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The Impact of Diagenesis and Dolomitization on the Reservoir Potential of Middle Jurassic Samana Suk Formation from Khanpur Dam Section Hazara Basin, Khyber Pakhtunkhwa Pakistan

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Abstract: Detailed study of the Samana Suk Formation has been carried out from the Khanpur Dam Section. Two lithological units have been identified in the studied section, limestone and dolomite (60% and 40% respectively). The dolomite is present in the form of beds or veins filling fracture and joints. In the field three types of dolomitization can be observed, yellowish, brown and saddle varieties. Microscopic studies reveal either partial, complete and selective dolomitization, which include (1) fine crystalline planar-euhedral, subhedral dolomite and non-planer anhedral dolomites (2) fine to medium crystalline non-planar-anhedral dolomite, (3) medium crystalline planar-euhedral dolomite, (4) coarse crystalline planar-subhedral dolomite, (5) coarse crystalline non-planar-Anhedral dolomite and (6) saddle dolomites. The dolomitic facies have intercrystalline porosity compared to limestone facies, which is characterized by inter-particles, moldic, vug, intraparticle, fractures and burrows porosities. The porosity of the limestone facies varies between 3% and 6%, which increase to 12% in the fractured samples, while the porosity of the dolomitic facies is in the range of7% and 14%. It has been concluded that the increasing porosity is the direct result of dolomitization. This interpretation is consistent with the field and petrographic observation, which indicate that dolomitization is secondary in nature. The dolomitization is the direct result of fluid along the fault plane due to tectonic loading creating pressure gradient.

Keywords: Samana Suk Formation, diagenesis, dolomitization, Hazara basin, porosity analysis.

Introduction

The Samana Suk Formation named by Davies (1930) is exposed in the Samana Ranges near the Hangu town. Previously, different names were assigned by various researchers (Gee, 1945; Cotter, 1933; Latif, 1970 a), however, the Stratigraphic Committee of Pakistan in 1980, formalized the name as the Samana Suk Formation. The Samana Suk Formation has shallow marine depositional nature and mostly of coarse grain oolitic and pelletic composition (Qureshi et al., 2008). It is combined in the different proposition to form different microfacies. The exposed middle Jurassic limestone in the Hazara Basin contains maximum number of microfacies (Chaudhry et al., 1998 a). The Samana Suk Formation is exposed at many locations in Hazara-Kashmir Basin (Ahsan, 2008). A huge volume of literature is available on Samana Suk Formation (Ali et al., 2013, Hussain et al., 2013, Saboor et al., 2015, Qureshi et al., 2008, Nizami et al., 2009 a) focused on the depositional and sequence stratigraphic interpretation. Very little literature is available on its diagenetic signature and mostly the study is confined to the upper Indus basin. In the present work, the Samana Suk Formation from the Hazara basin is carried out in order to understand its diagenetic setting and its control on the reservoir potential. During this work, different diagenetic phases of the Samana Suk Formation were studied. These diagenetic phases lead to decrease or increase the porosity framework. Essentially, the dolomites were additionally inspected at both field and petrographically. From the field and petrographic perceptions, the conceivable starting point and diagenetic setting of dolomites has been assessed. Additionally, the impact of dolomitization on the porosity was also carried out. The sedimentological interpretation of the Samana Suk Formation in Khanpur has not been analyzed previously. The present study will provide better understanding on the structural complexities of the Khanpur area as well as the reservoir potential of the Samana Suk Formation.

Geological setting of the study area

The study area is the part of the Hazara Basin situated in lesser Himalayas. The Hazara Basin is bounded by Main Boundary Thrust in south, while at north by Panjal thrust (Fig. 1) (Ahsan, 2008). Due to Himalayan orogeny and the compressional tectonics environment, the area is structurally well-developed. The study area possesses many thrust faults, anticline, and synclines. The Hazara Hill Ranges signify the passive margin sediments of the Mesozoic-Cenozoic age of Indian Plate that have been shortened and uplifted along the Main Boundary Thrust (Izzat, 1993). Stratigraphically the area of southeastern Hazara forms a part of the much larger than Kohat and Potwar sedimentary basins (Ghazanfar et al., 1990). The study area composed of a thick succession of Precambrian, Jurassic, Cretaceous, Paleocene, Eocene and Miocene rocks. The oldest formation in the study area is of Pre-Cambrian age Hazara Formation and the youngest is Muree Formation of Miocene age (Fig. 1). The outcrops are well exposed along elevated highs.

