sequences in Bhuj Formation); six major erosional events (one each at the end of Jamaywadi Member, Ler Member and Dhosa Oolite Member of Chari Formation, one each at the ends of Marutonk Dungar Member and Jadura Member of Katrol Formation, and one at the end of Bhuj Formation before eruption of Deccan Trap lava flows) and around 70 to 80 storm generated events (represented by BS subfacies, BL, IC and BTS lithofacies and by megaripple marks). Many of these events are controlled by the eustatic sea level changes, regional tectonic movements, intrusive phases, and physiographic and biologic responses. All these events are perhaps related to the plight of the Indian subcontinent from the moment of its separation from Pangea and the possible rotational movements occurred during the course of its travel.

The oldest sedimentary unit in the area of study is the Chari Formation with an approximate thickness of 250 m. It is represented by JWM of Middle Callovian age, GM of Middle Callovian age, LM of Upper Callovian age and DOM of oxfordian age. In its initial depositional phase (JWM), a shallow shelf condition existed in the dpeositional basin which was being filled by the intercalated finer clastics. The basin was, in all possibilities, shallowing with finer clastics and gradually being shifting towards coarser clastic sequence to form barriers, lagoons, beaches and tidal flats in the region (fig. 17). The overall conditions were constructive creating net sedimentation in the basin. The existence of lagoons and beaches is very well documented in the sedimentary record and sequential trace fossil evidences. This shallow shelf sedimentation by far was such that it developed quick intercalations of shales, siltstones and sandstones, with or witout ripple markes but always finely laminated. Such an episode was characterised by typical trace fossil assemblages and scattered remains of marine fossil forms.

The formation of barrier and beach environments as pointed earlier are sandstone dominated and characterised by lateral extension of individual beds with more or less uniform thickness, parallel to inferred shoreline but quick thinning perpendicular to it, and showing massive to horizontal stratification with local cross bedding structures.

The lagoonal sediments on the other hand (fig. 17) are distinguished by intercalations of siltstones and sandstones and the dark coloured shales that are often black carbonaceous. In this case ripple marks may or are not present but lamination or ripple laminations are very distinctive.

In case of tidal flats in the study area, typical feature include the presence of intercalated sequence of sandstone-siltstone-shale, but sandstone dominates over thin gray shales. Various types of ripple marks are common, e.g.straight crested symmetrical or oscillation ripples, interference ripples, etc. Formation of tidal gullies and small channels are rather characteristics.

Active progradation of barriers and beaches are thought to have continued after prolonged deposition of finer clastics in shallow shelf on a linear clastic shoreline set up, in parts of east-west elongated stretch extending across the study area, which is represented in thick sequence of SS facies (from Gangeshwar to Jamaywadi and surrounding areas of JWM exposures).

The fluctuating sediment supply of argillaceous and arenaceous material has been recorded in the quick alternation of SS and LSS facies, in a transition zone between sub-tidal and shallow shelf. (Such depositional nature has also been observed in LM, MDM, JM, and TM).

The evidences of hiatus and sub-aerial erosion of some of the beach- barrier and lagoonal sediments or earlier formed LM and other deposits are preserved on JWM, LM, DOM, MDM, and TM. This has occurred, in all possibilities under arid semiarid conditions in JWM and yielded small to large rounded boulders out of then exposed youngest sandstones of JWM, which later on entrapped in the rejuvenated deposition, at various levels in the lower most beds of GM.

The erosion at the end of LM, MDM and TM, resulted in large uneven surfaces, truncation of beds against unconformities and absence of several uppermost beds in many areas below unconformity, development of undercuts etc. In DOM, this has occurred in between the deposition of OL facies. These are in many cases related to episodic tectonic event which is reflected in overlapping sequences of JM and TM above unconformities, as well as variation of dip on both the sides of unconformities in case of DOM-GRM, MDM-JM and JM-TM. Here, some tilting is related to the tectonic activity in above examples.

The renewed sedimentation in many cases is resumed by development of shallow marine conditions where primary environment was set on to the beach and supra-tidal conditions in the belt of Jogi-timba, 1.5 - 2.0 km west of Ler to Satpura Dungar south of Jamaywadi. This was immediately encroached by transgressing sea and the beach to supra- tidal sediments were mostly settled in sub-tidal conditions in form of reworked, relict to palimpset deposits. Such fluctuating tidal subtidal conditions remained established for a prolonged time to give rise to thick sequence of sandstones as final deposition under subtidal conditions. The sedimentary structures often indicate wave dominated shoreline conditions, while the trace fossil associatons indicate high energy conditions. Sedimentary episodes of this nature are observed in GM, JM and TM.

