

Sedimentology, Sequence Stratigraphy and Reservoir Characterization of Samana Suk Formation Exposed in Namal Gorge Section, Salt Range, Mianwali, Punjab, Pakistan

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Abstract: Samana Suk Formation of Bathonian-callovain age, exposed in Namal Gorge Salt Range, has been studied for microfacies and sequence stratigraphic investigation. The formation is mainly composed of limestone, with minor beds of sandstone and marl. The limestone is grey, yellowish and purple in color. Limestone is fine grained, thin to medium bedded with algal laminations. The sandstone is light yellowish brown, brick red in color, calcareous and quartzose. Within Samana Suk Formation one 2nd order sequence and two 3rd order sequences have been identified. Their regional correlation through fine-tuned dating helped to develop basin fill model and to understand facies dynamics. A facie belt comprising a wide belt of carbonate facies characterized by Peloidal Packstone microfacies represents inner ramp setting and Pelletal/ Peloidal Wackstone, Mud-Wackstone and Mudstone microfacies represent the low energy lagoonal environment. The sandstone lithofacies represents high energy beach environment which indicates aggrading to pro-grading pattern. The porosity analysis has been done on different samples of limestone and sandstone. For the porosity analysis the Image J software is used. In limestone the porosity ranges up to 6% while in sandstone the porosity ranging up to 18%. From the field and porosity analysis it is concluded that Samana Suk Formation in study area is good reservoir.

Keywords: Salt Range, microfacies, sequence stratigraphy, reservoir characteristics.

Introduction

Mianwali district consists of sedimentary province and called museum of geology. Earlier workers in the area include Shah (1977) Fatmi (1973, 1972), Kummel and Tiechert, (1970) etc. The research area under study is Namal Gorge, Salt Range, Mianwali. The area lies in

Pakistan topographic sheet no 38p/9 which is located between latitude and longitude 32° 39' 58.3'' N; and 71° 47' 49.9'' E respectively.

Regional tectonic setting

Tectonically the study area is the part of Salt Range

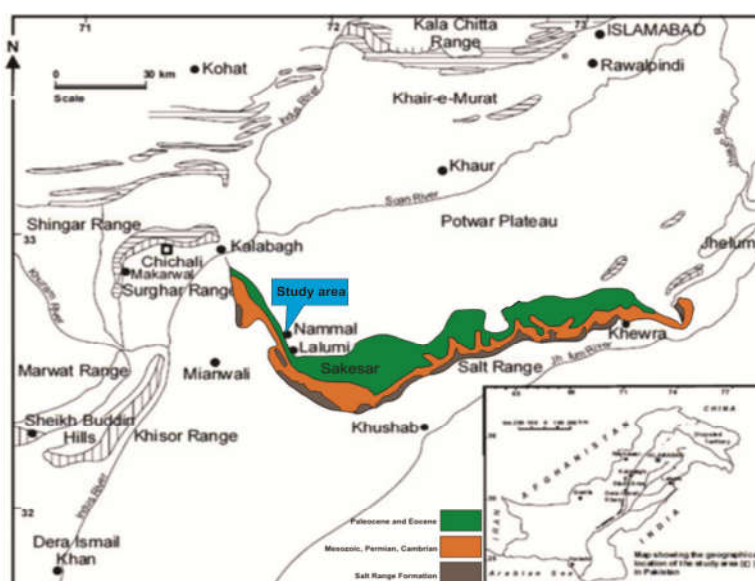


Fig. 1 Generalized geological map of Salt Range and adjoining area: The highlighted portion shows the Cis-Indus Ranges and location of the study area (after Gee, 1989). Rectangular inset shows the study area.

Thrust (SRT). Structurally, the Salt Range is the result of tectonic forces imposed during the later phases of the Himalayan orogeny in late Cenozoic time. The occurrence of the thick, incompetent Salt Range Formation at the base of the sedimentary sequence has strongly influenced the structures (Gee, 1989). The Salt Range is a complex Salt anticlinorium within which the Salt Range Formation is tectonically repeated by Cenozoic subsurface flow to attain a thickness of more than 2,000 m in some anticlines. The Salt Range anticlinorium is actually a series of Salt anticlines of the "Salt Pillow" type (Trusheim, 1960) in which the saline sequence has not penetrated the overlying non-saltiferous formations, but diapirism has been a major factor at a few localities namely Kalla Kahar, Vasnal, and strikingly at Mari Indus and Kalabagh near the Indus. Recent interpretation of seismic reflection profile across the Potwar, Salt Range and alluvial plains to the south (Baker, 1987; Lillie et al., 1987) combine with drill hole, gravity (Farah et al., 1977) and paleo-magnetic data (Johnson et al., 1979, 1986), indicates the presence of decollement along which the Eocambrian and overlying Paleozoic-Cenozoic sequence is displaced southward at least 29 km in the Central Salt Range, Eastward the Salt Range

folded (Gee, 1989). Westward, the Kalabagh Fault separates the Salt Range from Trans Indus Ranges (McDougall and Khan, 1990). Southward the Salt Range is truncated by the Salt Range Thrust (Fig. 1).

General Stratigraphy

The rocks under investigations are carbonates and some siliciclastic materials of Jurassic Samana Suk Formation, overlie Datta Formation and underlain by Hungu Formation. Davis (1930) for the first time introduced the name Samana Suk for limestone succession in the Samana Suk peak of Samana Range, which lies in the west of Hungu in District Kohat. In the study area the formation is chiefly composed of limestone with sandstone and marl inter-bedded. The limestone is grey, yellowish grey and yellowish brown in color. It is fine grained, medium to thick bedded, nodular, channelized, rippled surface in limestone unit which have interbedded sandstone and stylolitic at places and thin conglomerate beds are present at various intervals. The sandstone is light yellowish brown, brick red in color, calcareous, quartzose and contains beds of clay in the middle unit (Fig. 2). To avoid log repetition brief descriptions of the

