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DIAGENETIC STUDY AND MICROFACIE ANALYSIS OF CALLOVIAN-BANTHONIAN (JURASSIC) SAMANA SUK FORMATION, EASTERN KALACHITTA RANGES (LESSER HIMALAYAS), PAKISTAN

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Abstract

The Samana Suk Formation, exposed in the Trans-Indus Ranges of Pakistan, is composed of stratified Jurassic age carbonate rocks. To understand the deposition setting and microfacies of the Samana Suk Formation, fieldwork, petrographic study and microfacies analayis were conducted. The sequence in the study area, exhibits a variety of sediments, and structures, and is composed predominantly of limestone and dolomitic limestone with minor interbedded marl. Microfacies analysis reveal four microfacies i.e. bioclastic wackestone, packstone, and dolomitic grainstones, demonstrate the considerable lateral and vertical changes of the carbonate platform deposits. The microfacies associations signify carbonate deposition in a shallow marine environment with variable hydrodynamic energy conditions, and within the inner to middle shelf. The host Limestone has undergone diagenetic alterations which have formed Dolomites. The dolomitic grainstone facies indicate high-energy conditions in the subtidal zones while the bioclastic wackestone and packstone facies represent low to moderate energy conditions in the inner shelf zones. The lateral facies transitions and textural variations are the result of local alterations in sedimentation topography, water depth, salinity, and energy. Overall, the study resulted in the development of a conceptual depositional model which beastly explains inner to middle shelfal environment for Samana Suk Formation of the Jurassic successions in the Trans-Indus Ranges.

INTRODUCTION

Microfacies analysis is one of the methods for understanding the depositional environments of sedimentary carbonate rocks, as well as the rocks' post-depositional histories. It consists of the detailed ore microscopic examination of thin sections to identify variations in types of grains, matrix, fossil fragments, sedimentary textures and structures, and the various diagenetic features. Each combination of the aforementioned features characterizes a certain microfacies, and, in turn, a given set of depositional conditions within the carbonate system (Flügel, 2010). The identification of such microfacies and their classification enable the paleoenvironmental settings to be reconstructed as well as the interpretation of the

varying sedimentation water depths, energy levels, and sedimentation (Dunham, 1962; Embry & Klovan, 1971).

Understanding spatial and vertical arrangement of facies within the Samana Suk and other carbonate formations makes microfacies analysis important within carbonate formations. It identifies and differentiates environments such as restricted lagoonal, open-marine, shoal, and tidal flat, the thin sections of which contain varying lithological and biological characteristics (Tucker & Wright, 1990). Besides, the microfacies analysis serves as the groundwork for studying the diagenetic processes of cementation, dolomitization, compaction, and recrystallization, which textures of the original deposition may lack. (Flügel, 2010). The study of microfacies and diagenesis collectively facilitates the outlining of principal alterations within the carbonate system and identifies the secondary processes that the system of the carbonate reservoir's quality, and porosity, primary deposition, and secondary alterations (Tucker & Wright, 1990).

Geological Setting

In northern Pakistan, the most recent thrusting has occurred along the eastern and western Salt Range Thrust (SRT) and the Trans-Indus Ranges Thrust (TIRT) (Blisniuk et al. 1998). The frontal thrust system has accommodated approximately 20 km of shortening in the Salt Range (Lillie et al. 1987) and 10 km in the Trans-Indus Ranges (Blisniuk 1996). Along this thrust front, the Eo-Cambrian Salt RangeFormation of the Salt Range (Gee 1980), Permian rocks in Surghar Range (Meissner et al. 1974), and Cambrian Jhelum Group rocks in Khisor Range (Hemphill and Kidwai 1973) are repeatedly thrust over the southward Punjab foredeep (Fig.1).

Kalabagh Re-entrant constitutes one of the re-entrants of the Salt Range Thrust Sheet. A change in the strike of the thrust sheet is attributed to a transpressional fault system (McDougall, 1985) or as a lateral ramp in the thrust sheet (Butler et al, 1988). The most significant north-south structural characteristic at the border between the Potwar and Kohat plateaus is the Kalabagh Fault, with an approximate surface trace of 120 km. Kalabagh Fault is positioned at N15W and exhibits transpressive right-lateral strike-slip movement (McDougall, 1985). Microseismicity along the Kalabagh Fault indicates either the Salt Range detachment is still active (Seebar and Jacob, 1979), or there is some active strike-slip in the basement below the detachment.

