Journal of Himalayan Earth Sciences 39 (2006) 15-38

Steep depositional slope and absence of back barrier: The controlling factors of complex lithofacies association in a foreshore beach environment (Southern Balochistan)

Khawar Sohail Sheikh[1], Abdul Salam Khan[2] and Muhammad Ahmad Farooqui[2]
[1]Geological Survey of Pakistan, Quetta
[2]Centre of Excellence in Mineralogy, University of Balochistan, Quetta

Abstract

The Miocene to Pliocene Hinglaj Formation dominantly composed of sandstone and shale is widely exposed in the southern Balochistan stretching from Nal to Bela area and extends upto southwest Ormara, Mekran. The present study aims at to document the depositional environment of the Hinglaj Formation near Nal.

Twelve facies in the 1443 m thick Hinglaj Formation of Nal section have been recognised. The detailed facies analyses indicate a foreshore beach environment. The facies of shale, shale with interbedded sandstone, arenaceous limestone and hummocky cross-stratified sandstone were deposited on the lower shoreface. Bioturbated sandstone and shale clasted sandstone were deposited on lower shoreface to transition zone, whereas the deposition of low angle cross-bedded sandstone, trough cross-bedded sandstone and turriform gastropod shell lag facies are interpreted to have been deposited in upper to middle shoreface environment. The herringbone cross-stratified sandstone with oyester shell fragments represents deposition in swash zone. The facies distribution of these silisiclastic rocks reflects the complex interaction of fluvial and marine processes.

Seven zones of transgressive and regressive complexes have been identified. The transgressive complexes involve the shoreface retreat of the topographically higher parts of the beach during storms and continuous reworking of the sediment input by wave action during fair weather conditions. The shoreface retreat storm events produced shell lag beds of turriform gastropod and oyester which characterize the initial transgression and secondary transgression respectively. On the other hand the regressive complexes originated during the period of prolonged calm and quiescent intervals accompanied with lower reworking, reduced wave energy and sporadic subaerial exposures.

1. Introduction

The Hinglaj Formation comprises a significant Cenozoic (Miocene to Pliocene) strata in the southern Balochistan and widely exposed in southern Balochistan and parts of the Axial Belt (Shah 1977). Vrendenburg (1906) renamed the Mekran Series of Blandford (1872) as Mekran System and devided it into three series. The upper series was the Hinglaj Sandstone. The lower series were Nari and Gaj that were hypothetically correlated with rock units of Sind.

H.S.C (1960) termed the formation as Hinglaj Group and adopted the original usage of Vrendenburg (1906) except the Haro Conglomerate at the top and the Parkini Mudstone at the bottom. H.S.C. (1960) has reported a maximum thickness of about 13,000 feet for Hinglaj Group.

The Hinglaj Formation (Vrendenburg, 1909, Cheema et al, 1977) forms the lower part as well as the bulk of the Neogene Succession of Balochistan. The Hinglaj Mountains in the Southern Mekran are considered as the type locality. The formation rests transitionally on the Oligocene Khojak Formation in the south Bela while in the south eastern part of the region, the Hinglaj Formation overlies unconformably the Nisai Formation, the Parh Limestone and the older rocks with a conglomeratic base.

Shah (1977) has described the Hinglaj Formation as restricted to the Arenaceous Zone of the Axial Belt and Mekran-North Zhob Regions of the Balochistan Basin. The Chatti Mudstone and the Parkini Mudstone have been designated as its upper and lower members respectively. Shah (1977) has reported the thickness of Hinglaj Formation as 4545 m thick in Talar area, 3030 m in Jiwani and about 4000 m in the Hinglaj Mountains.

The studied section lies along the Ornach-Nal fault which borders the Hinglaj Formation in the east (Fig. 1). The stratigraphic units around the study area have been briefly described in Table1.The Hinglaj Formation exposed in the vicinity of Nal area is less effected by structural deformation having magnificent exposure, making it possible to study the vertical facies variations. The Hinglaj Formation is heterolithic in composition and comprises dominantly sandstone and shale. The measured section is 1443m thick having the cumulative thickness of sandstone, shale and shale with intercalated sandstone fractions as 886, 233 and 324m respectively. The sandstone horizons mostly exhibit more than one types of sedimentary structures associated together. The facies classification has been made on the dominant sedimentary structure possessed by such horizons.

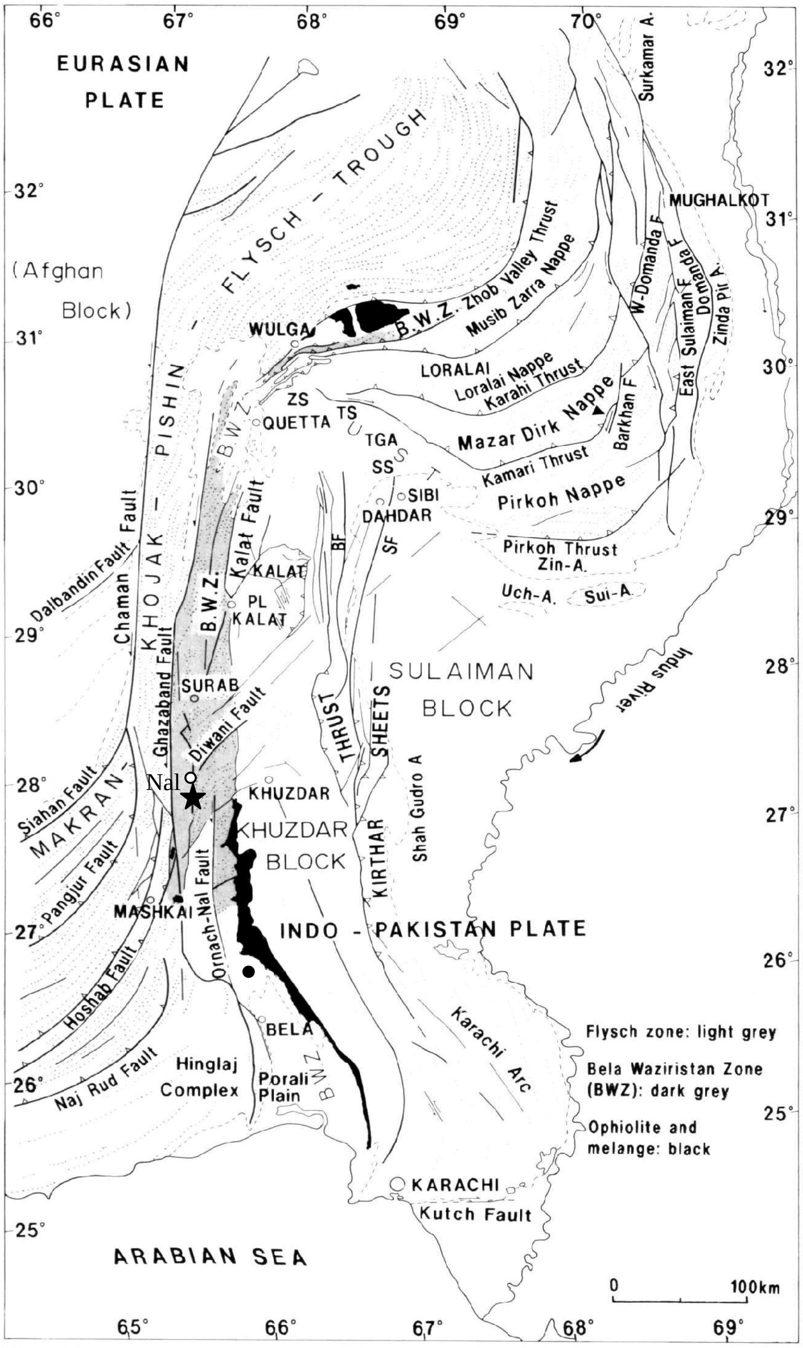


Fig. 1. Dominent structures in the Balochistan Basin, Kirther Foldbelt and Sulaiman Foldbelt of Pakistan (After Bannert et al.1992). Star delineats the location of the studied section. A: Anticline; BF: Bolan Fault; BWZ: Bela-Waziristan Ophiolite Zone; SF: Sanni Fault; SS: Sangan Syncline; TGA: Tor Ghar Anticline; TS: Timur Syncline; UST: Urak Sibi Trough; ZS: Zarghoon Syncline.

Table 1. Generalized stratigraphic succession of the area.

Age	Formation	Lithology	Reference
Pleistocene	Haro Conglomerate	Mostly clasts of Hinglaj Formation with minor sandstone and siltstone	HSC (1960)
Miocene to Pliocene	Hinglaj Formation	Khaki brown, rusty, whitish to greyish green sandstone, mostly unconsolidated, coquinoid to argillaceous with subordinate greyish green shale.	HSC (1960)
Late Oligocene to Early Miocene	Nal Limestone	Mostly yellowish white to pinkish limestone with subordinate sandstone like that of Hinglaj Formation and khaki brown sandy to silty shale.	HSC (1960)
		Erosional Unconformity	HSC (1960)
Late Paleocene	Wad Limestone	Brecciated to bedded limestone, sugary yellowish brown sandstone and white chalky marl.	HSC (1960)
Late Cretaceous to Paleocene	Thar Formation	Dark green sandstone, mostly maroon calcareous shale, nodular marl, pebbly and brecciated volcanic rock fragments and basaltic lava flow.	HSC (1960)
Cretaceous	Pab Sandstone	White cream or brown thick bedded to massive quartzose sandstone with subordinate shale and limestone.	HSC (1960)
	Bela Ophiolites	Pillow basalts and breccia, massive flow, diabassic and gabbroic sills and melange with clasts of variable composition.	Sarwar (1992) Gnos et al. (1998)
	Parh Limestone	White or cream coloured, bedded, porcellanous limestone.	Shah (1977)
	Goru Formation	Thin bedded limestone with subordinate shale (usually maroon coloured)	Shah (1977)
	Sembar Formation	Black to greenish shale with siltstone, nodular and argillaceous limestone.	Shah (1977)
Upper Triassic to Middle Jurassic	Anjira Formation	Dark grey, fossiliferous, thin to thick bedded limestone with subordinate partings of marl and calcareous shale.	Anwar et al. (1992)
	Malikhore Formation	Greyish thick bedded to massive and shelly limestone with subordinate calcareous shale and marl.	Anwar et al. (1992)
	Kharrari Formation	Grey to brownish Grey, thin bedded, flaggy, micritic and unfossiliferous limestone. Grey to light grey, medium bedded quartzose sandstone and subordinate siltstone and shale.	Anwar et al. (1992)

2. Lithofacies

The following lithofacies have been identified in the Hinglaj Formation of the Nal area. The sedimentologic-stratigraphic column is given as Figure 10.

1. Shale
2. Massive to thin bedded sandstone without inorganic sedimentary structure
3. Arenaceous limestone
4. Shale with intercalated sandstone
5. Low angle crossbedded sandstone
6. Shale clasted sandstone
7. Trough crossbedded sandstone
8. Planar crossbedded sandstone
9. Oyster shell lag beds
10. Turriform gastropod shell lag beds
11. Herringbone cross-stratified sandstone
12. Hummocky cross-stratified sandstone

2.1. Lithofacies 1 (Shale)

2.1.1. Description

This facies has a cumulative thickness of 195m with an average thickness of 9.28m. The minimum and maximum thickness range from 0.4 to 13.60m respectively. The vertical spacing between shale horizons is from 2 to 575m, which considerably increases upward. Generally the thickness and frequency decrease up-section. The horizons having the thickness of 1-1.50m are common. The shale is olive green to greenish grey with some bauxitic and oxidized bands in the lower part. Few horizons with considerable thickness of 10m appear to give blackish hue. At places it shows well developed siltstone and discordant laminations laterally traceable upto one metre. This mm scale laminations shows a distinct colour variation of yellowish, greenish grey and brownish hues.

