CHAPTER V

LITHOFACIES AND TRACE FOSSIL DISTRIBUTION

Any objective interpretation of depositional environments the writer believes has to begin with lithofacies description, and can then progress after appreciation of lateral facies variations and consideration of modern environments and processes. In most cases it is only after this stage has been reached that depositional environments can be relatively inferred (Reading, 1978). In recently published literature there is a growing tendency to name facies for their inferred depositional encironments (e.g. "delta front facies "-------" braided fluvial facies" etc.), and indeed Middleton (1978) and Walker (1979) have stipulated that any particular facies will be representative of a single environment. Although, both Middle_ton (1978) and Walker (1979) stressed the importance of objectivity in facies deposition, direct one-to-one correlation of a single facies with a particular environment can bypass the important step of process inference emphasised by Reading (1978), and can unnecessary raise questions of the subjectivity. Even if such questions are unwarranted, it would seem more reasonable that the name of an objectively defined facies should reflect the characteristic of the rocks assigned to that facies.

In the present study each lithofacies is first defined on purely objective grounds, and is then used as a basis for its inferred depositional environment discussed later. Facies are first defined at their type/important sections and are then compared with other outcrops in the study areas for detail interpretations. The limited occurrences and poor areal distribution of exposures limits the establishment of detail regional facies trends. As a result this study is focussed mainly on vertical facies relationships exhibited at each outcrop. The inferred lateral relationships based on the characteristic biogenic sedimentary structures of each facies are presented in the following Chapter VI.

In order to gain detailed facies information, stratigraphic sections were measured at the following ten localities given in Table No. 6. Lithologic correlation was accomplished by "walking out" the strata and by referring the individual beds to their stratigraphic positions below or above the three important time plane viz., the Mudstone band, the lower Astarta bed, and the upper Astarte bed.

The Wagad Group of rocks in eastern Kutch consists of six principal lithofacies. This descrimination is based on area of occurrence, lithofacies geometry and stratigraphic position, lithology, and texture, physical and biogenic sedimentary structures and on patterns of vertical sequences. Representative lithofacies are shown in figure 14-(W,C,M) and in figure 15. There will be a consideration of the relations among these lithofacies following a brief description and

TABLE - 6

THE FIRST TEN LOCALITIES LISTED BELOW ARE THOSE AT WHICH DETAILED STRATIGRAPHIC SECTIONS WERE MEASURED. THE REMAINING LOCALITIES ARE THE SECTIONS THAT WERE EXAMINED FOR THEIR TRACE FOSSIL CONTENT AND SUPPLEMENTARY STRATIGRAPHIC DETAIL.

Locality	Latitude		Longitude		Sheet No.	
Adhoi	23°	24'	70°	33'	41	I/11
Chitrod	23°	24'	70°	42'	41	I/11
Halrae	23°	25'	70°	27'	41	I/ 7
Mae	23°	26'	70°	22'	41	I/ 7
Manfara	23°	29'	70°	21'	41	I/ 7
Nara	23°	26'	70°	35'	41	I/11
Kanthkot	23°	29'	70°	28'	41	I/ 7
Washatwa	23°	25'	70°	37'	41	I/11
Ramwao	23°	27'	70°	24'	41	I/10
Tramau	23°	30'	70°	34'	41	I/10
Badargarh	23°	24'	70°	33'	41	I/11
Gamdau	23°	25'	70°	33'	41	I/11
Kakarwa	23°	29'	70°	24'	41	I/ 7
Lilpur	23°	28'	70°	26'	41	I/ 7
Mewasa	23°	24'	70°	46'	41	I/11
Wamka	23°	26'	70°	26'	41	I/ 7
Wandh	23°	28'	70°	28'	41	I/ 7