The sequence of GM and TM is attributed to the large scale tectonics and purely sedimentary processes. The sedimentary processes, which are responsible for the development of bimodal planar and trough cross bedded sequences ultimately results into herringbone structures, have been identified as tides under intertidal to subtidal conditions along a linear clastic shoreline. Meso to macro tidal processes possibly induced migration of sand waves, megaripples and antidunes in a pulsatory manner during successive tides to produce such structures in arenaceous sediments.

In both the above examples the sedimentation has been resulted due to sand influx along with rejuvenated basinal conditions. And in such cases lagoons and barriers are not developed.

Normal storm episodes seem to be persistent, and assisted by prevalent spring tides have created erosional surfaces on individual cross stratified units evacuating top set beds and depositing single grain layer on it. Reactivation surface or next cross stratified units occur on such layer. These patterns can be observed in GM, TM and BM.

In other cases, during sea advancement, very thin (0.6-0.9 m to 5.0- 6.0 m) veneer of beach, lagoonal and barrier sediments deposited in the initial part. Sediment supply, in this type of condition was possibly very low, comprising principally fine sands and suspended fine terrigenous material, leading to shallow shelf conditions, without much deposition of basinally proximal sediments (under which calm deposition of shale-siltstone intercalations takes place). In some cases deposition from suspension directly occurred on erosional surfaces under shelf conditions (e.g. DOM). A thin extrabasinal conglomerate layer at the base represents such an event. These events are located in LM, DOM, GRM, JM and TM. In case of MDM most probably due to moderate to high sand supply, thick well defined lagoonal and barrier facies are developed. The biogenic sedimentary structures clearly indicate these features. During tidal to shallow shelf conditions, reworked or exhumed Intraformational Conglomerates, shell beds or coquinas or Bioclastic Limestones, Bivalve Sandstones and Bioturbated Sandstones and mega rippled beds accumulated to form moderate to high energy storm generated deposits. Such deposits are found in JWM, LM, DOM, GRM, MDM, TM and BM. They also indicate omission, early diagenesis and hard ground developments.

Condensed horizons with much less terrigenous sediment supply and generation of basinal authigenic sediments in shallow shelf conditions have resulted to produce condensed Oolitic Limestone deposits.

The deltaic sedimentation probably started with the characteristic ephemeral changes (short lived, or transitory changes), a delta would undergo during its initial development.

In all possibilities, a delta lobe having delta front sands existed in the west, southwest central and southern parts of study area, especially around Fakirwadi, Satpura Dungar, Gangeshwar and Gunawari river. Active progradation is thought to have continued through different distributary channels to produce sedimentary sequence from base to top, two main deltaic sub-environments: prodelta and delta front alongwith delta slope.

The delta front sandstone dominated environments evolved laterally in a large high constuctive lobate shape is indicated by their down depositional dips due west, southwest and south.

The sand rich delta front facies and its cyclic nature of progradation probably resulted from the variations in the style of delta front and sand accumulation. Such a change could be predicted in the presence of a broad, lobate shaped complex of delta front sands comprising two coalescing, overlapping and coarsening upward sequences. As indicated by the occurrence of delta front in patchy localised accumulation within prodelta sediments, the deltaic deposition must have continued under the least influence of wave action and the long shore currents. It is likely that during delta advancements, sediments consisting principally suspended fine terrigenous material settled near the sea ward parts of the delta to form the prodelta deposits. These localised development of deltaic sequences have been observed in GRM exposures, in Fakirwadi, Satpura Dungar, Gunawari river, Gangeshwar, Ler etc., areas. The physical and biogenic sedimentary structures, and the nature of outcrops in the field clearly indicate most of these features.

In BM of Bhuj Formation, at essentially all exposures along the two east-west outcrop belts, the sedimentary sequence from base to top have developed estuarine and related facies with storm generated beds. The coarse grained sandstones with bimodal planar and trough cross stratification with erosional and reactivation surfaces and occurrence in broad channel form appears to have been deposited by migration of sand waves, megaripples and antidunes induced by flood and ebb tides to form estuarine sedimentation. In all possibilities, meso- to macro- tidal processes are responsible for the sedimentation, as the dimensions of physical structures and the geometry of lithounits indicates.

