CHAPTER - 4

DESCRIPTION OF LITHOFACIES

4.1 INTRODUCTION

The study and interpretation of textures, sedimentary structures, fossil content and lithologic association of sedimentary rocks on the scale of an outcrop, well section or small segment of a basin comprises the subject of facies analysis (Miall, 1984). As suggested by Miall (1984), the word facies is used in both, a descriptive and an interpretive sense. According to him, descriptive facies include certain observable attributes of sedimentary rock bodies, which can be interpreted in terms of depositional processes. An individual lithofacies is considered to be a rock unit defined on the basis of its distinctive lithologic features, including composition, grain size, bedding characteristics and sedimentary structures. Each lithofacies represents an individual depositional event, which are characteristic of particular depositional environments. These are commonly cyclic, and form the basis for defining sedimentation models (Miall, 1984). According to Miall (1984) with the help of lithofacies studies, one can understand depositional environments and palaeogeography existing at the time a rock unit was formed and can be better placed to make predictions and extrapolations about lateral changes in thickness and composition.

4.2 LITHOFACIES DESCRIPTION

Present study on Mesozoic sequence is focused mainly on vertical facies relationships exhibiting six lithofacies and four subfacies (Table 4.1), each composed of genetically related sediments. The discrimination of the lithofacies is based on the stratigraphic position, distinctive lithologic features including composition, textures, structures, biological character, bedding characteristics, colour and physical and biogenic sedimentary structures. These lithofacies are repeated in their vertical extent and also integrate with each other in their lateral extent. Vertical distribution of facies also varies from outcrop to outcrop.

Three sections were measured (Fig. 4.1, 4.2 and 4.3); which show the vertical distribution of the lithofacies for the Mesozoic sequence of Jhura Dome of Mainland Kachchh.

No.	Lithofacies and their Subfacies
1	Limestone Lithofacies (LL) Badi Limestone Subfacies (BLs) Nodular white well bedded Limestone Subfacies (NWWLs)
2	Conglomerate Lithofacies (CL)
3	Calcareous Silty Shale Lithofacies (CSSL)
4	Oolitic Limestone Lithofacies (OLL) Golden Oolite Subfacies (GOs) Dhosa Oolite Subfacies (DOs)
5	Rippled Marked Calcareous Sandstone Shale Lithofacies (RMCSSL)
6	Greenish Grey Shale Lithofacies (GGSL)

Table 4.1 Lithofacies of the Mesozoic sequence of Jhura Dome

4.2.1 Limestone Lithofacies (LL)

4.2.1.1 Badi Limestone Subfacies (BLs) – Member A (Jhurio FM.)

Description: This subfacies is defined on the basis of predominance of carbonate material over the fine silty and clayey argillaceous components and bioclasts or fossil fragment. This subfacies is about 19 m thick and is found to be well developed at the base of Jhurio Formation overlying by CSSL (Fig. 4.3) and exposed at the core (Plate 4.1) of the Jhura dome. The subfacies is named after the small village nearby a main nala (seasonal stream) along which it is well exposed and shows structural dips in all directions. Rocks of this subfacies consist of thick white coloured, hard and compact limestones alternating with thin bands of the shales (0.5 to 15 cm). The limestones are white, pale brown and grey, fine textured muddy micrite. The shales are greenish and grey massive fine textured quartzose shale. Some limestones are oolitic with small golden ooliths and some are 'lump sparite' containing streaks and lenticles of fine golden-oolite aggregates. This facies is fossiliferous and mainly consists of bivalves (*Alectryonia*) and brachiopods (*Rhynchonellids*).

This lithofacies is moderately bioturbated and consists of abundant traces (*Zoophycos circinnatus, Z. brianteus, Thalassinoides horizontalis, T.* paradoxicus, *Urohelminthoida dertonensis, Rhizocorallium irregulare* and *Ophiomorpha nodosa*).

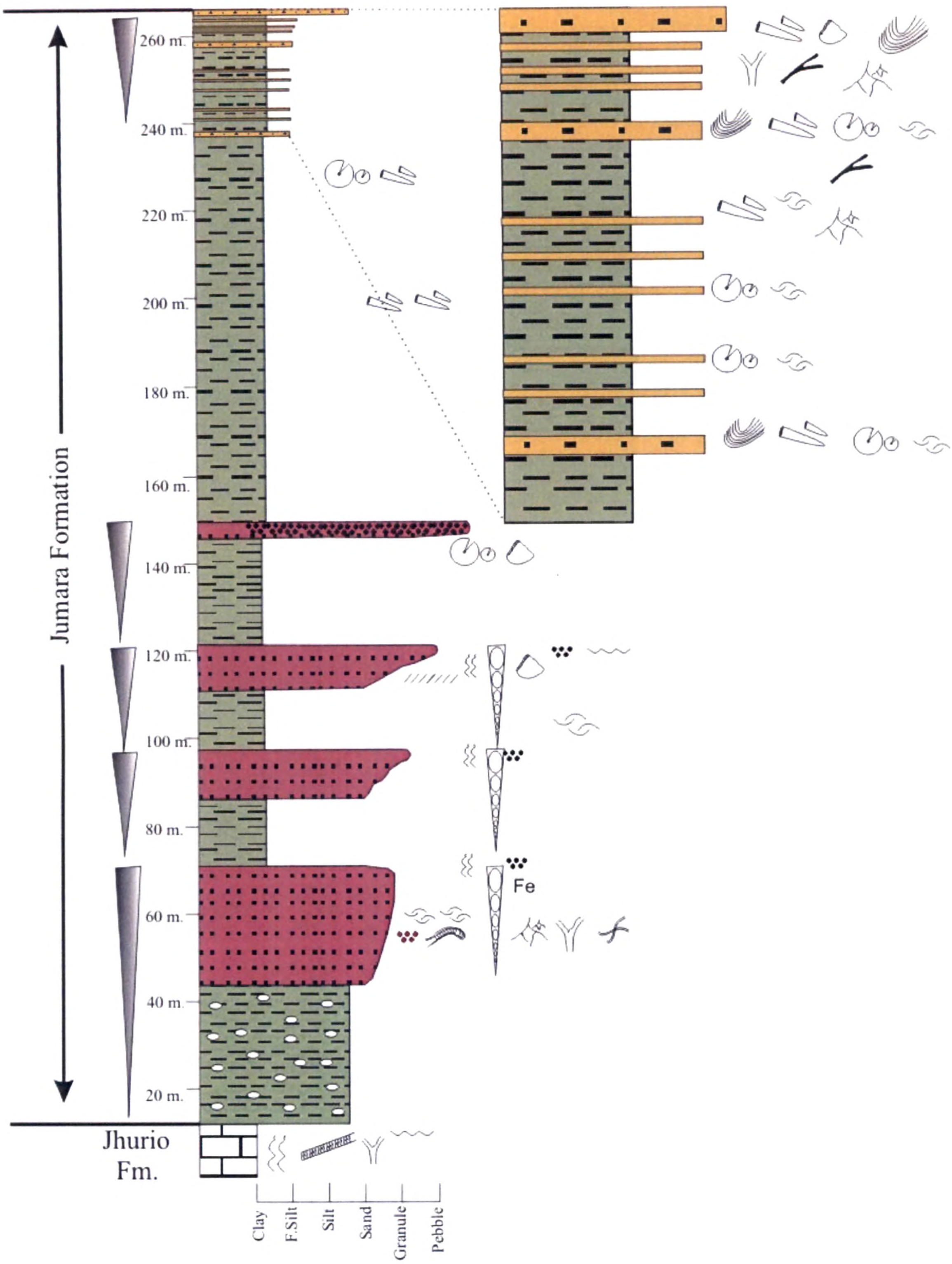

Fig. 4.1 Sodha Camp outcrop section – Jhura Dome, Kachchh Mainland.

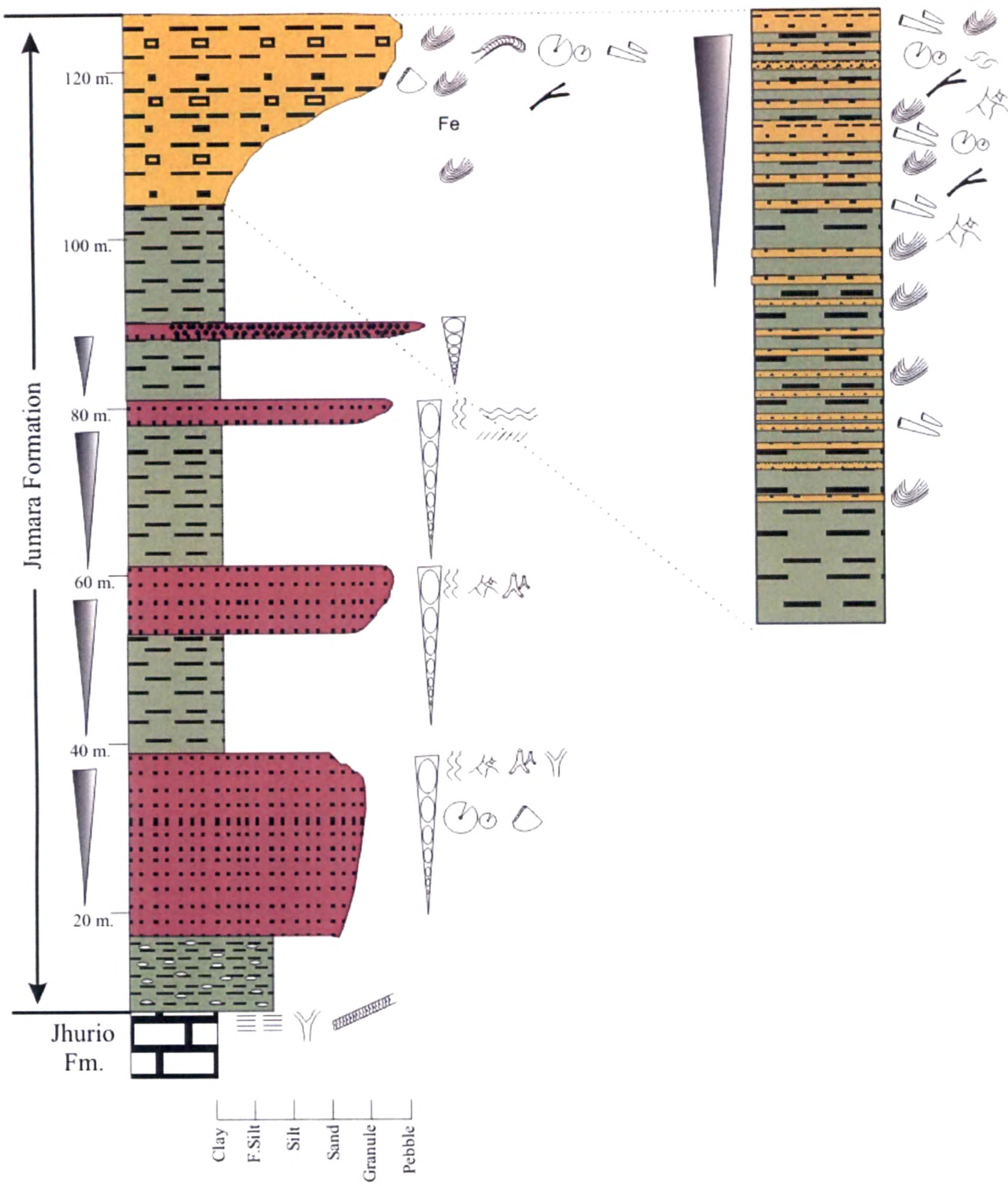

Fig. 4.2 Kamaguna outcrop section – Jhura Dome, Kachchh Mainland.