The Kohat Plateau is located in the westernmost region of the fold and thrust zone deformation of the southern region. The southward shift of the deformation front during the late Miocene period also impacted this region. The Main Boundary Thrust contacts the northern section of the plateau and overlays the intensely deformed Mesozoic rocks of the Kohat Range on the Eocene-Miocene sediments of the Kohat Plateau (Yeats & Hussain, 1987). In the west, the Kurram Fault juxtaposes the Kohat Plateau's Eocene to Miocene sediments against the highly deformed Mesozoic rocks of Samana, Darsamand, Thal, and North Waziristan Agency . It is interpreted to be a left lateral transpressive boundary. In the south, the region is bounded by the undeformed sediments of the Bannu Basin and by the surghar Range to the southeast, which is the southern plateau boundary. The passive roof duplex, as interpreted by Banks & Warburton (1986), is believed to underlie the area in addition to the northern Kohat and Potwar Plateaus and has a similar structure to the Kirthar Range in the south.

The area of the study action falls within the Southern Deformed Fold-Thrust Belt, which encompasses the southern Kohat Basin and its associated foothill ranges, specifically the Surghar-Shinghar, Marwat-Khisor, Pezu-Bhittani, and Manzai ranges (northern Sulaiman). These ranges are referred to collectively as Trans-Indus ranges.

The stratigraphic succession exposed in the Trans-Indus ranges are ranging from Permian to Miocene (Fig.2) comprised of Zaluch Group (Amb Formation, Wargal Formation, Chidru Formation) Musa Khel Group (Miawali Formation, Tredian Formation, Kingriali Formation), Surghar Group (Datta Formation, Shinwari Formation, Samana Suk Formation, Chichali Formation, Lumshiwal Formation), Makarwal Group (Hangu Formation, Lockhart Formation, Patala Formation), Chharat Group (Nammal Formation, Sakessar Formation) and Siwalik Group (Chinnji Formation).

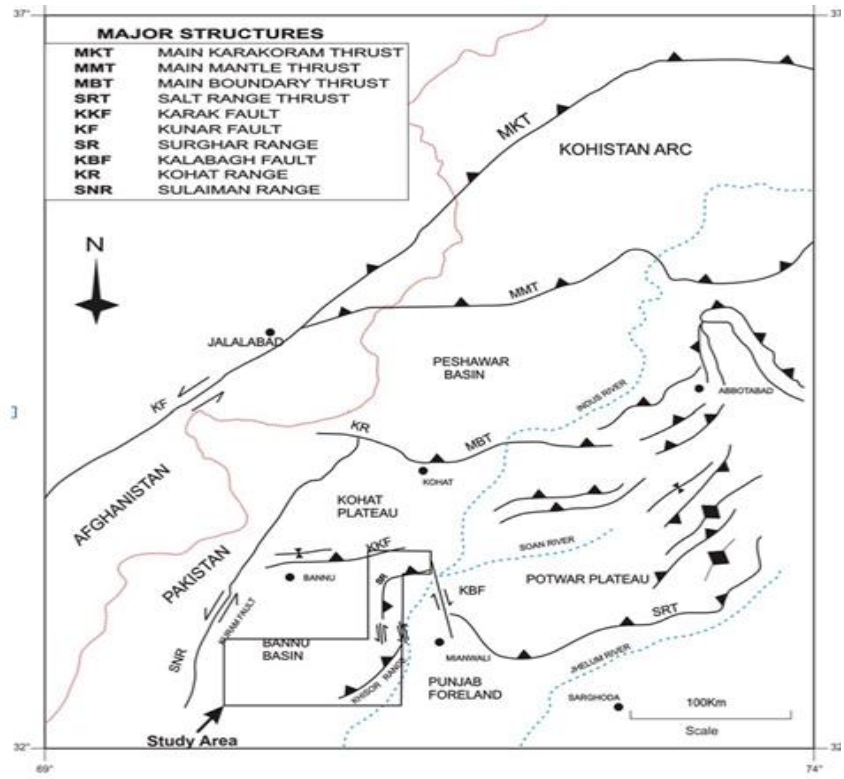


Figure 1. Tectonic map of north Pakistan, showing major structural feature (modified after Kazmi and Rana, 1982). Inset show location of the study area.

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Methodology

Field Work and Sampling

In the East Kalachitta Ranges, field investigations were conducted, where the Samana Suk Formation is well exposed in several accessible and stratigraphically complete sections. Detailed measured stratigraphic sections were logged documenting lithological variations, sedimentary structures, fossil occurrences, bedding, and color changes. Observations were made in fresh outcrops in order to mitigate the effects of weathering and surface alteration.

Rock samples were collected at regular stratigraphic intervals and from each lithological unit representing different facies. The total samples ranged from about 30-50 representative samples, all limestone, which were collected from the lower to the upper part of the formation. Each sampling site with regards to the field observations was recorded in field notebooks and was complemented by outcrop photographs which also recorded GPS coordinates and lithologic descriptions. Once collected, the samples were labeled and stored for transport to the laboratory, where thin sections for petrographic analysis were prepared.