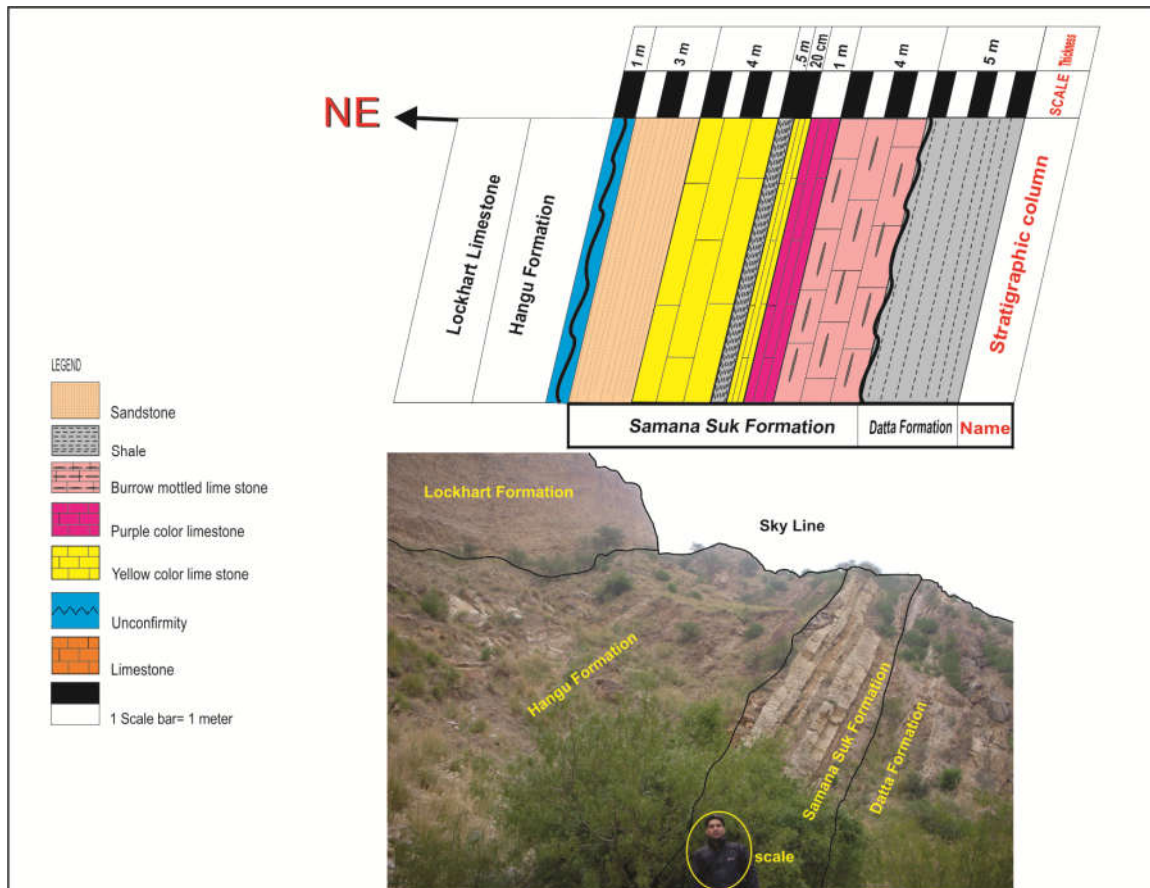


Fig. 2 Lithological units of Samana Suk Formation in Nammal Gorge section.

bifurcates into two northeast trending ridges (the DilJabba and Chambal-JogiTilla ridge) which are also

stratigraphy of study area are given (Fig. 3).

Objectives of present investigation

The present study is carried to investigate the following objectives;

- To interpret depositional settings of Samana Suk Formation.

- To establish sequence stratigraphy of Jurassic (Samana Suk Formation) in Nammal Gorge based on microfacies investigations and outcrop observations.
- To find out the reservoir potential of Samana Suk Formation.

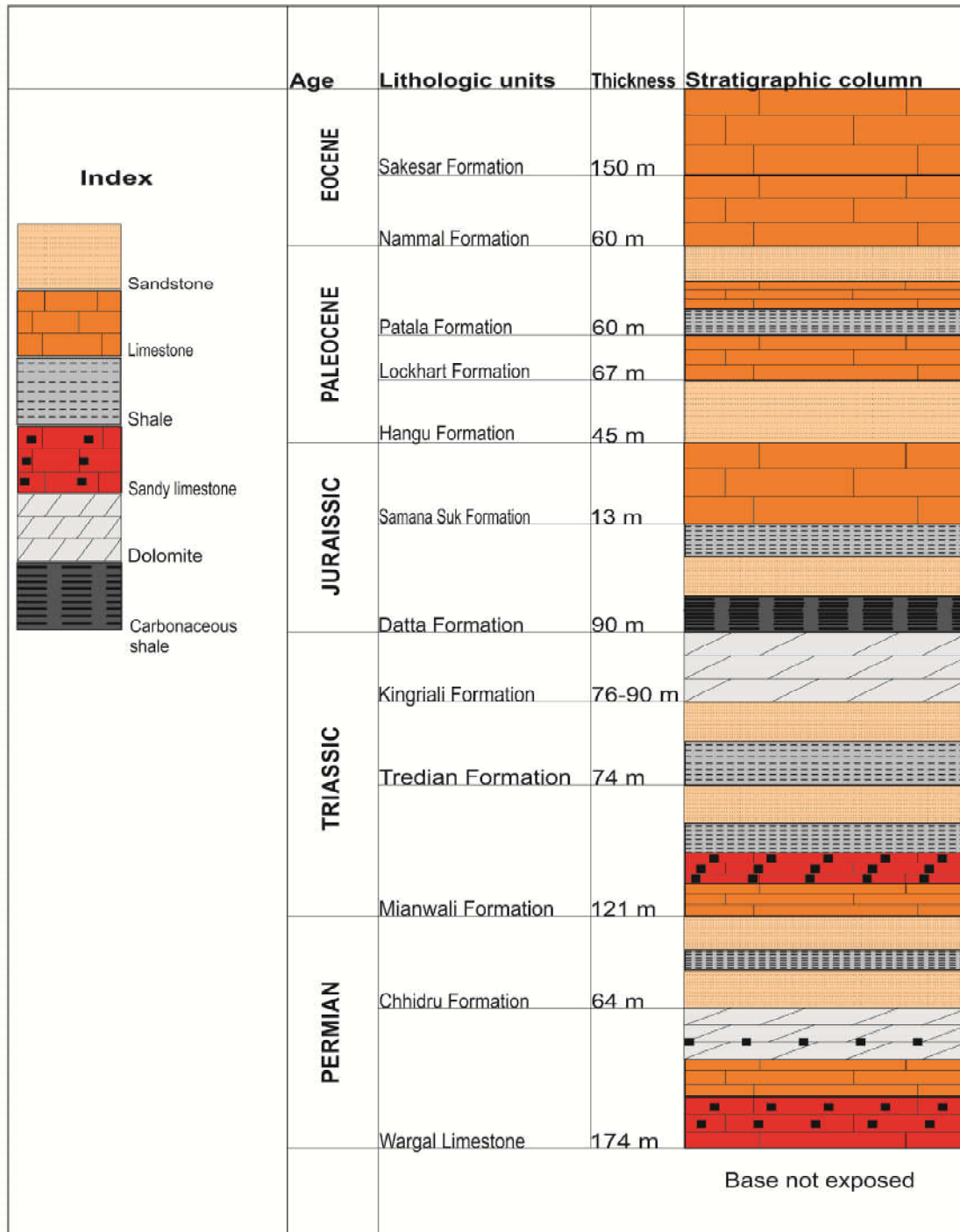


Fig. 3 Generalized stratigraphic succession of Nammal Gorge, Salt Range, Punjab, Pakistan.

Materials and Methods

Field work

The Samana Suk Formation was measured with Jacob's staff and samples were collected where textural and faunal changes were observed.

Thin section study using polarizing microscope

Petrographic data such as percentages of allochems, matrix and cements were generated and based on such data the limestone was classified using the classification schemes of Dunham (1962) and Folk (1959). The allochems type was further identified to determine sub-environments of deposition. After photographic analysis photomicrographs were taken for describing the microfacies. All the lab work was carried out in systematic manner for meaningful interpretation.

Porosity analysis

Newly developed methodology is used for the porosity analysis. The computerized software Image J (IJ) is used for the porosity analysis. The image J are working on Java script and counting the pore spaces in microphotographs. The methodology is used by Grove et al., (2011) and Haeri, (2015). The Image J required high resolution microphotographs. The microphotographs will be converted to 32 bit type (black/white color) to remove the different color complexities. After that, the threshold (Color threshold) will apply. In threshold window the "Dark background" is marked because the threshold color will only cover the background which is the pore spaces behind the allochems and cementing materials. After the threshold adjustment the analyzed particles command will apply. The analyzed particles commands have different calculations in which there are the calculations of percent area by applying this option the covered percent area will be displayed which will be the percentage porosity. This methodology is applied on five selected samples and percentage porosity was determined.