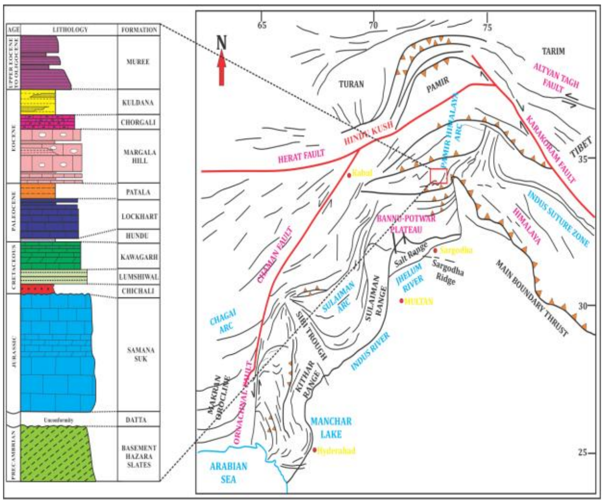

Fig.1 Regional tectonic map of Pakistan and the stratigraphic profile of the study area (Rahman et al., 2016 a).

Materials and Methods

The Samana Suk Formation is measured and sampled in Khanpur Dam section. The specimens were taken in stratigraphic order, while some random samples were also taken to encounter different diagenetic changes. About fifty mixed samples were taken from limestone and dolomitic facies for comparative analysis. The specimens were packed in sampling bag to protect it from water and other contaminations. The outcrop was also laterally studied to encounter all the diagenetic fabric variation. The thin-sections were prepared from specimens and studied under the polarised microscope. In the petrographic study, all the diagenetic fabrics were studied and compared with field observations. All the diagenetic features were studied in chronological sequence by their cross cut relationship. From chronological sequence, a diagenetic model was evaluated which shows diagenetic history and effect on the porosity. The dolomites were petrographically studied and classified according to Sibley and Gregg (1987) classification of dolomites on the basis of crystals size and geometry. The high-quality microphotographs were taken from each thin-section on different variations. From field, petrographic, structure and tectonic setup, the possible dolomitization model was developed. The comparative analysis of porosity has been done to find out the impact of dolomitization on the porosity by comparing it to limestone facies. For the porosity analysis, the computerised software Image J (IJ) was used. The methodology was inspired from Grove et al., (2011), Haeri et al., (2015), Hayat et al., (2016), Rahman et al., (2016 a). The ImageJ works on Java Script languages. It counts the pore spaces within the allochems and matrix.

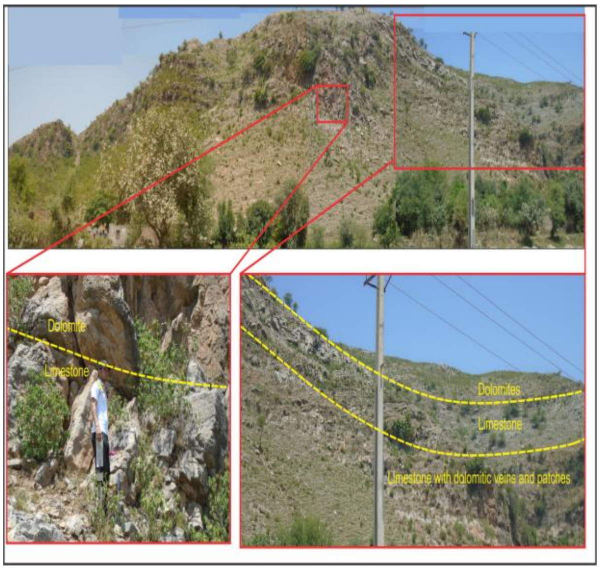

Fig. 2 Plates show studied section with the limestone and dolomitic beds in zoomed view and dolomitic beds having vegetation cover.

Results and Discussion

Diagenetic setting

The diagenetic fabric of the Samana Suk Formation have been studied in order to find it's diagenetic setting and effects of diagenetic phases on reservoir potential. The base for chronological sequence of diagenetic phases is the cross cut relation of diagenetic fabrics (Fig. 6). Each diagenetic fabric is discussed in detail below.

Cementation

Cementing material in case of carbonate rocks may be intergranular or intra-granular. The post-depositional diagenetic changes have been interpreted by Harris et al (1985), which shows diagenetic changes occurring in marine and the freshwater phreatic environment. One of the diagnostic features of Samana Suk Formation is its well cemented character thus making it more resistant to cutting. Likewise, it shows resistance to physiochemical weathering due to which the formation has elevated ridges (Fig. 2). Petrographic study shows that the formation is well cemented by micrites and sparites. In each section, the micrites and sparites are varied from 15 to 35 % (Fig. 3 A, B, C and D), while some cementing materials are converted into well-developed crystals of calcite (Fig. 3 B). Cementation reduces the primary porosity of the rock.