Laboratory Work and Thin-Section Preparation

In the laboratory, each sample was meticulously cleaned, trimmed, and labeled. Representative pieces from each hand sample were selected for thin section preparation, ensuring coverage of all lithological and textural variations. The preparation of thin sections following standard procedures, as outlined by Flügel (2010). Sample were with a diamond saw, mounted them on glass slides with epoxy resin, and ground them to 30 micrometers in thickness. Then, the sections were polished, covered them with a glass slip, and prepared them for detailed petrographic observation.

Petrographic and Microfacies Analysis

To identify various characteristics of each rock sample's texture, composition, and diagenesis, all thin

sections were evaluated. For all petrographic studies, a polarizing microscope provided studies at both plane and crossed polarizations. The carbonate texture was used Dunham (1962) and Embry & Klovan (1971) classifications while Flügel (2010) provided the microfacies interpretations.

Each thin section was studied concerning details of the diagenesis, fossil content, texture relationships, matrix and cement, type and composition of the grains, sedimentary and biogenic structures.

From these studies, varied samples were typed into different microfacies (SMF1-MF4) based on texture and composition and grouped accordingly. The individual recorded samples were also analysed concerning their deposition environments, which entails how energy and water depth varied, and their position on the carbonate ramp. Each microfacies type was described and explained using representative photomicrographs snapped to highlight the defining characteristics.

Group	Age	Formation	Lithologies	Thickness
Siwaliks	Miocene	Chinji Fm	Sandstone and Clay	500 m
Charat Group	Eocene	Sakesser Fm	Nodular limestone	220 m
		Nammal Fm	Shale, Marl and limestone	130 m
Makarwal Group	Paleocene	Patala Fm	Nodular limestone and Shale	30 m
		Lockhart Fm	Nodular limestone and Shale	60 m
		Hangu Fm	Nodular limestone, limestone and Shale	90-110 m
Surghar Group	Cretaceous	Lumshiwal Fm	Sandstone and Mudstone	70 m
		Chichali Fm	Sandstone and Shale	66 m
	Jurassic	Samana Suk Fm	Dolomite and Limestone	30 m
		Shinawari Fm	Limestone and Shale	150 m
		Datta Fm	Sandstone, Mudstone and Shale	150 m
Musakhel Group	Triasic	Kingriali Fm	Dolomite, Limestone and Sandstone	91 m
		Tredian Fm	Sandstone and Shale	76 m
		Mianwali Fm	Shale and Sandstone	135-187 m
Zaluch Group	Permian	Chidru Fm	Sandy limestone and Sandstone	64 m
		Wargal Fm	Limestone	174 m
		Amb Fm	Sandstone, Shale and Limestone	47 m

Figure 2. Generalize stratigraphic column of Trans-Indus Ranges.

Results and Discussion

Petrography

Analyzing the thin sections under a polarizing microscope allowed for the study of the mineralogy and textures of the Samana Suk Formation. For the petrographic description, the types of allochems, matrix, and cement, as well as the diagenetic changes, were identified and described. Considering the grain size, allochem composition and the matrix, four microfacies were identified and classified under the Dunham (1962) carbonate rock classification. These were SMF-1: Dolomitic Grainstone, SMF-2: Bioclastic Wackestone–Mudstone, SMF-3: Bioclastic Peloidal Wackestone, and SMF-4: Glauconitic Sandstone Lithofacies. Each of the aforementioned microfacies signifies the distinct conditions of deposition within the carbonate ramp, and reflect the range of energy, water depth, and sediment supplied. The diagenetic processes of micritization, compaction, cementation, recrystallization and dolomitization were all noted.

Dolomatic Grainstone microfacies (SMF-1)

Description and Interpretation

In this microfacies, the unzoned dolomite grains possess unorganized microtextures characterized by the presence of point and extremely rare sutured contacts. Dolomite crystals, mostly anhedral-subhedral and constituting 30 to 45% of the rock volume, have a mean subhedral texture and thus mean a dolomite grain shape and texture imply a positive crystal habit (Fig. 3 A, B). Micritization is quite extensive with allochems micritized and retaining partially preserved internal microstructures. Micrite is common, as is recrystallized calcite showing polysynthetic twinning under crossed nicols. Dolomite rhombs with outlines of high relief and discernible edges display original growth forms, which means they replaced earlier carbonate minerals. Rare cases show dolomite crystals that calcite encloses, which indicates that calcite precipitation was a precursor to dolomitization in the late diagenetic stage (Flügel, 2010; Tucker & Wright, 1990).