Results and Discussion

Microfacies of Samana Suk Formation

Microfacies analysis of Samana Suk Formation is based on detailed field work and petrographic studies, bedding characteristics, allochems type and textural variations, all are used to identify and interpret depositional condition of each microfacies according to Dunham's classification (1962). Microfacies of Samana Suk Formation in Nammal Gorge Salt Range are as follows.

SMF1-Peloidal Packstone Microfacies

SMF2- Pelletal/ Peloidal Wackstone Microfacies

SMF3-Mud to Wackstone Microfacies

SMF4- Mudstone Microfacies

SMF5- Grainstone/Sandstone Microfacies

Peloidal Packstone Microfacies

In outcrop view, this microfacies shows burrows and mottling in limestone. The limestone is grey color on fresh surface and yellowish color on weathered surface. This limestone is 4 meter thick which is present at the base of exposed Samana Suk Formation. The limestone showing this microfacies is represented by NG-S1.

Petrographic description

Allochems range in percentage from 01-48% approximately. Allochems are comprised of Peloids (48% approximately), Intraclasts (5% approximately), recrystallized bioclasts (2% approximately), ostrocod (1% approximately) and sponge dendrites (5% approximately). While the remaining content is composed of approximately 42% micrite. The sub microfacies is composed of allochems and micrite as a cementing material (Plate 1).

Interpretation

Based on the features like burrows, mottlings, non-skeletal allochem (Peloids and Intraclasts) and restricted skeletal allochem of ostrocod, sponge dendrites and recrystallized bioclasts, inner ramp setting is suggested for this microfacies. This microfacies is compared with RMF-4 of Wilson (1975) and Flugel (2004).

Pelletal Packstone Microfacies

On outcrop scale this microfacies is comprised of purple color limestone which have thickness of 1.0 meter.

Petrographic description

This microfacies comprise of allochems in the form of pellets, bivalves, sponge dendrites, and recrystallized bioclasts. Pellets are 50% approximately, bivalves are 3% approximately, sponge dendrites 3% approximately and recrystallize bioclasts 4% approximately. The cementing contents are micrite. This microfacie is present in NG-S2 thin section. Most of the peloids are fecal pellet (Plate 2).

Interpretation

On the bases of the restricted fauna and micrits as a cementing material with dominant fragments of non-skeletal particles (Fecal pellets) suggest that, the environment of deposition is in low energy condition, lagoonal environment. This microfacies is compared with microfacies of Rahim Mahari (2013).

Mud-Wackstone Microfacies

On outcrop scale, this microfacies is represented by NG-S3 which is thin bedded yellow color. Total thickness of this microfacies is 20 cm.

Petrographic description

This microfacies is comprised of Mud-Wackstone fabric with some parts are completely mud supported fabric with no abundant flora and fauna while in rest of it contains 10-12% approximately recrystallized bioclasts and bivalves (2% approximately). The allochems are completely recrystallized into rhombic crystal (Plate 3).

Interpretation

Due to lack of diversified faunal contents, predominance of lime mud as a matrix, this microfacies is interpreted to represent deposition in a low energy lagoonal setting. This microfacies is similar to standard microfacies of RMF-18 Wilson (1975) and Flugel (2004).

Mudstone microfacies

Petrographic description

This microfacies is composed of micrite as a cementing material with dominantly composed of sponge dendrites (2% approximately), recrystallized bioclasts (1% approximately) and echinoderm spines (less than 1% approximately) (Plate 4).

Interpretation

Based on micrite as a dominant component and lack of fauna suggested deposition in low energy lagoon environment, it is compared with RMF-19 of Wilson (1975) and Flugel (2004).

Sandstone lithofacies

In outcrops sandstone lithofacies is represented by grayish gray sandstone of 4 meter thick, thin to medium bedded.

Petrographic description

In thin section sandstone lithofacies is represented by quartz, feldspar and some rock fragments. The allochems are cemented by carbonate matrix. Some siliceous matrix is also present which represents quartz overgrowth. The abundant quartz is sub rounded to round in nature. So, it represents mineralogical and texturally mature sandstone (Plate 5).

Depositional environment

The studied samples, representing part of the middle

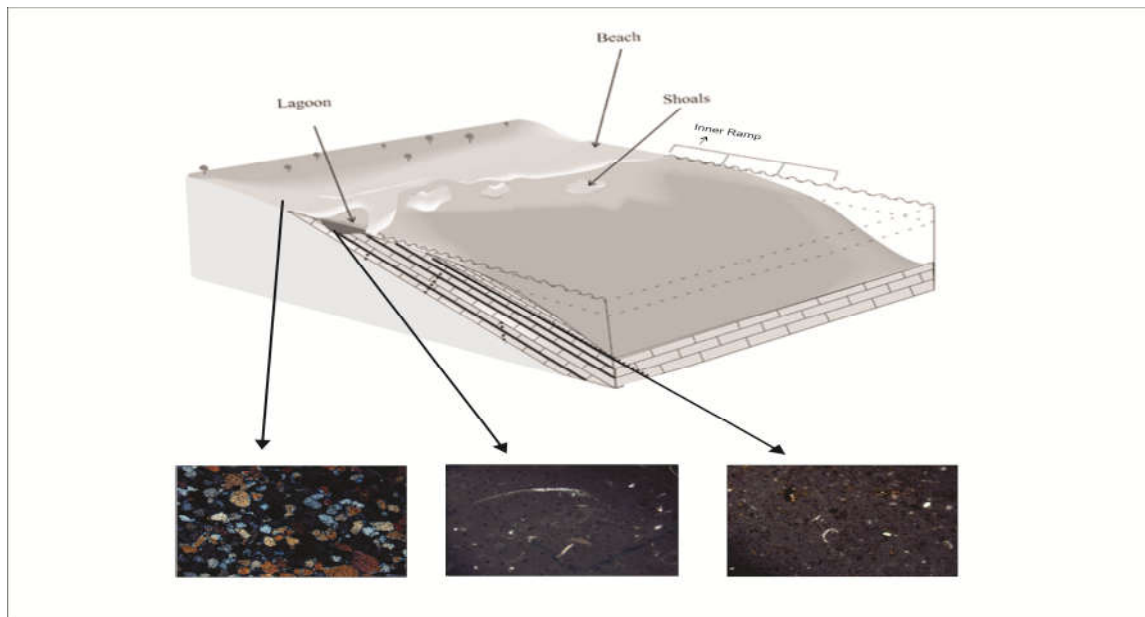


Fig. 4 Depositional model of Samana Suk Formation.

This microfacies at outcrop is represented by inter bedded algal laminated limestone and grey color medium bedded limestone. This microfacies is represented by NG-S4 thin section. This microfacies represents a total thickness of 4 meter and present at the top of exposed section of Samana Suk Formation in Nammal Gorge section.

Jurassic Samana Suk Formation correspond to the deposition in gently sloping inner ramp to beach environment. This interpretation is based on microfacies identification and their vertical succession in the studied section. In such carbonate settings, local variation in topography, water depth, salinity, and temperature and

energy condition are responsible for microfacies variation. The changes in energy condition are marked by stratigraphic variation from Peloidal Packstone to Sandstone lithofacies. Various microfacies are identified and interpreted from the studied samples. The Peloidal Packstone microfacies represent inner ramp setting. The Pelletal/Peloidal Wackstone, Mud-Wackstone and Mudstone microfacies represent the low energy lagoonal environment. The sandstone lithofacies represents high energy beach environment (Fig. 4).