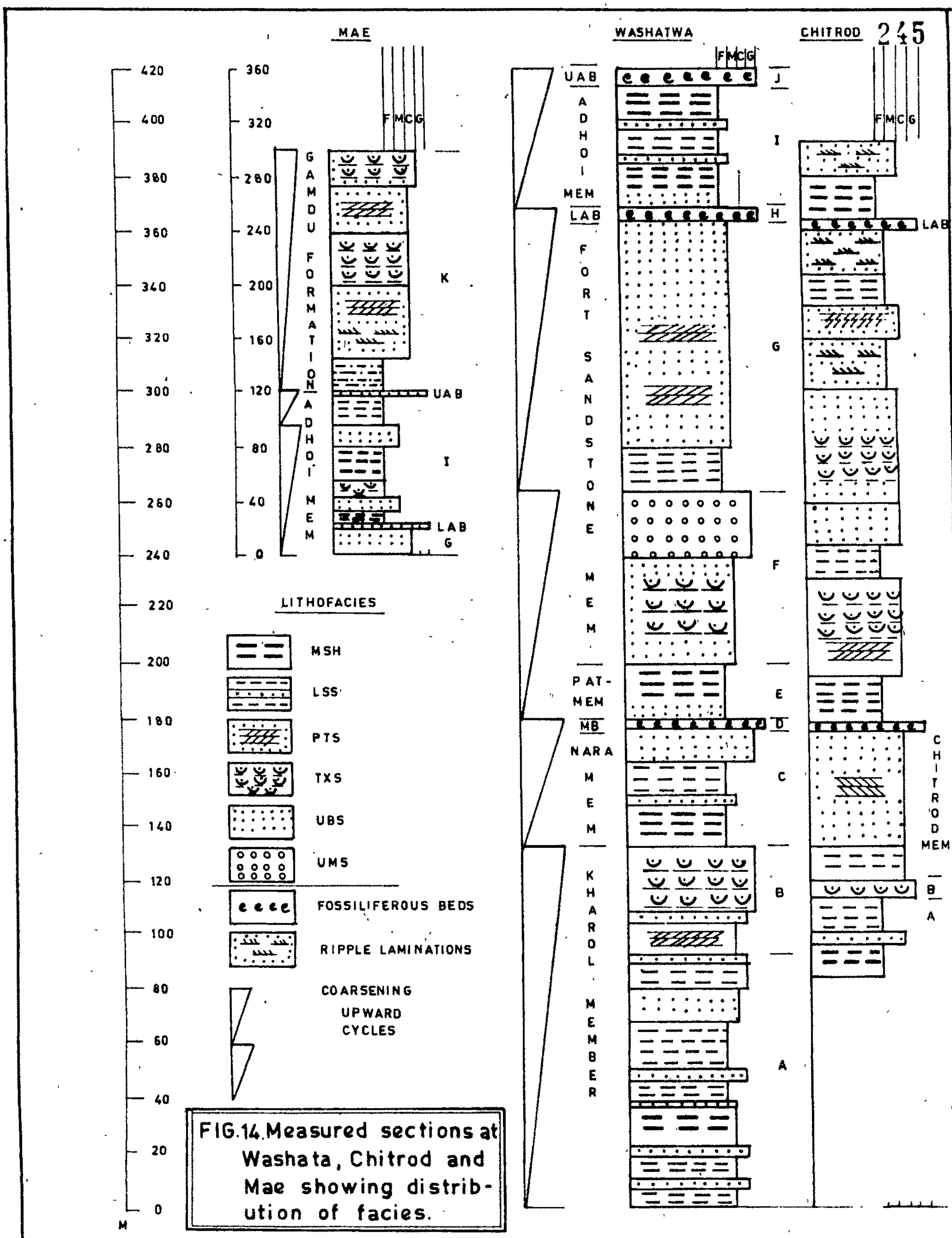


FIG.14. Measured sections at Washata, Chitrod and Mae showing distribution of facies.

