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# SHALLOW SHELF SEDIMENTATION OF THE JURASSIC SAMANA SUK LIMESTONE, KALA CHITTA RANGE, LESSER HIMALAYAS, PAKISTAN

BY

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**Abstract: -***Detailed sedimentological studies of the Samana Suk Limestone (type section Samana Suk Peak, Samana Range, Pakistan) have been carried out from the Kala Chitta Range, Pakistan as the first comprehensive contribution of its kind. Two lithologs from Surg and Chapra have been extensively studied to elaborate the sedimentological details. The stratigraphic name refers to the Upper Triassic to Liassic Kioto Limestone of earlier literature, which has now been differentiated into the Triassic Mianwali Formation, the Chak Jabbi Limestone, the Kingriali Formation and the Jurassic Datta Formation, and the Samana Suk Limestone.*

*The Samana Suk Limestone is well-bedded limestone and can be identified in the field into oyster bearing beds, micritic beds, shelly limestone composed of gastropods and pelecypods, sandy limestone and the oolitic limestone. These observations are indicative of shallow shelf deposits. The microscopic studies have identified most common microfacies into the mudstone (micritic facies), bioclastic wackestone, packstone where the skeletal elements are the oysters, gastropods and the pelecypods, while the grainstone is non skeletal represented by the oolitic grains. Apart from the microfacies analysis, the diagenetic imprints have also been elucidated. All these features also substantiate its shallow shelf sedimentation. In other words, it represents a carbonate platform deposition.*

## INTRODUCTION

The Kala Chitta Range is a part of the foreland-fold and thrust belt, which forms the northern border of the adjoining hydrocarbon bearing Potwar Basin (Fig. 1)

The stratigraphic name Samana Suk Limestone was introduced by Davies (1930) for his Upper Jurassic Limestone Unit from the Samana Range, the type locality being the Samana Suk Peak in the Samana Range.

In the Kala Chitta Range, this formation formed part of the Upper Triassic – Liassic Kioto Limestone of Cotter (1933) which is now formalized by the Stratigraphic Committee of Pakistan (Fatmi, 1973) into the Triassic Mianwali Formation, the Chak Jabbi Limestone and the Kingriali Formation, the Lower Jurassic bauxite bearing Datta Formation and the Middle Jurassic Samana Suk Limestone. This terminology has also been extended to the Salt Range, Potwar and the Hazara Mountains of northern Pakistan.

The Samana Suk Limestone comprises thin to thick-bedded limestone, dolomitic limestones and dolomites alternating with marls and marlstone. Occasional sandy limestone beds are also present. Cyclic or rhythmic bedding has also been observed.

The Samana Suk Limestone is light grey, yellowish grey, olive grey to grayish orange in colour. The weathering colour is usually medium dark grey to grayish brown. These are predominantly bioclasts bearing wackestone to packstone or pure lime mudstone (the calcisiltites). However, peloidal, oolitic and intraclastic packstone and grainstone are also commonly repeated. The individual bed varies in thickness from 3 cm to 30 cm. However, thick