Sequence Stratigraphy

Sequence stratigraphy is relationship between global sea level changes and sedimentation or the relationship between Eustasy, tectonics and sedimentation (Vail, 1987) prior to the concept of sequence stratigraphy proposed by Vail (1987).

5.1. System Tracts in Samana Suk Formation

There is one 2nd order sequence in Samana Suk Formation and two 3rd order sequences i.e. system tracts. The correlation of local sequence with fine-tuned (Haq et al., 1987) global sequence helped us to develop

basin fill model and to understand facies dynamics.

Locally one 2nd order sequence in Samana Suk Formation are i.e. NSM 1, while the global (Haq et al., 1987) sequences i.e. LZA 2.1 and LZA 2.2. There are two 3rd order sequences in Samana Suk Formation i.e. TST and HST while in global scenario 3rd order sequences are six i.e. TST, HST, SMW. The absence of Shelf margin wedge (SMW) and one complete 2nd order sequence in Samana Suk Formation may be because of;

1. The depositional setting of Samana Suk Formation at this particular location does not represent the shelf margin.
2. The carbonate production on the end of HST is lower than the sea level rise and that is why the SMW is missing.
3. The depositional setting of Samana Suk Formation at this particular location may not be fully developed because it is just 13.00 m thick while in other area in Upper Indus Basin its thickness is more than 242.00 meters at Shikh Buden Hills (Krishnan, 1960).

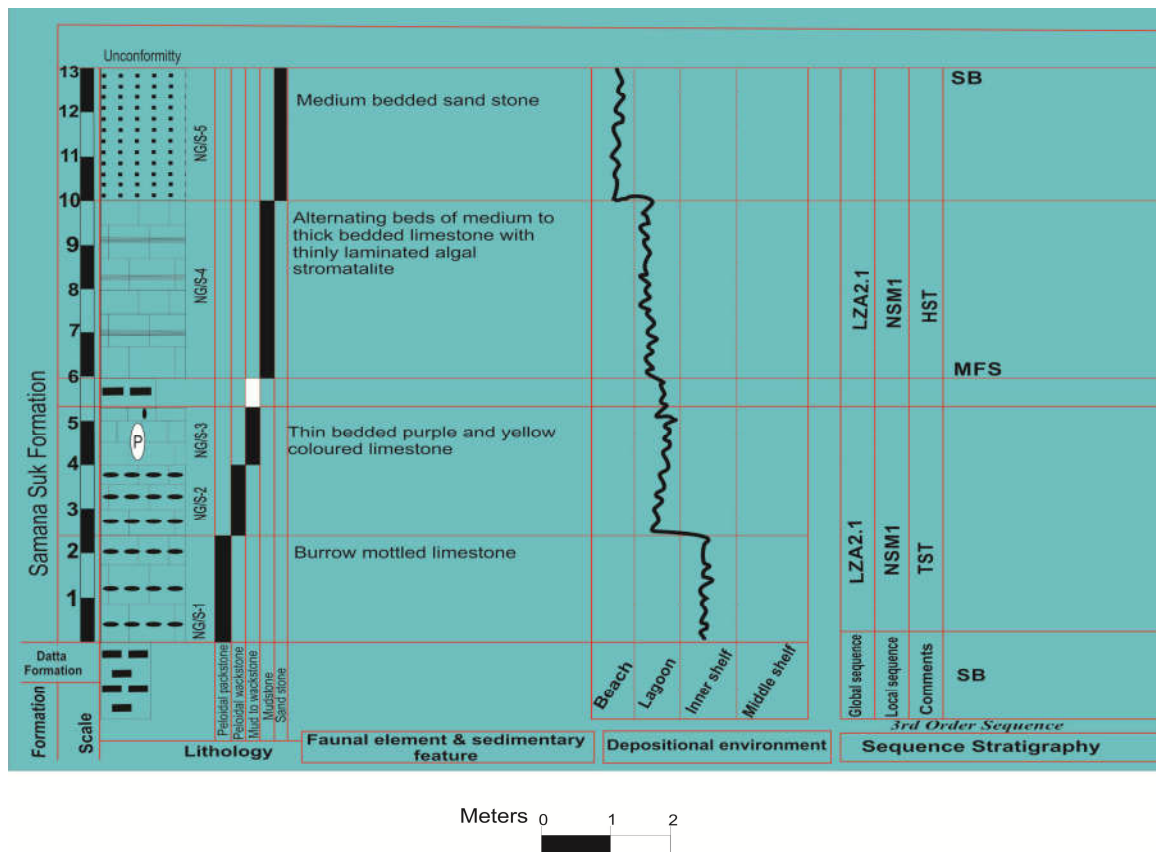


Fig. 5 Shows the depositional environment of microfacies and sequence stratigraphy of Samana Suk Formation in Nammal gorge, Mianwali, Punjab, Pakistan.

5.1.1. NSM 1 Sequence in Samana Suk Formation

Locally present NSM 1 is represented by TST and HST. SMW is present in global sequence while locally it is absent. It is because of the reasons defined above. TST and HST are described below.

5.1.2. Transgressive System Tract

The 3rd order sequence of NSM1 is represented by burrow mottled limestone and purple yellow coloured limestone of inner ramp and lagoonal geological environment. It has total thickness of 6.00 meter which is bounded by sequence boundary coinciding flooding surface at the base and maximum flooding surface at the top of this unit. These features reflect the

transgressive system tract (Fig. 5).

5.1.3. High Stand System Tract

The 2nd order sequence of NSM1 is represented by thick bedded limestone with thinly laminated algal stromatolite of lagoonal environment. It has total thickness of 4.00 meter which is bounded by maximum flooding surface at the base and sequence boundary at the top of this unit. There are two orders

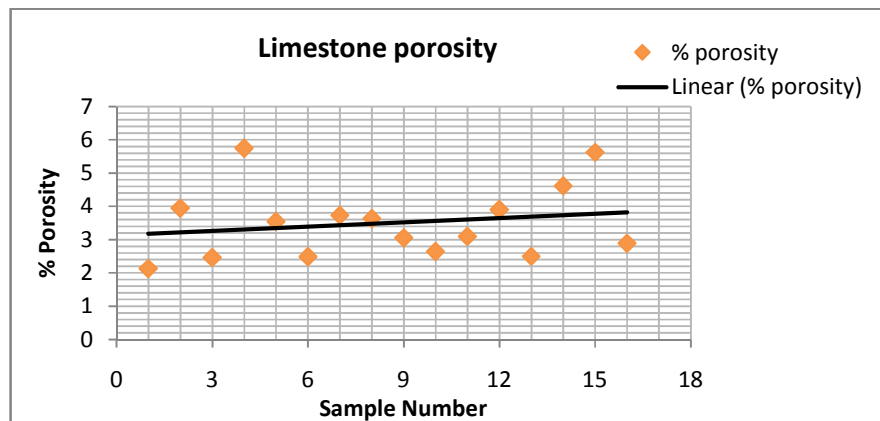


Fig. 6 Show the percentage porosity in limestone beds of Samana Suk Formation.