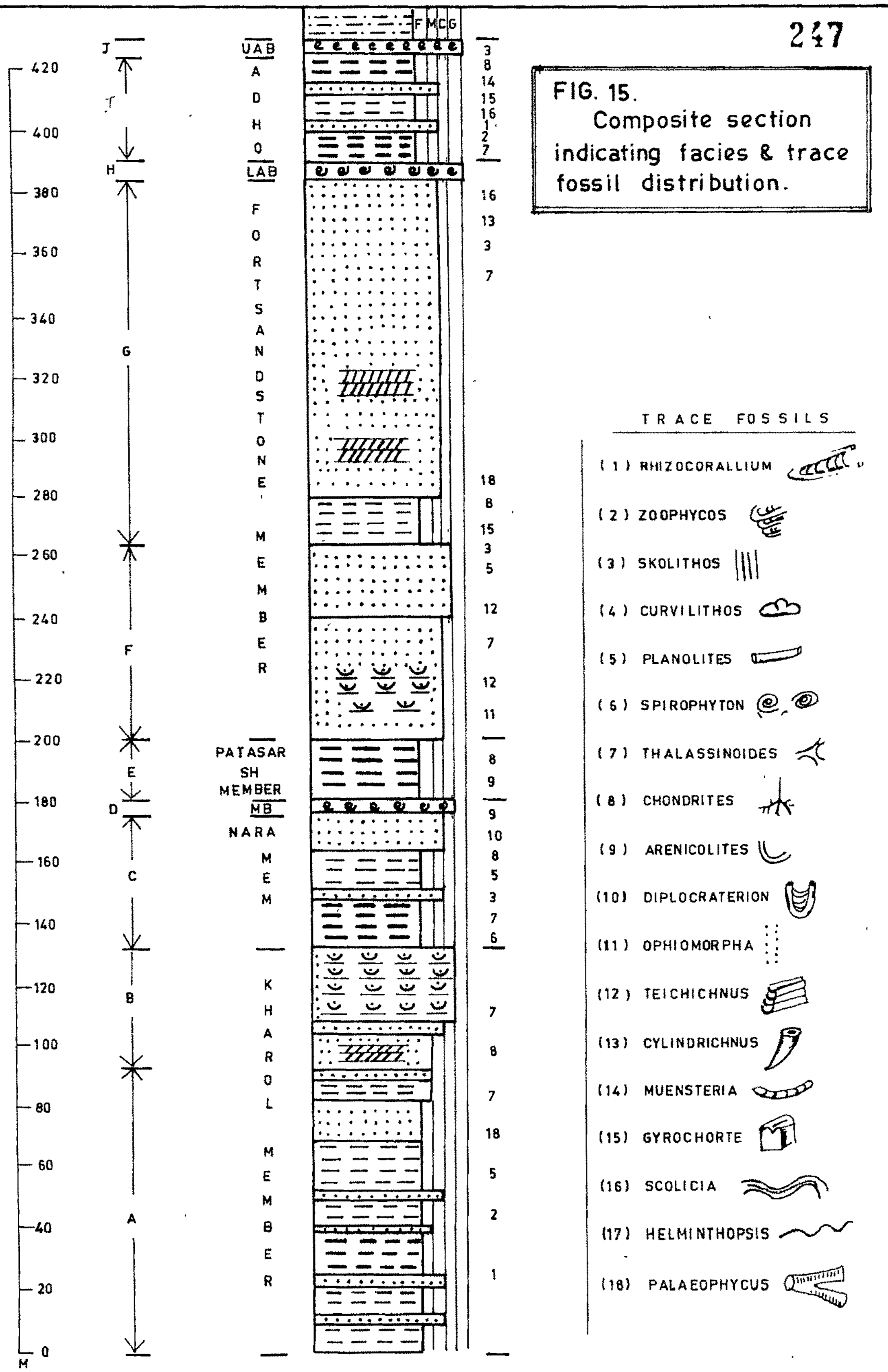
interpretation of each lithofacies. It should, however be noted that most of these lithofacies are repeated in their vertical extents and also integrate with each other in their lateral extent.

LITHOFACIES

(i) Facies MSH, Massive Shale:

Description:- Massive, grety to olive-green and light to purple coloured, mottled shales occur in units "A", "C", "E", and "I" in the stratigraphic columns (Fig. 14 & 15)(W,C,M). The thickness of this facies varies in all these units. The shale is composed of silt-size quartz grains, occassionally concentrated into laminae with a micaceous and clayey matrix. It is difficult to know whether the colour originated from weathering in the source area, developed through in situ oxidation or reduction at the time of deposition or as the result of diagenetic or weathering process after burial. A high degree of colour mottling in many beds indicates that post-depositional modification was at least locally important. The extensive mottling also perhaps reflects widespread bioturbation which was possibly responsible for destroying an original lamination. The lower part of unit "A" also contains oyster shells.