During estuarine deposition sand ridges are developed, inbetween the paths of flood and ebb channels, with coarse sands as their main sediment load. It is demonstrated by unimodal cross stratification showing opposite directions of palaeocurrents toward north and south in adjacent areas and horizontally bedded to southernly cross stratified strata inbetween. Such deposits are located in Ganga and Nagavanti nadi near Chakar and Kera respectively. At the time of later part of ebb tides or during normal fluviatile processes within estuarine set up, rippled and finely cross laminated siltstone and shale deposited in between cross stratified coarse sandstones to form still stand or calm time deposits. These are documented near Kera and produce thin sequence (0.1 to 1.0 m) within estuarine facies.

Furthermore, flood deposits produced by migration of shifting channel bars during floods often recognised in form of coarse planar cross stratified 1.0 to 2.0 m thick sandstones alongwith slump structures, contortion and sandstone dykes. These physical structures clearly indicate deposition under very fast rate by the depositional agencies. Association of such typical facies alongwith above mentioned deposits depicts deposition under overall estuarine conditions. Very often the adjacent parts in these sequence have developed marsh, swamp, tidal flat, lagoon conditions, which is exhibited by occurrence of variegated to carbonaceous shales, extensive sandstone beds, etc. Their sedimentary structures, and equally well documented trace fossil are recorded in BM of Bhuj Formation.

In conclusion the deposition of Mesozoic sedimentary sequence in Kutch seems to be controlled by the balance between subsidence and sediment supply to the depositional basin. This balance, however, was frequently disturbed at certain non-uniform intervals, and shallow marine to shoreline depositional conditions and nondepositional time spans when erosional unconformities were introduced in the marine shallow shelf system.

The fluctuations in sea levels and other environmental conditions are reflected in abundance and diversity of biogenic sedimentary structures in various Members in the study area. The example can be sited from the paucity of trace fossils in GRM, which normally should have a high trace fossil preservation potential, instead of lower faunal diversity and density. This may have happened on account of the possible influence of fresh water and fluctuating conditions within a nearshore low salinity system.

The depositional basin in the area of study is further claimed to have witnessed cycles in which transgressive events (subsidence rate > sedimentation rate), altered with progradational or regressive events (subsidence rate < sedimentation rate). Such repetition patterns seem to be largely "allocyclic" - resulted from external events like relative sea level fluctuations, tectonic events, compaction of underlying sediments, eustatic sea level changes or any combination of these parameters. The exception being GRM and BM where alternate cycles of deposition are mostly "autocyclic" - produced by shifting patterns of sedimentations in a continuously subsiding basins. Although the overall sedimentological and ichnological evidences at various localities of the study area support possibilities of both the autocyclic and allocyclic nature of deposition upto certain extent.

Development of omission and hardground surfaces, and episodic sedimentation indicating slower deposition, depositional breaks without much erosion and event stratification respectively, are observed in many localities indicating various phenomena including nondepositional periods, development of hard grounds and storm deposition.

In conclusion, the marine sedimentary record in the area of study shows a diachronous pattern of deposition that is typical of a regressive mega-sequence. This essentially corresponds to a number of transgressive - regressive cycles and development of linear clastic shoreline and shallow shelf complex with localised deltaic (GRM) and estuarine (BM) conditions which filled a slowly subsiding basin during the Callovian to the post Aptian time. This is followed by final retreat of the Mesozoic sea in mainland Kutch giving way to short term denudational processes and Cretaceous-Tertiary volcanic eruptions.

Evidences from trace fossils assemblages described by the author give definite indications of relative energy levels, oxygenation and turbidity but provides no absolute limits for depth. It has very well demarcated the response of infaunal benthic communities to numerous aspects of physical environments. The most important of this appears to be the salinity, interstitial oxygen, sediment composition and texture, and hydrodynamic energy of depositional environment in terms of rate of sedimentation, frequency of erosion events and orientation of waves and current. The trace fossil association in the investigated area are, therefore, remarkable in their density, diversity and excellent state of preservation.

The tectonic events - to be specific - can be related to the plight of the Indian subcontinent and its rotation which occurred during its course of journey to its present state. This may have been responsible for quick shifting of wave dominated conditions to the tide dominated conditions in individual Members within geologically small fraction of time span. Dominance of waves, in the Recent environment can be seen in the direction of prevalent winds, mostly in open parts of seas and characterised by microtides. As very well known, this is westward in subtropical-tropical areas, while dominance of tides have been observed in protected areas due to interaction of sun and moon, most probably not in prominent wind directions (Johnson, 1978; Defant, 1958; Mooers, 1976; Madsen, 1976). Thus, in such situations, meso- to macro-tides are the prominent features. Comparable quick shifting of environments in the same area in the geological sequence therefore have much significance. It is therefore hypothized that the Middle Jurassic Callovian time recorded in - GM is possibly related to the Indian subcontinents' migration after its breaking from the Gondwana land, is most significant. In the same way, end of the Jurassic and commencement of the Cretaceous (recorded in TM) is equally of much significance, when, the Indian subcontinent began to accelerate its maximum speed (Worsley et al., 1984, 1986; Harland et al., 1976; Barron et al., 1981; Smith et al., 1982), and perhaps had a direct bearing on the various depositional episodes of Kutch Mesozoics including the area investigated by the author.