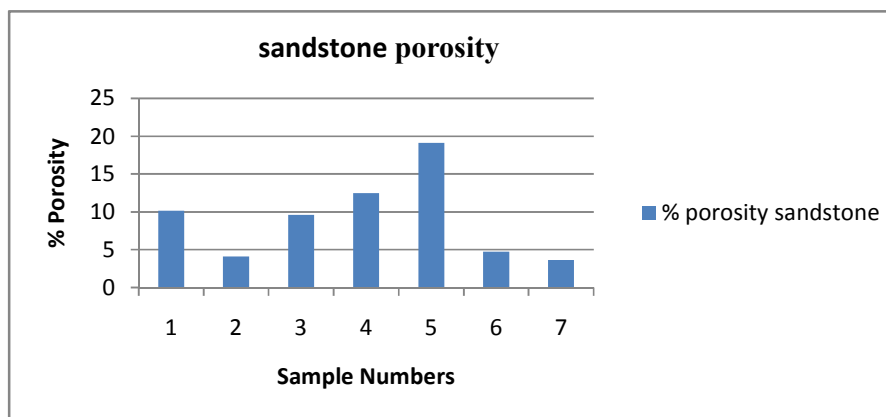
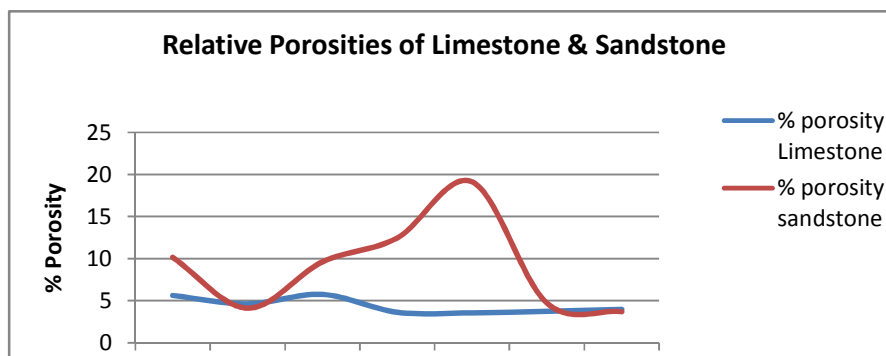


Fig. 7 Show the percentage porosity in sandstone bed of the Samana Suk Formation.



Plates 1

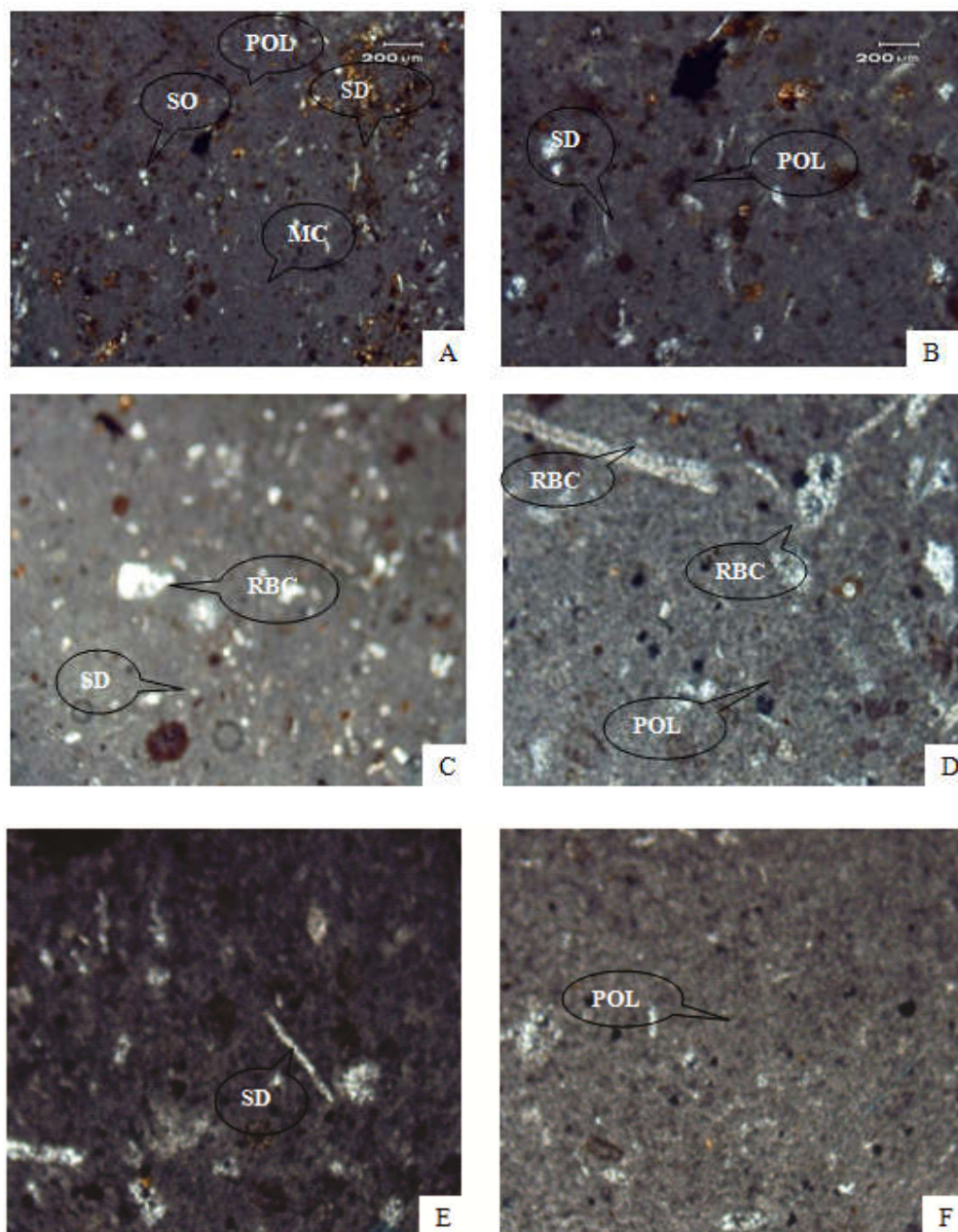


Plate 1

Fig. A: Photomicrograph showing Peloidal packstone microfacies having sponge specule (SO) Peloids (POL) and micrite (MC). (Sample NGS1).

Fig. B: Photomicrograph showing Peloidal packstone microfacies Peloids (POL) and sponge dendrites (SD) (Sample NGS1).

Fig. C: Photomicrograph showing Peloidal packstone microfacies having recrystallized bioclasts (RBC) and sponge dendrites (SD) (Sample NGS1).

Fig. D: Photomicrograph showing Peloidal packstone microfacies having recrystallized bioclasts (RBC) and Peloids (POL) (Sample NGS1).

Fig. E: Photomicrograph showing Peloidal packstone microfacies having sponge dendrites (SD) (Sample NGS1).

Fig. F: Photomicrograph showing Peloidal packstone microfacies having Peloids (POL) Sample NGS1).