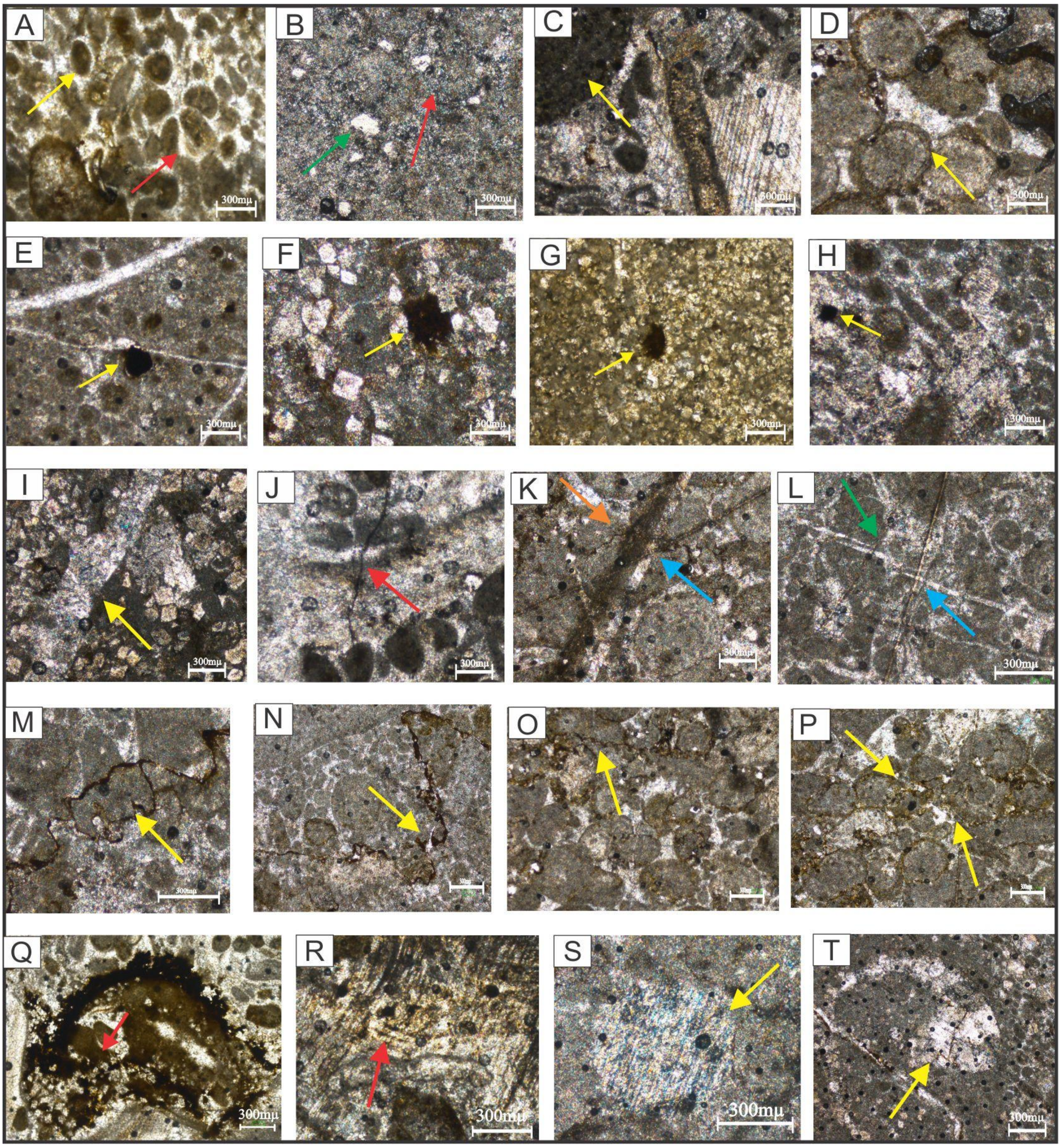

Fig. 3 Photomicrographs show different diagenetic fabric. In A, B the yellow arrow shows sparite, green arrow shows spary calcite. In C & D the yellow arrows show micritic envelopes. In E, F, G and H, the yellow arrows show pyrite crystals. In I yellow arrow shows dolomitic vein. In J, the red arrow shows unfilled late stage fracture. In K and L, the blue, green and orange color arrow show different fluids filled cross cut fractures. In M, N, O and P, the yellow arrows show stylolites, which cross cut allochems and other fabrics. In Q and R, the red arrows show recrystallization of cementing material and allochems. In S, the yellow arrow shows recrystallization, which give twinning. In T, the yellow arrow shows recrystalized fossil. All the photomicrographs are taken in plane polarized light (PPL).

Micritization

According to Harris et al., (1979) in the marine environment the boring of endolithic algae, forms the micritic fabric. During the growth time of algae, excavate tabular boring into ooids surface which are later filled by micron size calcite crystals. Such micritic fabrics are common in ancient ooids. Petrographically, micrites are observed as cementing materials and as well is in the form of micritic envelopes (Fig. 3 C & D). The micritic envelopes are recognised around the ooids and peloids. Besides envelopes, it disturbed the internal structures of the allochems.