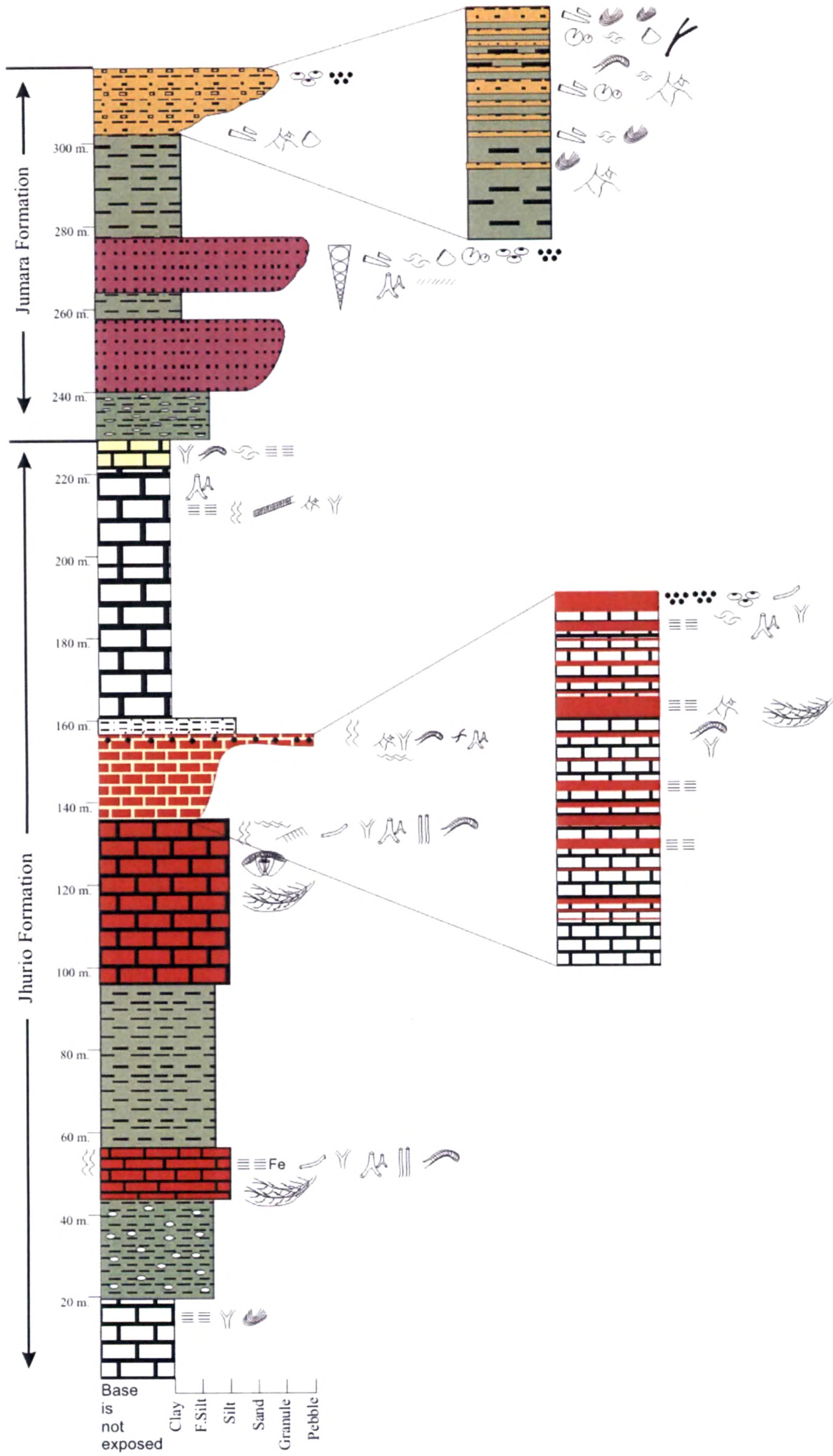

Fig. 4.3 Badi Nala outcrop section – Jhura Dome, Kachchh Mainland.

Fig. 4.4 Legend – I for Fig. 4.1, 4.2 and 4.3.

The limestones are yellow, finely crystalline with silty sparite, foraminiferal shells and occasionally containing few pellets, slender quartz prisms and clay aggregates with silt size detrital quartz of terrigenous constitution (Plate 4.2). These are coarsely crystalline, saccharoidal limestones (clayey sparite), characteristic (Plate 4.2, g-h) of the subfacies. The thin sections of the Plate 4.2 represent different stratigraphic positions; Plate 4.2, a-d represents the upper; e-f the middle and g-h thin sections show the lower part of the lithofacies. It has been observed that the micritic cement is converted in to sparitic cement and there is an overall increase in fossil content, oolites, pellets and intraclasts (rock fragments) from bottom to top. As per the Folk classification (1962), BLs is typically allochemical in nature. The matrix is sparite to microsparite, coarser grained calcite crystals formed during diagenesis in the upper part and micrite, fine grained carbonate mud in the lower (older) part. In general, sections are classified as biomicrite (e-f); intrasparite (a-d) and intramicrite (g-h) as per Folk classification (1962). Thin sections (Plate 4.2) feature stratified shell fragments (bioclasts), lithic grains (intraclasts), oolites and matrix (cement). The shell fragments are mainly of foraminifers, bryozoans, gastropods, lamellibranches, small ammonoids and echinoderm spines.

Plate 4.1 Badi Limestone subfacies

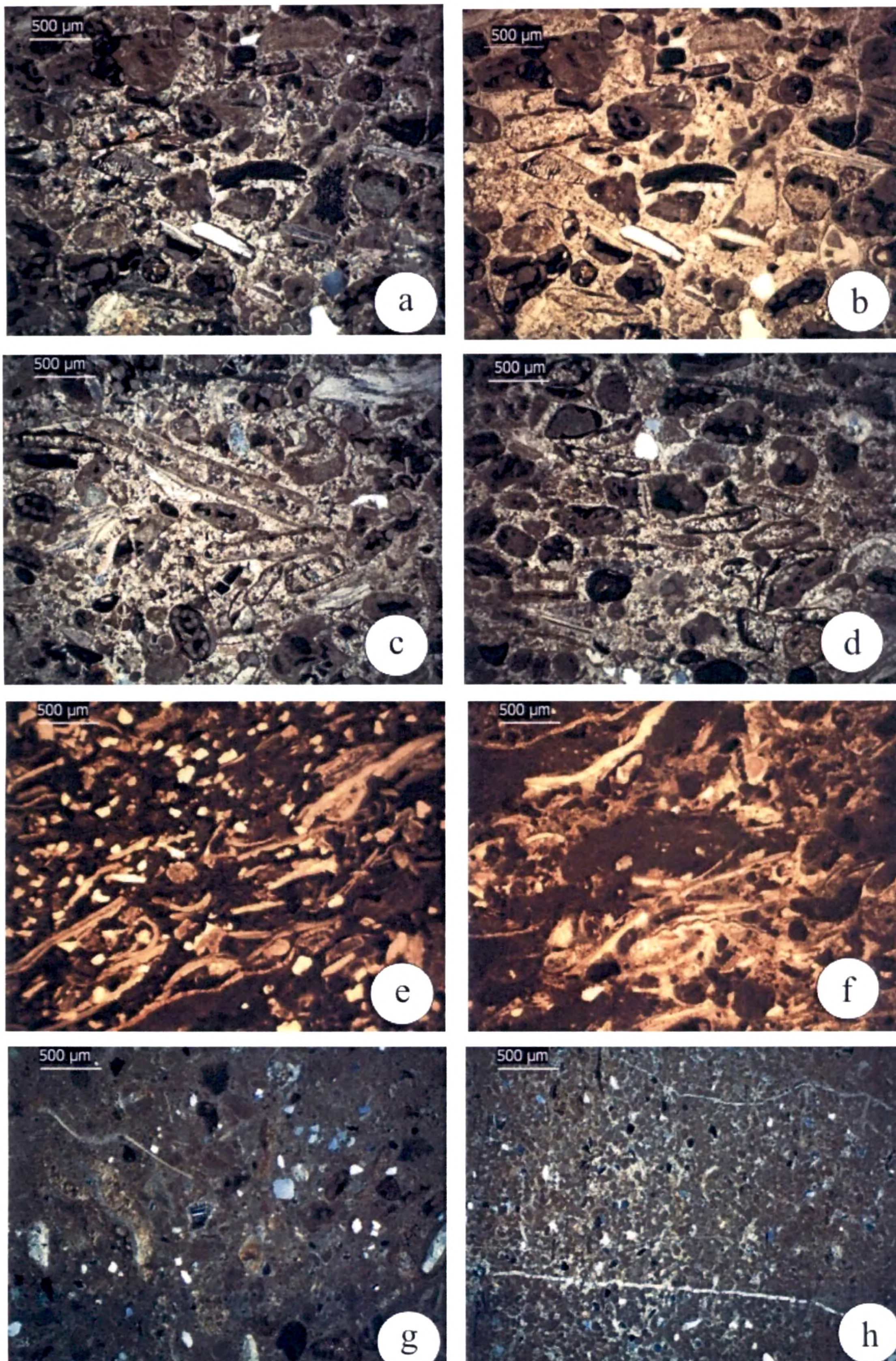

Plate 4.2 Thin sections – Badi Limestone subfacies

Interpretation: The lithological association of the formation is predominantly biomicrites and bio muddy micrite at base and biosparites to biointrasprite with few peloids at top. In the beginning, the lithofacies consists of allochem and terrigenous materials in subordinate amount where as orthochem grains are present towards the top. The lithologic association indicates near shore deposition in a slowly transgressive sea under relatively stable conditions and occasionally influenced by storm, an event which has supported enormous bioclast preservation in the middle part of lithofacies. These limestones are therefore, genetically marine autochthonous limestones of Pettijohn (1957).

4.2.1.2 Nodular white well bedded Limestone Subfacies (NWWLs) – Member F and G (Jhurio FM.)

Description: This facies consists of 65 m thick white colour, hard and compact well bedded and nodular limestone (Plate 4.3, 4.4) alternating with thin bands of shales at the top of the Jhurio Formation (Fig. 4.1, 4.2 and 4.3). The upper limestone is white, grey and cream coloured well bedded limestone which is jointed and nodular in appearance (Plate 4.4). Some terrigenous matter is invariably present as silt and/or clay showing thin parallel laminations (Plate 4.5). The thin beds are separated by greenish shaly partings along the sharply defined smooth bedding planes. Fossils are always present.