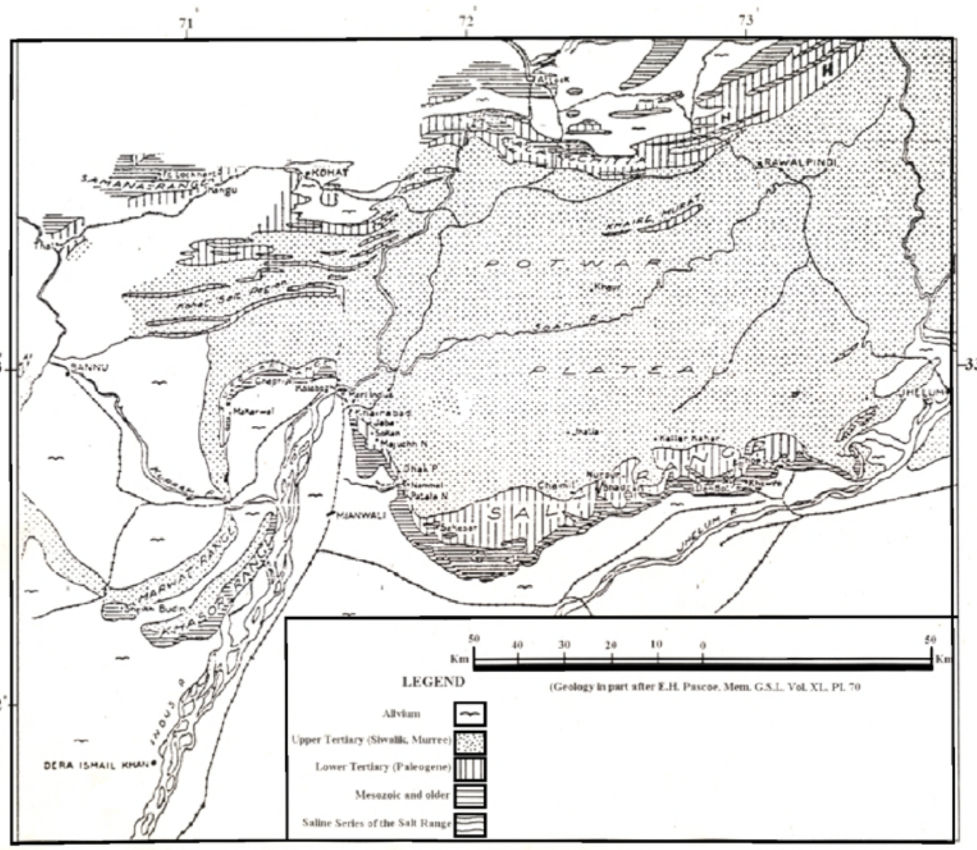



**Fig. 1.** Location map of the Kala Chitta and Samana Ranges (after Davies and Pinfold,1937)

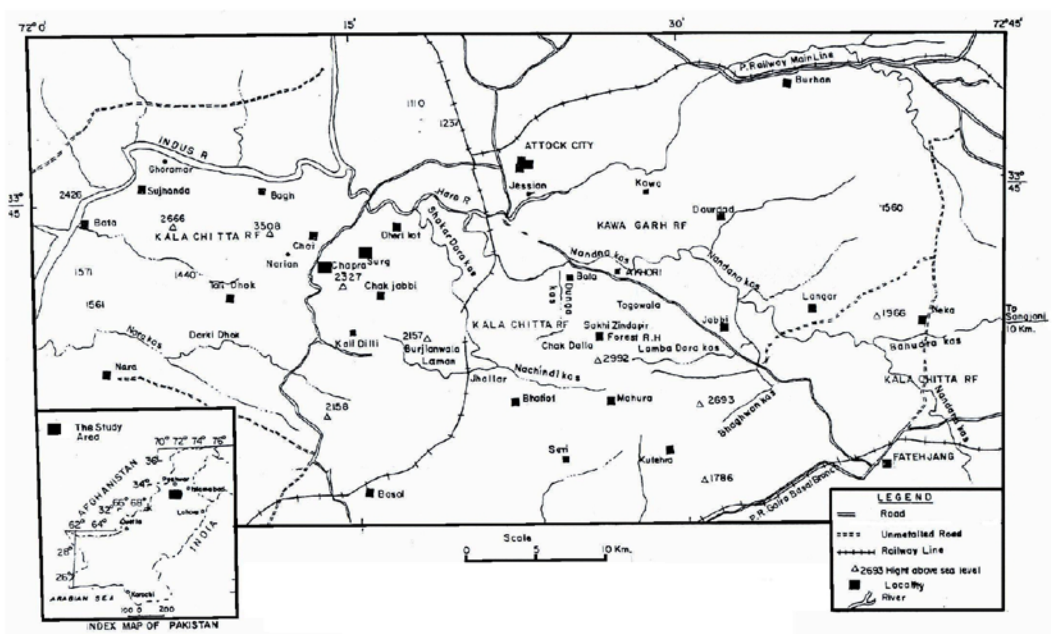



**Fig. 2.** Location map of the study area of Surg and Chapra  Kala Chitta Range.

beds (over 50-cm thickness) are also frequent. Massive beds (over 2 meter thickness) are not uncommon especially in the upper part of the formation.

The marls are usually compact, nodular, yellowish grey to light grayish yellow and vary in thickness from 5 cm to 1 meter. The marls being soft are mostly squeezed between compact limestone beds. In the upper part of the formation, well developed marlstone zone of 25 meters thickness (125 meters above the base of the formation) in Surg section and of 12 meters thickness (130 meters above the base) at Chapra Section are found.

Dolomitization of varying intensity has been observed at various levels in the formation and has been described in detail. Troughs cross bedding and parallel lamination, flaser bedding, ripple marks and bioturbation are common sedimentary structures observed in the field. Stylolitization is also very frequently present.

The lower contact with the underlying Datta Formation is gradational, whereas the upper contact with the overlying Chichali Formation is unconformable. Apart from the skolithos type burrows and residual lateretized film over the top surface of the Samana Suk Limestone, the presence of abrupt and non gradational change from limestone to pyritic, glauconitic sandstone and shale accompanied with limestone clasts at shale-limesotne interface, the irregular topography of the limestone surface and small scale banking of shale against such relief are the strong evidences of the erosional upper surface of the Samana Suk Limestone.

The Mesozoic succession of the Kala Chitta Range as formalized by the Stratigraphic Committee of Pakistan (Fatmi, 1973) has been tabulated here as follows.

| | **Nomenclature of the Stratigraphic Committee of Pakistan (Fatmi 1973)** | **Nomenclature after Cotter (1933)** |
|---|---|---|
| Upper Paleocene | Lockhart Limestone<br>(Thanetian)<br>Sequence Boundary<br>(Absence of Maastrichtian-Danian) | Hill Limestone |
| Upper Cretaceous | Kawagarh Formation<br>(Coniacian to Campanian)<br>Sequence Boundary<br>(Absence of Cenomanian-Turonian) | Kawagarh shales |
| Lower Cretaceous | Lumshiwal Formation | Giumal sandstone |
| Upper Jurassic | Chichali Formation<br>Sequence Boundary<br>(Latritic Crust) | Spiti shale |
| Middle Jurassic | Samana Suk Limestone | Kioti Limestone |
| Lower Jurassic | Datta Formation | Ferruginous beds in the kiotos |
| Triassic | Kingriali Formation<br>Chak Jabbi Limestone<br>Mianwali Formation | Kioto Limestone |

Base not exposed by virtue of the Thrust Fault

Detailed sedimentological and digenetic framework of Chapra and Surg (Fig. 2) have been carried out as the first comprehensive research of this kind. Various microfacies have been illustrated (Plates 1-3) Two lithologs of Chapra and Surg (Figs. 3-4) are presented here.