Microspar

Folk (1959), introduced the term ‘Microspar’ for the fine-grained inorganic calcite crystals with grain size ranging between 4 to 30 μm (mostly 5-15μm). It is obvious that microspar typically showing mosaic-like texture indicates the diagenetic origin. In recrystalized lime mudstone, the microspar is well represented, where micrite is converted to neo-morphic blocky calcite passing through the microspar and pseduospar stages. Like micrites, the sparites are also observed in Samana Suk Formation. Approximately in all grainstone microfacies, the sparites are observed as cementing materials and as well as sparites are also filled cavities (Fig. 3A, B).

Pyritization

For the pyritization process, the reducing condition is required and such condition is available during early burial stages of diagenesis (Larsen and Chilingar, 1979). In Samana Suk Formation, the pyrites are observed at outcrop in the form of iron leaching. The pyrite leaching is not much common, but it is present in significant quantity. At outcrop, pyrite leaching is present in various shapes e.g. oval shape, rounded and subrounded (Fig. 4 A, B). Likewise, it is also varying in size, some are larger than coins while some are small. Petrographically, the dark blank spaces are recognised as pyrite/iron leaching. Approximately in half samples, the pyrites are observed (Fig. 3 E, F, G, H).

Fractures

The fractures system occurs in the carbonate rocks at various stages of sedimentation and diagenesis, but the calcite-filled veins are due to the brittle failure and tectonic fracturing of lithified carbonate rocks caused by stress and shear displacement. Extensional movements and natural hydraulic fracturing is also responsible for the formation of micro-fractures (Sibson, 1975). In Khanpur Dam section, the Samana Suk Formation is highly fractured. Varities of fractures are present at the section, calcite filled and dolomite filled, unfilled, small and large fractures. These fractures crosscut each other which indicate it's multistage of occurrences (Fig. 4 C, 7 A, B). Same phenomena like field are seen in petrographic study (Fig. 3I, J, K, L). It is noticed that, the dolomitic filled fractures are thicker in size as compared to calcite filled fractures (Fig. 3 I). Petrographically, the ratio of the unfilled fractures is not good, but has considerable volume (Fig. 3 J). Fractures in carbonates enhance the secondary porosity and permeability.

Dolomitization

Dolomitization is the post-depositional process in which Magnesium (Mg) ions replace the half of Calcium (Ca) ions in limestone (Land, 1985). A large volume of the limestone of Samana Suk Formation is affected by dolomites, which are present in the form of beds, veins and augen like spots (Fig. 4, 7, 8). The dolomites are hosted by limestone facies due to which it is believed that theses dolomites are secondary in nature. Likewise, the dolomites crosscut the limestone facies which is against the depositional nature of sedimentary rock and supported the secondary nature of dolomites (Fig. 4 C).Various dolomite types were recognized on the basis of color variations like, yellowish, brownish and yellow-brownish. The grain size is fine to coarsening upward. Petrographically, the rhombic crystals (40μm to 450μm ranging in size) were recognized as dolomites (Fig. 4 G, H).

Breccia

Brecciated rock textures are common and may be associated with insitu deformation of rock (e.g., from hydro-fracturing), cataclastic deformation in tectonic shear zones. At the outcrop, the brecciated beds were recognised. These brecciated beds are of different sizes some are thin up to few centimeters, while some were very thick up to 1.5 meters. In the brecciated beds, the angular particles were observed, which vary from very small particles to one-foot large particles. The small particles are dominant as compared to large particles. Particles are present in the irregular pattern, which is cemented by calcite cementing materials (Fig. 5 A, B).

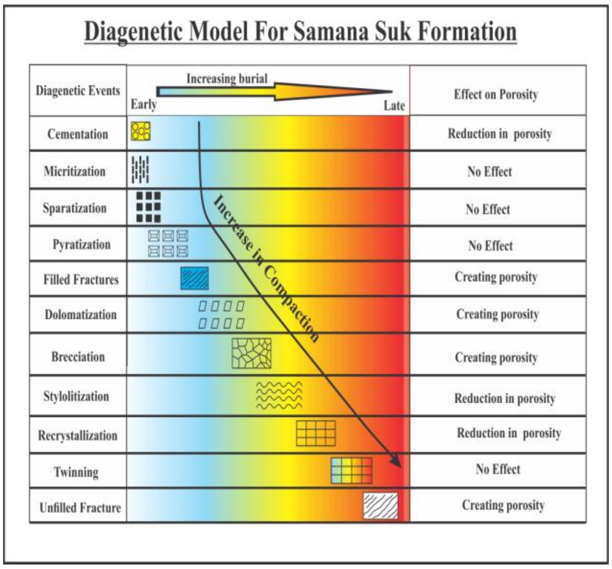

Fig. 6 Shows diagenetic model for Samana Suk Formation.