The lower part of the facies is distinguished by white to grey and brownish grey, very finely crystalline clayey pelmicrite. The micrite is composed of pellets, clay, free calcite and a few foraminiferal shells (Plate 4.6). This part is very distinctive for its chalky white appearance and brick-like structure produced by the intersection of bedding plane and closely spaced vertical joints. This facies is highly fossiliferous and consists of *Rhynchonella* sp., *Terebratula* sp. and Belemnites and Crinoid stems with a few small ammonites (? *Macrocephalitids)*.

This lithofacies is highly bioturbated and consists of abundant traces of *Ancorichnus ancorichnus, Beaconites antarcticus, B. coronus, Chondrites intricatus, C. patulus, Cochlichnus anguineus , Cosmorphaphe carpathica, Keckia annulata , Lockeia ornata , L. siliquaria , Palaeophycus annulatus , P. tubularis , Phoebichnus trochoides , Protovirgularia dichotoma , Scolicia strozzii , Thalassinoides horizontalis, T. suevicus* and *Zoophycos brianteus*

Thin sections (Plate 4.6) consist of predominantly inorganic peloids of uncertain origin and clayey lithoclasts (orthochemical). These are embedded in a matrix consisting of coarser grain calcite crystals, sparite or microsparite. Size of the orthochems / peloids is more or less similar, rounded to sub-rounded and they are closely packed. Sections are texturally mature, grain supported, highly packed consisting micro sparry calcite of secondary origin during diagenesis. Thin sections often show fossil fragments (Plate 4.6, f) of bivalves, brachiopods and gastropods, most of them are classified as biosparite. Where as some of the sections (Plate 4.6, a-d) are rich in peloids, classified as pelsparite.

Plate 4.3 Nodular white well bedded Limestone subfacies

Interpretation: The limestones with low clastic content show deposition away from the littoral zone and a gentle rate of subsidence when the rate of erosion was low. The alternations of micrite and sparite again indicate repetition of quiet and high energy conditions respectively. While the micrites are generally deposited below the average wave base, the occurrence of sparites indicates interventions of higher energy states perhaps during repeated storm cycles.

The abundance of fossils, especially the benthonic forms like brachiopods, corals and annelids together with epipelagic nektonic forms like ammonites and belemnites of neritic realm, indicate deposition in the upper offshore (sublittoral) to shelf environment within the photic zone. Among the brachiopods, Rhynconellids and Terebratulids are predominating.

Plate 4.4 Nodular white well bedded Limestone subfacies

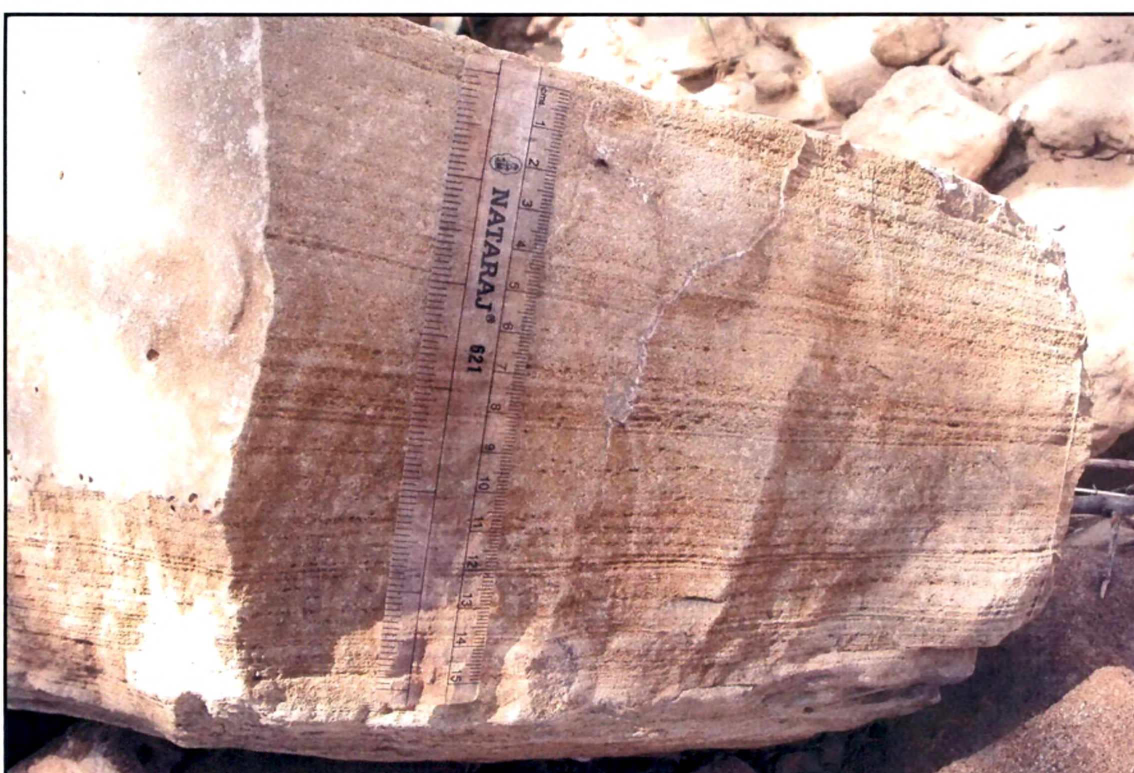

Plate 4.5 Parallel laminations; Nodular white well bedded Limestone subfacies

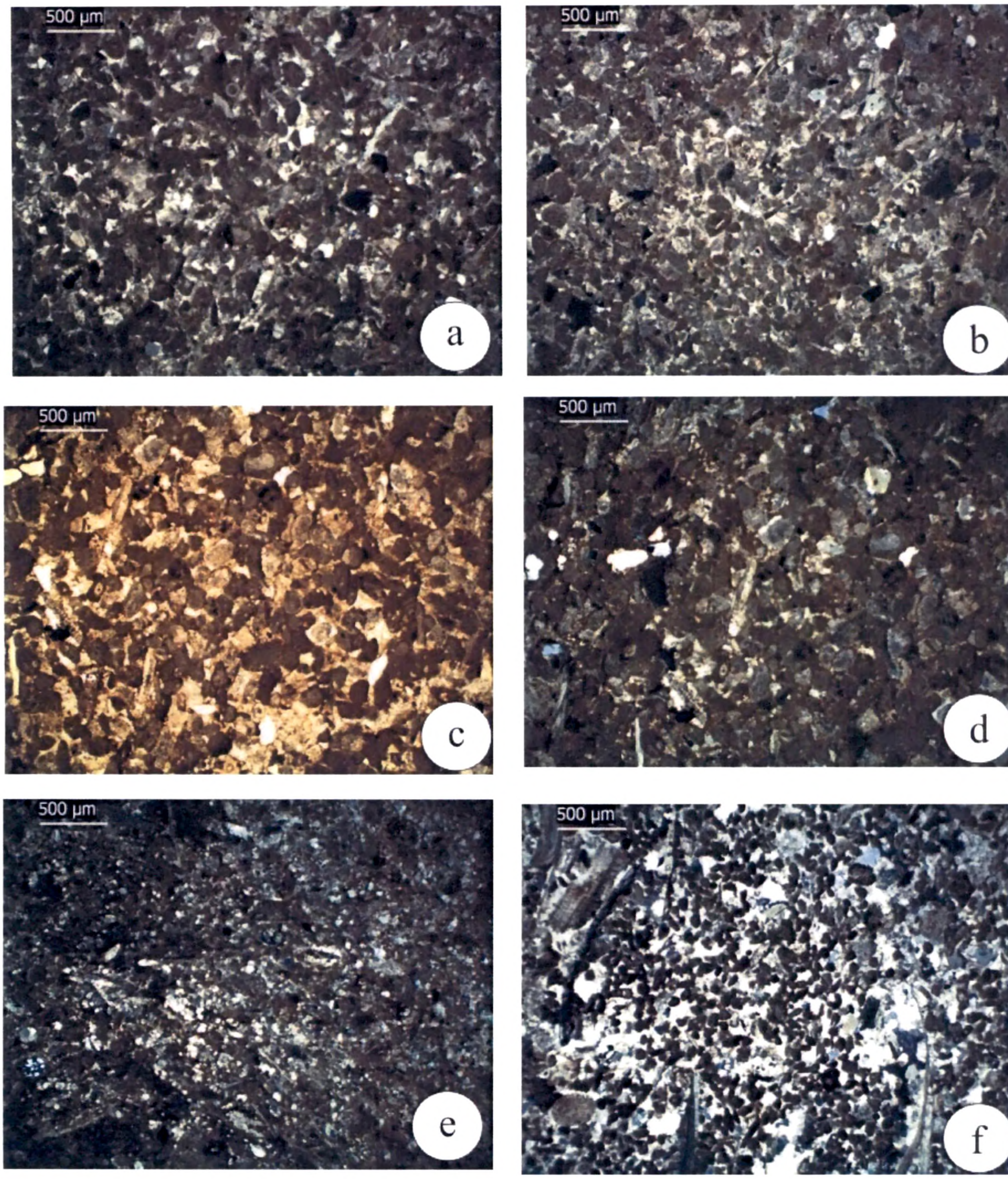

Plate 4.6 Thin sections – Nodular White well bedded Limestone subfacies

The latter occurs in the zone between the shoreline and 180 m. depth, where as the Rhynchonellids do not live at depths less than 25 m. (Woods, 1958). This restricts the environment of deposition within the sublittoral zone below the 25 m. bathymetric level. These suggest a shallow, upper offshore to shelf deposition where free circulation and aeration predominates. Lithological and biological features characterize a lower offshore (sublittoral) to shelf depositional environment, although local variations of the environment produced variation in sedimentation.

4.2.2 Conglomerate Lithofacies (CL)

Description: The facies incorporates clasts of different sizes from underlying rocks and are reported at three different levels overlying the GOs, RMCSSL and DOs. The thickness varies from 7 cm to 55 cm, the maximum being in the upper part of GOs (Plate 4.7). The conglomerate unit above the RMCSSL (Plate 4.8) and DOs (Plate 4.9) have shown an average thickness of 45 cm. These rocks are occasionally conglomeratic with reddish-brown pebbles of lateritized rocks and more commonly sub angular fragments of a greenish marly rock. Often small sub-angular to well rounded pebbles are seen coated with golden yellow films. The clasts vary in size from 2.0 cm to 7.0 cm in diameter. These are mainly composed of matrix supported flat pebbles of white micritic mudstones (marl) and yellow and red ferruginous claystone pebbles. The clasts are polymictic to oligomictic and autoclastic. Brachiopods and bivalves are found attached to the clasts. The clasts are rounded or elongated to spherical, oblong to bifurcating in many cases. On the surface of many pebbles subaqueous dehydration cracks are present, suggesting dehydration under water at the time of diagenesis. GOs has shown cross laminations containing oriented shell fragments followed by conglomeratic sediments towards top, exhibiting a crudely upward-coarsening package. The RMCSSL consists of cross cutting joint pattern, predominantly cross stratification and has also revealed upward-coarsening sequence.