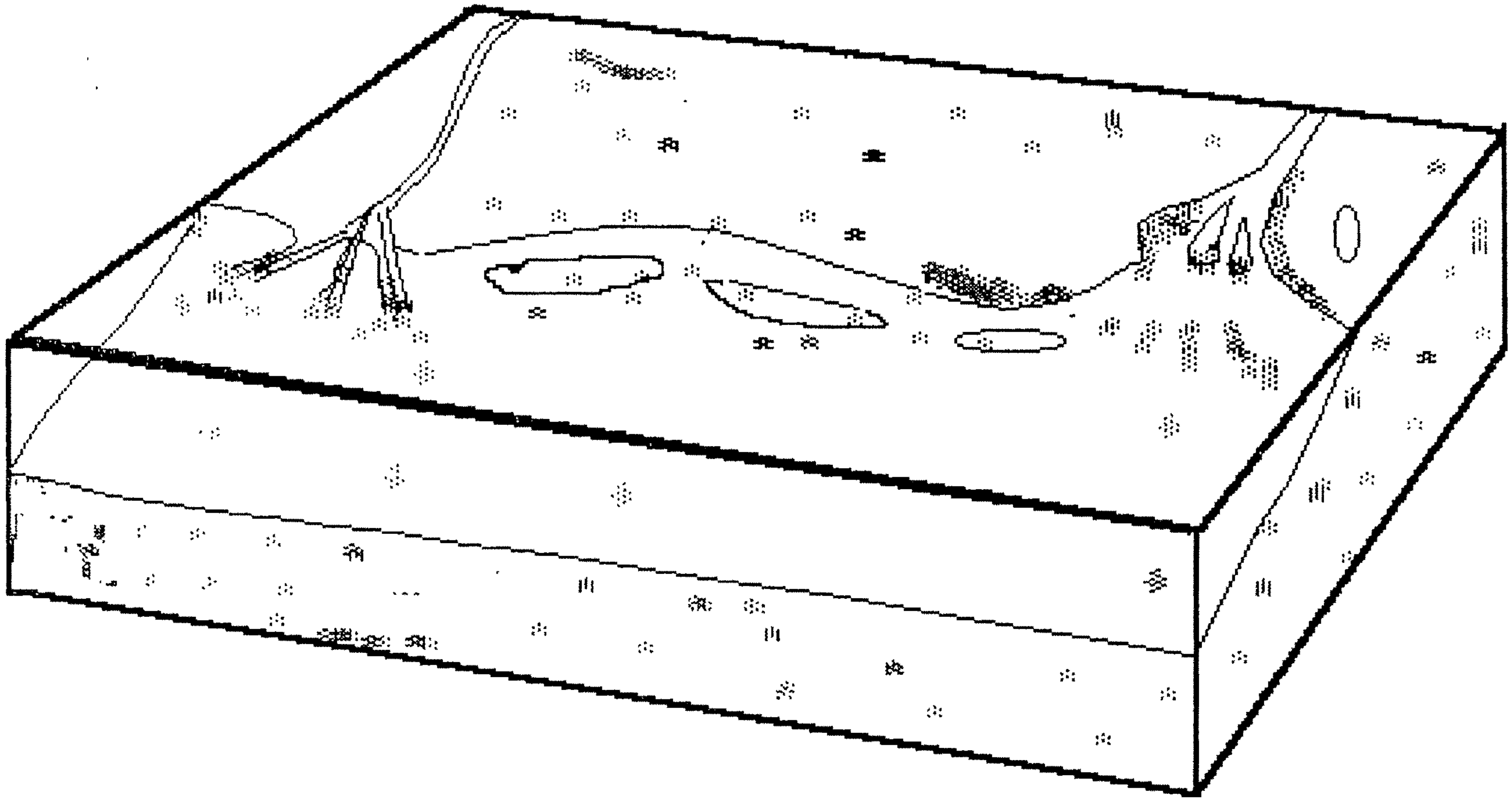


Figure 18. THREE DIMENSIONAL SEDIMENTATION MODEL OF MESOZOIC SEQUENCE.