Stylolitization

The diagenetic feature stylolite often occurs in carbonate rocks (limestone and dolomite) as a rough zigzag surface that developed due to the localised stress-enhanced pressure, dissolution and are characterised by insoluble residue (IR) concentrations (Lun, et al., 2010). According to Buxton and Sibley (1981), the stylolites are the product of physiochemical processes induced by the burial compaction and tectonic compression. Stylolites are one of the three pressure solution features along which the solution seams and fitted fabrics. At the outcrop, the stylolites are abundantly present. These vary in size, length and having different trends, horizontally and vertically (Fig. 5 C, D). The vertically trending stylolites are thick, while horizontally stylolites are thin. The

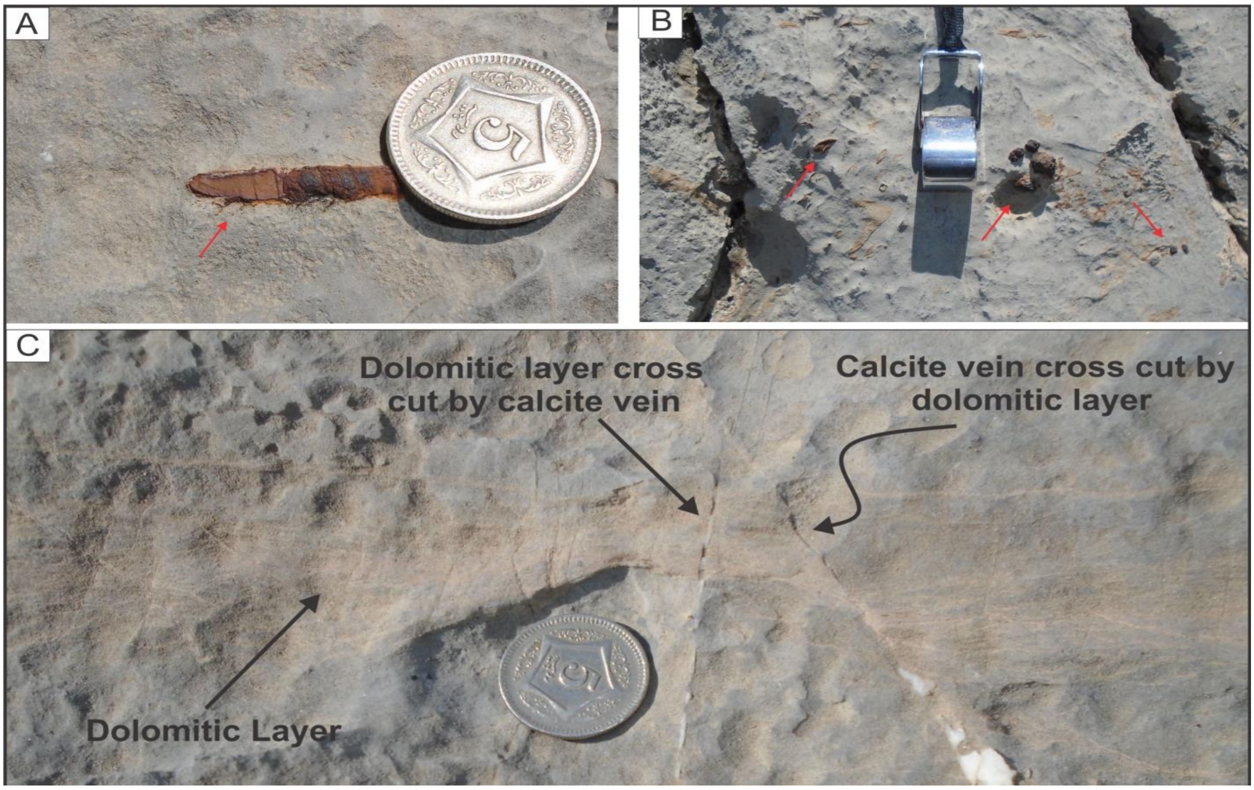

Fig. 4 (A & B) showing pyrite nodules, while plate (C) shows multistage fracturing, which are filled by calcite and dolomitic rich fluid during secondary processes. It can also be observed that dolomitic vein is cross cut by calcite filled fracture.