This lithofacies includes both, intraformational and extraformational conglomerates. The units overlying the GOs and DOs are varieties of intraformational conglomerates whereas RMCSSL is origin of extraformational conglomerate. In first case the rock is ortho-conglomerate, polymictic mainly containing gravel and pebble size clasts, quartz as foreign material, peloids and ooids (Plate 4.7a); or red or white or yellowish silty micromicrite or biomicrite to ferruginous material. The colour of such clasts is due to ferruginous impregnation. Rocks are mainly grain supported with few oolites with high fossil content. A huge event supported ooids comprising quartz, peloids, intraclasts and bioclasts as multi-nuclei (Plate 4.7a, a) shows typical characteristics of storm generated facies. Many of the clasts show two to three phases of their origin, where sharply defined red or white core is covered by a thick layer of ferruginous micritic mud followed on the outer part by ferruginous or sparitic envelop. In such cases clasts are in contact with each other forming clast or framework supported conglomerate. Large sizes of ammonites with abundant belemnite species are found. Few clasts show their two phase origin where inner whitish core is covered by ferruginous material. This is observed in upper part of DOs. In the second type, rock is also ortho-conglomerate, oligomictic and polymictic, matrix supported, consist of dirty white, pale yellow, reddish to brownish ferruginous hematitic to silty-sandy micritic or mix material, well packed, consisting mainly gravel and pebble size quartz and huge bioclasts. In absence of ooids, pellets, peloids and matrix (micrite or sparite), and presence of ripple marks, the RMCSSL terminate as extraformational conglomerate.

Plate 4.7 Conglomerate Lithofacies - GOs

Interpretation: The overall character of the CL facies is indicative of exhumation of concretions under stormy conditions in upper shoreface, where due to interaction with substrate, waves were converted into unidirectional currents. Hence, in such part current dominated over wave action. The evidence is depicted in the alignment of pebbles and absence of wave induced structures like symmetrical wave ripples and migratory, ripple-generated cross stratification and by erosional scoured base. The pebbles in the conglomerates are interpreted as being of concretionary origin. According to Ball et al., (1967) and Aigner, (1985) the sharp contact, mostly scoured at the base of the facies is most likely due to erosional episodes during storms.

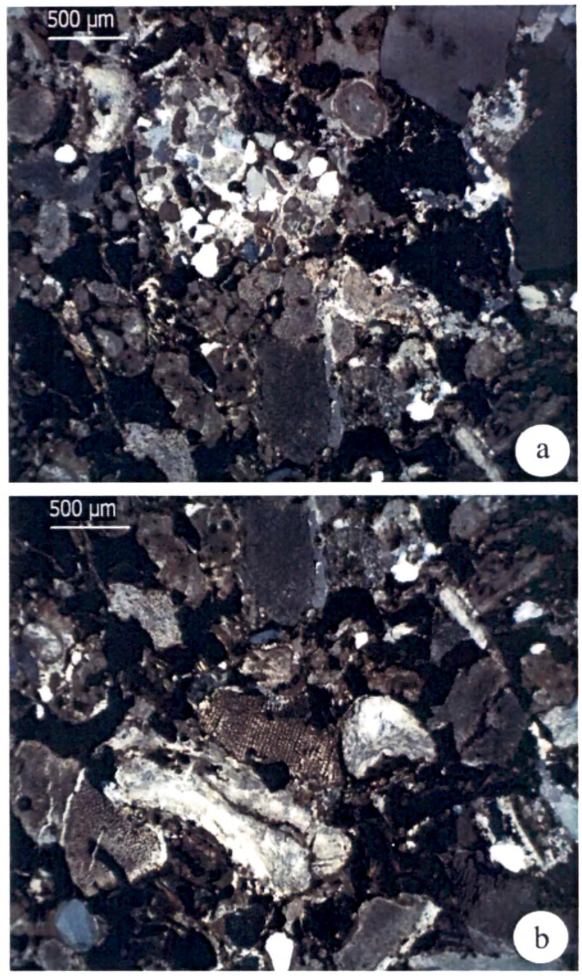

Plate 4.7a Thin sections – Conglomerate Lithofacies – GOs

Plate 4.8 Conglomerate Lithofacies – RMCSSL

Plate 4.9 Conglomerate Lithofacies - DOs

During the storms, the micritic and ferruginous mud along with quartz and other detrital grains and fragmented material seem to have produced mud dominated bottom regimes. Due to the cohesive nature at the time of waning energy conditions, which is seemingly settled along with exhorted concretions -pebbles and bioclasts, -formed matrix and cement of the conglomerate provided setting grounds for pebbles and cobbles, while finer argillaceous clayey sediments were probably transported elsewhere along with storm generated currents.

The overall characters of the conglomerate facies in RMCSSL and GOs, shows a much lesser proportion of bioclasts in comparison to pebbles while in Dos the proportion of pebbles is less as compared to bioclasts. This facies indicates storm generated deposits (abundant mega fossils) in much shallower conditions, where in upper regimes storm flow dominated.

4.2.3 Calcareous Silty Shale Lithofacies (CSSL) – Member B; Member D (Jhurio FM.) and Member – I (Jumara FM.)

Description: This facies is found to occur in the Jhurio and Jumara Formations and is often associated with GOs (Fig. 4.3). It exhibits a thickness of about 40 meter in association with GOs and at base of Jumara Formation; it un-conformably overlies NWWLs (Fig. 4.1, 4.2 and 4.3). This facies consists of an association of grey to greenish calcareous, quartzose shales, khaki coloured, laminated, silty shales and laminated calcareous shales with lenses of crystalline calcite. It also shows thin parallel laminations which are occasionally silty in nature.

This facies also consist of few species of belemnites and ammonite (*Macrocephalites*). It consists of abundant trace fossils which includes - *Rhizocorallium uraliense, R. jenense, R. irregulare, Urohelminthoida dertonensis, Thalassinoides suevicus, Scolicia strozzii, Sabularia ramose, Planolite isp., P. annularis, Pilichnus dichotomus, Phycodes circinnatum, Palaeophycus tubularis, P. hebeti, P. striatus, P. annulatus, Monocraterion tentaculatum, Margaritichnus reptilis, Laevicyclus mongraensis, Gyrochorte comosa, Diplocraterion isp, Calycraterion Samsonowiczi, Chondrites targionii, C. patulus, C. recurvus, C. intricatus, Biformites isp., Bergaueria isp., Arenicolites carbonarius.*

Plate 4.10 Calcareous Silty Shale Lithofacies

Interpretation: The shale forms the bulk of the lithology and dominates the lower part with alternations of golden oolite rocks. Thus, the quieter conditions of shale deposits were periodically interrupted by the higher energy states. During the slow transgressive periods the shales were deposited by reworking of the residual clays. Perhaps the subsidence was intermittent. At times when the rate of subsidence was too low or the basin subsidence, stopped for a short period, the depth of water was reduced and thick bed of golden-oolite-rocks were deposited under shoreface (littoral) conditions. The shale deposition followed again as the subsidence resumed. During the slow transgressive periods the shales were deposited by reworking of the residual clays. This facies is deposited in stable, calm, offshore conditions where terrigenous fine grained sediments input/supply were less.

4.2.4 Oolitic Limestone Lithofacies (OLL)

4.2.4.1 Golden Oolite Subfacies (GOs) – Member C and Member E (Jhurio FM.)

Description: This facies occurs with CSSL of the Jhurio Formation and consists of three thick beds of golden-oolite (Fig. 4.3). Two thin bands of golden oolites are intercalated with well bedded limestone at the base of the NWWLs of the Jhurio Formation. Lower band is hard and dull green to reddish colour; middle band consists of a massive bed of golden oolite rock with a thin bed of limestone; and upper band represents intercalations of bedded brown and grey limestones with golden oolite rocks. The middle band gives a brick red colour and also shows the presence of physical sedimentary structures like current ripples; wave ripples (Plate 4.11, 4.12 and 4.13) cross bedding parallel laminations. Lower part of each of these bands consists of reddish brown pebbles of lateritized rocks and sub angular fragments of a greenish marly rock and sub-angular to well rounded pebbles coated with golden yellow films. The golden-oolite-rocks are well bedded with sandy sparites and usually the upper and lower parts consist of pink limestone bands having few ooliths. These are highly fossiliferous and consist of bivalves, brachiopods, gastropods, cephalopods, crinoids, bryozoans, ostracods, foraminifers and echinoderm. Bioclasts (usually less than 20%) are crushed and well rounded, sometimes coated by a thin ooidal cortex (superficial ooids). Detrital quartz is rather common (up to 20%) and large (average 0.3 mm in diameter). A few oncoids/oncolites and small oolite debris are also present. Flat clay-silty pebbles, up to several millimetres in size frequently contain an admixture of quartz grains and ooids, often completely micritized.

The subfacies comprise totally of oolites; mostly ellipsoidal in shape, between 0.2 and 2.0 millimeters length/diameter. Oolites have concentric and/or tangential internal structure where as pellets similar to oolites has no internal structure. Ooids (usually 80-90%) 0.2-0.5 mm in diameter, are well preserved. Ooids cores are composed of quartz grains, peloids or bioclasts. However, the most common cores are older, micritized, abraded or partly dissolved ooids and small oolite debris comprising 1-3 ooids cemented with sparite. Such ooids with oolitic cores and 1-3 laminae of well preserved banded radial cortex are interpreted as reworked ooids. Presence of compound oolites along with sparite cement is very common.

They are fossiliferous oosparite, made of large golden and brown ooliths, shell fragments and silt-size quartz grains as nuclei of oolites. The matrix is composed of mainly sparite;

occasionally it shows clayey-muddy micritic material. The ooliths are ovoid with concentric layers – round / oblong nuclei of quartz, calcite and silt or shell fragments. They are frequently flattened and deformed as *spastoliths*. The concentric layers of ooliths are composed of chamosite which on oxidation give 'the golden yellow' colour. The terrigenous material, mainly sand and silt grade quartz, is less than 20%.

There are abundant single and multi nuclei Oolites that have quartz, fossil fragments, peloids or calcite grains as nuclei (Plate 4.15). Quartz is angular to sub rounded in nature. However, some thin sections showcolder cores with micritized (Plate 4.15, a, e, f) nuclei. Sparry calcite cement as matrix will give different colours in between cross nicols due to calcite grains with some quartz, which is angular to sub-angular. The oolites (up to 60%) and oncoids (5-10%) are present in the sparry matrix whereas small oolite debris comprising 2-3 ooids are cemented with micritic and sparitic (Plate 4.15, a, b) cement. Variable packing of allochems in oolites are also observed (Plate 4.15, a-b). Overall, the lithofacies is matrix supported with fine grain carbonate mud as matrix. In the process of diagenesis, micritic matrix present at the time of deposition converted in to coarser grain calcite crystals which are supported by floated nature of ooids and bioclasts within sparitic material. Ooids have sparry nuclei as intraclasts (fragmented grains of calcareous origin), which were earlier formed as matrix fragments within the basin.