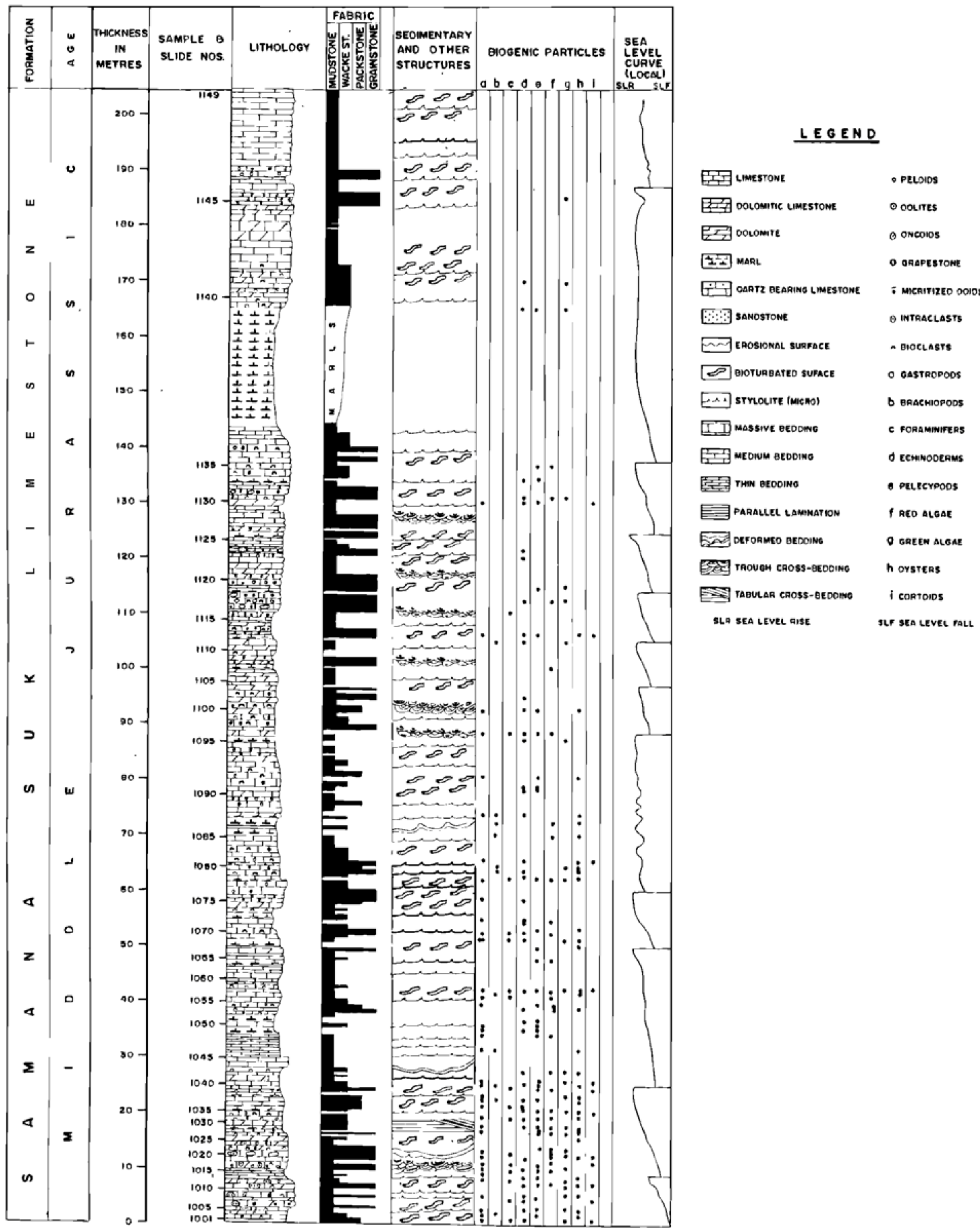



**Fig. 3..** Lithostratigraphic section of the Samana Suk Limestone at Surg, Kala Chitta Range.

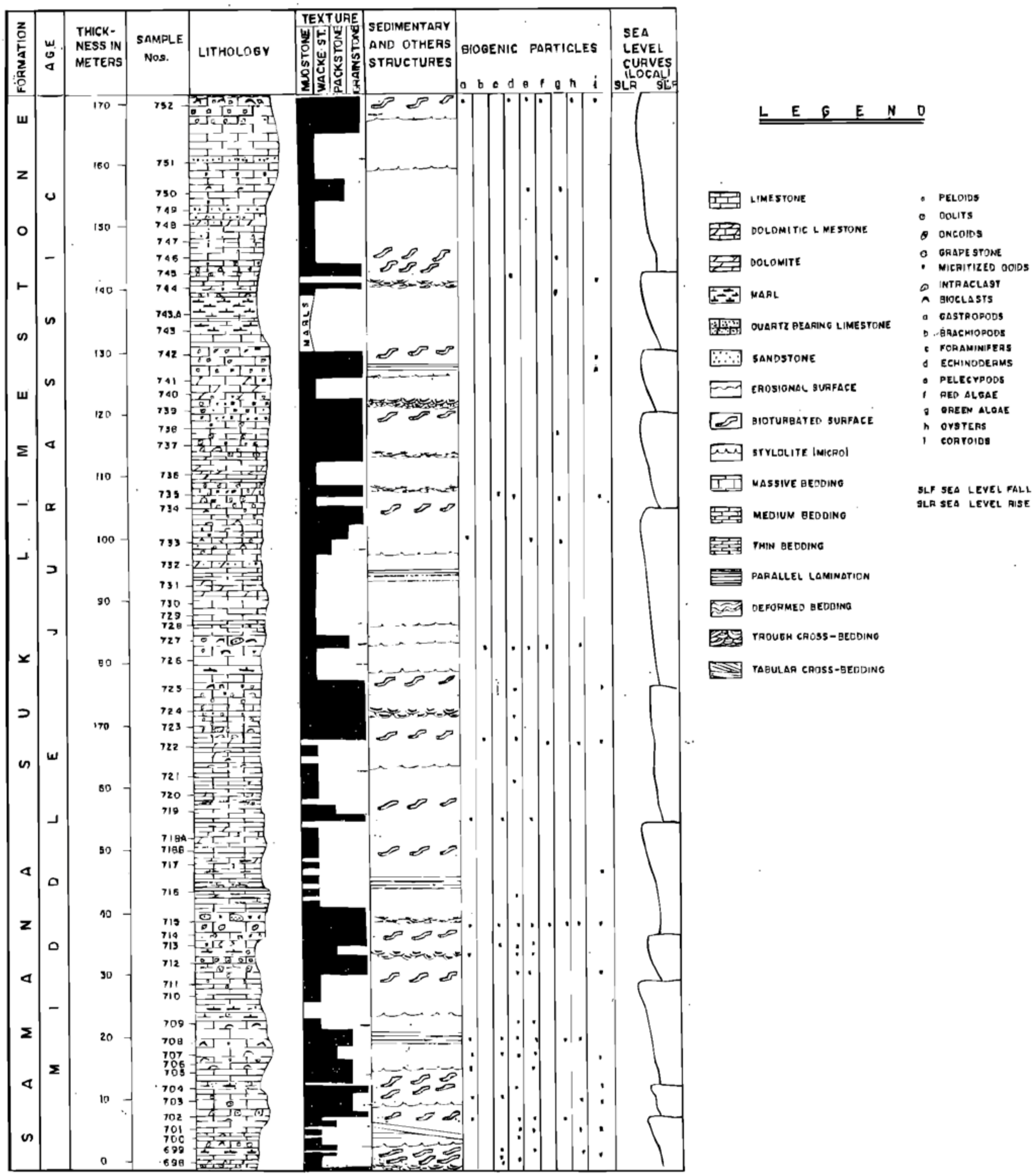
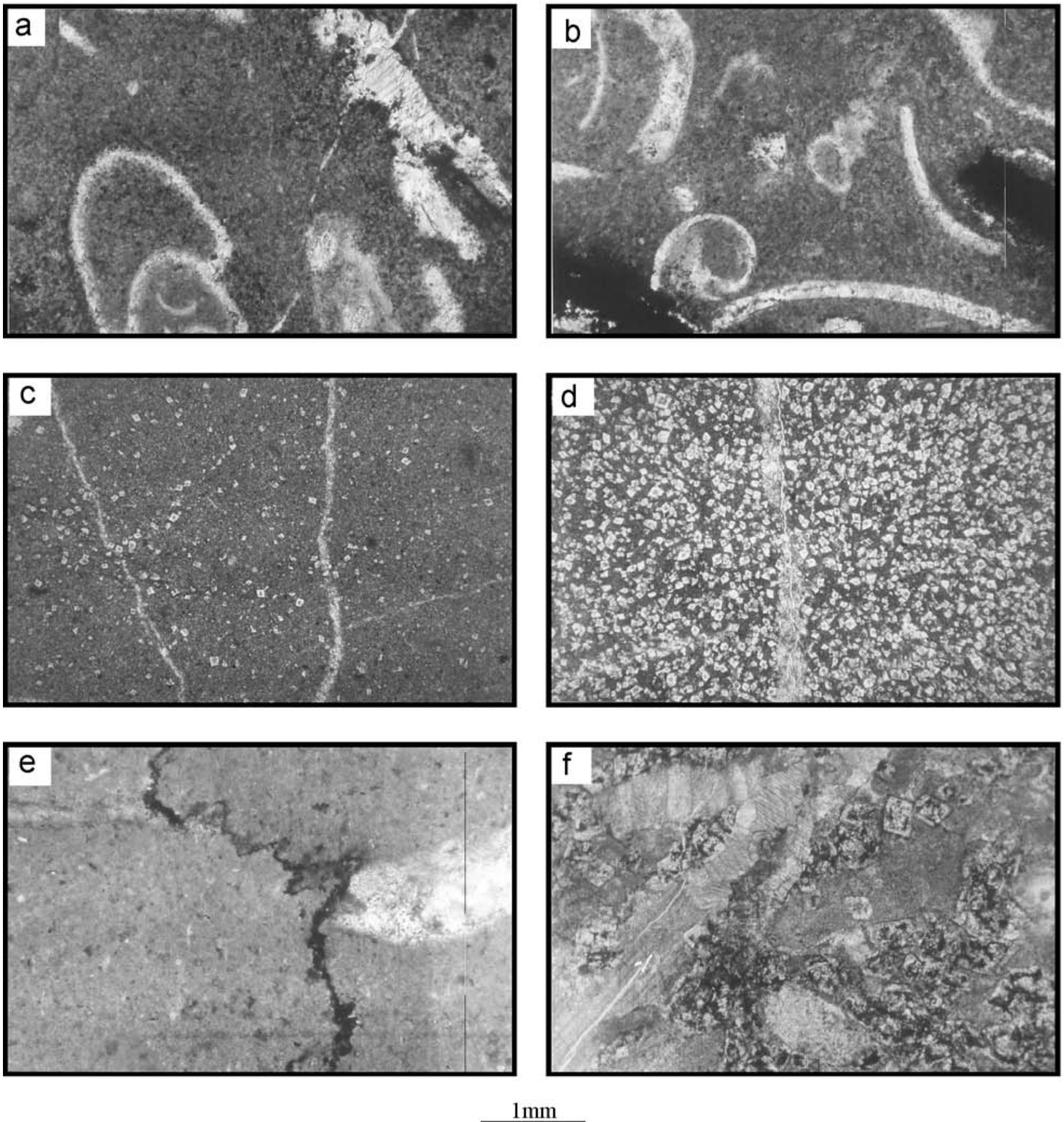