Bioturbation is uncommon however some horizons in the lower portion are rarely mottled by very thin burrows with diameter of 1cm. No macrofauna was observed. Transitional contacts are rare in this facies and it is mostly overlain or underlain abruptly and sharply by other facies having rare sign of erosion.

2.1.2. Interpretation

This facies suggests deposition out of suspension in quite water or low energy environment with a sporadic current activity or traction currents producing varicoloured fine silt lamination. Their development is influenced by low rate of sedimentation, absence of storms and reduction of wave produced currents (Pickerill and Hurst, 1983).

Burrows in the lower part of the greenish grey shale are interpreted to have been formed during a short oxygenated period. Disturbance in the water stratification and down welling of oxygenated water allowed a short lived benthic community to survive (Byers, 1977). The greenish colour of shales may be due to glauconitic content. Occurrence of glauconite is consistent with poorly oxygenated shelf environment (Pettijohn et. al., 1972; Porrenga, 1967).

The scarcity of an indigenous fauna implies oxygen deficiency that was hostile for organic activity (Pickerill and Hurst, 1983). It is suggested that the blackish fissile shale seems to occur close to a transgressive marine (Hallam and Bradshaw, 1979) with restricted dampened currents and wave generated activities (Schalanger and Jenkyns, 1976).

The rare truncating laminae in siltstone horizons reflect gradually increasing flow power (Haszeldine, 1984). The alternation in grain size was probably provided by pulses of sedimentation (Pickerill and Hurst, 1983).

The stratigraphic position and lithological characters of the shale clearly point out its deposition in quite water below fair weather wave base in a lower shoreface to inner shelf setting. As the features which are characteristic of back barrier lagoonal shales, including buried and less fragmented oysters and other invertebrate marine fauna as wash-over sediments (Plint, 1984), tidal channel incision (Oertel et. al., 1991) and traces of plant roots and peat lenses (Reinson, 1984) are absent.

2.2. Lithofacies 2 (massive to thin bedded sandstone without inorganic sedimentary structure)

2.2.1. Description

This facies comprises a total cumulative thickness of 101m. The average thickness is 6.33m while the minimum and maximum thicknesses are 2 to 13m respectively. The thickness of beds is usually 5-10cm at the base and 30 to 50cm at the top. Bases are very sharp and some tops have scarcely wavy appearance. Inorganic sedimentary structures are totally absent in this facies, even in those horizons which are not intensively bioturbated. This facies is mostly developed in fine to medium grained, clean, well sorted quartzose sandstone which is devoid of any biogenic material. However base of some beds are highly calcareous and show a gradual increase in quartz dominated detrital influx.

Some horizons are frequently bioturbated with the diameter of burrows from 1 to 3cm. Horizontal burrows are more common at the base of the beds and laterally traceable upto 2m. Some burrows display a well developed spreit and mostly rounded in cross sectional view. A lenticular morphology and coarsening upward trend with slight decreasing burrow intensity may also be noted in most of the horizons.

Some horizons in the upper part show reddish to bauxitic yellow top. In places coarse patches are also encapsulated. At two localities these bedded horizons, where it is sandwitched between the facies 4 (shale with interbedded sandstone) display desiccation cracks, horizontal burrows and shale clasts at the top. The contacts with the overlying and underlying facies are variable and abrupt but most frequently this facies is overlain or underlain by facies 4 (shale with interbedded sandstone).

2.2.2. Interpretation

This facies is interpreted to have been deposited below fair weather wave base and probably below storm wave base (Riemersma and Chan, 1991). The wide spread burrowing, absence of any physical sedimentary structure and the stratigraphic position supports this statement.

Reineck and Singh (1980) have described the deposition of bioturbated structureless sandstone with no inorganic primary structure in transition zone, occur between lower shoreface to inner shelf. Wingall et al. (1996) have described the bioturbated sandstone to have been deposited in upper off shore environment. Inadequate sand supply and lower energy conditions may have prohibited the formation of wave bed forms. The slight coarsening upward trend in most cases is reflective of shallowing water conditions and indicate that the biological conditions were also optimal for complete homogenization of the bed (Riemersma and Chan, 1991).

Planar or flat beds are known to form in a wide range of sediment size under a wide range of current velocities. They may be produced by plane bed traction under unidirectional or multidirectional flow, by settling without traction, or by bed migration with low verticle accumulation rates. Deposition by such flow under lower flow regime, flat beds may be formed (Harms et al., 1975). The slight wavy appearance in some horizons reflect the climbing ripples at very low angles (sub critically climbing translatent strata of Hunter, 1977) is possible.

Another interpretation may be derived from Adams et al, (1988) of his idea regarding the generation of plane or vaguely bedded strata. Which states that low density water decouples the deeper water bottom due to surface winds stresses, thus inhibiting the downward influx of momentum, and preventing the formation of storm strata. Here the reworking ratio falls to zero and the stratification is largely owing to the snacking back and forth of the turbid surface plume as it pushed around by wind stress. Since the storm diastems are largely lacking, the deposits appear massive or bedded.

Moreover Brenchley et al. (1979) has suggested the plane regular layers of siltstone as typical of shallow water inshore shelf environment, occurring in water depths commonly 1-15m. That is above normal fairweather wave base. Such beds are commonly interpreted as resulting from rapid deposition from storm generated ebb currents.

The stratigraphic position of this facies suggest that its origin is fluctuating from upper shoreface to lower shoreface. The desiccation cracks, oxidized colour and burrowing activity suggests that it was repeatedly exposed subaerially accompanied with sufficient oxygenated conditions (Plint, 1984). The thickening upward trend can be prescribed due to low reworking ratio and high sedimentation rate (Niedoroda et al., 1989).

2.3. Lithofacies 3 (arenaceous limestone)

2.3.1. Description

Arenaceous limestone constitutes a small part of the formation in the lower portion. It occurs as two consecutive horizons having the thickness of 4 and 3.5m respectively. The lower horizon (4m) displays a highly nodular morphology of creamy white arenaceous limestone having bed thickness from 40 to 70cm. Frequency and thickness of the nodular beds increases upward. Some of the beds are highly mottled by straight burrows having the diameter of 3-4cm, traceable downward upto 1m.

In the upper horizon the light brown calcareous sandstone occurs in association with greenish grey shale and shows lensoid morphology. The bioturbation in this horizon is horizontal. The frequency and thickness of the arenaceous limestone decreases upward whereas proportion of the shale increases upward. Most of the beds have sharp flat base and diffuse to irregular tops. Parallel lamination and micro-hummocky cross-lamination, disrupted by burrows can be traced in some beds. Rarely, fossil allochems (mainly nummulitic foraminifers) mixed with sandy matrix are present at the base of some beds.

2.3.2. Interpretation

This facies records a short period of low rain fall and reduced clastic input (Plint, 1984). Driese et al., (1991) has classified this facies to be deposited in near shelf setting characterised by low energy terrigenous input. The alternating shale and nodular arenaceous limestone pattern reflect a post storm quiescent period for shale and alternating high energy storm conditions for arenaceous limestone (Driese et al., 1991), as some un-mottled beds show micro-hummocky cross lamination. The nodularity of the beds may be due to the complex interplay between storm induced currents or due to the effects of along shore storm tracks and coriolis effect (Aigner, 1985).

2.4. Lithofacies 4 (shale with sandstone intercalations)

2.4.1. Description

This facies has a cumulative thickness of 375m with minimum and maximum thickness of 2m and 80m respectively. The average thickness is 17m. The frequency and thickness of intercalated sandstone / siltstone beds is increasing upward (Fig. 2). It persists laterally upto 20m and mostly exhibits lens shaped geometry. The sandstone beds display sharp and flat base and top. However, some of the beds in the upper part show a wavy or ripple like appearance at the top. The thickness of sandstone beds range from 5-30cm and rarely exceeds 1m. The colour of the sandstone is mostly greenish grey, however in the lower part of the section some reddish beds have been observed. In places sandstone occurs as packages, showing coarsening and thickening upward trend, channalized morphology, patchy concentration of shale clasts. In some places sandstone beds are characterized by parallel to lowangle cross-laminations and trough crossbedding with bio-clastic lag at the base.

In the upper part of the section few horizons contain polygonal, tapering downward desiccation cracks (Fig. 3) developed in fine sandstone/siltstone with intercalated shale of bauxitic appearance. The sandstone beds immediately beneath the desiccation cracks show no fractures or other deformational sign. The greenish grey mud is the fracture filling material. The intercalated shale is mostly greenish grey and fissile. The contacts of this facies with overlying and underlying facies are quite variable.

2.4.2. Interpretation

This facies represents deposition in a middle to outer shelf setting, that was effected by episodic storms. The sharp flat bases are indicative of high flow velocities (Hunter and Clifton, 1982). The coarser sediments (interbedded sandstone) into a quiet muddy environment implies that a strong offshore current deposited these beds (Hamblin and Walker, 1979). The graded beds with bioclastic lag at the bases are diagnostic of storm deposits, especially when wave formed structures occur within same bed (Kreisa, 1981; Brenchley and Newall, 1982; Walker et al., 1983; Aigner, 1985). Abundant horizontal lamination in the fine to very fine sandstone and siltstone beds suggest conditions of plane bed deposition (Mount, 1982), with a maximum shear velocity at the bed of the order of 100cm (Dott and Bourgeoris, 1982).

Fig. 2. A thickening and coarsening upward trend in facies 4. Lower part comprising an alternating pattern of thin shale and sandstone beds. Intercalated shale is lacking upward.

Fig**.** 3. Desiccation cracks at the top most bed of facies 4 (shale with sandstone intercalations). The open part of the measuring tape is 50cm. The cracks are not extended into the underlying bed and filled by greenish grey shale.

The prevalence of wavy bedding in some cases (frequent sandstone beds in the upper part of an individual horizon) strongly points to deposition by combined flow currents (Aigner, 1985). Such combined flow currents are common during storms, as storm waves interact with the sea floor and are superimposed on a unidirectional mean flow (Aigner, 1985; Swift and Niedoroda, 1985).

The concentration of shale intra-clasts in some beds with a channel morphology implies storm scour of the muddy shelf substrate by intense storm flow (Kelling and Mullin, 1975; Walker, 1985). Sporadic occurrence of flute marks result from intense substrate scour produced by storm generated helicoidal fluid flow at the bed (Whittakar, 1973; Cotter, 1983; Aigner, 1985; Walker, 1985).

The prevalence of fissility, lack of identifiable biogenic sedimentary structures and lack of body and trace fossils imply either oxygen deficient, an-aerobic conditions on the shelf bottom (Rhoads and Morse, 1971; Byers, 1974, 1977; Cluff, 1980; Savrda et al., 1984; Savrda and Bottjer, 1986) or a substrate unfavourable for colonization by most benthic organisms (Walker and Diehl, 1986; Easthouse and Driese, 1988). The oxidized red beds in places and the desiccation cracks in the upper part suggest that the sea level drop was rapid enough, accompanied by low detrital sediment influx that subaerially exposed the shelf during the subsequent regression (Riemersma and Chan, 1991).

2.5. Lithofacies 5 (low angle crossbedded sandstone) (LACSS)

2.5.1. Description

Low angle cross-stratified sandstone is a dominant lithofacies of the formation. It comprises a total thickness of 329m with an average thickness of 9m. The minimum and maximum thickness is 2 and 40m respectively. Low angle cross stratified sandstone is widespread and developed in both clean and well sorted quartzose sandstone and less frequently in coarse to very coarse grained, shell rich hard sandstone (facies 9 and 10). Most of this facies show a lenticular morphology with an increase in upsection thickness and frequency. This facies also occurs as several stacked sets, each set is characterised by a thickening and coarsening upward trend. Some low angle cross-stratified horizons are interrupted by shales. Less commonly it is also associated with trough crossbedding, hummocky crossbedding and planar cross-stratification.