FIG. 15.
Composite section indicating facies & trace fossil distribution.



Trace fossils:

unit "A" - <u>Rhizocorallium</u>, <u>Zoophycos</u>, <u>Planolites</u>

unit "C" - <u>Arenicolites</u>, <u>Chondrites</u>, <u>Skolithos</u>, <u>Planolites</u>

unit "E" - <u>Arenicolites</u>, <u>Chondrites</u>

unit "I" - <u>Rhizocorallium</u>, <u>Zoophycos</u>, <u>Thalassinoides</u>, <u>Gyrochorte</u>, <u>Scolicia</u>, <u>Muensteria</u>.

<u>Interpretation</u>:- The facies MSH is very often found associated and interbeded with the facies LSS and PTS respectively. The deposition of this lithofacies indicates very slow deposition from settling of suspended fine hemipelagic material in a very low energy environment marked by the almost absence of coarse grade sands. It is possible that the finer detritus was probably placed in suspension by current and/or wave velocity in an adjacent higher energy environment. The concentration of quartz silt grains in some relict laminae presumably indicates an increase in grain size of suspended material in the overlying water body, possibly due to strom activity. There are no sedimentary structures indicative of wave or current activity, and perhaps the extent of bioturbation may have obscured any evidence. Unit "A" contain areally distributed oyster beds and with other evidences can be interpreted as forming in a coastal lagoon. Trace fossils in units "C", "E", and "I", clearly indicate marine influence and may represent coastal mouth, delta-plane and tidal deposition.

Facies LSS - Laminated Shale with Interbedded Sandstone:

Well-laminated shales with variable proportions of interbedded sandstones form 10 to 50 m thick coarsening upward sequences throughout the Wagad Group. Units "A","C", and "I" prominently represent such facies. The MSH facies described earlier usually interdigitate with these facies. The shales in LSS have the same detrital mineralogy as those of facies MSH, but in general have a greater proportion of quartz silt or fine sand, particularly towards the top of each cycle. In contrast to facies MSH, undisturbed laminae are much more common in shales of this facies. There are also some horizons with bioturbation mottling. The shales of the unit "A" are grey to dark grey in colour, but in higher units the colour observed is usually dark brown and purple.

Towards the base of each unit the sand beds are usually thin (approximately 8-10 cm) and randomly distributed, but in the top 5-10 m they increase in frequency, thickness and grain size. Sandstones are grain supported, and are composed mostly of quartz grains with subordinate other rock fragments and feldspars together with minor biotite. Interstices are filled with chlorite and/or hematitic clay, usually coating the grains. Although virtually all sandstone beds have sharp bases, there is variability in sorting and internal structure. Many beds are massive and well-sorted, with very rapidly gradational tops. Others are moderately to well-sorted and normally graded.

Trace fossils:

unit "A" - Rhizocorallium, Zoophycos, Planolites, Palaeophycus, Thalassinoides, Chondrites.

unit "C" - Spirophyton, Thalassinoides, Skolithos, Planolites, Chondrites, Arenicolites, Diplocraterion.

unit "I" - Thalassinoides, Zoophycos, Rhizocorallium, Muensteria, Gyrochorte, Scolicia, Chondrites, Skolithes.

Interpretation:- The laminations defined by varying concentrations of grain sizes of fine quartz grains probably resulted from storm-related (wave generated) variation in the overlying water body (cf. facies MSH). The decrease in endogenic forms appears to have prevented laminae destruction, the possible causes for which may include increased current strength, faster rates of deposition, or changes in the water chemistry. The sedimentary characteristics of this facies rules out changes in current strength or depositional rates as causative factors, indicating that water chemistry was the most likely factor. Support for this suggestion comes from unit "B" above the facies, where the reduction of trace fossils and presence of maroon shales and grey to olive-green sandstones is consistent with the rapid alternation between oxic and anoxic conditions at and below the sediment surface (Berner, 1981). The greater proportion and increased grain size of quartz silt and fine sand within the shales high in each cycle indicates close proximity to higher energy environments, as this material would settle rapidly out of suspension.