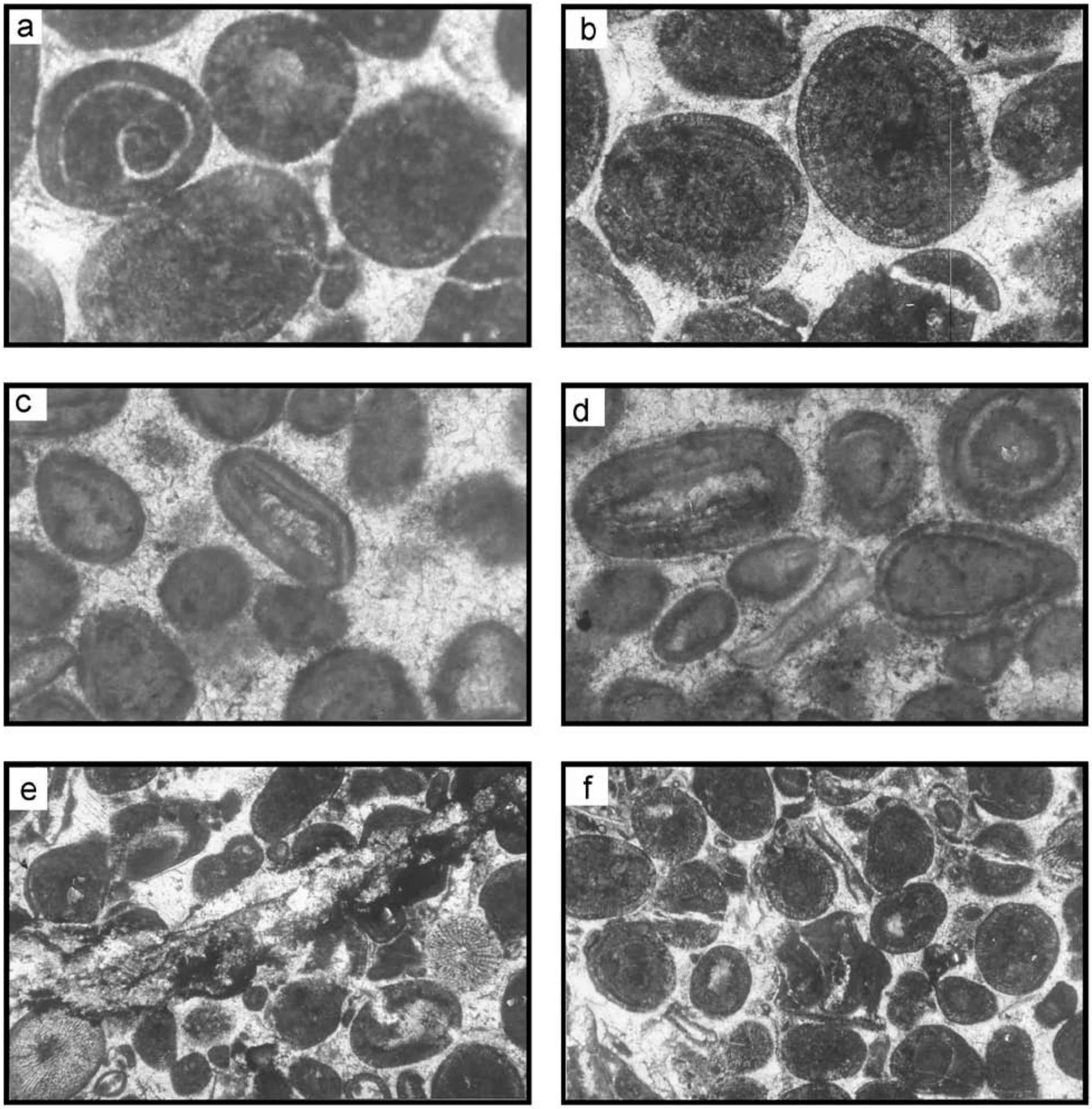

**Fig. 4.** Lithostratigraphic section of the Samana Suk Limestone at Chapra, Kala Chitta Range.

**PLATE 1**




(a-b) Bioclastic Wackestone. gastropods and bivalves are the bioclasts. Surg Section, samples 1050, 1005 respectively.
(c-d) Dolomicrite. scattered small sized (c) and closely packed small sized dolomite crystals (d). Surg Section, samples 1121, 1093 respectively.
(e) Mudstone showing high amplitude stylolite. Surg Section, sample 1090