The crossbed sets having the thickness of 1m are very common and maximum thickness of crossbed set ranges from 3 to 5m. Lowangle crosslaminae dip bidirectionally from 2-5°. In places the lamination comprises distinctive truncating couplets with a thickness of 1-2cm or less. Each couplet commences with a basal fine grained heavy mineral layer, overlain by a relatively coarse grained or light mineral layer of quartz.

Occasionally low angle cross-stratification in the middle and upper part of the section shows 5 to 10cm thick, upto 2m wide coarse patches that pinch-out laterally. Their morphological characters are same as described in the following section of Trough cross- bedded sandstone (Facies 7). The coarse patches are composed of rounded to sub rounded pebbly sandstone which is compositionally same as that of sandstone from Hinglaj Formation. Few low angle cross-stratified horizons show intercalated lenses of coarsely laminated LACSS.

This facies is very rarely bioturbated as burrows have been observed at only one locality in the lower part of the section showing verticle to sub-verticle traces.

2.5.2. Interpretation

The low angle cross-bedding reflect the migration of large bed forms with low amplitude (Leithold and Bourgeois, 1984). It forms mostly in the breaker zone of the middle shoreface (Walker, 1984).

The subtle truncation surfaces present in the LACSS reflect periods of erosion which often divide the lamination in discrete sets. The laminations are attributed to grain segregation under conditions of plane bed transport during swash and back wash flow. The lamination with a relatively high angle reflect the migration of the bedform of a larger size (Davies and Fox, 1972; Hine, 1979). The interpretation of associated coarse lenses has been described in the following section of Facies 7.

2.6. Lithofacies 6 (shale clasted sandtone)

2.6.1. Description

4 to 9m thick shale clasted beds are uncommonly and randomly distributed at various levels. Some beds have a very intense concentration of shale clasts (Fig. 4) as no other sedimentary structure is observable except a very clear erosive channel morphology having a basal scour upto 30cm. Shale clasts are mostly green to rarely yellowish and range in size from 2 to 4cm.

2.6.2. Interpretation

The intensive concentration of shale clasts strongly suggests that the net sedimentation rate accompanied with the bedform migration was too much declined at the time of deposition. The concept of erosional regression presented by Curray (1964) as a result of sea level fall, seems to be more suitable for the interpretation of this facies. The channalized morphology and erosive base supports this concept. In most cases the shale clasts are in the form of thin flakes reflect insufficient reworking and early flocculation of fine grained sediments (Curray, 1964).

Dune migration commonly involves the partial erosion of underlying mudstone and indicates intervals of no sedimentation. The intense concentration of shale clast reveals that a considerable thickness of underlying substrate was removed from the depositional setting at that time. The erosional events may correspond to major storm events on the shoreface when sediment was transported offshore or onshore. This facies is interpreted to have formed in the lower shoreface to transitional zone of a fair weather wave dominated shoreline that was punctuated by intervals of storm erosion and offshore sediment transport (Wingal et al., 1996).

2.7. Lithofacies 7 (trough crossbedded sandstone) (TCBSS)

2.7.1. Description

Trough crossbedded sandstone facies comprises a bulk of the formation. It has a total thickness of 147.30m. The average thickness of this facies is 8.23m with a minimum and maximum of 1.30m and 18m respectively. Generally the TCBSS shows a very clear lenticular morphology with increasing upward thickness and frequency. The vertical spacing between TCBSS horizons ranges from 2-40m. The TCBSS horizons are scarcely bioturbated by vertical to sub-vertical burrows of diameter upto 4 cm with a well developed spreit.

The trough crossbedding is mostly developed within fine to medium grained, moderately compacted quartzose sandstone which mostly display whitish grey colour (Fig. 5). Rarely, it is also developed in the ridge forming hard and compact sandstone horizons that are rich in winnowed shell fragments of oyster and gastropod (Fig. 8). Generally the laminae of TCBSS have a gentle dip of 15°.

Other sedimentary structures like herring bone cross-stratification, planar crossbedding, low angle crossbedding and shale clasted sandstone are also associated in the lower part of the TCBSS horizons. Rarely oscillatory and linguidal ripples and desiccation cracks cap the TCBSS. Some linguidal rippled surface also show super imposed movement of burrows. At one locality in the upper part very large ripples having more than one meter amplitude with super imposed small ripples have been observed (Fig. 6).

TCBSS also occurs as several stacked sets and each trough crossbedded set is characterised by a coarsening and thickening upward trend with trough thickness from 10 cm at the base to 250 cm at the top (Fig. 5).

In places TCBSS sets show a different paleoflow direction. Some of the TCBSS sequences are characterised by 50cm thick, irregularly distributed, closely spaced coarse patches laterally traceable upto150cm (Fig. 7). Most of them have a scoured base and sub-angular to rounded pebbles of sandstone are concentrated at the base within a fine sandy matrix. The TCBSS occupies a random position and sharply overlain or underlain by other facies.

2.7.2. Interpretation

Trough crossbedding has been prescribed by Crimes (1975), Frey (1975) and Rhoads (1975) as shallow, current agitated shoreface to foreshore environment of a marine system. Thom and Roy (1985) has supposed the origin of clean sand in the embayed parts of the beach in a period of stillstand. Also these white to tan coloured quartz arenite successions are interpreted to have been formed by migration of shoreface sandwave and mega-ripple deposits (Cotter, 1983). Offshore directed storm currents modify and shape the shelf sand sheet into a complex system of sand waves and mega ripples (Driese et al., 1991).

The TCBSS was deposited by unidirectional migration of mega ripples in a zone above the wave base. This migration may have occurred as a result of normal every day processes on the upper shoreface of a high energy near-shore environment. The sandstone may have been deposited in slightly greater depths (below fair weather wave base) during storms when wave base was lowered. The development of trough crossbedding in coarse shell lag beds suggest the lowering of the wave base (Thom and Roy, 1985).

Absence of clay drapes (interrupting feature) and less frequent bioturbation suggests that the migration of mega-ripples was not episodic but continuous. The multi-directional paleocurrent structures and differing axes of the troughs may reflect the occurrence of the several distinct currents (Wingal et al., 1996) and that may be longshore troughs (Driese et al., 1991). Hunter et al. (1979) has suggested the multidirectional flow indicators of trough crossbedding as reminiscent of the inner shoreface of barred shorelines. The thickness of the trough crossbeds reflect the thickness of the original dunes (Wingall et al., 1996).

The TCBSS sequences with rippled surface reflect fair weather conditions with reduced current velocities (Hiscott, 1982). In rare cases the burrows movement and desiccation cracks on a rippled surface reflect reduced clastic input, oxygenated conditions and short durational subaerial exposure (Riemersma and Chan, 1991). The mega-ripples with long wavelength and super-imposed small ripples (Fig. 6) reflect variable approach of waves with strongly different velocities in a very shallow water (Hiscott, 1982). Burrows having the diameter of 3-4cm suggest that only competent burrows were able to keep pace with the physical conditions (Haward, 1978).

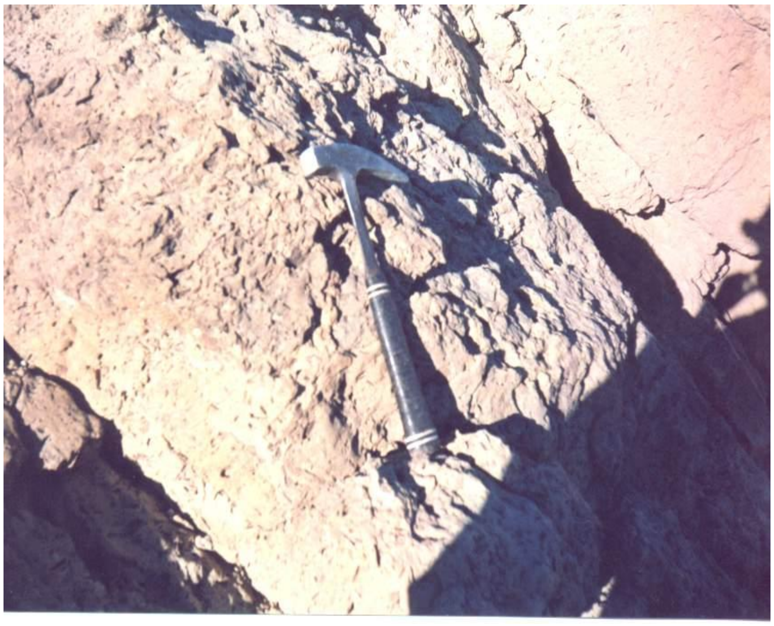


Fig. 4. An intensively shale-clasted sandstone bed. Shale clasts have been removed leaving empty spaces.

Fig. 5. Coarsening and thickening upward trend in two stacks of trough crossbedded sequences developed in quartzose sandstone.

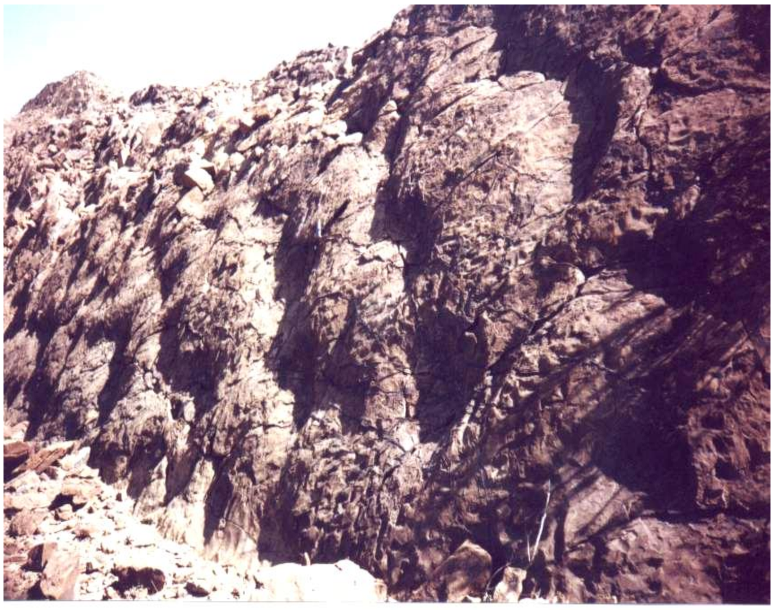


Fig. 6. Large (mega) ripples with superimposed small ripples. This view is 15 m across.

Fig. 7. Closeup view of coarse patches in TCBSS. Lateral extent is limited outlined by black line.

TCBSS in which coarse patches are encapsulated reflect the physical conditions during the fluctuating sea level. Their origin may have been caused by minor sediment input coupled with deep shoreface scour during transgression (Oertal et al., 1991) in a tide dominated environment (Hayden and Dolan, 1979; Oertal, 1987). These buried channels are also a good record of slight transgression.

Tide dominated coasts are characterized by closely spaced inlets. During transgression the retreating shoreface excavates material located in its path and these channels can be preserved in the rock record only if the initial channel extends deeper than the depth of the shoreface incision (Oertal et al., 1991). The channels of this type in the Hinglaj Formation have a low density. Nummedal et al. (1977) have suggested that wave dominated coasts have low density of tidal channels. The lithology of the pebbles (intraformational conglomerate) reflect their scouring from previously deposited substrate.

The progressive erosion of the channels is directed laterally toward down drift wall (Shepard, 1960) that is why the dimension of these channels in the Hinglaj Formation is upto 1m, higher than the downward scour. Oertal et al. (1991) has also suggested their origin as cut and fill of down delta shoals. These inlets were formed in shoreface environment because they are limited to the sandstones and absent in the other lithologies.