The interbedded sandstones thus indicate that the "background" of shale deposition was periodically overwhelmed by higher energy mechanisms with much greater rates of deposition. The thin ripple cross-laminated sandstone beds occurring in the unit "A" and "C" would have been deposited as migrating ripple bed forms under the influence of moderate strength currents.

The overall impression presented by LSS is of low energy, dominantly shale deposition at the base of each cycle, with the increase in frequency and grain size of sandstone beds and coarsening of detritus in shales in the upper parts of each cycle reflecting closer proximity to higher energy environment.

<u>Facies PTS - Planar Tabular Cross-stratified Sandstone</u>

<u>Description:</u>- Three units within the investigated sequence are dominated by planar tabular cross-stratified sandstones. The units "B", "F", and "E" although of quite

different morphology display these features.

Facies PTS of unit "B" outcrop in two excellent strike exposures being represented in figure (14-"W"+"C"). The maximum exposed thickness of PTS in unit "B" is 20 meters in section "W", and 5 meters in section "C". Largest exposures of this facies, however, are noticed in units "F" and "E" where the thickness range between 50 and 20 meters respectively. A number of broad channels occur towards the middle of the units "B" and "F" and "K". These channels both cut into and are infilled by the facies of PTS. Although rather variable, channel profiles in general have steep margins and relatively flat bottoms. Depth/width ratios for three measured channels are 0.5/7, 0.6/8 and 2/25 m, indicating that there is almost constant depth to width ratio of approximately 1:13.

The thickest individual PTS sets occur towards the base of "B", "G" and "K" units with largest observed sets of 2 m being in "G" and "K" that are dominated by 2-5 cm thick cross-strata. Towards the middle and top of units "B", "G" and "K" 20-40 cm thick sets with 0.5-1 cm cross-strata are most common, forset dips range from 8 to 35° being most common. Forset basal contacts are usually angular in most of the sets. In beds of normal thickness cross-strata are most commonly defined by grain size variation, so that a single set although may have a relatively wide grain size range, individual cross-strata are normally well or very well sorted. In general, the grain size in a unit range from medium to coarse sand grade.

Clastic mineralogy in all the units is dominated by sub-angular to subrounded quarts grains, with subordinate feldspar and fragments of mica. Clastic grains commonly have either reddish hematite or green chlorite/illite clay rims. The texture probably reflect post-depositional cementation process. Because of low variability in grain size and sorting the cross-strata are characterized mostly by dirty white to red/purple colour variation arising from variable development of clay rims. The paleocurrent determinations on bedding/corss-strata inter-sections show that deposition of unit "B" was from consistently east to west and south west directed currents and that of the units "F" and "E" from the northeast to southwest and westerly directed currents.

Trace fossils:

unit "B" - *Thalassinoides*, *Chondrites*.

unit "G" - *Skolithos*, *Planolites*, *Teichichnus*,

unit "K" - *Ophiomorpha*.

Interpretation:- The PTS probably originated in several different subenvironments within the near shore locations as defined by Shepard (1963). The facies contains vertical distribution of sedimentary features that is consistent with deposition in or near the surf zone of a relatively high-emergy coast. The dominantly south, south-west and westward directed cross-beddings (possibly paleo-seaward direction) can be interpreted as resulting from rip currents (Davidson, Arnolt and Greenwood, 1978; Hunter et al., 1979), fluvial activity, tidal currents, or structures formed by the intersections of surf and swash (Clifton et al., 1971). Rip channels of modern beaches migrate systematically along shore in the direction of the longshore currents (Hunter et al., 1979), producing an erosional surface similar to that separating the cross-bedded coarse-grained sandstone from the underlying bedded fine-grained sandstones. Some of the channellized deposits in facies "B", "F" may thus represent mouths of small coastal streams (Clifton et al., 1973). Migrating tidal inlets have been invoked to explain seaward dipping fore sets in other ancient coastal deposits (Hobday and Horne, 1977).

The dominance of rip channels in units "B", "F" and "K" and their trace fossil contents clearly suggest that bars oriented obliquely to the paleoshores may have been a common feature off the paleo shores during the Wagad deposition. Most of the trace fossil associations in units "B" and "F" indicate environments that range from surf zone (shallowest inner sublittoral) to shallow shelf (deep inner sublittoral). The large-scale PTS in unit "K" and its almost nonfossiliferous nature does not support the near shore intepretation, and therefore must have been influenced by the fluvial currents.