Plate 2

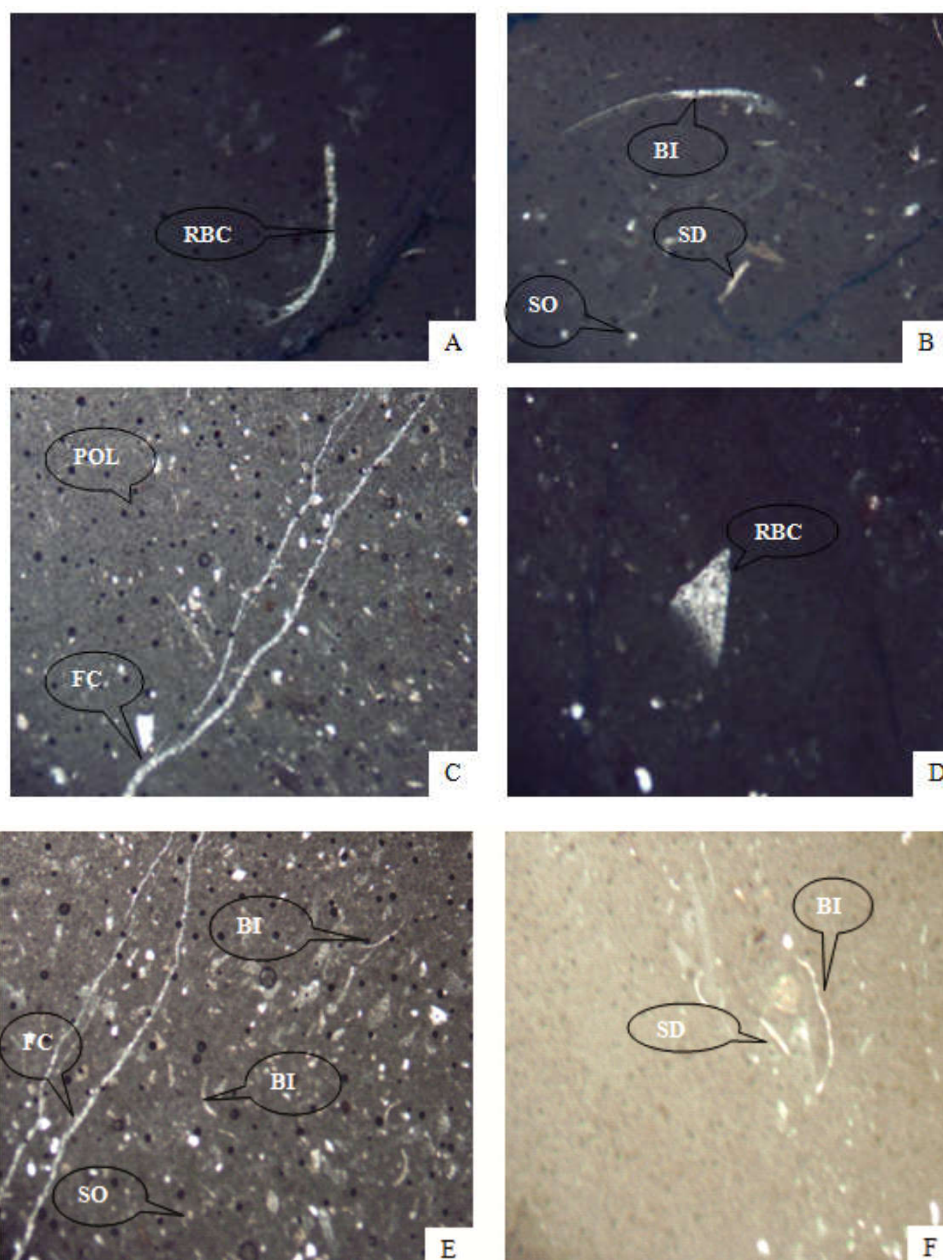


Plate 2

Fig. A: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having recrystallized bioclast (RBC) (Sample NGS2).

Fig. B: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having bivalves (BI) and sponge dendrites (SD) (Sample NGS2).

Fig. C: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having Peloids (POL) and fractures (FC) (Sample NGS2).

Fig. D: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having recrystallized bioclasts (RBC) (Sample NGS2).

Fig. E: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having bivalves (BI) fractures (FC) and sponge specks (SO) (Sample NGS2).

Fig. F: Photomicrograph showing Pelletal/ Peloidal wackstone microfacies having bivalves (BI) and sponge dendrites (SD) (Sample NGS2).

Plate 3

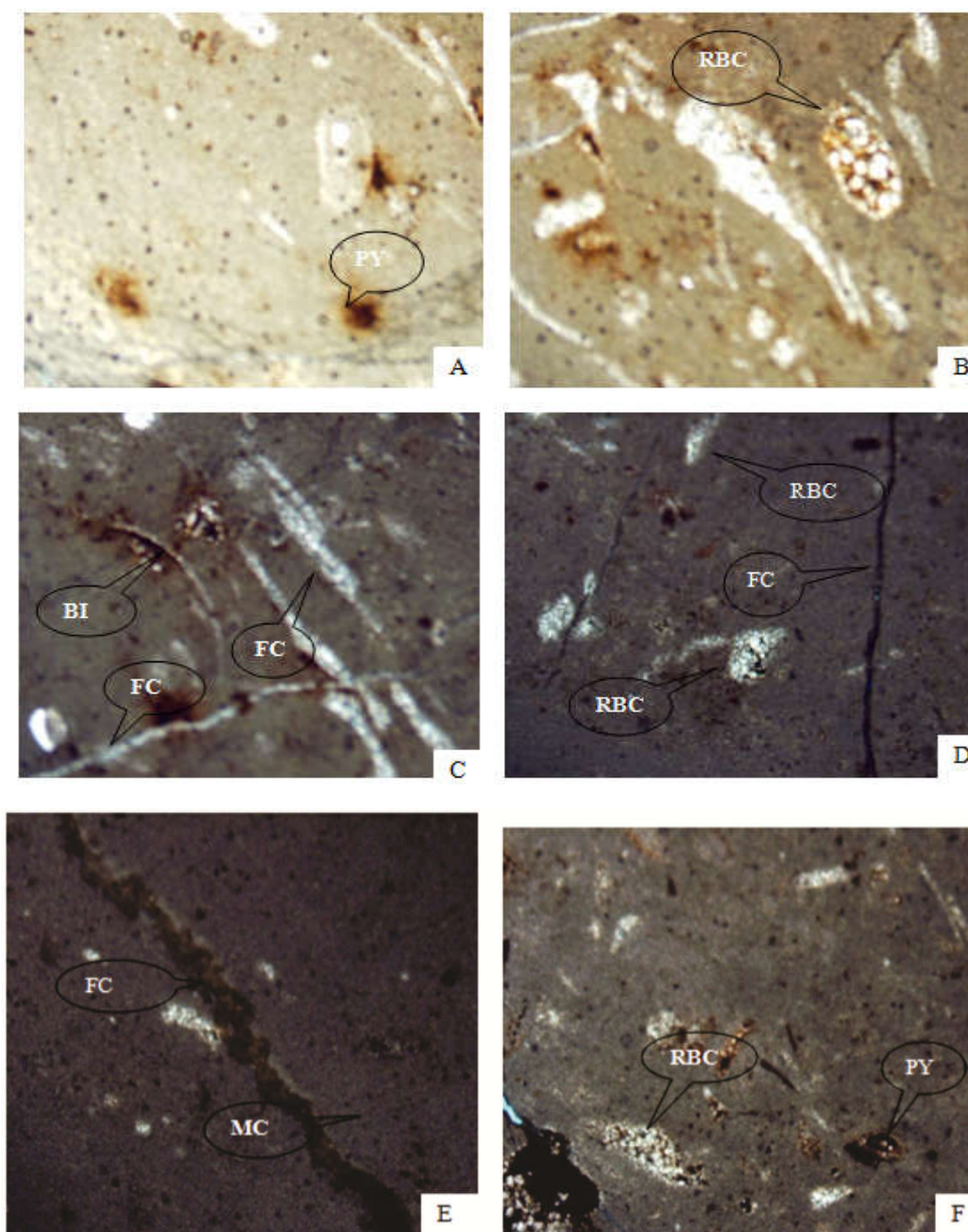


Plate 3

Fig. A: Photomicrograph showing mud to wackstone microfacies having pyritization (PY) (Sample NGS3).