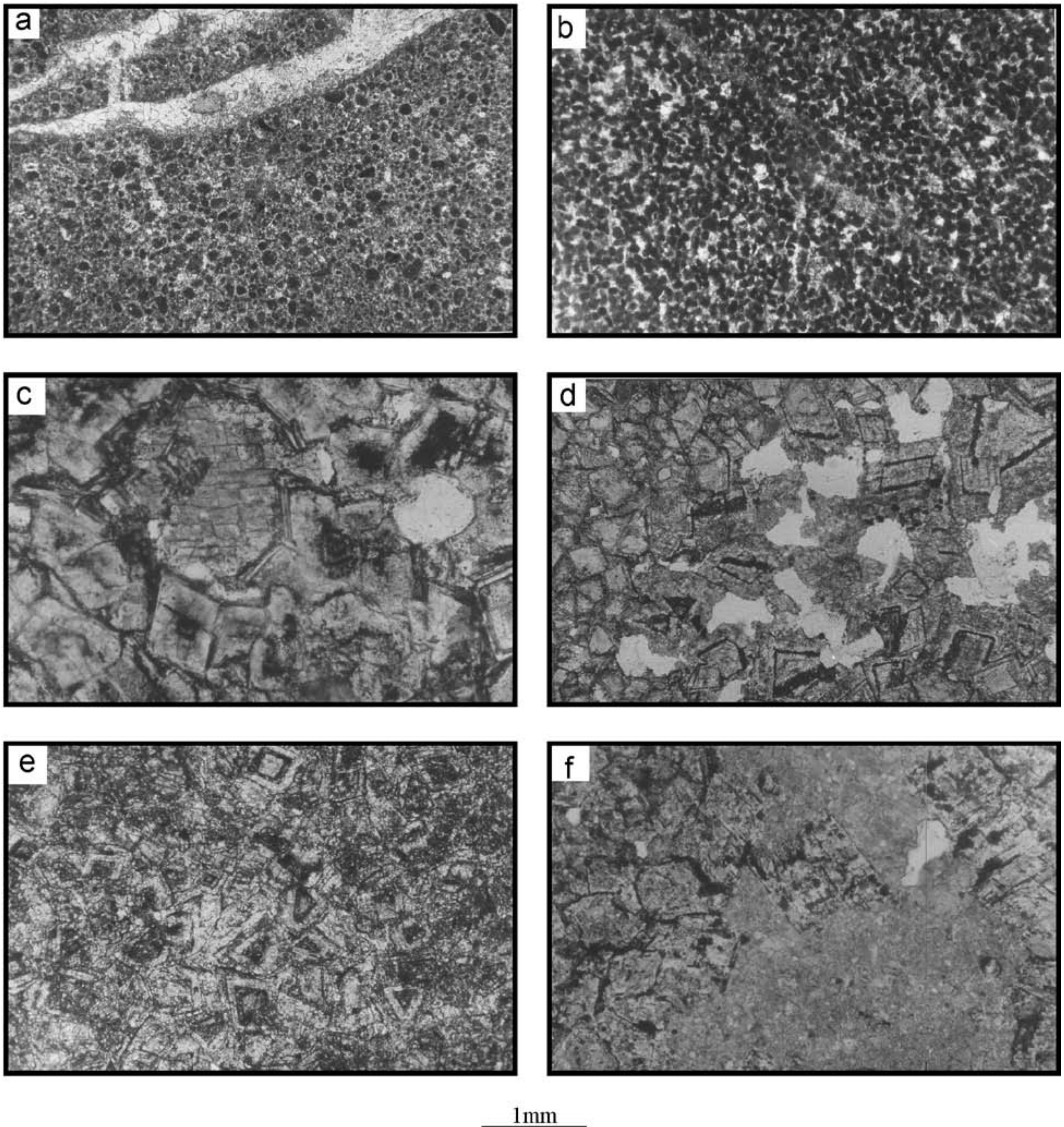
**PLATE 2**




1mm

(a-f) Oolitic Grainstone.
(a) a gastropod shell forming the nucleus in the ooid. Surg Section, sample 1128
(b) Ooids showing columnar cement. Surg Section, sample 1017
(c) stretched ooids. a molluscan shell seen in the centre (d) Chapra Section, sample 737
(e) Echinoderms grains, one in the right extremity and the other at the bottom left corner. Surg Section, sample 1017
(f) Spar filled fracture in few ooids, one even extending into the echinodetm grain upper right corner Surg Section, sample 1017

**PLATE 3**




(a-b) Peloidal Grainstone. Surg Section, samples 1097, 1094 respectively
(c) Dolospar showing large size dolomite crystals. Surg Section, sample 1111
(d) Dolospar showing large size dolomite crystals. Surg Section, sample 1129 The voids are the result of plucking During the thin Section preparation
(e) Dolospar showing zoned dolomite crystals. Chapra Section, sample 740
(f) Calcitization of the Dolospar. Surg Section, sample 1023

## DIAGENETIC FEATURES

A series of diagenetic events were recognised within the Samana Suk Limestone, which described below.

### Micritic Envelopes

The micritization of grains by endolithic algae and fungi is commonly observed in the Samana Suk Limestone. In this process the bioclasts are altered by boring around the grain margin and holes filled by fine-grained sediment or cement. If the activity is intense the grain is completely micritized. The micritic envelopes are generally associated with the packstones/grainstones. Furthermore, where the mineralogy was originally aragonitic, the fragment/shell is more susceptible to the formation of the micritic envelopes than if it were calcitic. However, there are evidences of 0-micritic envelope formation where the fragment was originally calcite.

### Cements

The precipitation of the cements in the carbonate rocks is a major diagenetic process and takes place when pore fluids are supersaturated with respect to cement phase and there is no kinetic factor inhibiting the precipitation (Sandberg, 1985). The cements are reasonably good indicators of the diagenetic events. However, on the other hand a similar type of cement can be precipitated in different diagenetic environment. The cements types distinguished in the Samana Suk Limestone at Surg and Chapra sections are as follows:

### Circumgranular Cements

**a. Isopachus acicular fibrous cement:** When the nucleation sites on the grain surface are many and the crystals are fine needles like growing at right angle to the surface. This isopachus acicular fibrous cement might be of marine origin and is found just above the middle part of the Samana Suk Limestone.