Facies TXS - Trough Cross-stratified Sandstone:

Description:- TXS dominate the unit "B" and "F" and constitute nearly 50% of the unit "K". Facies TXS usually form the top of most coarsening upward cycles overlying facies LSS shale-dominated units. Clearly defined horizontal bedding surfaces occur intermitently in units of this facies, and are more common towards the base of the units "B" and "K", respectively.

Grain size variation between the different facies of TXS units clearly show the coarsening upward trend as a whole. Grain size in unit "B" ranges from fine to coarse sand, compared with medium to coarse sand range in unit "F" towards the middle of the sequence and to coarse sand with granules in unit "K".

Apart from the trough cross-stratification, the only other bed form occurring in facies TXS units is minor planer lamination, occurring apparently randomly in lower and central parts of the "B" and "F" units. Cross-stratification in unit "F" occurs in very broad troughs which resemble planer tabular sets over short distances suggesting that this unit may represent a transitional stage between TXS and PTS.

The combination of essentially two-dimensional exposures oblique to trough axes and variable forset attitude make accurate measurement of true foreset dip angles extremely difficult. It is likely from general observation that steepest dip angles correspond reasonably closely with the common range of 25-30° suggested by Harms et al. (1975).

Clastic mineralogy and texture of facies TXS sandstones is essentially the same as facies PTS sandstones described above. The major difference being greater variability of sorting. The sandstone matrix consists mostly of silt-size clasts with the same mineralogy as the sand-sizes component, together with hematite or chlorite illite clay. Much of the clay fraction is concentrated as clay rim around larger grains. Laminations are defined by sorting, grain size and colour differences. The colour differences may be due to variability of compaction of the clay rims (red/purple or greenish chlorite/illite) and differences in the ratio of translucent quartz to white altered feldspar and other rock fragments.

Trace fossils:

unit "B" - *Thalassinoids*

unit "F" - *Thalassinoides*, *Teichichnus*,

unit "K" - ----

Interpretations:- Trough cross-stratified sands are formed by migration of dune bed forms in the upper part of the lower flow regime (Harms & Fahnestocks, 1965). Experimental data indicate that the required minimum current velocities to generate such forms is in the range of 50-60 cms^{-1} (Harms *et al*., 1975) and was perhaps considerably greater than this in the coarser upper parts in the units "B", "F", and "K". These parts of the sequence showing development of bedding planes presumably indicate periodic slakening of current flow, whereas the presence of thin shale laminae between sandstone beds in lower units in the sequence indicates that there were periods when flow velocities diminished considerably.

Facies UBS, Unbedded Siltstone and Fine-grained Sandstone:

Description:- In a complete cycle, unbedded siltstone/ or very fine-grained sandstone overlies and commonly forms the matrix of the upper part of the MSH and the fossiliferous beds.

Lithologically the finer part of the units appear equivalent to the underlying units of PTS and TXS. The fine grained rock contains abundant quartz that is relatively well sorted. Molluscs remains generally preservedin fossiliferous beds indicate marine influence. Burrow structures are often evident in the form of cylindrical burrows 2 to 3 cm wide lined by a nodular concentration of clay, similar to Ophiomorpha nodosa Lundgren. In the upper part, this deposit tends to grade slightly coarser in its grain size.

Trace fossils:

Ophiomorpha nodosa, polychate burrow tubes

Interpretation:- The unbedded siltstone and fine-grained sandstone facies appear to have accumulated in water deep enough that the rate of production of physical structures. The depth at which this should occur, however depends on the composition of the fauna, the depth in the sediment to which the organisms burrow, the texture of the sediment, the rate of deposition, and the characteristics of the surf waves (Clifton, 1976). Completely bioturbated sediments does not necessary imply great water depth. Examples can be cited from the southern California (Clifton, 1976) where large long-period swell predominates, and fine sand deposited is completely bioturbated at depths as shallow

10 m. The thin layers of coarse-grained sediments in this facies accumulate as lag deposits and indicate that the bottom was reworked at least intermittently by large waves.