Fig. B: Photomicrograph showing mud to wackstone microfacies having recrystallized bioclasts (RBC) (Sample NGS3).

Fig. C: Photomicrograph showing mud to wackstone microfacies having bivalves (BI) and fractures (FC) (Sample NGS3).

Fig. D: Photomicrograph showing mud to wackstone microfacies having recrystallized bioclasts (RBC) and fractures (FC) (Sample NGS3).

Fig. E: Photomicrograph showing mud to wackstone microfacies having fractures (FC) and micrite (MC) (Sample NGS3).

Fig. F: Photomicrograph showing mud to wackstone microfacies having recrystallized bioclasts (RBC) (Sample NGS3).

Plate 4

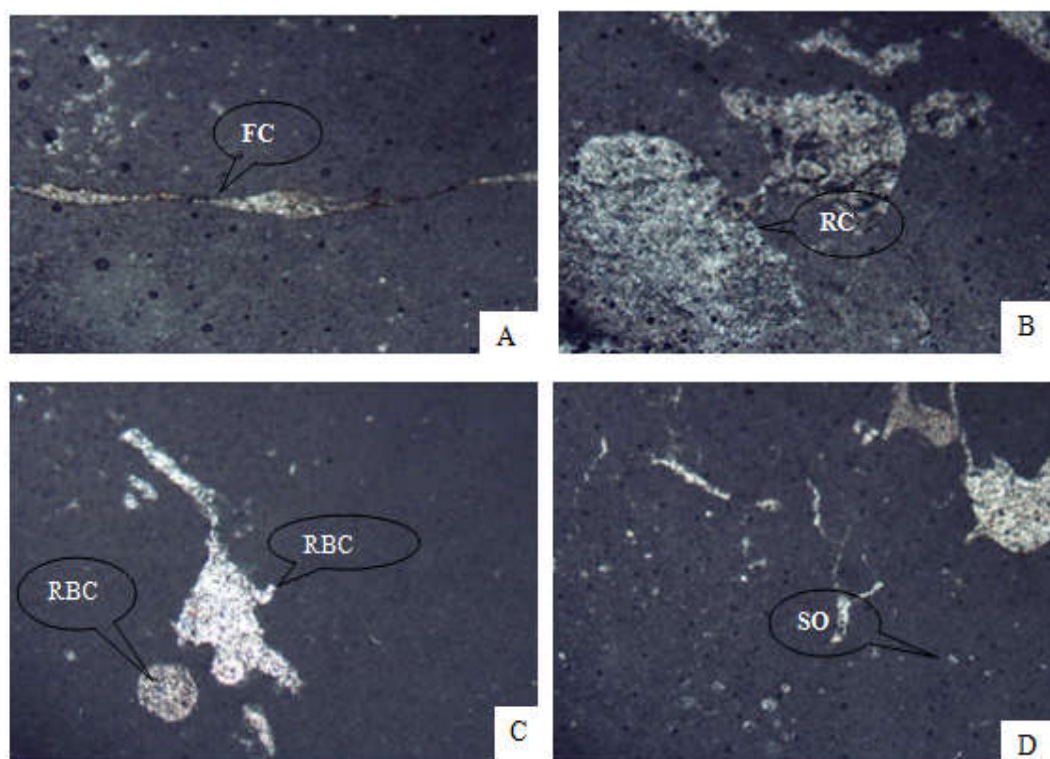


Plate 4

Fig. A: Photomicrograph showing mudstone microfacies having fractures (FC) (Sample NGS4).

Fig. B: Photomicrograph showing mudstone microfacies having recrystallization (RC) (Sample NGS4).

Fig. C: Photomicrograph showing mudstone microfacies having recrystallized bioclasts (RBC). (Sample NGS4).

Fig. D: Photomicrograph showing mudstone microfacies having sponge specule (SO) (Sample NGS4).

Fig. E: Photomicrograph showing mudstone microfacies having recrystallized bioclasts(RBC) and sponge dendrites (SD) (Sample NGS4).

Fig. F: Photomicrograph showing mudstone microfacies having echinoderms (ECO) recrystallized bioclasts and sponge dendrites (Sample NGS4).