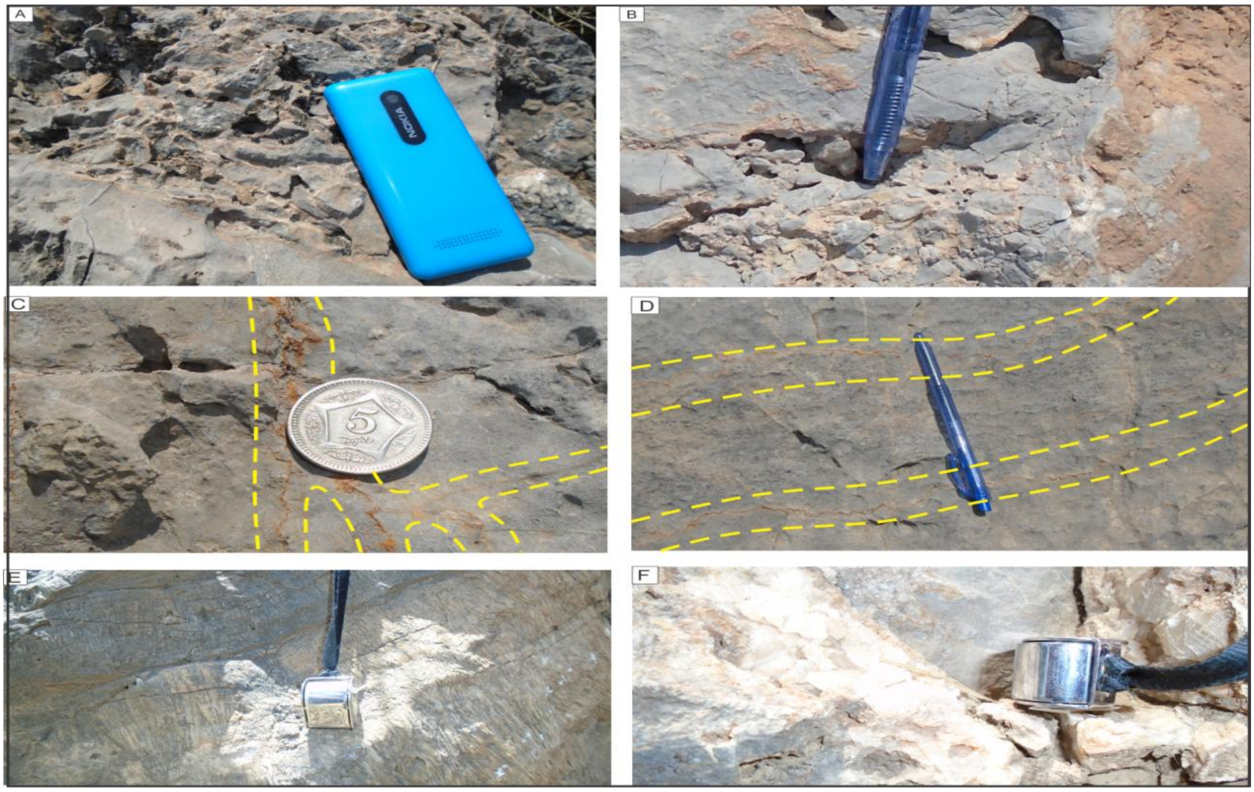

Fig. (5 A & B) Showing brecciated beds in Samana Suk Formation, (C & D) show stylolites having different orientation, (E & F): show recrystallization at the basal part of Samana Suk Formation.

different directional trending of stylolites demonstrates different pressure conditions with the passage of time. Petrographically, stylolites are observed in the different sections, which appear as a zigzag shape like ECG and having brown- dull color. It crosscuts the other petrographic fabric. The shape and size of stylolites are varying in both fields and petrographic observations, some are thick while some are thin (Fig. 3M, N, O, P). Stylolites indicate the compaction phase due to which the porosity decreases.

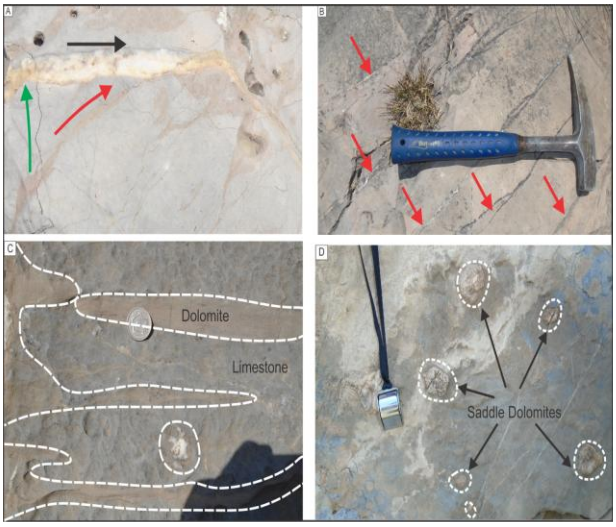

Fig.7 (A) Black arrow indicates the calcite filled fracture while red arrow indicates dolomite filled fractures, which cross cut calcite filled fracture. Besides, the green arrow indicates unfilled fracture, which cross cuts both calcite and dolomite filled fractures (B) the red arrow shows the parallel calcite filled fractures in dolomites (C) The brown color irregular dolomite filled veins in primary limestone facies, besides the limestone and dolomite, the white color telogenetic calcites are also present (D) shows saddle dolomites.