2.8. Lithofacies 8 (planar crossbedded sandstone)

2.8.1. Description

Planar cross-bedded sandstone (Fig. 9) comprises a total cumulative thickness of 105m with 12 horizons. The minimum and maximum thicknesses are 1.5 and 23m respectively with an average thickness of 8.73m. This facies is mostly developed in the clean, fine to medium, well sorted quartzose sandstone and rarely occurs in ridge forming hard sandstone.

It is sporadic and occurs randomly in association with trough crossbedding. Discrete planar cross-stratified horizons are uncommon. A slightly decreasing up-section frequency of this facies may be observed. Most of the horizons have basal large scale cross-sets overlain progressively by smaller scale cross-sets. The individual bed thickness decreases upward and ranges from 1m at the base to 10cm at the top, accompanied by a slightly coarsening upward trend. Few horizons may be termed as compound cross-sets as subsidiary smaller scale cross-stratification is developed within thick large scale foresets with uncoincident dip direction of inclined laminae.

The truncation of laminae and abundant reactivation surfaces or pause planes are very clear in some horizons. Foresets are generally inclined from 20 to 45^0 and a clearly visible difference in the dip angle of the laminae may be seen up-section (Fig. 9). Very few sets have convex type inclined laminae. Few horizons are vertically and horizontally bioturbated.

2.8.2. Interpretation

Planar crossbedding indicate deposition in a shallow current agitated shoreface to foreshore marine environment. (Crimes, 1975; Frey, 1975; Rhoads, 1975; Chamberlain, 1978; Seilacher, 1978; Ekdale et al., 1984). Strong storm currents modified and shaped the shelf sandsheet into complex system of sandwaves and megaripples. The migration of two dimensional megaripples and sandwaves under the influence of storm flow are responsible for its generation (Driese et al., 1991). The presence of reactivation surfaces does not preclude a possible tidal influence (Klein, 1977), as the thick beds show a unimodal transport while few interspersed thin beds show a reverse flow.

The sparse bioturbation and absence of other lithic clasts suggest that the bedform migration was continuous.The few bioturbated horizons suggest deposition in a shallow current agitated (shoreface to foreshore) environment in a moderate energy possibly coinciding with reduced sediment influx thus bioturbation was able to keep pace physically with the sedimentation (Horward, 1978).

2.9. Lithofacies 9 (oyster shell lag beds)

2.9.1. Description

This facies comprises a total thickness of 21.15m with 14 horizons. The minimum and maximum thicknesses are 0.2 to 6m respectively. Their average thickness is 1.62m. They are mostly characterised by brown to yellowish brown, coarse to very coarse sandstone. The oyster shells are intensively comminuted into cm scale fragments and can be differentiated owing to their undulatory and flaky type shell pieces. Disarticulated shell of 15cm length have also been observed.

Oyster shell fragments megascopically comprise upto 40 to 50% fraction of a bed, mostly concentrated at the base and occasionally in the basal scour where they seems to be purely concentrated and appear like coquina. The oyster shells are mainly concentrated within the laminae of herringbone cross-stratification possessing sharp boundaries. Rarely, it shows concentration in the laminae of trough cross-bedding (Fig. 7). The thickness of the laminae ranges from 1 to 1.5cm. The bioturbation in this facies is very infrequent and occurs at two levels only.

Some low-angle cross-stratified horizons which have coarser patches of pebbly sandstone or intraformational conglomerate also contain oyster shell fragments. The detailed examination of the oyster shell lag beds reveal their zone wise distribution (zones 3 and 5, discussed later). These zones (3 and 5) show a decreasing upward content of oyster shells and increasing upward amount of turriform gastropod shells. The palecypod shells, pebbles and mud clasts are rarely incorporated at some lower levels.

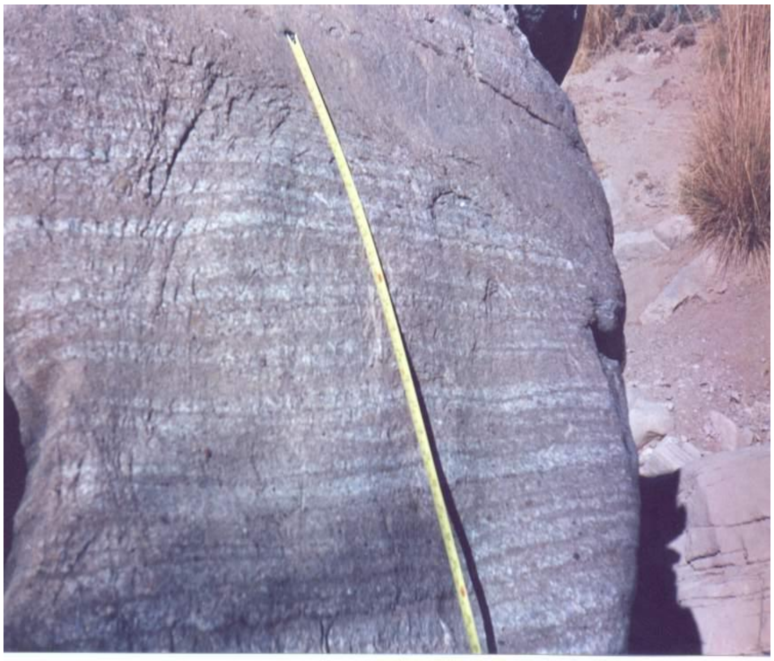


Fig. 8. Highly comminuted fragments of oyster shells (white lines), concentrated within the laminae of trough crossbedding.

Fig. 9. A thinning upward trend in the planar cross- stratification. The differential dip of laminae is also clear.

2.9.2. Interpretation

Oyster is a brackish water molluscan fauna and is a resident of back barrier lagoonal environment (Reinson, 1984). The interstratification of oyster lag beds in back barrier lagoonal sediments is more probable (Selley, 1969). The back barrier sediments are not identified in the studied section. The frequent incorporation of oyster shell fragments in the herringbone cross-stratification suggest that small associated bays were present as sub-environments, which were the ultimate source of oyster harbouring. Some oyster shell lag beds which are sandwiched between shale horizons in the lower part of the section, indicate sub-aqueous lagoonal origin (Walker, 1984). The communited shell material reached in the swash zone with the sea level rise and incorporated within the laminae of herringbone cross- stratification.

2.10. Lithofacies 10 (turriform gastropod shell lag beds)

2.10.1 Description

This facies is frequently distributed at several levels in the designated zones of 2 and 4 (discussed later). The total cumulative thickness of this facies is 11m with an average of 50cm. The minimum and maximum thicknesses range from 10 to 250cm respectively, having 22 horizons. Coarse to very coarse beds mostly low-angle cross-stratified having brown to yellowish brown colour are the characteristics of this facies. In most of the cases the lenticular morphology is clear. Bioturbation in this facies is absent. In the lower horizons 3-4cm long turreted gastropod shells are very well preserved. The shell preservation rapidly decrease upward as in the upper parts they are highly fragmented and concentrated in the laminae of low angle cross-stratification and rarely in the laminae of the medium scale trough crossbedding.

Apparently the maximum shell content varies from 30 to 60%. Intense concentration and very tight packing of the shell debris are present at the bases of such beds reflecting the appearance like the coquina. Besides shell fragments the pebbles/intra-formational conglomerates and shale clasts have also been incorporated in places. In most of the cases such beds cap the trough crossbedding developed in well sorted quartzose sandstone.

2.10.2. Interpretation

According to the Thom and Roy (1985) the sandstones containing a turreted gastropod variety which they termed as "regressive sandstones", (turriform gastropod) may be characterized as a resident of shore bank. This fossil specie indicates aproximity to shore line, which was well adopted to life on a sandy substrate in a turbulent water (Addicot, 1980). The shell lag represents a post-mortem reworking (Plint, 1984) of gastropod shell debris. Their preservation in the lower part suggests that they were not subjected to prolonged abrasion (Addicot, 1980). The extensive concentration and fragmentation in their upper distributions suggest a rapid biogenic environment and the shells remained unburied due to very slow sedimentation from landward side. Fragmentation is more effective in day to day wave processes rather than a short lived high energy conditions associated with storms (Kreisa, 1981).

Their concentration in laminae of the low angle cross stratification and rarely in trough cross- bedding is due to their further reworking after derivation from an immediate source due to storm surge ebb currents (Kelling and Mullin, 1975).

2.11. Lithofacies 11 (herringbone cross-stratified sandstone)

2.11.1. Description

The herringbone cross-stratified sandstone is a minor facies and developed in the middle part of the section. It constitutes a total cumulative thickness of 23.55m appearing at 6 horizons. The minimum and maximum thicknesses are 50 and 500cm respectively. The vertical spacing between two herringbone horizons varies up-section from 150, 82, 13, 55,195 and 56m. These horizons show a discrete development of herringbone cross stratification while in some horizons it is associated with planar cross bedding and parallel lamination.

The thickness of individual set varies from 10 to 40cm and there is an upward increase in the thickness of the bedding. All of them show a lenticular and lensoid geometry and laterally persistent upto 20m. Bioturbation is absent in all such horizons. It is mostly developed in coarse and hard sandstone. The herringbone cross-stratification in the lower part of the section is devoid of fossil fragments whereas upsection they show increasing richness in fossil fragments of oyster. This facies has also irregular and random occurrence.

2.11.2. Interpretation

The herringbone cross-stratification is a unique feature of peritidal environment (Boggs, 1987). A wide tidal range and the absence of strong wave action is necessary to form tidal flats. Alternations of black mud with fine silt and sand layers are characteristic of long durational tidal flat environments. They are very sensitive to small changes in sea level and do not accumulate for longer periods in one place (Boggs, 1987). Tidal flat environments can be divided into three parts:

(1) The lower tidal flat (coarse sand)
(2) Mid flat region (sand, silt and mud alternation)
(3) Upper tidal flat (total mud)

The association of this facies at various levels indicate that a complete sequence of peritidal environment was not developed. Occasionally a short durational sub tidal zone/lower tidal flat was developed owing to highest tidal current velocities which records both storm and ebb tidal delta. Absence of bioturbation reflects a continuous and intense working of tides.

2.12. Lithofacies 12 (hummocky cross-stratified sandstone)

2.12.1. Description

The discrete hummocky cross-stratified sandstone horizons comprise a total cumulative thickness of 17.3m with an average thickness of 2.88m. The minimum and maximum thickness of such horizons are 50 and 650cm respectively in which hummocks have few cm thick patchy distribution. It is mostly typified by coarse to very coarse units rich in cm size fragments of turreted gastropods. Occasionally they are also developed in the fossil debris free sandstones with few cm thick truncating laminae. Besides this the hummocky cross-stratification (HCS) is also associated with the horizons that do not show the discrete development of hummocky cross-stratification but other sedimentary structures such as low-angle cross-stratification, trough crossbedding, linguidal ripples, coarse pebbly patches, desiccation cracks and shale clasts are also associated with them.

The hummocky cross-stratification (HCS) is mostly developed in the upper part of the section and occupies an asymmetric and random stratigraphic position having a slightly decreasing upward frequency.

2.12.2. Interpretation

Hummocky cross-stratification (HCS) is produced by a combination of storm-wave generated oscillatory flow and a storm generated unidirectional mean flow (Swift et al., 1983). Swift and Niedoroda (1985) further interpreted HCS to represent storm flow regimes in which the wave orbital component is high relative to the mean flow. HCS represents deposition in a more proximal position relative to wave ripple lamination and graded beds of distal shelf (Aigner and Reineck, 1982; Aigner, 1985).