**b. Columnar or bladed cement Cleaved crystals growing at right angle to the grain margin:** The fibrous nature of these cements is the main criterion for their possible formation in marine phreatic zone, which refers to warm shallow seas (less than 100 m) with sediments in which all pores are filled by marine waters. Marine aragonite cement is typically present as fibrous crystals and the textures depend upon the nature of substrate, nature of vugs and rate of crystallization (Tucker and Wright 1992)

### Intergranular Cements

The intergranular calcite spar is characterized by crystal sizes generally larger than 10 micron and by light coloured translucent crystals, in plane polarized light.

**a. The drusy calcite spar:** The sparry calcite cement with drusy mosaic constitutes spar crystals filling a cavity or void. The size of the crystals increase towards the centre of the cavity. This mosaic is called drusy mosaic and is characteristic of meteoric phreatic environments, but may also continue into burial environments.

**b. Equant spar:** When the equicrystalline mosaics of spar or the size of the crystal remains almost constant the fabric is termed as equant spar equicrystalline mosaic. The equant cement may be related to burial phreatic or meteoric phreatic environments when it does not surround the particle. However, the circumgranular equant cement might be related to the meteoric phreatic environments (Tucker and Wright, 1992).

**c. Ferroan calcite spar:** The calcite spar containing ferrous iron is considered to be probably precipitation in the phreatic zone where the interstitial waters has low Eh. (Tucker and Wright, 1992). The vadose waters are oxidizing and most iron is present in ferric form, which does not substitute for calcium.

**d. Syntaxiaal overgrowth cement:** These are developed as an overgrowth on existing grains within a sediment, in many places growing in optical continuity of the grain or the substrate usually abundant on echinoderms. These cements are interpreted to be of meteoric origin in burial environments (Walker, 1990). This cement is repeatedly found on the echinoderms grains in many horizons of the Samana Suk Limestone.

**e. Poikilotopic cement:** These are also disconformable cements in which crystal grow from few nucleation points on the grain and enclose the grain. These are interpreted as precipitated in burial environments that postdate pervasive dolomitization and intergranular cements.

### Texture preserving dolomitization

The texture preserving non-mimic dolomitization is restricted to matrix and is commonly seen throughout the Samana Suk Limestone. This dolomitization where increased, becomes texture destroying and only minor original features are visible.

## HARD GROUND SURFACES

Prominent hard ground surfaces have been observed, in the Samana Suk Limestone, Kala Chitta Range. Each surface marks the culmination of a local depositional cycle caused by regression. According to Bathurst (1986), “A limestone bed is regarded as hard ground if its upper surface has been bored, corroded or eroded (by abrasion). If encrusting or other sessile organisms are attached to the surface and/or if the clasts or pebbles derived from a bed occur in the overlying sediment”. Other features which have been recognized from various parts of the world (Garrison and Fisher, 1969; Flugel, 1982; Tucker and Wright 1992) include impregnation by glauconite and phosphate, iron or manganese salts. Commonly the upper surface of hard ground coincides with paleontological non-sequence.

A hardground surface represents an early lithification and consolidation before the deposition of the overlying sediment (Purser, 1969). Various features confirming hardground surfaces in the Samana Suk Formation are as under:

**Field observations:** The presence of hardground surfaces has been observed in the field. The important features observed include:

Cyclic thick bedded peloidal/aggregate grain/lithoclastic or ooids bearing packstone/grainstone with bored, corroded or iron leached surfaces invariably marking the top underlain by thin bedded argillaceous lime mudstones and thicker middle unit of peloidal bioclastic wackestone/packstone.

Surfaces having ferruginous pits, spots and films on uneven beds.

Bioturbated and burrowed beds, burrows filled by secondary yellow coloured dolomitized material forming patchy look.

Oyster encrusted surfaces repeatedly present in the formation marking the hard lithified substrate for the oyster to attach.

Hardground surfaces followed by reworked intraclasts bearing horizons. These intraclastic horizons just over hardground suggest a transgressive phase during which the rudstone broken by storm current have been incorporated in the over lying fine sediment.

## COMPACTION

Due to progressive increase in the overburden, the sediments in the Samana Suk Limestone are subjected to compaction. Both mechanical compaction and chemical compaction has been observed, resulting into fracturing and stylolitisation. These are described as under:

**a. Mechanical compaction: More** overburden pressure resulted in denser confirguration the sediments resulting into point, planer and interfering grain contacts. Shelter porosity is created when a larger grain forms bridge between smaller grains. Increased overburden pressure results in the destruction of shelter porosity by brittle fracture. Several phases of fracturing with one or more episode of calcite fracture fill can be observed in the Samana Suk Limestone.

**b. Chemical Compaction: According** to Tucker (1990) the chemical compaction takes place in two ways (i) is an uncemented sediment by dissolution at isolated stressed grain to grain contact, (ii) within cemented sediment by dissolution being concentrated along a particular surface, usually irregular, termed as stylolite. The dissolutioning of grain contacts due to chemical compaction has commonly been observed in the Samana Suk Limestone. Progressive solution compaction leads to alteration of grain to grain contacts from original point contact to interfering or sutured contacts.

## STYLOLITES

A variety of stylolites and stylocumulates have been observed in the Samana Suk Limestone, representing dissolution within cemented sediments along a particular surface. High peak stylolite horse tail stylolite and stylocumulate horse tail stylolite and stylocumulate have been observed during the thin section study. These solution seams also represent considerable amount of dissolutioning in the subsurface and may locally source cementation, lessening the permeability of the zone surrounding the solution seams (Park and Schot, 1968). Various phases of chemical compaction has been observed as calcite filled vein being cut by younger veins and stylolites. There appear to be two distinct periods of stylolitization. Firstly, the stylolitization prior to dolomitization, thus resulting into stylocumulate. In the post-dolomitization phase the stylolites are cutting the dolomite crystals. The stylolite may act as barriers to fluid migration or when have little insoluble residue and high amplitude may become pathways of preferential fluid migration that may later be filled by cements.

## EXTENSIVE DOLOMITIZATION

Extensively dolomitized limestones and dolomite beds are frequently present within the Samana Suk Limestone and a large variety of modes of crystallization have been observed during thin section study. Evidences of both early and late stage dolomitizations are present. In general at least two (may be more) phases of dolomitization have been established from the close association of zones and unzones dolomite crystal in some individual samples.