Plate 5

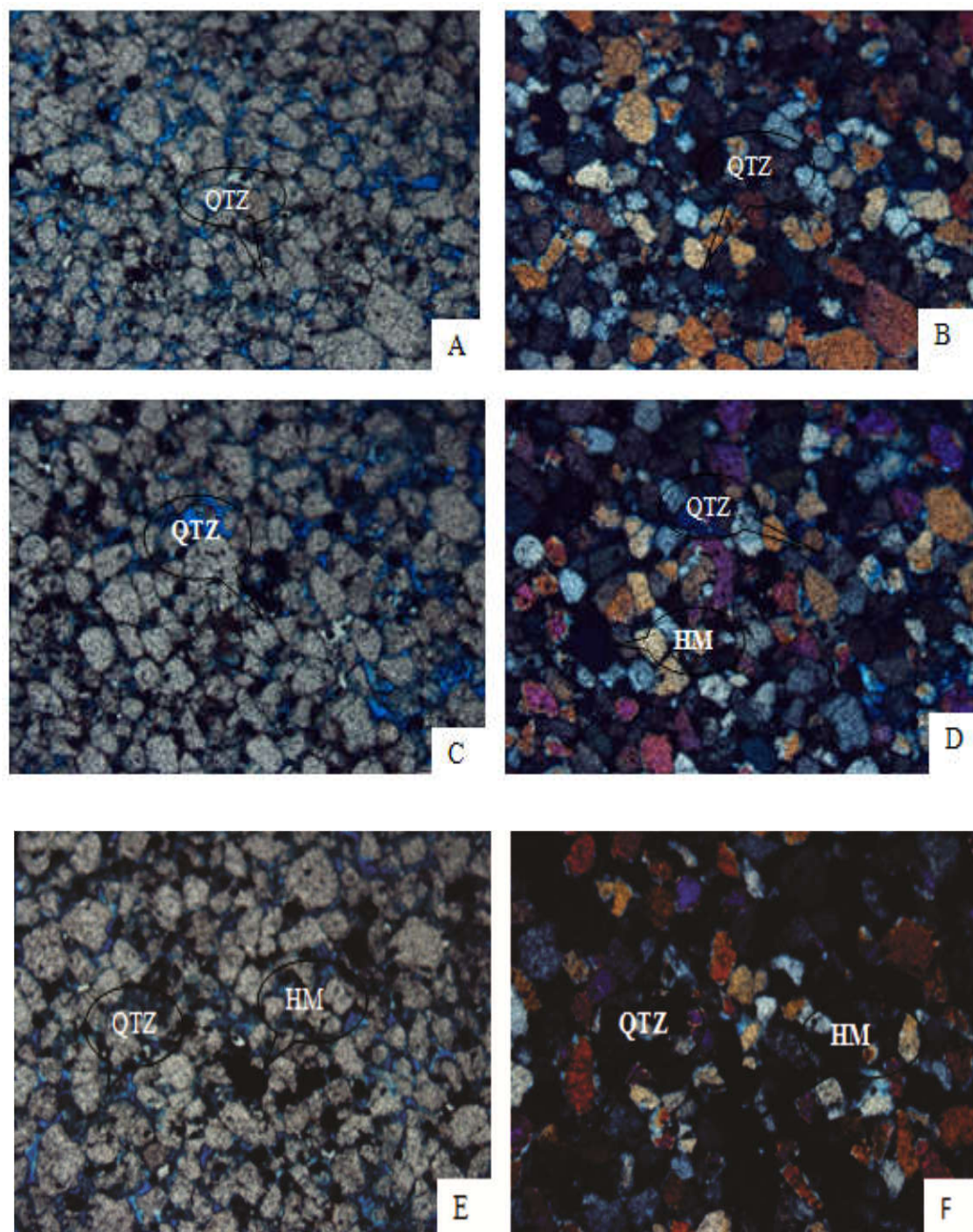
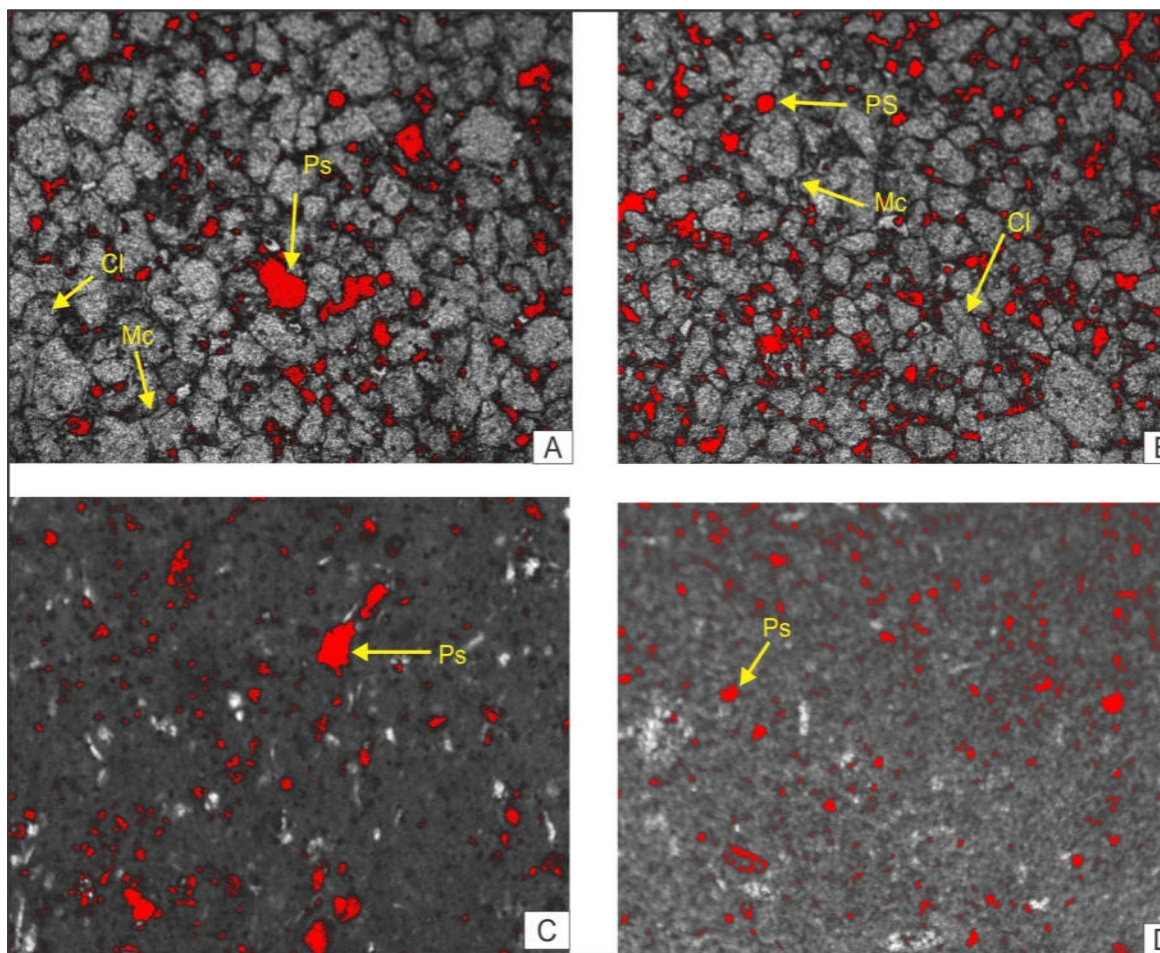


Plate 5

Figs. A -F: Photomicrographs showing Grainstone / sandstone microfacies having quartz grain (QTZ) and heavy minerals (HM) (Sample NGS5).

Plate 6**Plate 6**

Shows the porosity threshold of Image J. Figs. A & B show Sandstone threshold while C & D show limestone threshold. In Plate 8.1, Pore spaces (Ps), Clasts (Cl) and micrites (Mc).

of depositional episodes, from lagoon to lagoonal-beach and from lagoonal-beach to beach environment (Fig.5.). These features reflect the High Stand System tract (HST).

Reservoir characterization

Carbonate rocks (limestone and dolomite) account for approximately 50% of oil and gas production around the world as a reservoir (Halley and Schmoker, 1983). In present study both the carbonate and clastic rocks (sandstone beds in Samana Suk Formation) are studied. In present study the micro and macro both porosities are studied. The macro porosities are studied at field in the form of fractures and joints etc. The Samana Suk Formation in the study area has filled and unfilled fractures and joints which indicate that it has

macro porosity. On the other hand the micro porosity is studied in detail. The term *microporosity* refers to very small pores that can be recognized only with the assistance of a high-powered binocular microscope or thin-section (Choquette and Pray, 1970; Pittman, 1971). Micropores, have different types and shapes on the bases of which it may be divided into: (1) birds eye pores in tidal flat deposits; (2) intra-particle pores within small particles; (3) inter-crystalline pores between dolomite crystals or between calcite cement crystals; (4) inter-crystalline pores within the nuclei or cortices of oolites; or (5) intra-crystalline pores within individual dolomite or calcite cement crystals. In the present study the intra-crystalline, inter-crystalline and individual pores are observed as well as micro fractures. In present investigation in limestone the percentage porosity are ranging from 2% to 6% (Fig.

6) which is good enough as a reservoir because it is only the micro porosity (Nurmi, 1986). On the other hand the porosity ranging in sandstone beds up to 18% (Fig. 7) which is a good ratio for a reservoir. On the comparison of porosities of the limestone and sandstone it is concluded that the sandstone porosity is mostly higher than limestone (Fig. 8). From the sandstone, limestone porosities and field observation it is concluded that the Samana Suk Formation is recommended as a good reservoir in the study area. The threshold color porosity is presented in Plate 6.

Conclusion

As a result of this investigation the concluding remarks are as follows.

1. Samana Suk Formation is an integral part of Jurassic succession exposed in geology of Pakistan which represents carbonate with some assemblages of siliciclastic materials (marl/sandstone). The limestone is gray, yellowish and purple in color which is thin to medium bedded and inter-bedded with algal stromatolite.
2. Several microfacies have been developed in the Jurassic Samana Suk Formation on the basis of petrographic study, including 1) Peloidal Packstone microfacies; 2) Pelletal/Peloidal Wackstone, 3) Mud-Wackstone Microfacies, 4) Mudstone microfacies and 5) Sandstone lithofacies represent deposition in inner ramp, lagoonal to beach setting respectively.
3. About 13.00 meter thick carbonate sediments of Samana Suk Formation represent 2nd order and 3rd order sequences i.e. Transgressive Systems Tract (TST) and High stand Systems Tract (HST).
4. From porosity analysis and field observation it is concluded that the Samana Suk Formation in study area is good reservoir because the mix carbonate and clastic nature in the study area added extra potential to the reservoir potential.

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