The absence of zonation in dolomites, the presence of microtextures in point and sutured contacts along with the crystal habit of dolomites that changes to euhedral and the grain provided texture points to deposition in high energy shallow zones and marine streams. The deposits in sub-tidal zones and shoals are well-sorted as indicated by the presence of sparry cement, and the high energy currents that winnowed the deposits are strong, which supports the deposition theory where coarse carbonate grains and early marine cementation are formed (Wilson, 1975; Flügel, 2010). Recrystallization and dolomitization as subsequent diagenetic processes altered the original depositional fabric while retaining textural evidence of a high-energy environment characteristic of an inner to mid-ramp carbonate system.

Bioclastic wackstone-mudstone microfacies (MSF-2)

This microfacies type exhibits a skeletal mud microfacies texture with sponges, pelecypods, echinoderms, and ostracods skeletal bioclasts, some of which are bioclasts and substantial skeletal bioclasts. Silicification of the bioclasts varies and quartz, ranging from microcrystalline to macrocrystalline, replaces the original carbonate framework (Fig. 3 C, D). Late stage diagenetic cementation occurs with the formation of calcite which fills fractures and has well developed crystal growth along the fracture planes. Diagenesis and cementation are seen in the calcite which fills fractures and has well developed crystal growth along the fracture planes (Flügel, 2010; Boggs, 2009).

The bowl shaped mud matrix, bioclastic, and the weight of the sediment suggest deposition in a low energy marine environment, likely in the inner shelf or lagoon. The presence of sediment below the fair weather wave base adds to this general description of the area and enhances the reliability of the description is added. The presence of ostracod and other delicate fossil material suggests low energy and quiet depositional environments with little to no current during sedimentation (Fig. 3 C, D). Overall, this facies represents deposition in a low-energy subtidal setting, typical of the inner ramp or lagoonal portion of a carbonate platform (Wilson, 1975; Flügel, 2010; Tucker & Wright, 1990).