Fig. 8 (A) Shows yellow color augen like dolomites (DIII) in fine grained light grey limestone (LII) facies of Samana Suk Formation at basal part.(B) bedding parallel dolomitic beds light yellowish in color (DI) in dark grey to bluish limestone (LI) facies of Samana Suk Formation at middle part (C) brownish dolomite (DI) in limestone facies. (D): irregular dolomitic effect on limestone facies, light yellowish dolomite (DI), dark grey to bluish limestone (LI), (E) Thick dolomitic bed (DI) is cross cut by dark brown dolomitic vein (DII). (F) Limestone facies (LI) is cross cut by brownish dolomitic beds (DI).

Recrystallization

The recrystallization occurs at burial depth due to which the calcites are converted into well-developed crystals. Samana Suk Formation is highly recrystalized. At outcrop, many kinds of recrystallization have been observed. The lower part of outcrop is highly recrystalized and well-developed crystals of calcites are present. These crystals vary in size from very fine size up to few inches. On weather surface, it looks like multi-lining from up and down which converges at the middle (Fig. 5 E). These crystals make small beds/packages. On the fresh surface, it is well-developed and transparent, which completely breaks on hammering (Fig. 5 F. Petrographically, well-developed crystals indicate recrystallization at deep burial diagenesis. The argument is further supported by the twinning on their surfaces (Fig. 3 Q, R, S, T).

Twinning

A crystal with strong development of twinning (twin lamellae) in calcite crystals, Intense twinning commonly involves dissolution as well as crystal dislocation and is typically a result of burial pressure or tectonic deformation. Twin lamellae are developed for more easily in calcite than in dolomite and indeed can be a way of differentiating the two minerals in the absence of staining or analytical information (Scholle and Halley 1985). Petrographically, the alternate lining is recognised as a twinning. The twinning is developed on the surfaces of calcite which indicate deep burial diagenesis. The twinning crystals of calcite have high relief unlike other crystals (Fig. 3 S).

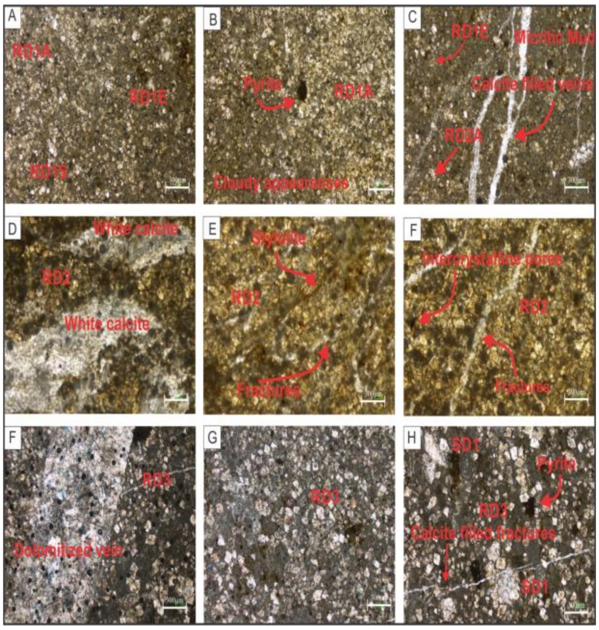

Fig.9 (A, B, & C) Shows fine crystalline planar-euhedral dolomites (RD1E) fine crystalline planar subhedral dolomite (RD1S), fine crystalline non-planar anhedral dolomites (RD1A). (D, E, and F) show fine to medium crystalline non-planar-anhedral dolomite (RD2). (F, G, and H) show medium crystalline planar-euhedral dolomite. All the photomicrographs are taken in plane polarized light (PPL).

Evolution of diagenesis

The chronological sequences of diagenetic fabrics are given below.

After the deposition, the cementation takes place (Flugel, 1975). Cementing material fills up the pore spaces due to which porosity decreases.