This facies contain body fossils such as *Alectryonia, Rhynchonella, Terebratula* small ammonites (*Macrocephalites*) and corals (*Montlivaltia, Isastrea, Trochosmalia*). The trace fossils identified from this facies are: *Arenicolites carbonarius, Beaconites coronus, Chondrites intricatus, C. patulus, C. isp., C. targionii, Calycraterion isp., C. Samsonowiczi, Didymaulichnus isp., Diplocraterion isp., Gordia marina, Keckia annulata, Margaritichnus reptilis, Monocraterion tentaculatum, Ophiomorpha nodosa, O. recta, Palaeophycus heberti, P. striatus, P. tubularis, Phycodes circinnatum, P. curvipalmatum, Phymatoderma isp., Pilichnus dichotomus, Planolites annularis, P. beverleyensis, P. isp., P. montanus, Rhizocorallium irregulare, Sabularia ramose, Skolithos linearis, Taenidium cameronensis, T. satanassi, T. serpentinum, Thalassinoides foedus, T. horizontalis and T. paradoxicus.*

Plate 4.11 Golden Oolite subfacies shows mega-ripple marks

Plate 4.12 Golden Oolite subfacies consists cross bedding

Plate 4.13 Corals in Golden Oolite subfacies

Plate 4.14 Golden Oolite subfacies showing intensive Bioturbation

Interpretation: The Golden Oolites (ooidal ironstones) are associated with a major sequence boundary and subsequent transgressive surface (Taylor et. al. 2002).They have been deposited under conditions of low net sediment accumulation in well-oxygenated bottom-water conditions, with episodic storm events reworking the sediments. They either have been deposited in an estuarine environment or have been deposited in a shallow-marine environment. Oolites are dominated grain-rimming and pore-filling siderite or sparite, with later ferroan dolomite and calcite in the ooidal ironstone. Petrographic, geochemical, and isotopic evidence, coupled with thermodynamic considerations, indicates that the ooidal ironstone mineralogy formed during suboxic diagenesis (Taylor et. al. 2002). The conditions

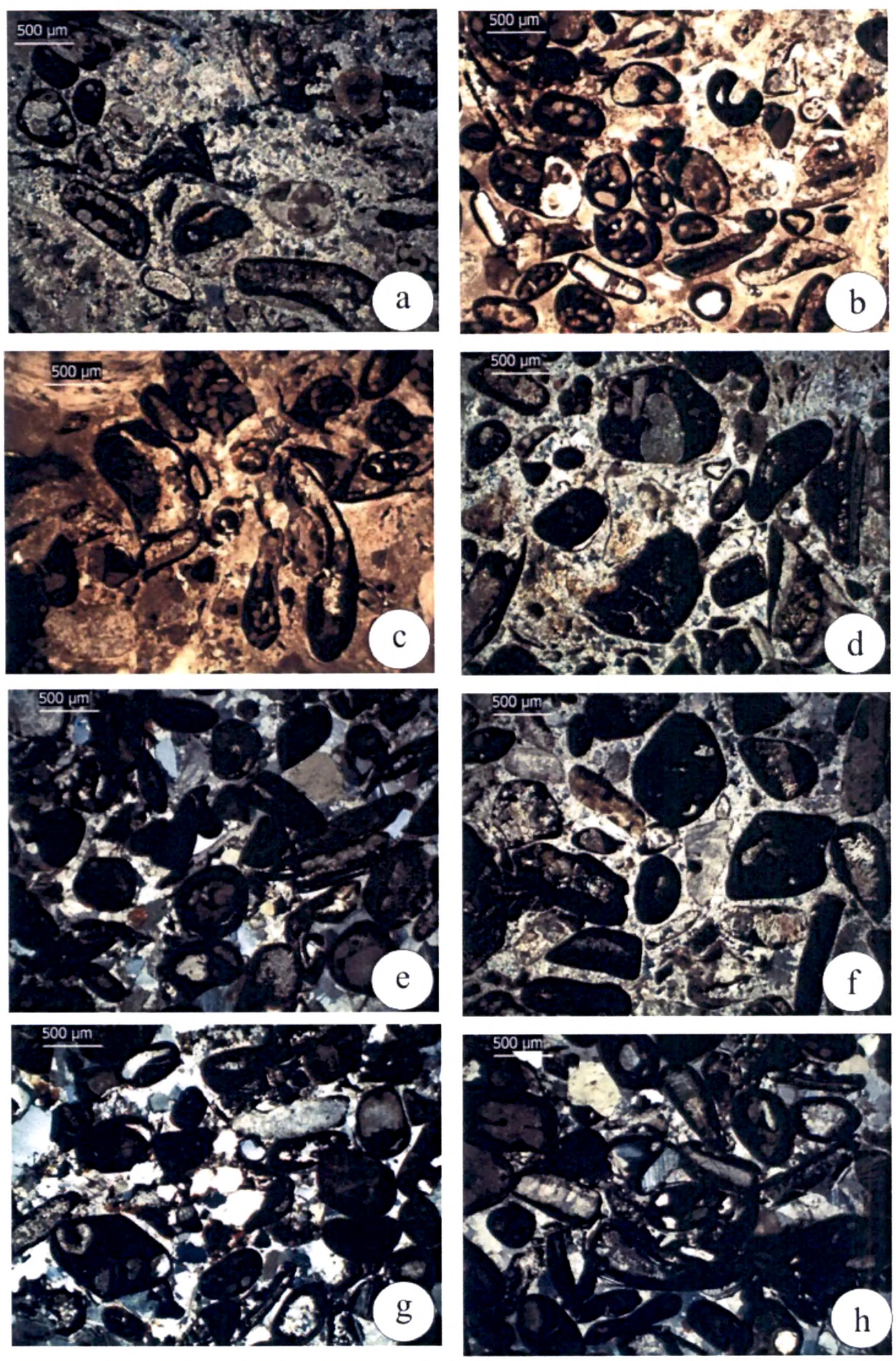

Plate 4.15 Thin sections - Golden Oolite subfacies

required for suboxic diagenesis were extensive sediment reworking and slow net sediment accumulation rates. These conditions occurred as a result of marine transgression during the initial relative sea-level rise following the development of a sequence boundary. Ooidal ironstone formation ceased once sedimentation rates increased and transgression deepened water depths considerably. These results illustrate the association between ooidal ironstones and major stratal surfaces in sedimentary successions, and highlight the complexity of early digenesis at such surfaces. Ooidal ironstone units in sedimentary successions are relatively uncommon, yet distinctive and occur in both Siliciclastic and Carbonate dominated successions (Young 1989). Ooidal ironstones have a distinctive mineralogical composition of iron silicates (berthierine and chamosite), carbonates (siderite), and oxides (goethite and hematite) (Young 1989; Macquaker et al. 1996). Their distinctive mineralogy is generally considered to be a result of early diagenetic transformation of iron hydroxides and clay minerals, originally derived from either soil material (Taylor and Curtis 1995) or volcanic processes (Sturesson et al. 2000).

The golden oolite rocks are pebbly and ferruginous and indicate deposition where energy was high. Thus, the quieter conditions of shale deposits were periodically interrupted by the higher energy states. The limestone with low clastic content indicates deposition away from the littoral zone and a gentle rate of subsidence when the rate of erosion was low. The alternations of micrite and sparite again indicate repetition of quiet and high energy conditions respectively. While the micrites are generally deposited below the average wave base, the occurrence of oolites indicates interventions of higher energy states perhaps during repeated storm cycles. The golden colour of chamosite ooliths in golden oolite rocks and the prevailing light colouration of the biomicrites and biosparites indicate conditions of oxidation. Towards the end, the deposition of carbonate followed when the micrites were deposited below the wave base in quieter conditions and sparites during high energy periods. The occurrence of giant wave-ripple marks on the golden-oolite-rock bands associated with the cross bedding also suggests that strong waves were present during the deposition. These suggest a shallow, open shelf deposition where free circulation and aeration predominated. All these features characterize a sub-littoral / shoreface depositional environment.

The deposition of the facies seems to have taken place in sub-littoral environment under more or less stable shelf conditions when the rate of subsidence was slow and sea was encroaching gradually over the old land. This is a highly bioturbated (Plate 4.14) and disturbed sequence which most likely got deposited in the lower shoreface to transition zone.

4.2.4.2 Dhosa Oolite Subfacies (Dos) – Member IV (Jumara FM.)

Description: Dhosa Oolite subfacies (Plate 4.18) is found to occurs in Dhosa Oolite Member at the top of Jumara Formation (Fig. 4.1 and 4.2) and is about 23 meter in thickness and comprises of alternating bands of oolitic limestones and shales. The lower part of the subfacies is characterised by thick greenish grey gypseous shale with few centimetre thick hard feeruginous / calcareous sandstone bands, lacking in bioturbational structures indicate anaerobic and dysoxic condisions. The upper part (Plate 4.16 and 4.17) consists of 0.2 to 1.5 m thick hard, resistant, greenish brown, oolitic bands where the uppermost bed (Plate 4.16) of the Oolitic limestone is represented by an intraformatinal conglomerate which consists of large size of boulders of oolitic limestone, ammonites and abundant belembite guards (Plate 4.19 and 4.20). All these are indicative of a high wave and current energy or storm events or may even point to a catastrophic event. Trace fossils in this part of the sequence are eventually absent. The upper oolitic limestone bands which are thoroughly bioturbated and well aerated had provided suitable conditions for infaunal elements. There are twenty-three oolitic limestone bands intercalated with shale present in the south flowing nala section near village Kamaguna. The facies is characterized by the presence of varying proportion of ooids in the hard bands. The facies contains varied types of lithology, which range from oolitic, bioclastic, calcareous sandstone to oolitic, micritic or sparitic limestone. Texturally, rocks are sub-mature to immature, contain rounded to sub rounded, silty to medium sand size quartz with few microcline, plagioclase grains, scattered in micritic mud. Grains are coated with either ferruginous or calcareous material. Majority of the grains are corroded and few are coated with either ferruginous or calcareous material. Sometimes two to three quartz grains stick together by coating. The cement is micritic to microsparitic but in some cases ferruginous patches have also been observed. The ooids enclose microfossils of ostracods and other fossil fragments

The ooids are of various origin - some of them are made up of micritic material and coated by similar type of material with inner part slightly neomorphosed, recrystallised, and showing radiating arrangement in several cases. Second type of ooids are micritic, coated by yellowish brown ferruginous concentric layers, few of them are partly recrystallised. Other type of ooids are brown, ferruginous with various number of concentric layers which may be ferruginous or micritic or microsparitic. In some cases radiating, fibrous, calcareous material in the core is found covered by thick micritic layer, followed in the outer part by thin micritic to ferruginous layers. The overall nature of limestones of the facies is micritic except for a few patches that are recrystallised to form sparitic crystals. A few patches of ferruginous material are also present. Sometimes it is microsparitic with poikiloclastic textures, incorporating detrital grains and ooids.