Truncation surfaces common within hummocky sandstone beds, record superimposed storm events (Dott and Bourgeois, 1982). The hummocky sandstone facies reflects an increase in sand supply and dominance of physical wave processes over biological reworking of the sediments. This facies preserves a record of rapid but episodic (high energy) sedimentation. It is interpreted as a shelf storm feature produced in a zone effected by storm waves and wind induced currents (Harms et al., 1975; Hamblin and Walker 1979; Bourgeoris, 1980). It is also suggested by Dott and Bourgeoris (1982) that hummocky cross-stratified sandstone is deposited during storms by the accumulation below fair-weather wave base of sand scoured from the shore face.

Many ancient deposits of shoreface are dominated by siltstone and fine sandstone which contain HCS in the lower shoreface and swaly cross-stratified beds in the upper shoreface (McCrory and Walker 1986; Plint, 1988; Hart and Plint, 1993). Both these styles of stratification are characteristics of storm generated combined flow deposits (Duke et al., 1991). The coarser shoreface deposits can also record storm events (Wingal et al., 1996) as evidenced by HCS in shell lag beds of the measured section.

Hummocky cross-stratification may be produced by storm surged ebb currents (Brenchley and Newal, 1982). In shelf and near shore environments storms of hurricane proportions entrain sands and silts in the shallow water environments, creating a density current that flows seaward as a turbidity current (Hamblin and Walker, 1979). Deposition as a turbidite is followed by its reworking by storm waves (of the same storm) to create HCS to the depth of storm wave base. The numerous truncation surfaces of HCS (amalgamated HCS) suggest that alternating erosion and redeposition was common sporadically (Hamblin and Walker, 1979).

The amalgamation of successive hummocks provides evidence of frequent storm events and storm deposits above storm wave base (Dott and Bourgeois, 1982). The rare coarse grained horizons of this facies reflect inefficient sorting of suspended sand during transport. The amalgamated sandstone facies appears to be a high energy variant of hummocky cross-stratification, in which swales are preferentially preserved and hummocks are eroded, resulting in numerous truncation surfaces (Dott and Bourgeois, 1982).

Shell lag common at the base of the swales may have been swept offshore during storms and deposited at the erosive base of the beds or winnowed during subsequent storms events. Each lamina of HCS is interpreted to represent deposition from a single wave or set of waves (Dott and Bourgeois, 1982). The desiccation cracks and shale clasts at the top of the HCS horizons show sub-aerial exposure and erosion of substrate respectively, shortly after storms (Driese et al., 1991). This facies represents what Riemersma and Chan (1991) has termed a middle shoreface environment which is just below fair-weather wave-base and is heavily influenced by storm events. The vertical association of the hummocks with other sedimentary structures shows gradually wanning currents (Driese et al., 1991).

3. Discussion

The depositional history of Hinglaj Formation was primarily controlled by the changes in the sea level, tectonic activity and fluctuations in the sediment supply. The facies represent a shoreface to inner shelf depositional environment, influenced by high and low flow regimes. Under these conditions recurring and frequent sediment transport took place during periods of high agitation and increased turbulence accompanied with high sediment input. In contrast the periods of low water agitation is reflected by the deposition of shale/mud. As a whole infrequent bioturbation reflects decreased level of dissolved oxygen in bottom water. The summary of the facies associations and zone wise distribution is given in Table 2.

The examination of distribution, composition, association and thickness of facies of Hinglaj Formation helps to evaluate the following mechanism to reconstruct the depositional history. On the basis of the dominant facies distribution, seven zones of various facies associations have been identified.

3.1. Zone 1and 7 (Representative Regressive Complexes)

These zones extend in the given sedimentary log from 0-312m and 1190-1430m respectively. The overall facies association are reflective of deposition on lower shore-face to inner shelf indicated by thick sequences of shale with interbedded sandstone (facies 4) and shale (facies 1) respectively. A lower clastic input and oxygenated conditions are reflected by arenaceous limestone and shale in the lower part of the section, which is sufficiently burrowed. The characteristics of the lower portion points out that the physical conditions were suitable for organic activity for very short periods.

Occasionally the zone was sculptured by higher flow regime, river mouth by passing, combined flow and erosional regression which is recorded by the low angle cross- stratification, sporadic hummocks and shale clasted beds respectively.

Table 2. Summary of the zone wise distribution of Hinglaj Formation near Nal

ZONES	Dominant Lithology	Sedimentary Structures	Depositional Environment	Range in the sedimentary log (Meters)
1	Shale with interbedded sandstone, less commonly interrupted by sandy horizons	intermittent low angle cross-bedding, planar cross bedding and very rare hummocks	Regressive zone. Lower shore face to inner shelf	0-312
2	Well sorted sandstone capped by coarse, shell lag beds of turriform gastropods	Trough crossbedding and low angle crossbedding	Initial Transgression; Alternating fair weather and storm conditions	312-500
3	Well sorted sandstone capped by coarse, oyster shell lag beds	Herringbone cross-bedding, trough cross-bedding and low-angle crossbedding.	Secondary Transgression; alternating fair weather and storm conditions at the proximal position as compared to the previous zone.	500-680
4	Well sorted sandstone capped by coarse, turriform gastropod shell lag beds	Low angle cross-stratification	Repetition of the conditions as that of zone 2.	680-830
5	Well sorted sandstone capped by coarse, oyster shell lag beds.	Herringbone cross-stratification, Low angle cross stratification and trough cross bedding.	Repetitions of the conditions as that of zone 3.	830-1000
6	Generally fine to coarse sandstone capped by coarse turriform gastropod shell lag beds. Less frequent shale.	Hummocky cross-bedding, planar cross-bedding, trough cross-bedding.	Pre regressive zone. sedimentation dominantly on the lower shore-face shell debris transferred towards lower shoreface	1000-1190
7	Mainly shale with interbedded sandstone, interruptions by sandy horizons	Trough crossbedding and low-angle crossbedding with minor hummocks in sandy horizons	Regressive zone, deposition took place mainly on lower shore face	1190-1430

Infrequent planar cross-stratification, troughs cross-bedding and coarse patches (intra-formational conglomerate) indicate a prolonged break after quite water deposition during which the sea level declined and the sandy influx experienced a strong wave action causing effective reworking and erosion of the substrate. The vertical association of facies records an increase in depositional energies.

Another regression dominated sequence has been categorized as zone 7. This zone is 228m thick and overall represents regressive facies pattern. The shale with interbeds of sandstone is the dominant facies which is upto 80 m thick and interspersed at various levels by wave (troughs) and storm (hummocks) dominated processes. The sub-aerial exposure was repeated several times reflected by the polygonal desiccation cracks and red oxidized horizons at the top most beds.

The subaerial exposure of this zone reflect that the river mouth bypassing mechanism (Swift and Thorn, 1991) was inactivated due to declination of sediment influx from landward side accompanied with a sea level fall (Swift, 1976) and also due to reduction of littoral energy force (Allen, 1970). The frequent occurrences of shale clasted beds also support the process of erosional regression (Curray, 1964).

3.2. Zones 2 and 4 (representative initial transgressive complexes)

These zones extend in the sedimentary log from 312-500m and 680-830m respectively. They have been described as transgressive zones because the facies of shale (Facies 1) and shale with interbedded sandstone (Facies 4), characteristic of lower shoreface to inner shelf are intermittently incorporated in these zones. The overall facies distribution of these zones represents wave to storm dominated conditions. The associations of lithofacies and sedimentary structures reveal that the middle shoreface conditions were the most dominant as reflected by the low angle to trough cross-stratified, well sorted quartzose sandstone capped by shell lag beds. The characteristics and distribution of shell lag beds are in support of transgression.

Transgressive dispersal systems are nourished by the erosional shoreface retreat (Swift and Thorn, 1991). Older sediments are penetrated by the erosional shoreface retreat processes and the deposition of coarse lag takes place. The transgressive systems are characterized by high concentration of skeletal grains (Swift et al., 1991) deposited by storm amplified rip currents. The concentration of biogenic material is most likely to occur by winnowing and reworking of shoreface deposits during initial sea level rise and extensively transfered offshore (Riemersma and Chan, 1991). Shell lag beds reflect high degree of erosion and reworking causing to the degradation of shell debris (Lethold and Bourgeois, 1984). The shell debris of these two zones are mostly composed of a turriform gastropod. This turriform gastropod variety is not the representative of brackish water. Thom and Roy (1985) has termed a beach sandstone containing resembling turriform gastropod as regressive sandstone. Considering that these turriform gastropods were resident of bank or near shore environments, these shell lag beds can be prescribed as initial transgressive lag of primary transgression.

The repetition of shell lag beds indicate that the turriform gastropod was the tolerant genus of the near shore turbulent water and was subjected first to erosional shore-face retreat process and deposited as shell lag beds. The preservation of these shell lag beds suggest their deposition below fair weather wave base where the reworking ratio was dropped after a major storm. The well sorted quartzose sandstone horizons which are capped by these shell lag beds reflect intense winnowing and grain attrition by wave action (Ferm, 1962) and these are the result of every day wave processes in fair weather conditions (Thom and Roy, 1985). Extreme wave heights are not possible in shallow water owing to wave breaking in fair weather conditions (Swift and Thorne, 1991).

3.3. Zones 3 and 5 (representative secondary transgressive complexes)

The extension of these zones in the sedimentologic-Stratigraphic column is from 500-680m and 830-1000m respectively. The zone 3 is 177m thick and records more fluctuating conditions on a wide range of depositional environment. Planar cross bedding and the herring bone cross stratification are the characteristic features. The sandy horizons are less frequently sculptured by deposition below the fair-weather wave-base. Another characteristic feature of this zone is decreasing upsection frequency of gastropod shell lag beds and at the same time increasing upward frequency of oyster shell fragments. The oyster shell fragments are frequently associated with low angle crossbedding and herring bone crossbedding.

The zone 5 (159m thick) of the section is also comparable with the zone 3 in the sense that it display resembling characteristics, accompanied with more frequent incorporation of oyster shell lag beds giving the appearance of coquina. The shell lag beds either cap low angle cross bedded sandstone or trough crossbedded sandstone. The association of sedimentary structures, the well sorted quartzose nature of sandstones reflect that the deposition was dominantly took place in foreshore environment and extended upto swash zone.

The herringbone cross-stratification with concentration of oyster shells in the laminae clearly points out that the area was emergent during low tides with a minimal relief and a slight rise in the sea level. Short durational small bays, favourable to harbour oyster (not identified in the measured sections) occurred in a close proximity to the swash zone. The highly comminuted nature of oyster shells reflect that they were continuously reworked previously due to wave action, as a single storm or swash action can not make them so fragmented (Kreiza, 1981). These transgressive sequences (zone 3 and 5) suggest that they were originated on a more proximal position than the previously described zones having turriform gastropod shells. In this sense they can be prescribed as representing the second order transgression. A slight effect of regression at the upper level of zone 5 is reflected by the gradual reincorporation of the turriform gastropod shells.

3.4. Zone 6 (pre regressive complex)

This zone extends in the sedimentary log from 1000-1190m. The distinctive feature of this zone (Fig. 10) is the development of discrete hummocky cross-stratified beds at various levels. The proportion of shale and shale with sandstone intercalations is very minor, indicative of short durational calm conditions and low sediment influx from landward side. Another distinctive feature of this zone is the association of three different types of sedimentary structures i.e. low angle cross-lamination, planar cross-lamination and hummocky cross-lamination within a single package of sandstone. The association of linguidal ripples capping the hummocks and troughs is also present. The vertical association of sedimentary structures reflect a waning storm flow.