The various dolomite fabric and facies observed are described as under:

**a. Dolomicrite:** It is fine grained dolomite that resulted from the dolomitization of micrite which provide nucleation point for the development of scattered or closely packed euhedral dolomite crystals. The dolomitization is not intense enough to completely recrystallize the rock rather the original fabric of the limestone is still easily recognized. In some cases the small subhedral-anhedral dolomite crystals have haphazardly affected the bioclasts and the matrix. The dolomite crystal size is essentially less than 20 Um.

**a. Dolospar:** This facies is composed of brownish yellow to pinkish coloured dolomites beds in the Samana Suk Limestone. These are composed of 90 – 100% large size dolomite rhombohedron. The crystals are in every case more than 20 Um in size. The facies commonly exhibits porphyrotopic texture with large crystals surrounded by small crystals. Poikilotopic texture is also present in the facies. Other components including bioclasts, lithoclast constitute less than 5% of the rock.

The following four types of dolospar are recognizable in the Samana Suk Limestone. Oolospar with scrosic mosaic: These have euhedral dolomite rhombs with a porous mosaic.

Dolospar with xenotopic mosaic: These dolomites have large size anhydral dolomite crystals with curved inter-crystalline boundaries.

Dolospar with hypidiotopic masaic: The dolomite crystals with subhedral rhombs constitute this facies. The inter-crystalline boundaries are planer and in most of the cases, the crystals are cloudy and unzones.

Dolospar with idiotopic mosaic: Dolospar with euhedral dolomite crystals texture.

Gregg and Sibley (1984) experimentally showed that in the occurrence of xenotopic and idiotopic dolomite mosaics, the temperature at which the crystals were growing was the major factor. At low temperatures a smooth crystal surface is energetically favoured so that crystal mosaics consists of euhedral-subhedral crystals, whereas above a critical roughening temperature (CRT) a rough surface is favoured leading to mosaic of anhedral crystals. Some idiotopic texture can form at high temperature where crystals grow into cavities or are affected by impurities such as clay and aragonite matter.

In addition to temperature affecting dolomite textur, the saturation stage of dolomitizing fluid also plays an important role. Where saturation rate in high then dolomitization is likely to be persvasive and all components, whatever their mineralogy and crystal size will be replaced. Where it is low only more susceptible components (aragonite, high Mg-calcite and finely crystalline low Mg-calcite) will be dolomitized.

**Dedolomitization**

When calcite spar replaces dolomite rhombs, the process is termed as dedolomitization or more accurately as calcitization. In the Samana Suk Limestone calcitization has been frequently observed. In some cases moulds and relics of dolomite rhombs are identifiable, whereas in others fabric destruction takes place.

## COMPARISON WITH OTHER AREAS

### Trans Indus Range

Mensink et al. (1991) measured and described Jurassic sequence and facies from localities in the Trans Indus Range (Lat. 32°55′; Long. 71°10′). A total of nine microfacies have been described in the Shinawari/Samana Suk Limestone. The details of the section is as follows:

**Facies of the Jurassic rocks in the Surghar Range (Mensink et al., 1991)**

| | |
|---|---|
| Chichali Formation<br>(Upper Oxfordian to Valanginian) | Glauconitic sandstone facies |
| -----------Disconformity ------------- | |
| Samanak Suk Limesotne<br>(Middle Jurassic) | • Palletal sparitic limestone facies<br>• Pelletal limestone facies<br>• Micrite facies<br>• Bioclastic-pelletal limestone facies<br>• Biogenic-Pelletal limestone facies<br>• Oolithic limestone facies<br>• Intraclastic limestone facies<br>• Sandy limestone facies<br>• Fe oolithic limestone facies |
| Datta Formation (Lower Jurassic) | • Sandstone facies |
| -----------Gradational contact ------------- | |
| Kingriali Formation (Triassic) | • Dolomite facies |

The paleoenvironments during the deposition of the Shinawari/Samana Suk Limesotne are interpreted as to be ranging between carbonate platform phase to open marine subtidal phase in the upper part with a number of internal cycles punctuated by various firm grounds/hard grounds and mud cracks of local interest.

### Hazara

Sangargali Section (Latitude 34°12′50″; Long. 73°19′).

A section of the Samana Suk Limestone in the vicinity of Sangargali area, District Abbottabad, Hazara has been recently studied and described (Sheikh et al. 2001, Qureshi et al. 1997, Masood, 1989). A total of fourteen microfacies types have been identified. These include seven oosparitic (or ooidal grainstone) four lime-mudstones, one cortoid bearing biosparite (or bioclastic grainstone) one lag unit and one oncoid bearing oosparite (or the oncoidal-ooidal grainstone). A number of diagenetic cements including acicular, bladed, equant granular, drusy, syntaxial overgrowth has been observed and are interpreted to be formed in meteoric-phreatic environments. Dolomitization and dedolomitization is significantly seen and include unzoned and zoned dolomite crystals. The depositional environments are interpreted to range from facies zofne 6 to facies zone 9 of the middle shelf environments as explained by Wilson (1975).

The abundance of ooidal horizon in the Samana Suk Limestone at Sangargali and the presence of sandy limestone and intraclastic grainstone in the Surghar Range show more shallower body of water with high energy conditions at both sites as compared with the Samana Suk Limesotne at Kala Chitta Range where the dominance of pure lime mudstone and aggregate grain/graphestone bearing packstones/grainstone indicates common prevalence of more restricted and relatively low energy environments.

**Balochistan:** In the Balochistan Basin, the equivalent rocks are named as the Chiltan Limestone and Zidi Formation. The microfacies analyses from these areas are not available; thus it is not possible to draw precise environmental inferences from these areas. In general, however, shallow marine shelf environments are considered to be prevailing during the deposition of Jurassic sequences in those areas (Fatmi, 1986; Bender and Raza, 1995).

## DIAGENETIC HISTORY

The presence of micritic envelopes and circumgranular acicular cements suggest an early phase of marine diagenesis. The presence of early diagenesis is also supported by the occurrence of peloids produced by the complete micritization of the skeletal partices and non-skeletal grains. Following the burial, the meteoric fluids lead to the formation of syntaxial overgrowth cements on echinoid/crinoids grains in the grainstones. This was followed by the precipitation of outer zones of zoned dolomite crystals and also the poikilotopic cements.

The late diagenetic features including the formation of fractures, might be related to the uplift as a result of weathering and erosion following a break in deposition and also afterwards due to tectonic overburdening resulting from the emplacement of various thrust sheets. Some sparry cements postdate the fractures. The dolomitization was probably the last phase of the diagenesis.