The trace fossils observed in this facies indicate environments that range from the inner sublittoral to shallow outer sublittoral, generally less than 15 m deep. These depths are consistent with the presence of the trace fossil "Ophiomorpha nodosa", Such structures have also been interpreted elsewhere as burrows of marine decaped callianassa, a genus common in various present-day shallow marine environments (Weimer and Hoyt, 1964).

Facies UMS, Unbedded Medium-grained Sandstone:

The lower part of the Chitrod Sandstone Member and that of the Fort Sandstone Member consists of unbedded medium-grained sandstone units. These units occur sporadically as thick beds upto 10 m in height with grain size medium to coarse and the sorting moderate to poor. The sandstones grade downward into PTS and upwards into the MSS/LSS. The sandstone is usually reddish in colour but locally contains greenish-grey, chemically reduced tubules that form the Ophiomorpha type burrows.

Trace fossils:

Thalassinoides, Spirophyton, Arenicolites, Diplocraterion, Ophiomorpha, Skolithos, Chondrites.

Interpretation:- As indicated by the trace fossils the unbedded medium-grained sandstone contains many features indicative of an ancient foreshore deposit. The small vertical burrows in the upper part of the facies resemble those produced by amphipods as the upper part of the present-day beaches in California and Oregon (Clifton, 1976). The unbedded medium-grained sandstones of Wagad thus be interpreted as representing upper beach area where the bioturbation, plant growth and soil formation destroyed the internal structures.

LITHOFACIES RELATIONS

The overall coarsening-upward trend throughout the Wagad Group of rocks as observed in eastern Kutch reflect transition from low-energy marine self sedimentation to high-energy nearshore or terrestrial deposition. Superimposed on the overall coarsening-upward trend are six individual coarsening-upward cycles (Fig. 14) with the top of each cycle becoming progressively coarser up in the sequence. Each coarsening-upward cycle presumably represents progradation into the local depositional environments of the locus of maximum sediment supply, followed by abrupt shift of this locus elsewhere. Each small-scale coarsening-upward cycle is, therefore, believed to represent distributory channel establiment.(Fig. 16). The trace fossil evidences as presented in the later parts of this study provide conclusive confirmation to this inference.

Occurrences of ichnogenera in the WASHATWA Formation

ICHNOGENERA	KHAROL MEMBER								NARA SHALE MEM.						CHITORD SANDSTONE MEM.					
	W	a	C	a	Kh	a	D	a	W	a	Me	a	C	a	C	a	W	a	Me	a
Rhizocorallium	+	1	+	1																
Pelecypodichnus	+	3	+	3	+	1	+	1												
Paleophycos	+	3	+	2	+	3	+	1	+	5	+	2	+	3	+	2	+	2	+	2
Zoophycos	+	1	+	1																
Chondrite	+	3	+	3	+	2	+	2	+	2	+	2	+	2	+	3	+	2	+	2
Thalassinoides	+	3	+	3	+	1	+	2	+	2	+	1	+	1	+	5	+	5	+	3
Spirophyton															+	4	+	2	+	2
Cylindrichnus															+	4	+	4	+	3
Rosselia															+	10	+	5	+	2
Lanicodichnus															+	10	+	2	+	2
Arenicolites															+	10	+	5	+	2
Diplocraterion															+	10	+	2	+	2
Skolithos															+	5	+	5	+	3
Planolites															+	3	+	5	+	4
Ophiomorpha															+	10	+	5	+	4

STRATIGRAPHIC SECTION AT W - Washatwa, C - Chitrod, Kh - Kharol;
D – Dabunda; Me - Mewasa;
a - Abundance - 1 = Low, 10 = High

Table. 7.