The overall association of facies and sedimentary structures of this zone depicts that there was a rapidly fluctuating hydrodynamic conditions in upper to lower shoreface due to changing sea level. The incorporation of turriform gastropod shells within the laminae of hummocks (swales and troughs) points out that the shell debris was sufficiently and efficiently transferred to the lower shoreface, as the most probable site of the hummocky cross-stratification is the lower shore-face (Riemersma and Chan, 1991).

Sufficient reworking of substrate (intra-formational conglomerate) is indicated by the roundness of pebbles and also the highly comminuted nature of shell fragments which inturn indicate intense reworking of shell debris due to long term wave action near the bank. Owing to the frequent incorporation of the hummocky cross stratified horizons and overlying regressive zone (7), the zone 6 can be designated as a pre-regressive complex.

4. Conclusion

Several depositional processes affected the carbonate free, clastic shoreface sedimentation owing to changing hydrodynamic regimes (Swift et al., 1991). The overall descriptive analysis of the facies suggests a paleo-shoreline associated with foreshore beach sedimentation.

The studied section has been subdivided into 7 zones on the basis of the thicknesses and abundances of transgressive and regressive units that are termed here as *regressive* and *transgressive* complexes. The transgressive and regressive complexes were intermittently interrupted at various levels by regressive and transgressive facies respectively. The facies analysis shows also that an ideal transgressive sequence, which involves the barrier, lagoon and estuary system, was not developed as described by Swift et al. (1991). The tectonic setting and sedimentation style prohibited the formation of a barrier. The absence of a barrier in turn caused the absence of back barrier lagoons and well developed estuaries. The absence of a barrier also indicates that after a storm or a stillstand period the readjustment of near shore gradients were not facilitative for the growth of a barrier (Thom and Roy, 1985).

The barrier is usually missing in the stratigraphic sequence and its place is taken by the erosional shoreface retreat processes (Niedoroda et al., 1985). This statement closely depicts the facies architecture of the studied section. The fairweather conditions gave rise to the well sorted quartzose and clean sandstone while transgressive events are recorded by thin shoreface retreat processes.

The association of sedimentary structures of contrasting hydrodynamic regimes within a single sandstone horizon, eg. hummocks at the base and desiccation cracks at the top are confusing. These features indicate a steep depositional dip with rapidly fluctuating hydrodynamic regime owing to an active tectonic environment in Miocene-Pliocene.

The division of the shell lag beds on the basis of the fossil specie has also been proved to be a good approach in analysing the depositional events and successive episodes of transgression. The incorporation of the turriform gastropod shell fragments in hummocky cross-stratified sandstone, further supports the idea of their residence near the shoreline. Whereas the incorporation of the oyster shell fragments in the herringbone cross-stratified beds indicate the very short durational semi emergent bays which harboured the oysters in brackish water. The retreat processes had sufficient gaps between them which allowed this tolerant specie of gastropod to rehabilitate its growth. The coarse nature of the shell lag beds suggests insufficient reworking of the sands (during storms in shoreface retreat processes) previously deposited by fluvial streams along the shoreline (Riemersma and Chan, 1991).

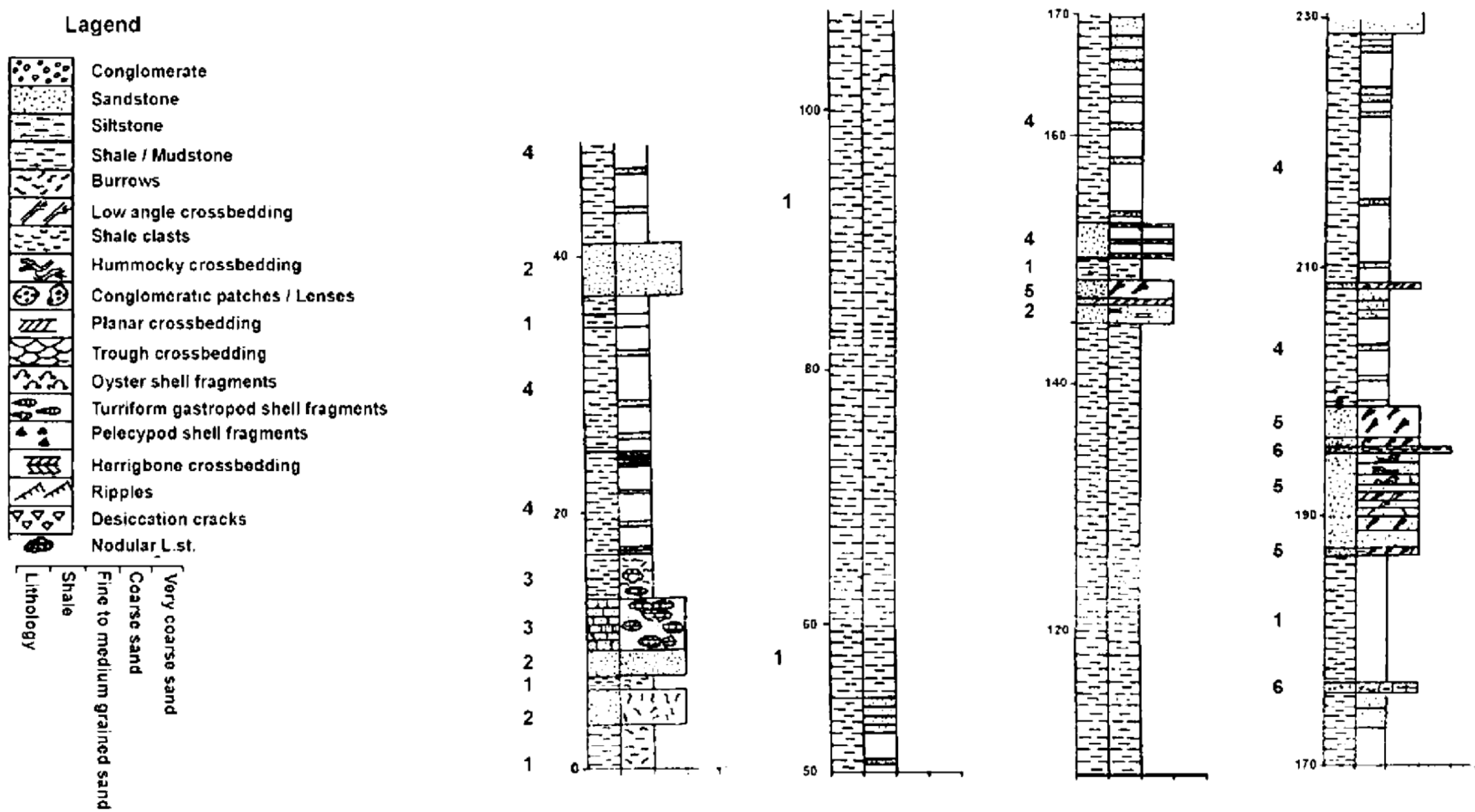
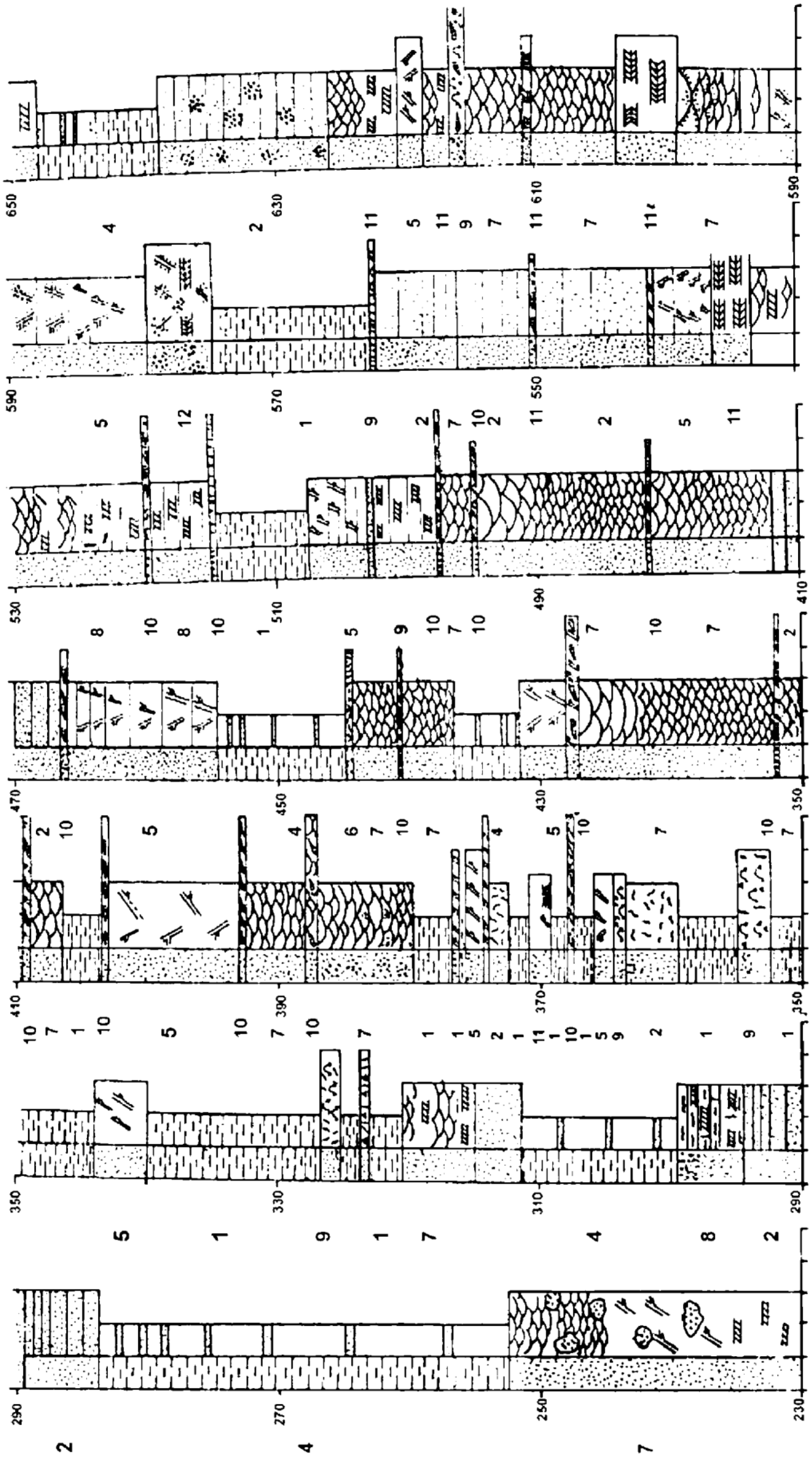
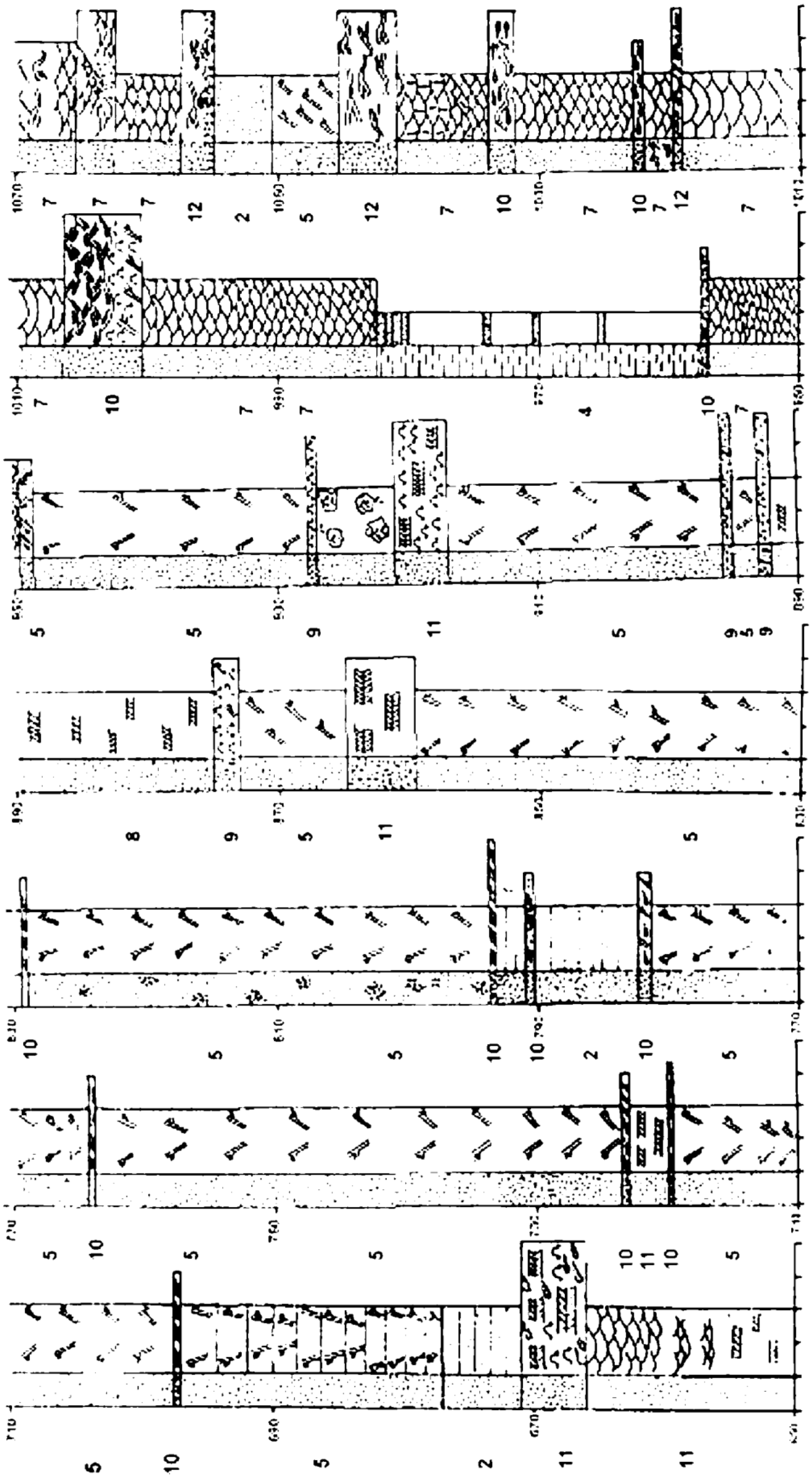
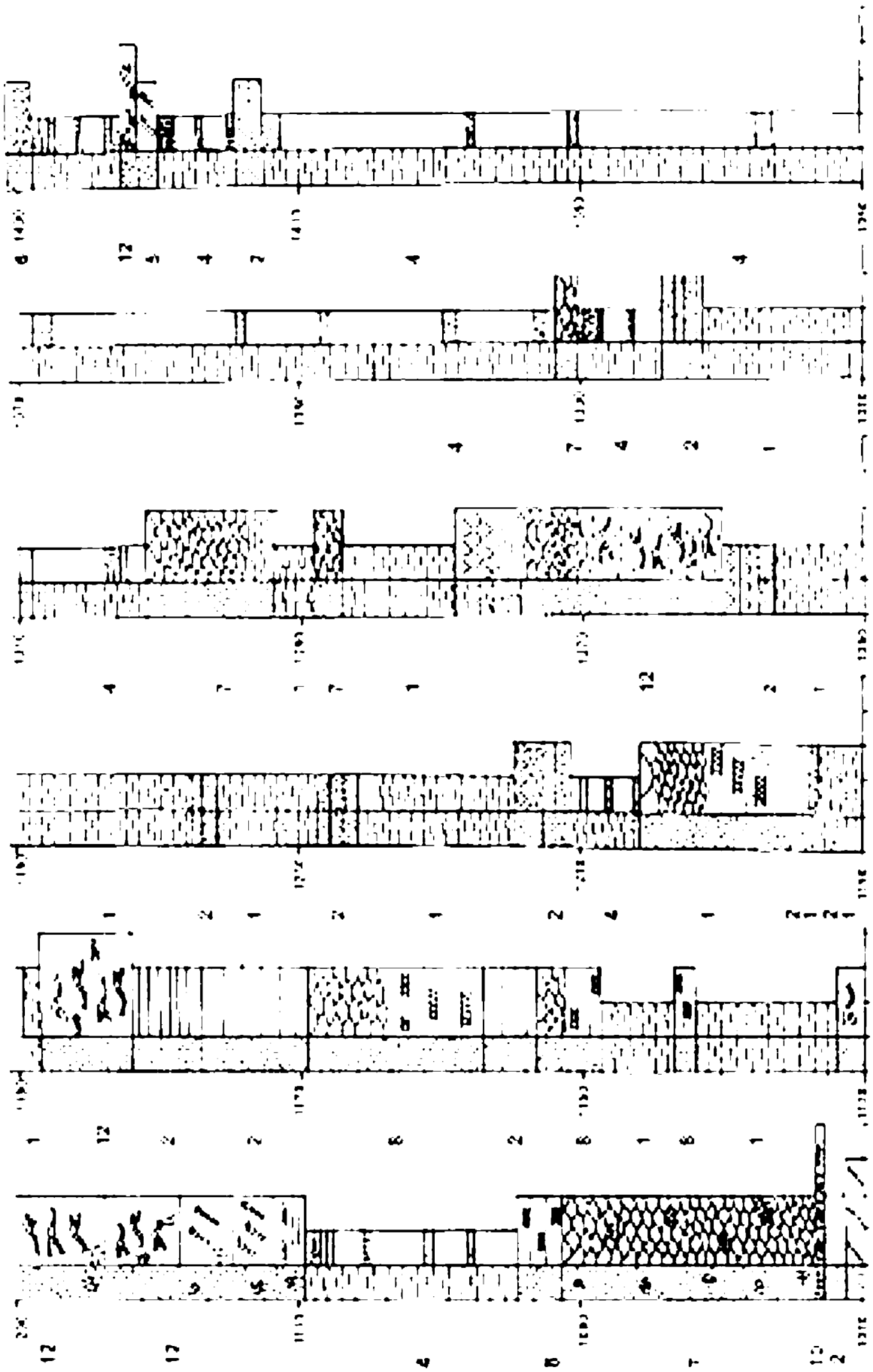