Microscopic observations has revealed that the subfacies is fine grained, well sorted, ferruginous, silty, intramicrudite and/or sandy micritic oolitic fossiliferous limestones (Plate 4.21). Deposits of this facies comprise elongated to sub-rounded ooids (up to 70%), quartz (15-30 %), intraclasts (less than 10%) and also bioclasts up to 70% at places (Plate 4.21, a-b). They are highly fossiliferous (Plate 4.21, a-b, f); bioclasts are mainly belemnites, bivalves, ammonites and brachiopods. Isopachous and irregular (gravitational?) rim cements around ooids and reworked micritized nuclei in the ooids are observed (Plate 4.21, c). The bioclasts are usually of large size (typically 2 to 3 mm). The diameter of the detrital quartz varies from 0.1 to 0.15 mm. The presence of numerous well preserved ooids under micritic matrix and larger bioclasts (Plate 4.21, a-b), as well as the presence of intraclasts of oolites, are characteristic features. Most of the intraclasts are very similar to the rocks of lithofacies. Some of the sections (Plate 4.21, d, e) have shown calcareous siltstone nature with microsparite as cement in presence of few ooids.

The Dhosa Oolite Subfacies is regarded as a slow sedimentation within transgression (Singh, 1989) which marks the top of the Jumara Formation. Fursich et al. (1992) suggested that the Dhosa Oolite forms highly condensed unit (Plate 4.17) characterized by hardground, intraformational cobbles, reworked concretions, iron oncoids and shell lag deposits.

Bioclasts (bivalve, brachiopods, cephalopods and gastropods) are mostly smaller in size, almost unaltered to completely recrystallized and neomorphosed. Belemnites and Ammonoids are abundant in the upper band of the facies (Plate 4.19; 4.20; 4.21, a-b). Trace fossils are also abundant and are represented by. *Chondrites intricatus, C. patulus, C. isp., C. targionii, Palaeophycus alternatus, P. annulatus, P. heberti, Rhizocorallium irregulare, R. jenense, Thalassinoides horizontalis, T. suevicus, Gyrochorte comosa, Zoophycos brianteus,* *Z. circinnatus., Z. laminatus, Z. villae, Z. Type A, Z. Type B, Z. Type C, Z. Type D,* and *Z. Type E.* Brown to black coloured, woody fibrous materials have also been observed.

Interpretation: The Oolitic Limestone Subfacies is indicative of prolonged phases of omission and frequent erosive intervals leading to a very slow rate of net sedimentation. This suggests an environment far away from terrigenous input. The wide geographical distribution of these features also points to an offshore position well below the fair weather wave base. While the iron ooids were probably derived from a near shore source, the carbonate components, large bioclasts, are formed locally by biological or mechanical degradation of shells. Erosion was most likely caused by offshore currents which winnowed finer sediment, leaving lag deposit behind. However, formation of extensive under cuts cannot have been the

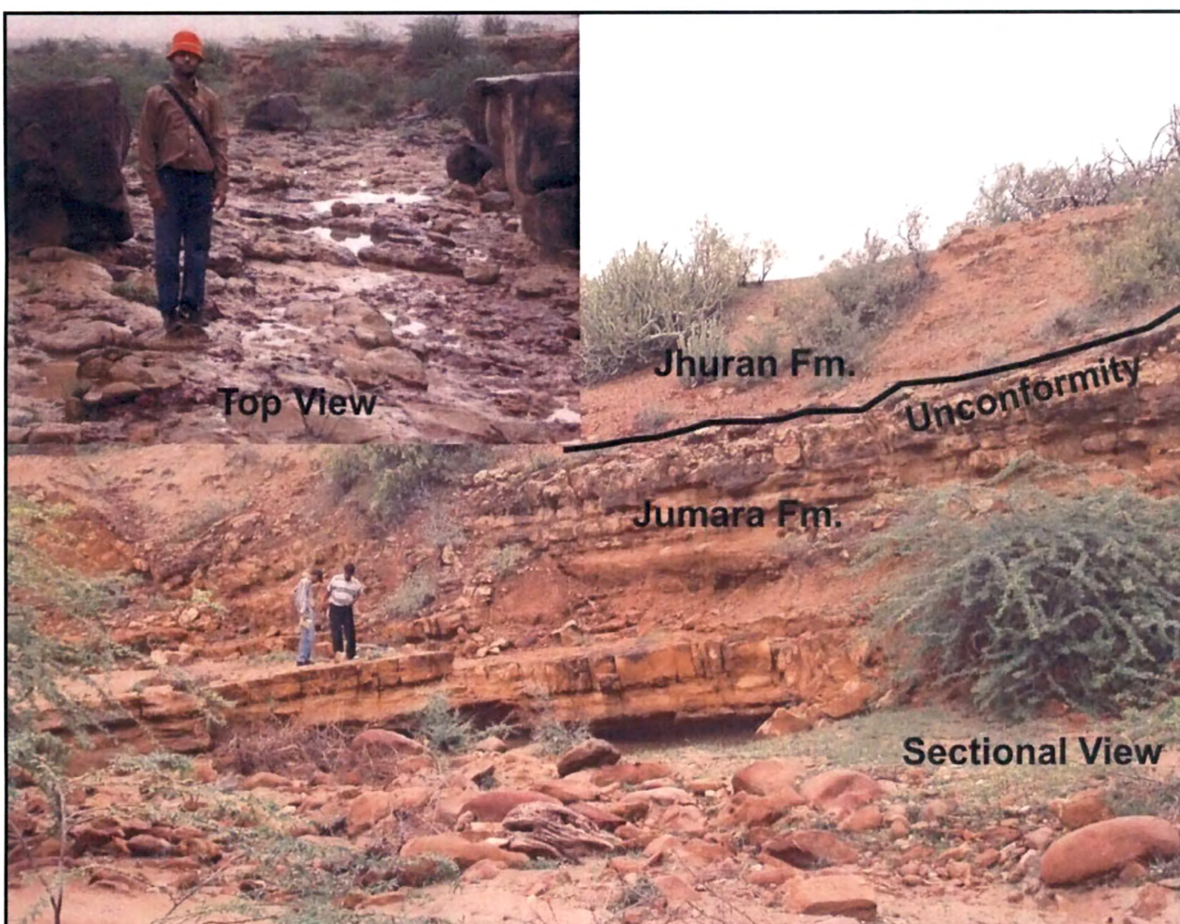

Plate 4.16 Dhosa Oolite Subfacies

result of winnowing alone. These features were probably produced by the scouring action of exceptionally strong storms which also might have distributed the iron ooids across the basin.

These undercuts might have partly been produced or aided by the formation of bioturbational activity under the same set up, below the fair weather wave base. Deposition of Oolitic Limestone facies, thus took place in a relatively uniform offshore setting, well below fair weather wave base, but still within the reach of singular storms. The uniform condition and the negligible sediment input most likely reflect a transgressive phase which persisted throughout the Oolitic Limestone facies deposition.

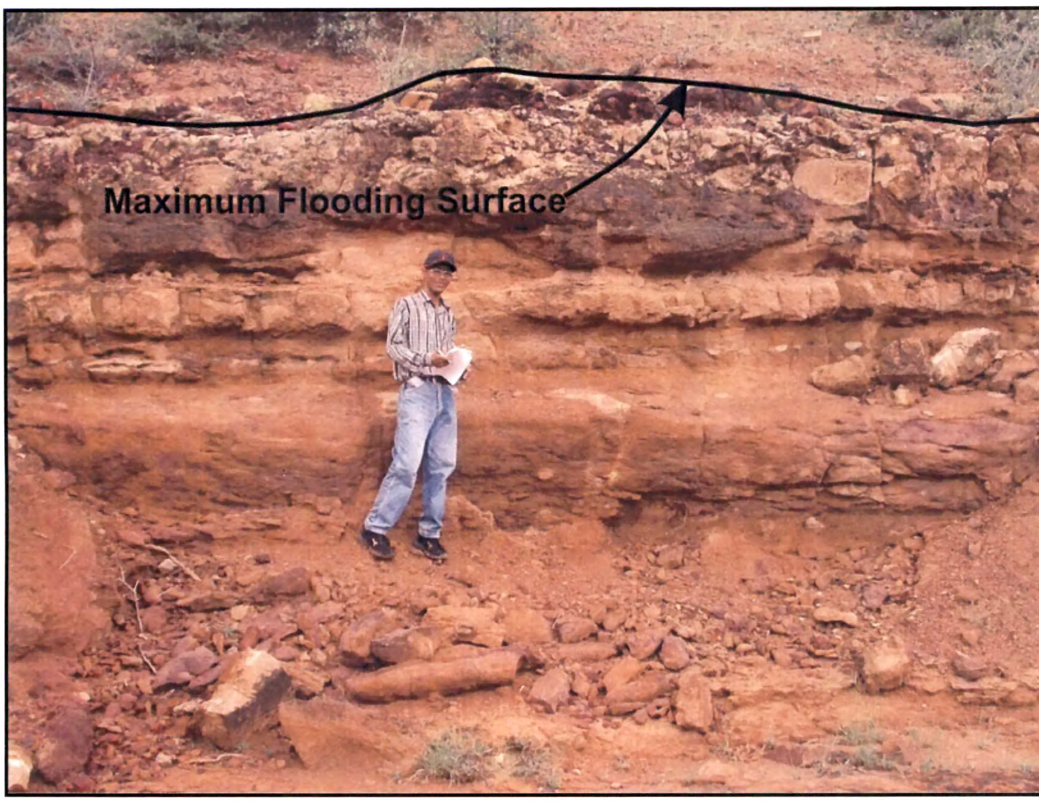

Plate 4.17 The maximum flooding surface – DOs

However, the lack of shallow water features, such as primary sedimentary structures, and the presence of features characteristic of iron crust and hard grounds are more in agreement with the interpretation of the facies as transgressive horizons. The dominance of *Zoophycos* and *Chondrites* and other feeding traces suggest generally low energy conditions with oxygenated substrate.