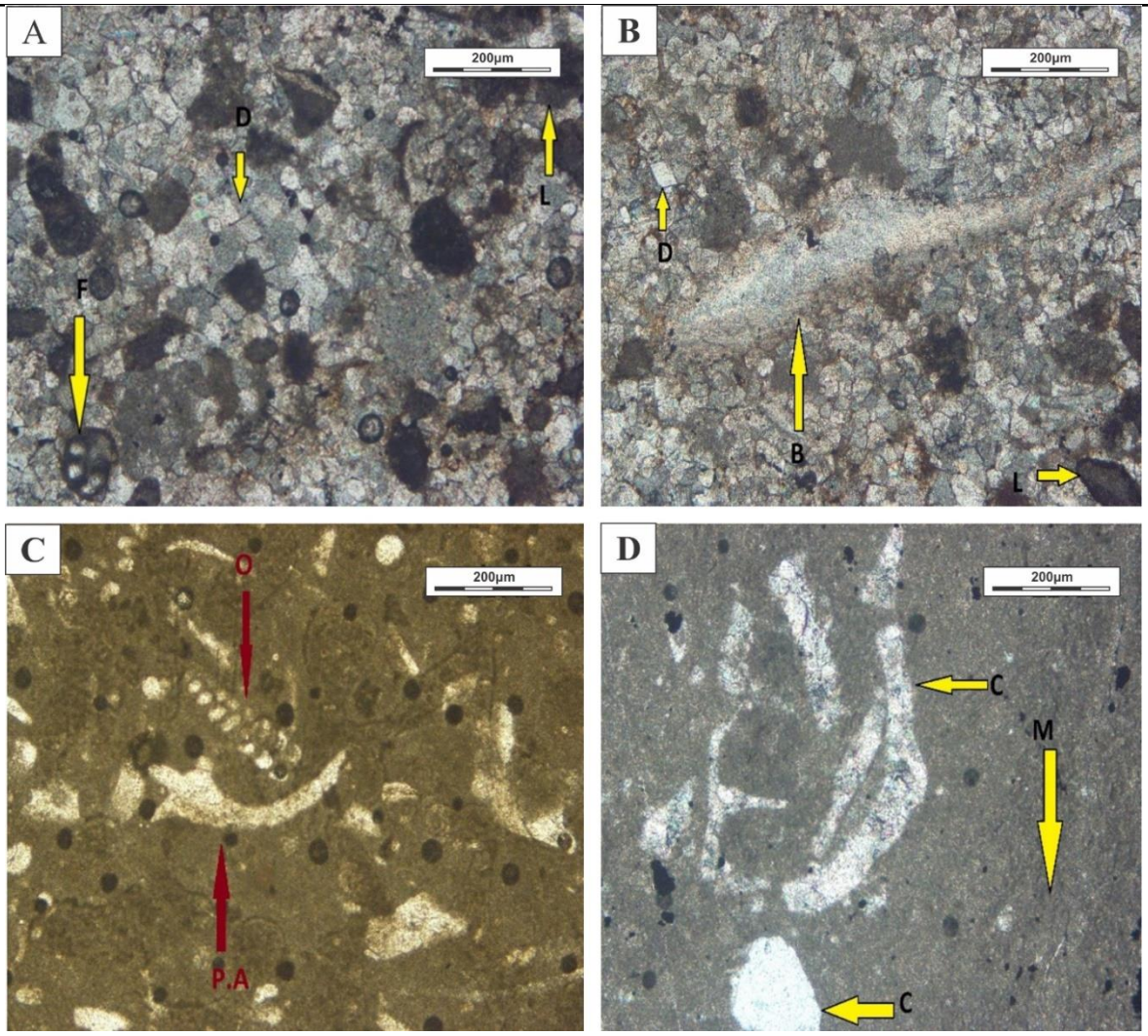


Figure 3. A and B Photomicromicrographs shows Dolomatic grainstone microfacies, C and B Photomicromicrographs Shows Bioclastic wackstone-mudstone microfacies. B=Bioclast, C=Calcite, D=Dolomite, F= Fossil, L= Leaching, M=Micrite, O=Ostracods and P. A=Pelliodal Algae.

Bioclastic Pelliodal wackstone microfacies (SMF-3)

This microfacies consists predominantly of peloids which are primarily structureless and lack internal organization possibly due to micritization by endolithic algae (Fig. 4 B). The peloids are found in a mud-supported matrix, and bioclasts of various sizes are broken and fragmented. Shell fragments are commonly broken and angular which implies they underwent limited transport before deposition. The matrix to cement ratio of about 2 to 3 suggests moderate cementation during burial. Detrital quartz grains which are rounded and sub-rounded are found dispersed within the carbonate framework, illustrating minor terrigenous input (Flügel, 2010; Boggs, 2009).

The combination of peloids and bioclastic debris, in addition to a mud-supported texture, suggests deposition in a moderate to low-energy environment on the outer to middle shelf of a carbonate ramp. The peloids lack internal structures which may indicate some prior to burial, reworking, and micritization by microbes or algae (Fig.4 A, B). The presence of sponge spicules indicates deposition in open, well-oxygenated marine waters, while small amounts of detrital quartz suggest limited terrestrial influx. Overall, this facies represents a transitional microfacies between the low-

energy inner shelf and the more agitated middle shelf environments (Wilson, 1975; Flügel, 2010; Tucker & Wright, 1990).

Glauconitic sandstone lithofacies (SMF-4)

This lithofacies includes quartz, glauconite, mica (muscovite), and tiny crystals of dolomite. Most of the framework grains, about 40-45% of the total modal composition, are quartz. The quartz grains are detrital, sub-rounded to rounded (Fig. 4 C, D), and display point to long contacts, suggesting moderate textural maturity and subaqueous transport. Further indicating authigenesis in marine settings, glauconite forms green rounded to ovoid pellets that fill intergranular spaces or partially replace detrital grains. Minor muscovite flakes, dolomite, and mivscovite and dolomite have been different characterized by high dolomite and flaky forms. Sparse dolomite rhombs are occasionally distributed in the matrix, reflecting minor early diagenetic dolomitization (Fig 4. C,D) (Tucker, 2001; Boggs, 2009; Pettijohn et al., 1987). The dominance of detrital quartz and the presence of authigenic glauconite suggest deposition in a marine shelfal environment characterized by slow sedimentation rates and moderate energy conditions. Glauconite formation typically occurs under oxygenated, slightly reducing conditions at or near the sediment-water interface, often associated with transgressive or condensed sections (Odin & Matter, 1981; Boggs, 2009). The occurrence of muscovite indicates a minor terrigenous influx from nearby continental sources. Overall, this lithofacies represents a shallow to mid-shelf depositional setting, where periodic sediment starvation favored glauconite authigenesis within a marine transgressive system (Wilson, 1975; Flügel, 2010; Tucker, 2001).