Fig. 10. Sedimentologic-Stratigraphic column of the Nal section of the Hinglaj formation. The facies no. are given on the left side of each column. (Thickness in meters).







References

Adams, J, J_R, Swift, D.J.P., Coleman, J.M., 1988. Bottom currents and fluviomarine sedimentation on the Mississippi Prodelta Shelf, February to May. Geophysical Research, 92, 14585-14609.

Addicott, W.O., 1980. Miocene stratigraphy and fossils, Cape Blanco Oregon. Ore Geology, 42, 87-98.

Aigner, T., 1985. Storm Depositional Systems. Springer-Verlag, New York.

Bannert, D. and Raza, H.A., 1992. The Segmentation of Indo Pakistan Plate. Pakistan Journal of Hydrocarbon Research, 4(2), 5-18.

Blandford, W.T., 1872. Note on the geological Formations seen along the coasts of Balochistan and Persia from Karachi to the head of the Persian Gulf, and some of the Gulf Island. Ibid Records, 5, 41-45.

Boggs, JR. S., 1987. Principals of sedimentology and stratigraphy. Merrill Publishing Company, Melbourne.

Bourgeois, J., 1980. A transgressive shelf sequence exhibiting hummocky stratification; The Cape Sebastian sandstone (Upper Cretaceous) Southwestern Oregon. Journal of Sedimentary Petrology, 50, 681-702.

Brenchley, P.J., Newall, G., 1982. Storm influenced inner shelf sand lobes in the Caradoc (Ordovician) of Shropshire, England, 52, 1257-1269.

Brenchley, P.J., Newall, G., Stanistreet, I., 1979. A storm surge origion for sandstone beds in an epicontinental platform sequence, Ordovician, Norway. Sedimentary Geology, 22, 185-217.

Byers, C.W., 1974. Shale fissility; relation to bioturbation. Sedimentology, 21, 479-484.

Byers, C.W., 1977. Biofacies pattern in the euxinic basins; A general model. In: Cook, H.E., Enos, P. (Eds.), Deep water carbonate environments. Society of Economic Palaeontologists and Mineralogists, Special Publication, 25, 5-17.

Chamberlain, C.K., 1978. Recognition of trace fossils in cores. In: Basan, P. B. (Ed) Trace fossil concepts. Society of Economic Palaeontologists and Mineralogists, Short Course Notes, 5, 133-183.

Cluff, R.M., 1980. Paleoenvironment of the New Albany Shale Group (Devonian- Mississipian) of Illinois. Journal of Sedimentary Petrology, 50, 767-780.

Cheema, M.R., Raza, S.M., Ahmad, H., 1977. Cenozoic. In: Shah, S.M.I. (Ed), Stratigraphy of Pakistan. Memoir Geological Survey of Pakistan, 12, 56-98.

Cotter, E., 1983. Shelf, paralic and fluvial environments and sea level fluctuations in the origin of the Tuscarora Formation (Lower Silurian) of central Pennsylvania. Journal of Sedimentary Petrology, 53, 25-49.

Crimes, T.P., 1975. The stratigraphical significance of trace fossils. In: Frey, R.W. (Ed), The study of trace fossils, Springer-Verlag, New York, 109-130.

Curray, J.R., 1964. Transgression and regression. In: Miller, R.C., (Ed), Papers in Marine Geology, McMillan, New York,175-203.

Daley, B., 1973. Fluvio-Lacustrine cyclotherms from the Oligocene of Hampshire. Geological Magazine, 110, 235-242.

Davies, R.A. JR., Fox, W.T., 1972. Coastal processes and near shore sand bars. Journal of Sedimentary Petrology, 42, 401-412.

Dott, (JR) R.H., Bourgeois, J., 1982. Hummocky stratification; Significance of its variable bedding sequences. Geological Society of America Bulletin, 93, 663-680.

Driese, S.G., Fischer, M.W., Easthouse. K.A., Marks, G.T., Gogola, A.R., Schoner, A.E., 1991. Model for the genesis of shoreface and shelf sandstone sequences, southern Appalachians; Paleoenvironmental reconstructions of an Early Silurian shelf system. International Association of Sedimentology, Special Publication 14, 309-338.

Duke, W. L., Arnott, R.W.C., Cheel, R.J., 1991. Shelf Sandstone and Hummocky Cross Stratification; new insights on a storm debate. Geology, 19, 625-628.

Easthouse, K.A., Driese, S.G., 1988. Paleobathymetery of a Silurian shelf system; application of proximality trends and trace fossil distributions. Palaios, 3, 473-486.

Ekdale, A.A., Bromley, R.G., Pemberton, S.G., 1984. Ichnology; the use of trace fossils in sedimentology and stratigraphy. Society of Economic Palaeontologists and Mineralogists, Short Course Notes, 15, 317.

Frey, R.W., 1975. The realm of ichnology, its strengths and limitations. In: Frey, R. W. (Ed), The Study of Trace Fossils, Springer-Verlag, New York, 13-38.

Halam, A., Bradshaw, M.J., 1979. Bituminous shales and oolitic ironstones as indications of transgression and regressions. Journal of Geological Society London, 136, 157-164.

Hamblin, A.P., Walker, R.G., 1979. Storm dominated shallow marine deposits, The Fernie-Kootenry (Jurassic) transition, southern Rocky Mountains. Canadian Journal of Earth Sciences, 16, 1673-1690.