Plate 4.18 Dhosa Oolite subfacies intercalated with shale lithofacies at Kamaguna

Plate 4.19 Ammonoids – Dhosa Oolite subfacies

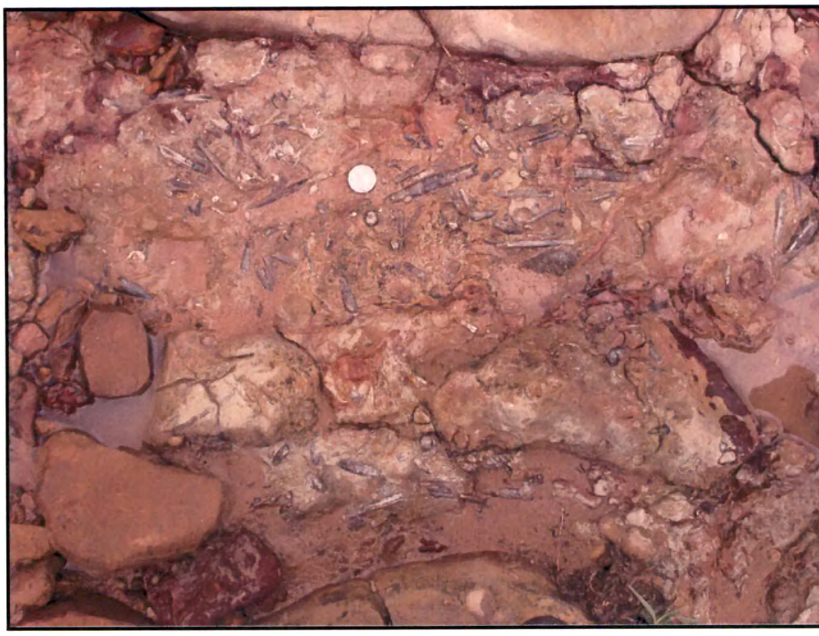

Plate 4.20 Belemnites – Dhosa Oolite subfacies

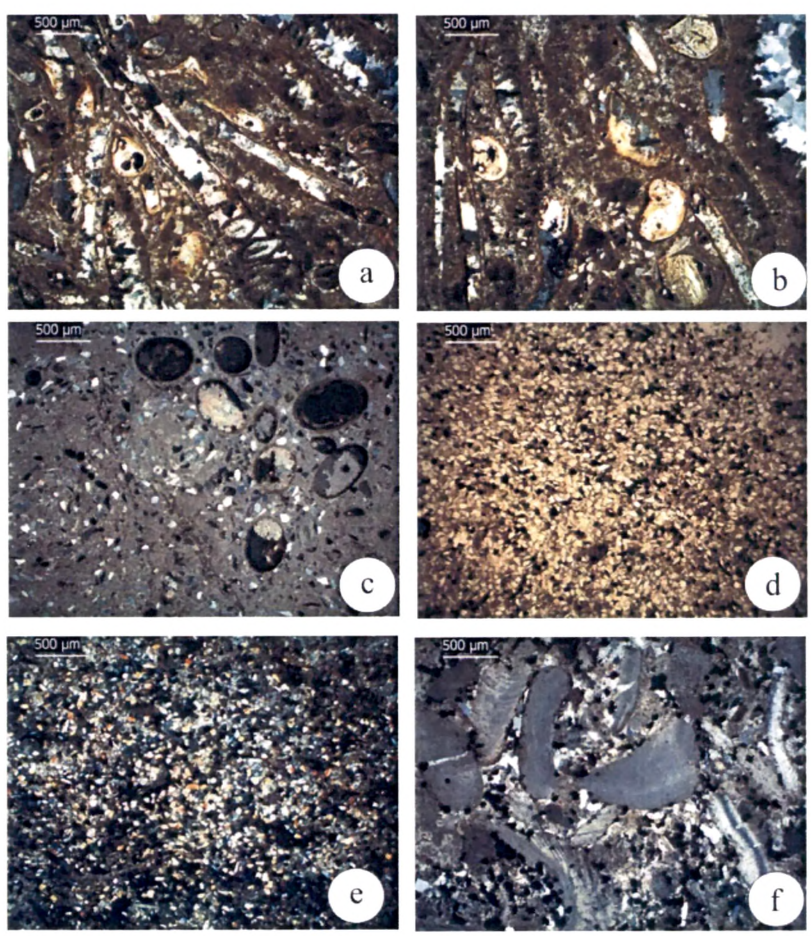

Plate 4.21 Thin sections – Dhosa Oolite subfacies

4.2.5 Rippled Marked Calcareous Sandstone Shale Lithofacies – Member II (Jumara FM.)

Description: The facies is defined on the basis of the presence of wave ripple marks (Plate 4.22) on the top; cross stratification and calcareous material as cement in the rock, along with presence of abundant mega-fossils. The rocks of the facies occur in Jumara Formation and consist of four hard calcareous sandstone bands intercalated with shale (Fig. 4.1 and Fig. 4.2). At places two hard calcareous sandstone bends are prominent and form a cliff like appearance called Ridge Sandstones which mark the periphery of the dome (Plate 4.23). Rocks are massive, horizontally bedded to cross bedded, graded to inverse graded and consist of up to 3 m thick bands. The top of the bed is persistently appearing as conglomeratic. Top of the beds is characterized by straight to gently sinuous ripple crests which is locally bifurcated or branched. This facies also consists of highly bioturbated ferruginous sandstone layers (Plate 4.24) at places which have obliterated the primary sedimentary structure of the rocks. Locally the facies shows poor graded nature, as well as within a single bed internal scouring and reactivation surfaces are present. The facies also contains flat pebbles of red to brown, ferruginous, argillaceous material and dirty white to yellow marl. Horizontal stratification and planar cross-stratifications are commonly obliterated by trace fossils. The facies is highly bioturbated and shows numerous regenerated or pause planes which indicate fluctuation in the sedimentation rate.

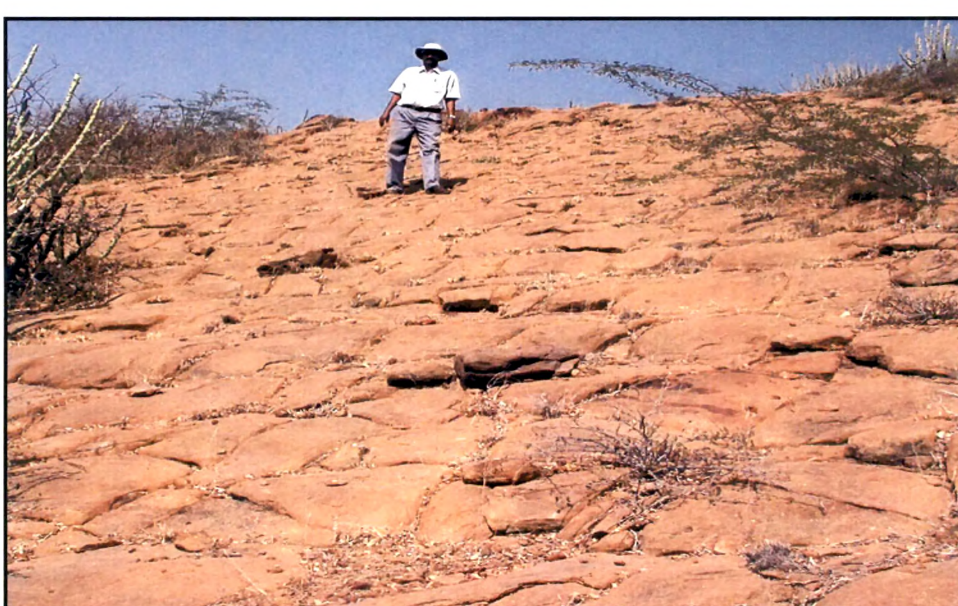

Plate 4.22 Rippled marked calcareous sandstone lithofacies

Thin section (Plate 4.25) studies depict that the grain size of the rock varies from fine sands to coarse gritty and gravely sand. Larger grains are angular to sub-rounded, smaller grains and matrices are angular to sub angular and in most of the cases poorly to moderately sorted. Elongated disc-shaped particles are also present in the rocks. Mineralogically, the rocks are immature and contain feldspar grains up to 10 % visually. Feldspar grains are mainly of microcline with some amount of orthoclase and plagioclase (Plate 4.25, f, h) and few small size mica grains are also present (Plate 4.25, b). Sand size quartz grains mainly show straight extinction, but a small amount of grains show undulose extinction, whereas large gritty - gravelly grains show either undulose extinction or polycrystalline nature. Cement is mainly micritic but in some cases scattered dolomitic to ankeritic crystals are also presents. Ferruginous cement also occurs in the form of small patches or disseminated form in few thin sections. Occurrence of micritic as well as ferruginous material as cement indicates two stages of diagenetic effects. Grains densely float in the cement or at times produce framework supported texture. Thin sections were indicating both grain and matrix supported structure. Presence of fossil fragments and free quartz in high quantity would give 'fossiliferous calcareous sandstone' name to the lithofacies. 5% to 10% pellets are also present in few sections which indicate intraformational origin.

Microscopically, it is representing >70% of quartz and<15% of feldspar, high compositional maturity, hence it is texturally clean, matrix free quartz sandstone or arenites (Folk 1962) (Plate 4.25, d-f, h). Some thin sections (Plate 4.25, a-c, g) represent 15% to 60% matrix content, argillaceous, texturally immature, matrix rich dirty sandstone, and very rich in fossil content.

The facies is characterized by the presence of abundant bivalves (*Trigonia, Astarte,* and *Oysters*). Other fossils included in the facies are gastropods, brachiopods, cephalopods, bryozoans, foraminifers, echinoids and brachiopod spines, algal filaments etc. This facies is highly bioturbated and consists of abundant Trace-fossils (*Ophiomorpha nodosa, Thalassinoides suevicus, T. foedus, T. horizontalis, T. paradoxicus, Rhizocorallium irregulare, Planolites montanus, Pl. annularis, Pl. beverleyensis, Pl. isp., Pilichnus dichotomus, Phycodes palmatum, Parahentzscheliana ardelia, Palaeophycus tubularis, P. annulatus, Monocraterion tentaculatum, Margaritichnus reptilis, Laevicyclus mongraensis, Gyrolithes polonicus, Gyrochorte comosa, Gordia marina , Diplocraterion isp.,* *Calycraterion Samsonowiczi, Chondrites targionii, C. intricatus, Bergaueria isp., Arenicolites carbonarius, Ancorichnus Ancorichnus).*