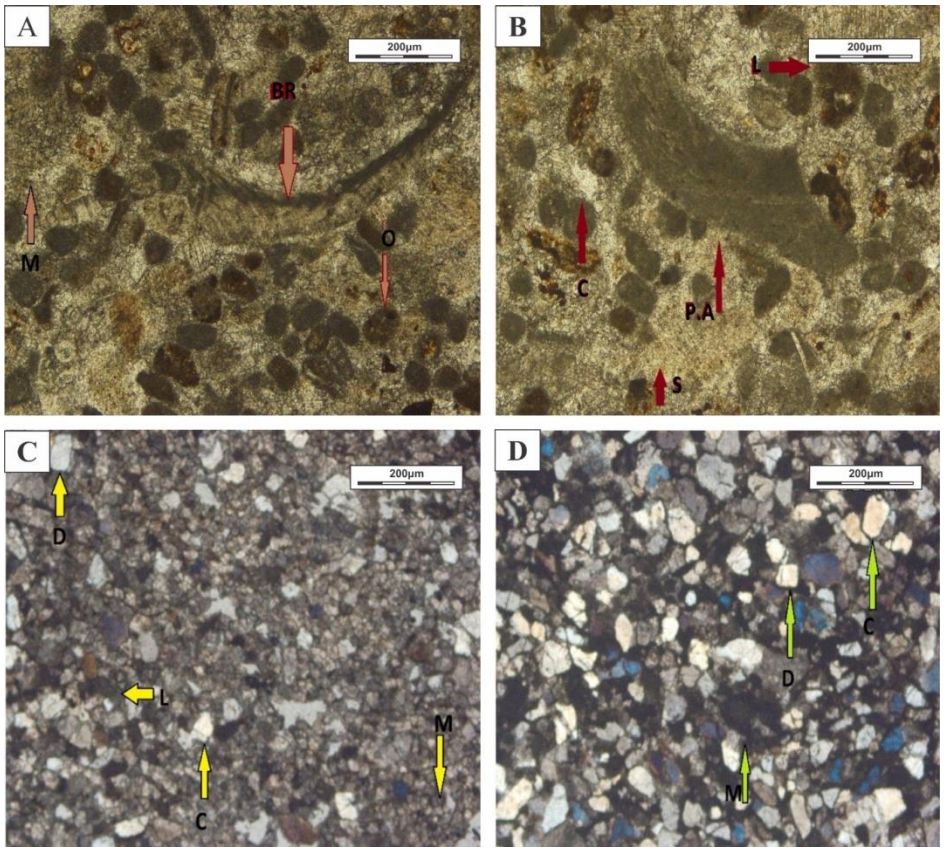


Figure 4. A and B) photomicrograph shows Bioclastic Pelliodal Wackstone Microfacies, C and D) photomicrograph Shows the Glauconitic Sandstone Lithofacies. C=Calcite, D=Dolomite, L=Leaching, M=Micrite, Br=Bracopods, S=Spar, B=Bioclast, M=Micrite and P.A=Pelliodal algae