Harms, J.C., Southard, J,B., Spreading, D.R. and Walker, R.G., 1975. Depositional environments as interpreted from primary sedimentary structures and stratification sequences. Society of Economic Palaeontologists and Mineralogists, Short Course. 2.

Hart, B.S., Plint, A.G. 1993. Origin of an erosion surface in shoreface sandstone of the Kakwa Member (Upper Cretaceous Cardium Formation, Canada); importance for reconstruction of stratal geometery and depositional history. International Association of Sedimentology Special Publication, 18, 451-467.

Hayden, B. P., Dolan, R., 1979. Barrier Islands, lagoons and marshes. Journal of Sedimentary Petrology, 49, 1061-1072.

Haszeldine, R.S., 1984. Muddy deltas in fresh water lakes and tectonism in the upper Carboniferous Coalfield of NE England. Sedimentology, 31, 811-822.

Hine, A.C., 1979. Mechanism of berm development and resulting beach growth along a barrier spit complex. Sedimentology, 26, 331-351.

Hiscott, R.N., 1982. Tidal deposits of the Lower Cambrian Random Formation, eastern Newfoundland; facies and paleoenvironment. Canadian Journal of Earth Sciences, 19, 2028-2041.

Howard, R.D., 1978. Sedimentology and trace fossils. In: P. B, Basan (Ed), Trace Fossils Concepts, Society of Economic Palaeontologists and Mineralogists, Short Course Notes 5, 13-47.

H.S.C. (Hunting Survey Corporation Ltd.),1960. Reconnaissance Geology of a Part of West Pakistan; A Colombo Plan Co-operative Project, Toronto, Published for Govt. of Pakistan by Govt. of Canada.

Hunter, R.E., 1977. Terminology of cross-stratified sedimentary layers and climbing ripples structures. Journal of Sedimentary Petrology, 47, 697-706.

Hunter, R.E., Clifton, H.E., 1982. Cyclic deposits and hummocky cross-stratification of probable storm origion in upper Cretaceous rocks of Cape Sebastian area, southwestern Oregon. Journal Sedimentary Petrology, 52, 127-143.

Hunter, R.E., Clifton, H.E., Phillips, R.L., 1979. Depositional processes, sedimentary structures and predicted vertical sequences in barred nearshore systems, southern Oregon coast. Journal of Sedimentary Petrology, 49, 711-726.

Kelling, G., Mullin, P.R., 1975. Graded limestone and limestone-quartzite couplets; possible storm deposits from the Moroccan Carboniferous. Sedimentary Geology, 13, 161-190.

Klein, G.D.V., 1977. Clastic Tidal Facies, Continuing Education Publication Company, Champaign, IL.

Kreisa, R.D., 1981. Storm generated sedimentary structures in sub tidal marine facies with examples from Middle and Upper Ordovician of south western Virginia. Journal of Sedimentary Petrology, 51, 823-848.

Leggett, J.K., 1978. Eustacy and Pelagic regimes in the Iapetus ocean during the ordovician and Silurian. Earth and Planetary Science Letters, 41, 163-169.

Leggett, J.K., 1980. British lower Paleozoic black shales and paleo-oceanographic significance. Journal of Geological Society London, 137,139-156.

Leithold, E.L., Bourgeois, J., 1984. Characteristics of coarse grained sequences deposited in near shore, wave dominated environment; examples from the Miocene of south-west Oregon. Sedimentology, 31, 749-775.

McCrory, V.L.C., Walker. R.G., 1986. A storm and tidally influenced prograding shoreline-Upper Cretaceous Milk River Formation of Southern Alberta, Canada. Sedimentology, 33, 47-60.

Mount, J.F., 1982. Storm surge ebb origin of hummocky cross stratified units of the Andrews Mountain Member, Campito Formation (Lower Cambrian), White-Inyo Mountains, Eastern California. Journal of Sedimentary Petrology, 52(3), 951-958.

Niedoroda, A.W., Swift, D.J.P., Thorne, J.A., 1989. Modelling shelf storm beds; Control of bed thickness and bedding sequence. In: Shelf sandstones, shelf depositional sequences and petroleum accumulation: a Symposium; Gulf Coast Section, seventh annual research conference proceedings; Society of Economic Palaeontologists and Mineralogists, Tulsa OK, 15-39.

Nummedal, D., Oertal, G.F., Hubbard, D.K., Hine, A.C., 1977. Tidal inlet variability-Cape Hateras to Cape Canaveral. In: Proceedings Coastal Sediments, 77, American Society of Civil Engineers, Charleston, SC, 543-562.

Oertel, G. F., 1987. Back barrier and shoreface control on inlet channel orientation. Coastal Sediments 87, American Society of Civil Engineers, New Orleans, LA, 2022-2029.

Oertel, G. F., Henry, V.J., Foyle, A.M., 1991. Implications of a tide dominated lagoonal process on the preservation of burried channels on a sediment starved continental shelf. In: Swift, D.J.P., Oertel, G. F., Tilman, R. W., Thorne J. A. (Eds), Shelf Sand and Sandstone Bodies; Geometry, Facies and Sequence Stratigraphy. International Association of Sedimentology Special Publication, 14, 379-393.

Pettijohn, F.J., Potter, P.E., Siever, R., 1972. Sand and Sandstone. Springer-Verlag, New York.

Pickerill, R.K., Hurst, J.M., 1983. Sedimentary facies, depositional environments and faunal association of the lower Llandovery (Silurian) Beechill cove Formation, Arisaig, Nova Scotia. Canadian Journal of Earth Sciences, 20, 1761-1779.

Plint, A.G., 1983. Facies, environments and sedimentary cycles in the Middle Eocene, Bracklesham Formation of the Hampshire Basin; Evidence for global sea level changes. Sedimentology, 30, 625-653.

Plint. A.G., 1984. A regressive coastal sequence from the Upper Eocene of Hampshire, southern England. Sedimentology, 31, 213-225.

Plint, A.G., 1988. Sharp based shoreface sequences and "Off shore bars" in the Cardium Formation of Alberta; their relationship to relative changes in sea level. In: C.K.Wilgus, H.W. Posamentier, C. A. Ross, C.G.St.C (Eds), Kendall Sea Level Changes; An Integrated Approach, SEPM Special Publication, 42, 357-370.

Porrenga, D.H., 1967. Glauconite and chamosite as depth indicators in the marine environment. Marine Geology, 5, 495-501.

Reineck, H.E., Singh, I.B., 1980. Depositional Sedimentary Environments, 2nd Edition, Springer-Verlag, Berlin.

Riemersma, P.E., Chan, M.A., 1991. Facies of the lower Ferron sandstone and Blue Gate shale Member of the Mancos Shale; Lowstand and early transgressive facies architecture. In: Swift, D.J.P., Oertel G.F., Tilman, R.W., Thorne, J.A., (Eds.), Shelf Sand and Sandstone Bodies; Geometry, Facies and Sequence Stratigraphy. International Association of Sedimentology, Special Publication, 14, 489-510.

Reinson, G.E., 1984. Barrier Island and associated strandplain systems. In: Walker R.G., (Ed), Facies Models, 2nd Edition. Geoscience Canada, Reprint Series, 1, 119-140.

Rhoads, D.C., Morse, J.W., 1971. Evolutionary and environmental significance of oxygen defficient marine basins. Lethaia 4, 413-428.

Rhoads, D.C., 1975. The Paleoenvironmental significance of trace fossils. In: Frey R. W., (Ed), The study of trace fossils. Springer-Verlag, New York, 147-160.

Sarwar, G., 1992. Tectonic Setting of the Bela Ophiolites, Southern Pakistan. Tectonophysics, 207, 359-381.

Savrda, C.E., Bottjer, A.J., 1986. Trace fossil model for reconstruction of paleooxygena-tion in bottom waters. Geology, 14, 3-6.

Savrda, C.E., Bottjer, D.J., Gorsline, D.S., 1984. Development of a comprehensive oxygen defficient marine biofacies model; evidence from santa Monica, San Pedro and Santa Barbara Basins, California continental borderland. American Association of Petroleum Geologists Bulletin, 8, 1179-1192.

Schlanger, S.O., Jenkyns, H.G., 1976. Cretaceous ocean anoxic events; causes and consequences. Geological Mijnbouw, 55, 179-181.

Seilacher, A., 1978. Use of trace fossils for recognizing of depositional environments. In: Basan, P.B. (Ed), Trace fossils concept. Society of Economic Palaeontologists and Mineralogists Short Course Notes, 5, 185- 201.

Selley, R.C., 1969. Near shore marine continental sediments of Sirt Basin, Libya. Geological Society of London, 124, 419-453.

Shah, S.M.I., 1977. Stratigraphy of Pakistan. Memoir Geological Survey of Pakistan, 12.

Shepard, F.P., 1960. Gulf coast barrier. In: Shepard F.P, Phleger F., Van Andel T., (Eds), Recent Sediments, Northwest Gulf of Mexico. Amrican Association of Petroleum Geologist, 197-220.

Swift, D.J.P., Figueireda, A.G., Freeland, G.J., Oertel, G.F., 1983. Hummocky cross- stratification and megaripples; a geologic double standard. Journal of Sedimentary Petrology, 53, 1295-1317.

Swift, D.J.P., Niedoroda, R.J., 1985. Fluid and sediment dynamics on continental shelves. In: Tillman, R.W., Swift, D.J.P., Walker, R.G. (Eds), Shelf Sands and Sandstone Reservoirs. Society of Economic Palaeontologists and Mineralogists, Short Course Notes, 13, 47-133.

Swift, D.J.P., Hudleson, P.M., Brenner, R.L., Thompson, P., 1987. Shelf construction in a foreland basin; Storm beds, Shelf sand bodies and shelf-slope depositional sequences in the upper Cretaceous Mesaverde Group, Book Cliffs, Utah. Sedimentology, 34, 423-457.

Thom, B.G., Roy, P.S., 1985. Relative sea level and coastal sedimentation in Southeast Australia in the Holocene. Journal of Sedimentary Petrology, 55. 257-264.

Vrendenburg, E.W., 1906. The classification in the Tertiary System in Sind with reference to the zonal distribution of the Eocene Echinoidia described by Duncan and Sladen. India Geological Survey Records, 34, 172-198.

Vrendenburg, E.W., 1909. Report on the geology of Sarawan, Jhalawn, Mekran and the State of Lasbela. Ibid. Records, 38, 189-215.

Walker, R.G; Duke, W.L., Leckie, D.A., 1983. Hummocky Stratification; Significance of its variable bedding sequences; discussion and reply. Geological Society of America Bulletin, 94, 1245-1251.

Walker, R.G., 1984. Shelf and shallow marine sands. In: Walker, R.G., (Ed), Facies Models, Geosciences Canadian Reprint Series, 1, 141-170.

Walker, R.G., 1985. Geological evidence for storm transportation and deposition on ancient shelf sands and sandstone reservoirs. In: Tillman, R.W., Swift, D.J.P., Walker, R.G., (Eds), Shelf Sands and Sandstone Reservoirs. Society of Economic Palaeontologists and Mineralogists, Short Course Notes, 13, 243-302.

Walker, K.R., Diehl, W.W., 1986. The effect of synsedimentary substrate modification on the composition of Paleocommunities; Paleoecologic Succession revisited. Palaios 1, 65-74.

Whittaker, J.H.M., 1973. "Gutter Casts" A new name and scour and fill structures with examples from the Llandoverian of Ringerike and Malmoya, Southern Norway. Norsk Geology Tidsskr, 53, 403-417.

Wignall, P.B., Sutcliffe, O.E., Clemson, J., Young, E., 1996. Unusual shoreface sedimentology in the Upper Jurassic of the Boulonnais, Northern France. Journal of Sedimentary Petrology, 66, 577- 586.