Occurrences of ichnogenera in the KANTHKOT Formation

ICHNOGENERA	PATASAR SHALE MEM.						FORT SANDSTONE MEM.						ADHOI MEM.					
	W	a	Na	a	Kh	a	C	a	W	a	Kn	a	Mn	a	Me	a	Ad	a
Arenicoites	+	4	+	3			+	2	+	2								
Chondrites	+	3	+	2	+	1	+	2	+	4	+	2	+	4	+	2	+	2
Gyrochorte	+	6	+	4							+		+	8	+	6	+	3
Palaeophycos	+	4	+	4	+	2	+	2	+	4	+	2	+	3	+	3	+	1
Muensteria	+	4	+	3	+	1	+		+	3			+	8	+	6	+	2
Diplocraterion					+		+	2	+	2	+	1						
Ophiomorpha					+		+	10		5								
Skolithos					+		+	2	+	4	+	1	+	1				
Thalassinoides							+	6	+	4	+	2	+	4	+	3	+	3
Rhizocorallium							+	1	+	2	+	4	+	2	+	2	+	1
Teichichnus									+	3	+	6	+	2	+	1	+	1
Mantle burrows									+	8	+	2	+	5	+	3	+	2
Scolicia									+	8	+	2	+	5	+	3	+	2
Spongeliomorpha													+	5	+	2	+	1
Cylindrichnus													+	5	+	3	+	2
Crosspodia													+	6	+	6	+	2
Walcottia													+	6	+	6	+	2
Pelecypodichnus									+	2	+	2	+	3	+	2	+	2
Zoophycos													+	1				
Scalarituba													+	2	+	2		
Taenidium													+	6	+	3	+	2
Paleodicton													+	1				
Helminthopsis													+	4	+	3		
Gyrophyllites													+	2	+	1		
Bolonia													+	5	+	3		

STRATIGRAPHIC SECTION AT W- Washatwa ; Na-Nara , Kn-Kanthkot C -Chitrod , Mn-Manfara ; Ad- Adhoi ; Me- Mae

a – abundance 1 = Low , 10 = High .

Table. 8.

Occurrences of ichnogenera in the GAMDAU Formation

ICHNOGENRA	MANFARA	a	MAE	a	HALRAE	a	ADHOI	a
Scoyenia	+	2	+	5	+	2	+	2
Chondrites	+	3	+	5	+	3	+	3
Crustacean burrow	+	4	+	4	+	7	+	7
Vertebrate track			+	1				
Skolithos	+	3	+	3	+	2	+	2
Planolites	+	3	+	3	+	2	+	2
Thalassinoides	+	3	+	3	+	3	+	3
Ophiomorpha	+	1	+	2	+	2	+	3

Table. 9.

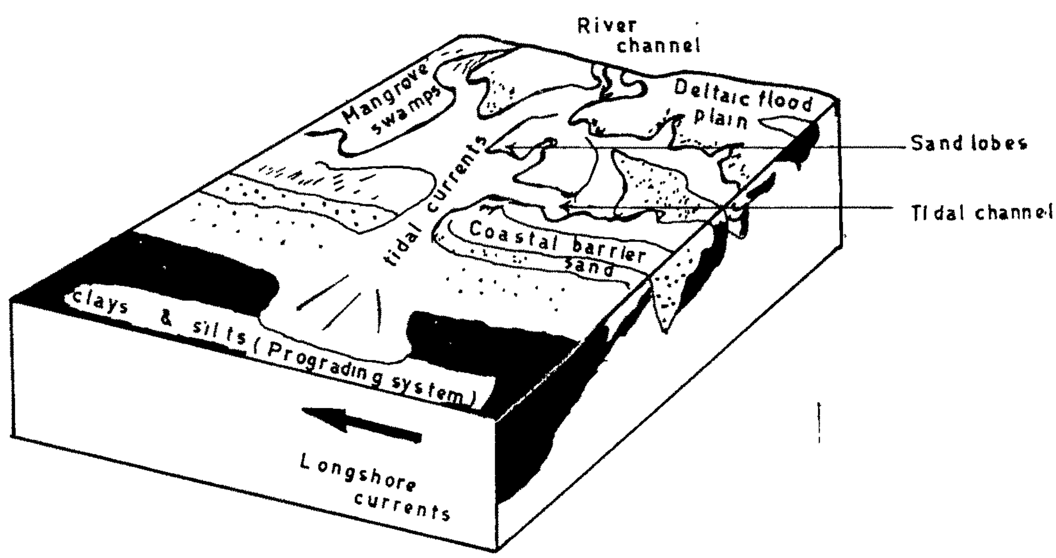


FIG. 16 - Schematic diagram showing range of environments represented in the eastern Kutch