## DEPOSITIONAL ENVIRONMENT

The Jurassic marine transgression reached Kala Chitta Range area during early Toarican with the deposition of *Bauleiceras* bearing transgressive beds of sandy limestones. The presence of concentric ooids with quartz grains constituting the core in the basal beds of the Samana Suk Limestone at Chapra Section indicates the presence of extensive terrigenous (sand) material on the shore face which served as the rolling nucleus for the precipitation of calcium carbonate ring during the advent of the early currents.

In the studied sections, the biogenic particles are frequent and diverse in the lower part, less common in the middle and sparse to completely absent in the upper part of the Samana Suk Limestone. The biogenic particles are dominated by echinoderm with substantial amount of pelecypods, gastropods, benthic foraminiferas brachiopods and oysters shell. Variety of red and green algae has also been recorded at various levels in both the sections. The abundances of organisms in the lower part and scarcity to total absence in the upper part suggests that initially the conditions were more conducive and favourable for life which include open marine, well oxygenated water with normal salinity. During the later part of its depositional history, however, more varied and changing conditions prevailed creating stress environment for the organisms to survive, these conditions may include waters with restricted circulations and higher to variable salinities, such conditions may exist in cut off ponds and protected shelf lagoons.

The ooidal grainstones are surprisingly limited at both the sections are compared with the reported and observed ooidal horizons in other areas like Trans Indus Range, Kohat and Hazara. However, peloidal grainstone/grapstone bearing grainstones are quite frequent. All these facies suggest variation in the shallow shelf areas from high energy shoal beaches and tidal bars, changing to more restricted water circulations in possible tidal flats, with warm water with normal to slightly higher salinity, essentially above normal wave base, where the activity of the currents continuously kept winnowing the mud.

The relatively deeper water environments prevailed in certain segments of the outer shelf where the deposition of packstone/wackestone with gravel sized bioclasts derived from shallow shelf areas are accumulated in wavy beds of depositional slopes shifted down flank, where finer sediments are infiltrated in the frame work with common geopetals and indicate slope or toe of slope depositional settings.

Cyclic marls/clays are persistently present in both the sections and in the upper part a well developed nodular marl zone (20 metes thick at Surg and 10 metes thick at Chapra Section) is present. The marls/clays are considered to be the periodic influxes from land followed by some distant uplift and erosion. This may also be due to the periodic climatic change in the adjoining landmass. The dolomitic limestone are persistently encountered in the Samana Suk Limestone, however, below marls horizons the dolomite horizons are more frequent. The presence or zoned dolomite crystals, with inclusion rich internal zone and clear outer zone and the clacitization are very prominent evidences based on which Sheikh (1992) proposed a mixed meteoric-marine water dolomitization model as to be most suitable for the dolomitization in the Samana Suk Limestone. The dolomitized zones underlying marls/shales might have been dolomitized to some extent due to the release of Mg-rich fluids from these rocks, as a result of burial compaction.

The detailed depositional environmental interpretations are given in section 3.2.3.2 under the Microfacies encountered and described from both the sections. All these condition, accompanied with features like varying bedding thicknesses, shoaling upward cycles, hard ground surfaces strongly indicate shallow marine shelf environments during the deposition of the Samana Suk Limestone at Kala Chitta Range.

## SHOALING UPWARD CYCLES

Shoaling upward cycles with lime mudstone at the base followed by bioclastic grainstone with rounded, worn and coated bioclasts grainstone and some well formed oolites and/or peloids grainstones are repeatedly present in the Samana Suk Limestone. These cycles have been observed during field and microscopic studies. According to Wilson (1975) these carbonate shelf cycles represent a general regressive earth history. They tend to multiply upward, becoming thinner, more restricted marine in character and less regular. In the Samana Suk Limestone interestingly, the upward shoaling lithologic cycles have close similarity with the Middle Jurassic deposits of Paris Basin (Wilson, 1975). The description of these cycles is as follows:

A lower argillaceous thin bedded bioclastic lime mudstone (or marl unit) overlain by thicker middle unit of bioclastic or cortoid bearing packstone/grainstone followed by thick bedded, light coloured peloidal/aggregate grains bearing grainstone units and occasional ooidal grainstone unit. Hardground surfaces begin to appear in the upper showing oxidized layers with large oyster plastering along it. In places evidences of bored and corroded surfaces are commonly associated.

The microfacies types through each cycle, generally illustrate the regressive sequence of events, these are:

Well-bedded, argillaceous lime mudstones / wackestone, off bank on the shelf.

Well bedded bioclastic peloidal wackestone / packstone off bank on the shelf.

Bioclastic peloidal packstone/grainstone with coated grains edge of the bank.

Cortoid bearing grainstone or ooidal grainstone at the edge of the bank.

Bioclastic-oncoid and/or coated particles packstone / grainstone.

Peloidal/aggregate grainstone.

The formation represents shelf facies with pure carbonate deposition and is hardly affected by terrigenous influx thus the variation in clastic sedimentation is not the cause for the cyclicity rather the sea level changes or the shoreline fluctuations has been the only cause of these shoaling upward sequences in the Samana Suk Limestone. The shoaling upward cycles are fairly well defined in the Surg section, whereas in the Chapra Section these cycles are not so clearly distinctive. As the two sections are close to each other, this change may be due to the location of the section either more within the shelf or near its landward side where exposure surfaces are prominent and cycle members are incomplete through non deposition. It can also be slightly on the outer edges of shelves, where subsidence is continuous and water is deep enough for the effect of sea level fluctuation to be reflected in the sedimentary record on a local basis. The idea is also supported by limited microfacies variations in the Chapra Section. There are other factors for the break in a complete cycle, like changes in degree of restriction of water circulation over the shelf, tidal variation, degree and frequency of periodic drop of sea level (Wilson, 1975).

These upward shoaling cycles show as if a relatively rapid rise of sea level occurred repeatedly on a steadily subsiding shelf and was followed by sedimentary progradation and fill-in of the inundated area over some period of time. The sea level rise and fall as depicted during the deposition of the Samana Suk Limestone is considered to be the local transgressions and regressions of the shore line and thus cannot be equated with the global eustatic sea level rises and falls. Vail et al. (1984) have cautioned for such curves to be correlated with the global eustatic curves and suggested that differing local and regional subsidence and sediment supply rates can produce apparent transgressions or regressions that may not be synchronous with the global cycles.

## CONCLUSIONS

The Samana Suk Limestone represents a variety of shallow marine shelf environments from high energy to low energy environment.

The sea level fluctuations represented by the Shoaling Upward Shelf Cycles terminated by hardground surfaces are well defined in the Surg Section in contrast to the Chapra Section.

Extensive post depositional dolomitization overprints is prominent. This dolomitization is of multigenetic origin.

Various cements including marine and fresh water are suggestive of different diagenetic environments.

The overprints of physical and chemical compactions are evident.

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