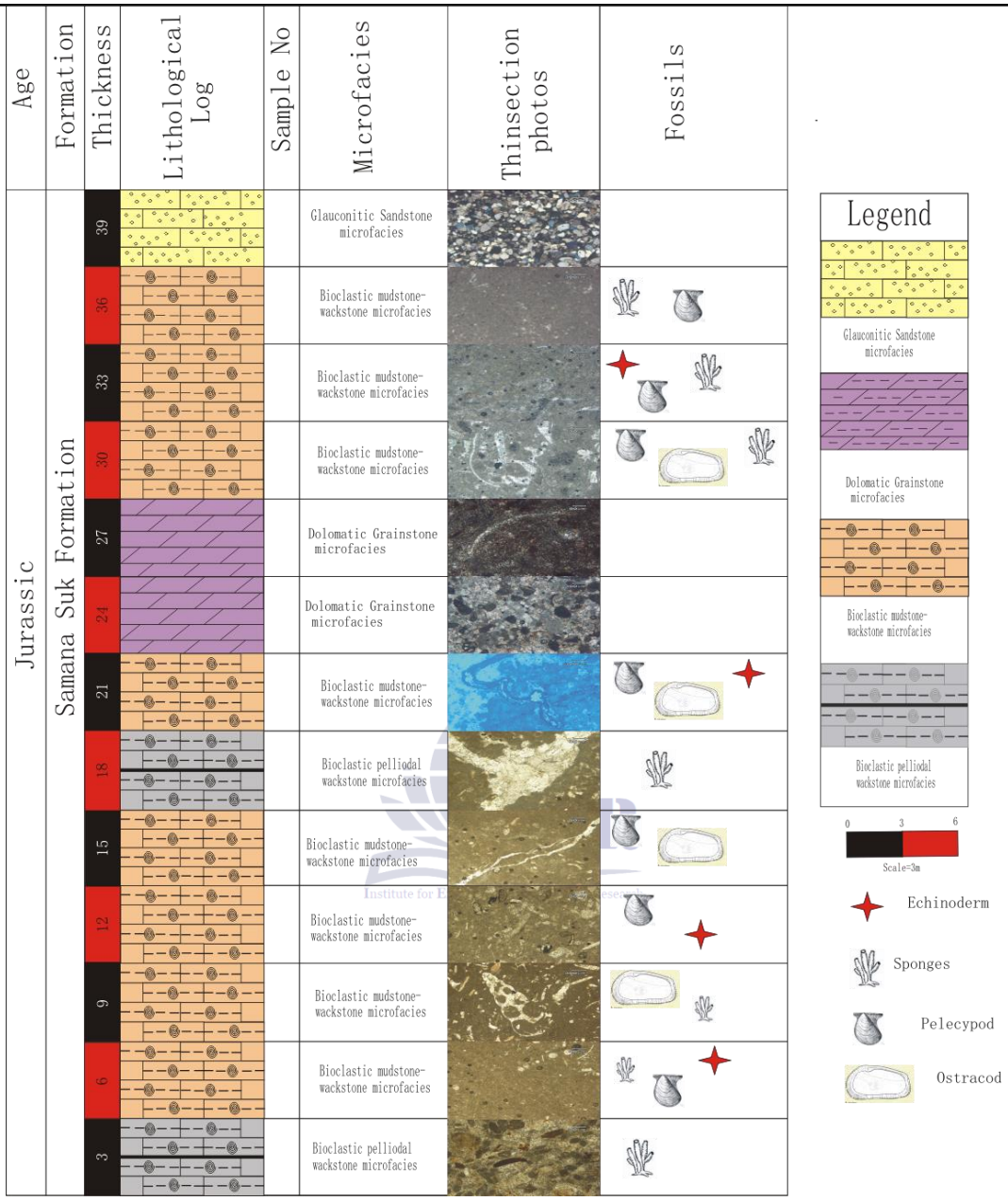


Figure.5 Microfacies Log Of Samana Suk Formation

Diagenetic Features

Micritization

After the sedimentation of strata diagenesis may occur at surface or in the shallow subsurface (Longman 1980). Dissolution, cementation or compaction (mechanical or chemical) usually alters the nature of carbonate sediments. Diagenesis plays vital role to control the reservoir properties of rock unit i.e. porosity and permeability modification. The fluids circulation in carbonate strata through the path provided by dissolution caused micritization and often intragranular cementation (Fig .6 A,b).

Within the Samana Suk Formation, diagenesis starts from the micritization of high Mg calcite (Aragonite) which is unstable near surface at low pressure. To get the stability it will move through the multiple phases. The dissolution subsequently replaced by calcite deposition.

Neomorphism

Neomorphism is replacement and recrystallization phenomenon. During neomorphism crystal size and mineralogy changed. In micritic limestone fine grained crystal are converted into coarse grained spary calcite (aggrading neomorphism) (Fig. 6 C, D).

Compaction

Compactional textures and fabrics are formed due to the increase in overburden pressure/stresses on carbonate rocks, some visible in the field i.e. stylolites and others more subtle. During compaction the bulk volume reduced. In the fine-grained rocks i.e. lime mud and shale the interstitial water is present due to overburden stresses/compaction it expels out. While in granular rock, compaction modifies the granular packing. Due to high grade of compaction, it will then flip to the chemical compaction where the dissolution takes place, and the formation of stylolites take places (Fig. 6 E, F). There are two type of compaction Mechanical Compaction and Chemical Compaction