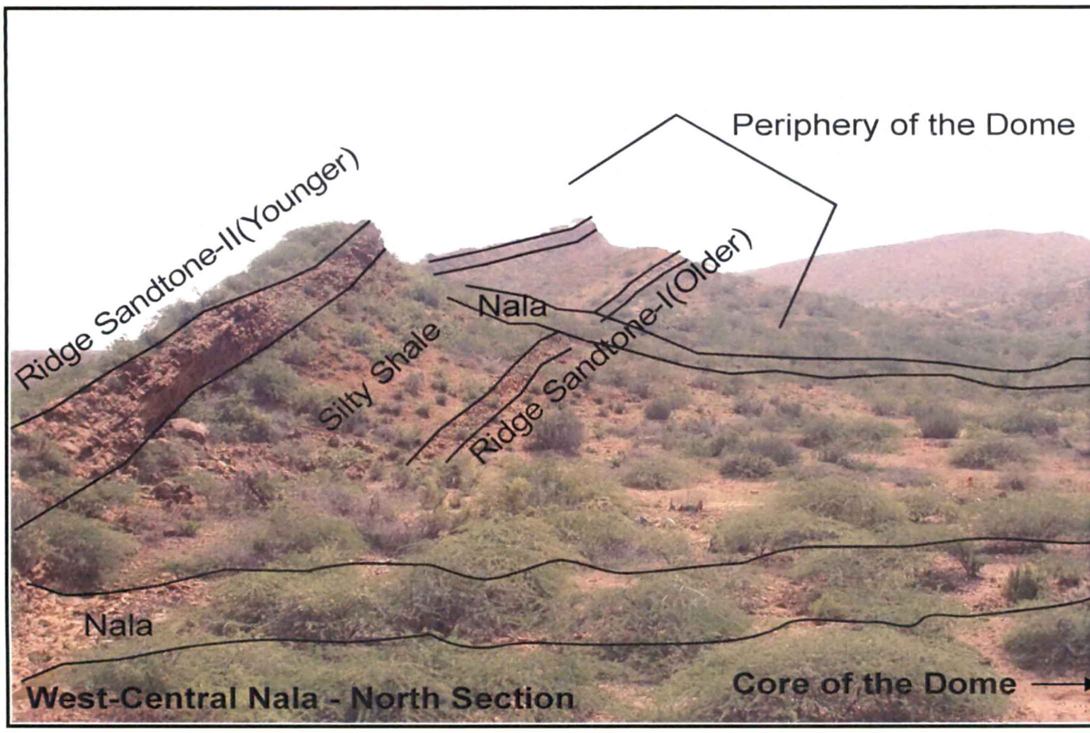

Plate 4.23 Arial view of the periphery of the dome

Plate 4.24 Highly bioturbated ferruginous calcareous sandstone lithofacies

Interpretation: The unsorted nature, pebbly to gritty grains, flat pebble layers and mega wave ripples depict storm generated nature. The cross stratification, which is planar to trough in nature, depicts its origin by movement - migration of sediment in the form of bed load. The lower erosional or scoured surfaces also suggest scouring during initial rising phase of the stormy event. Deposition of the facies under waves is suggested by the presence of straight and bifurcating, crested, symmetrical mega ripples on the top of sandstones. Presence of intrabasinal grains and pebbles suggest exhumation. The intrabasinal flat pebbles such as those described herein are commonly associated with fore shore and near shore zones (e.g. Hart and Plint, 1989). The erosional and reactivation surfaces present within a single bed of the facies suggest, that the packages were emplaced periodically by events within short time spans that generated extremely competent currents i.e. storms. The storm generated nature is also depicted by the mega wave ripples, unsorted nature, occurrence of smaller to larger detrital grains and bioclasts in the rock, as well as occurrence of intraformational pebbles normally at the base and overall gradational nature of the deposits. Coating and corrugated nature of some of the grains and bioclasts and ferruginisation of the fossils depict some amount of wear and tear and local transportation before deposition. The stable bedforms during the final phase of deposition were symmetrical mega ripples, preserved capping the facies under normal waves.

The ripple index indicates influence of both wave and current energy. The dominant straight crested symmetrical ripples on the other hand also point towards the oscillatory wave action during tidal cycles. The variation in bioturbation suggests deposition variation; where in, the upper part of tidal flat shows less intense burrowing than the lower part of the tidal flat, where the density of infaunal animals is high as suggested by Miller and Knox (1985). Occurrence of hummocky cross-stratification suggests undulating depositional surface and winnowing under higher energy conditions. The facies is highly bioturbated and shows numerous regenerated or pause planes which indicate fluctuation in the sedimentation rate.

The coarse sandstones are massive to trough, cross-stratified with frequent occurrence of bioclasts (oysters, belemnite guards, ammonoids and brachiopods) and biogenic structures. It indicates that the deposition of this facies has taken place in high wave and current energy environment above the fair weather wave base, in subtidal conditions.

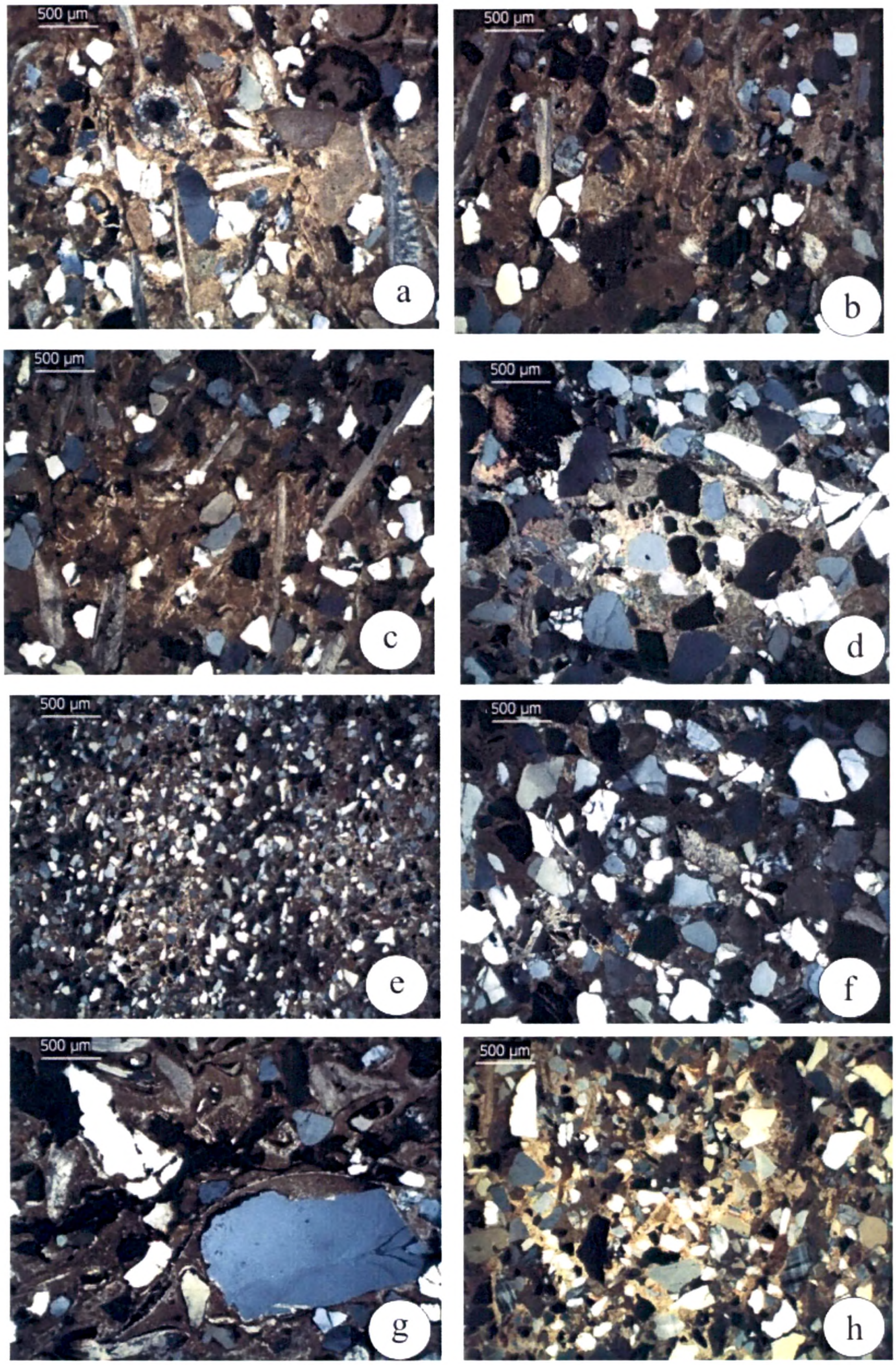

Plate 4.25 Thin sections - RMCSSL

4.2.6 Greenish Grey Shale Lithofacies (GGSL) – Member IV (Jumara FM.)

Description: The Greenish Grey Shale Subfacies (Plate 4.26) is greenish brown, yellow, red and brown to black in colour, consisting of varying shapes of abundant gypsum crystals. The facies forms a part of the Jumara Formation and is about 20 meter thick. This lithofacies also includes thin green glauconite and yellow limonitic layers, red ferruginous layers and few layers of calcareous concretions with sideritic nodules. The facies generally shows a thickness of 15 meter and consists of flat, fibrous and long (up to 40 cm) gypsum crystals and evaporated vein deposits. The shale often contains silt-size quartz grains with glauconite, argillite and fragments of plants.

The rocks are massive to laminated, fissile to non fissile and moderately compacted to loose or unconsolidated. Composition varies from felspathic, ferruginous, clayey to carbonaceous. Thickness ranges from 0.1 meter up to 2.0 meter and occurs in the form of elongated beds and lenses. It normally shows quick gradational lower contact and gradational, abrupt to erosional upper contact. Trace fossils are moderate in some rocks and rare to completely absent in others. Leaf impressions and plant fragments are abundant, but no root structures were observed. Body fossils are represented by fragments of scattered belemnites and ammonites. Burrows, when present, have deformed and collapsed due to fissility of the rocks. Infrequently, facies grades in to siltstones, showing in some cases trough and planar cross-stratification and symmetrical to asymmetrical ripple marks on top. Carbonaceous shales with abundant leaf impressions and burrowed ferruginous shales are commonly found in the lower part of the facies sequence.

Interpretation: Shale is generally considered to be deposited during the transgressive phase in a sedimentary basin. The Gypseous shales are green to greenish-grey, red-brown, splintery with yellowish limonitic partings and comprise of light coloured mottled fissile shale with well-developed gypsum crystals, embedded in the bedding plane. The fine grained nature of the facies suggests that the sediments were deposited in quiet water of low wave and current energy, i.e. protected environment e.g. lagoon. The predominant argillites with ferruginous layers indicate that the deposition has taken place in shallow marine environment, in reducing conditions. The well-developed gypsum crystals indicate that the body is separated from the main sea and evaporation has taken place. The dark colour of the black shale is difficult to ascertain: whether this colour originated by weathering in source area, developed through *in-*

situ oxidation or reduction at the time of deposition, or as a result of diagenetic changes after burial. However, high degree of dark mottling in shale also indicates post-depositional modification. Nodular siderite occurring in this unit appears to be significant as its presence in shale indicates brackish water or fluctuating salinity condition and moderately low pH and oxygen content (Woodland and Strenstrom, 1979).

Plate 4.26 Greenish Grey Shale Lithofacies

Paucity of structures in this facies makes environmental interpretation difficult, although it appears to have deposited under quiet water conditions. Rarity of biogenic structures may be due to, in part, poor exposures, rather than solely to the lack of trace producing animals as can be seen in felspathic and carbonaceous shales and mudstones. Occurrence of biogenic structures in ferruginous shales depicts favourable conditions for infaunal elements and oxygenated aerobic conditions.

Owing to the presence of evaporite deposits, very little bioturbation and abundant leaf impressions, a lagoon to intertidal origin for the shales can be postulated. The frequent repetition of these facies in the stratigraphic record indicate slowly subsiding basin, giving rise to repetitive phases of shallowing by sedimentation and evaporation in partially enclosed water bodies.