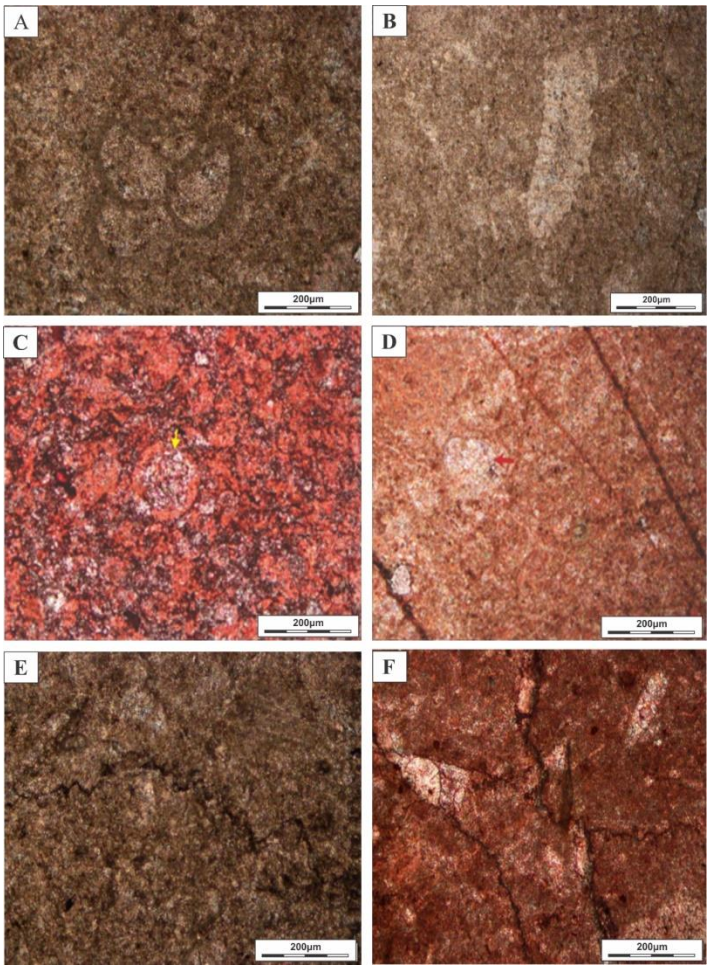


Figure. 6 A, B) photomicrograph shows micrite. C, D) shows neomorphism and E, F) shows stylolite compaction.

Environment of Deposition

The Samana Suk Formation from the Trans-Indus (Khisor–Kalachitta) Ranges indicates deposition in a carbonate shelf system, mainly covering the inner to middle shelf environments. In carbonate environments, the heterogeneity in microfacies and lateral facies distribution are influenced and controlled by local differences in substratum relief,

water depth, salinity, temperature, and hydrodynamic energy (Flügel, 2010; Wilson, 1975).

The Dolomitic Grainstone (SMF-1) microfacies suggest deposition in high energy subtidal environments influenced by waves and currents characteristic of shoal or open platform settings. The Bioclastic Wackestone–Mudstone (SMF-2) microfacies indicates deposition in low energy, inner-shelf lagoonal environments where fine carbonate mud and skeletal debris were sedimented in more restricted, trance-like, and calm waters. The Bioclastic Peloidal Wackestone (SMF-3) microfacies suggests more moderate energy conditions in an

outer to middle shelf setting and indicates the peloidal and skeletal elements were sedimented in an environment where gentle currents reworked the elements. Conversely, the Glauconitic Sandstone Lithofacies (SMF-4) indicates a shelfal marine environment with stagnant sedimentation and slack, gentle currents whereby transgressive marine conditions resulted in authigenic glauconite formation and deposition (Odin & Matter, 1981; Tucker & Wright, 1990).

Samana Suk Formation has recorded a transgressive-regressive cycle within an inner to middle shelf carbonate platform (Fig. 7). High and low energy conditions dynamically controlled the distribution of facies and their subsequent diagenetic overprinting. Such variation was reported previously for the Jurassic carbonates of the Lesser Himalayas and the Trans-Indus Ranges, Pakistan. (Shah, 2009; Fatmi, 1973).

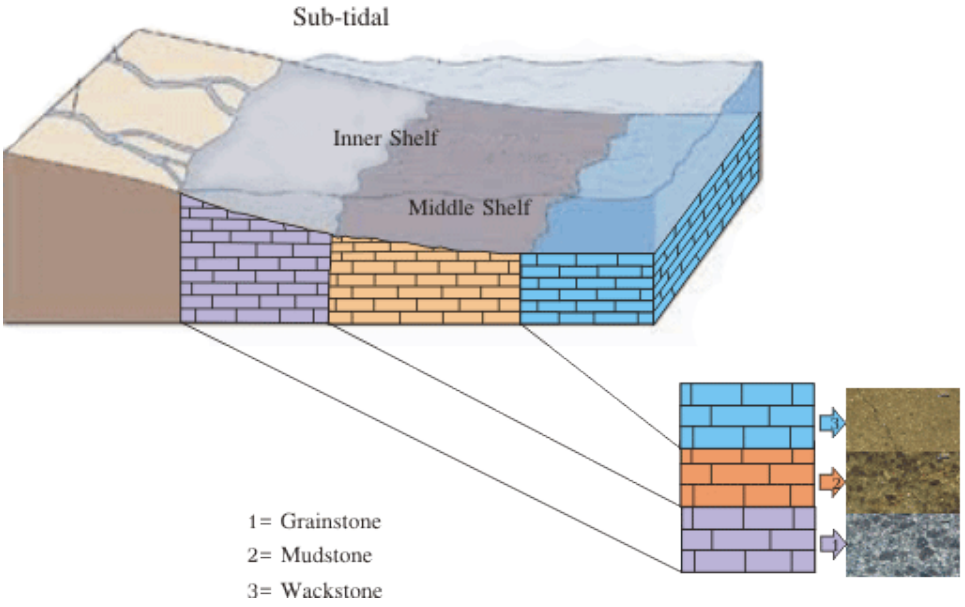


Figure.7 Proposed depositional model of the Samana Suk Formation.

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