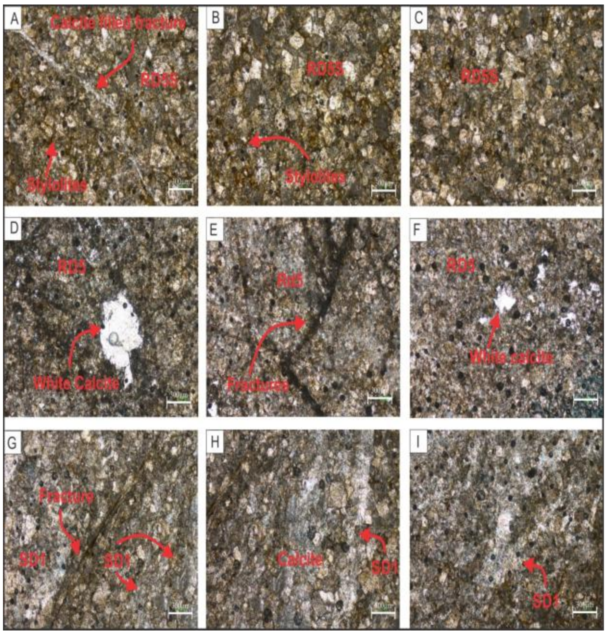

Fig.10 (A, B, and C) photomicrographs show coarse crystalline planar-subhedral dolomite (RD4S). (D, E, and F) show coarse crystalline non-planar-anhedral dolomite (RD5A). (G, H, and I) show saddle dolomites (SD1). All the photomicrographs are taken in plane polarized light (PPL).

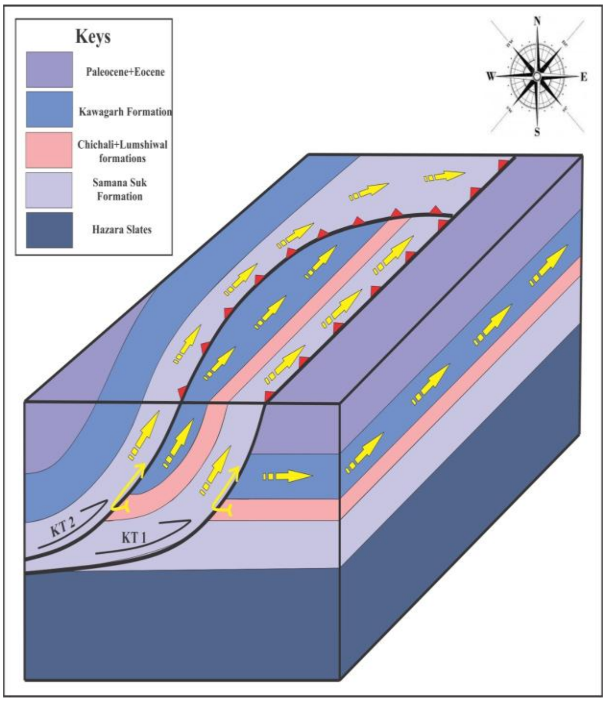

Fig.11 Show the dolomitization model for Samana Suk Formation, Khanpur Dam Section, Hazara Basin, KP, Pakistan.

After cementation, micritization and spratization take place because it is a shallow marine diagenetic process (Alexanderson (1972). Micritization and sparitization may have no effect on porosity because it occurs after cementation. The pyritization occurs at early burial stages (Larsen and Chilingar, 1979). Pyritization has no effect on the primary and secondary porosity of the rock.

Fracture occurs in carbonate rocks at various stages (Sibson, 1975). In Samana Suk Formation fracturing is common (Fig. 3 I to L). The unfilled fractures represent the most recent deformation. The fractures not only increase the porosity but improve the permeability due to which the rocks become effective reservoir. Dolomitization occurs due to the injection of the Mg rich fluid. Dolomitization destroyed all the earliest depositional and diagenetic fabrics e.g. cementing materials, allochems fractures (Fig. 3 G). Dolomites increase porosity by about 13%.

Due to the Mg rich fluid injection and dolomitization results in dissolution and collapsing. The collapsed rocks form the brecciated texture (Fig. 5 A, B). Breccia improves the rock porosity and permeability.

Stylolites occurred during the deep burial stage of diagenesis or due to tectonic stress (Buxton and Sibley 1981). In present research work, it is noticed that stylolites occur at late stage of diagenesis (Fig. 3 M to P). Stylolites are the product of compaction so it leads to the reduction in porosity. In recrystallized part of the section all the fabrics are missing, which indicate its late stage (Fig. 5 E, F). Calcite recrystallization results in the reduction of porosity. The twinning on the surface of calcite crystals (Fig. 4 S) is the product of deep burial diagenesis and tectonic compaction (Scholle and Halley, 1985). Unfilled fractures (Fig. 3 J) indicate the latest deformation. The unfilled fractures increase porosity and permeability.

Dolomitization in Samana Suk Formation

Host rock

The Middle Jurassic Samana Suk Formation exposed in Khanpur Dam section is the host rock for the dolomites. The field and petrographic observations indicate that the original limestone fabrics obliterated by dolomitization.

Outcrop

Approximately 130 metre thick outcrop of Samana Suk Formation is exposed in Khanpur Dam section. In the study area, the two major facies have been recognised; pure limestone and dolomites (Fig. 2).

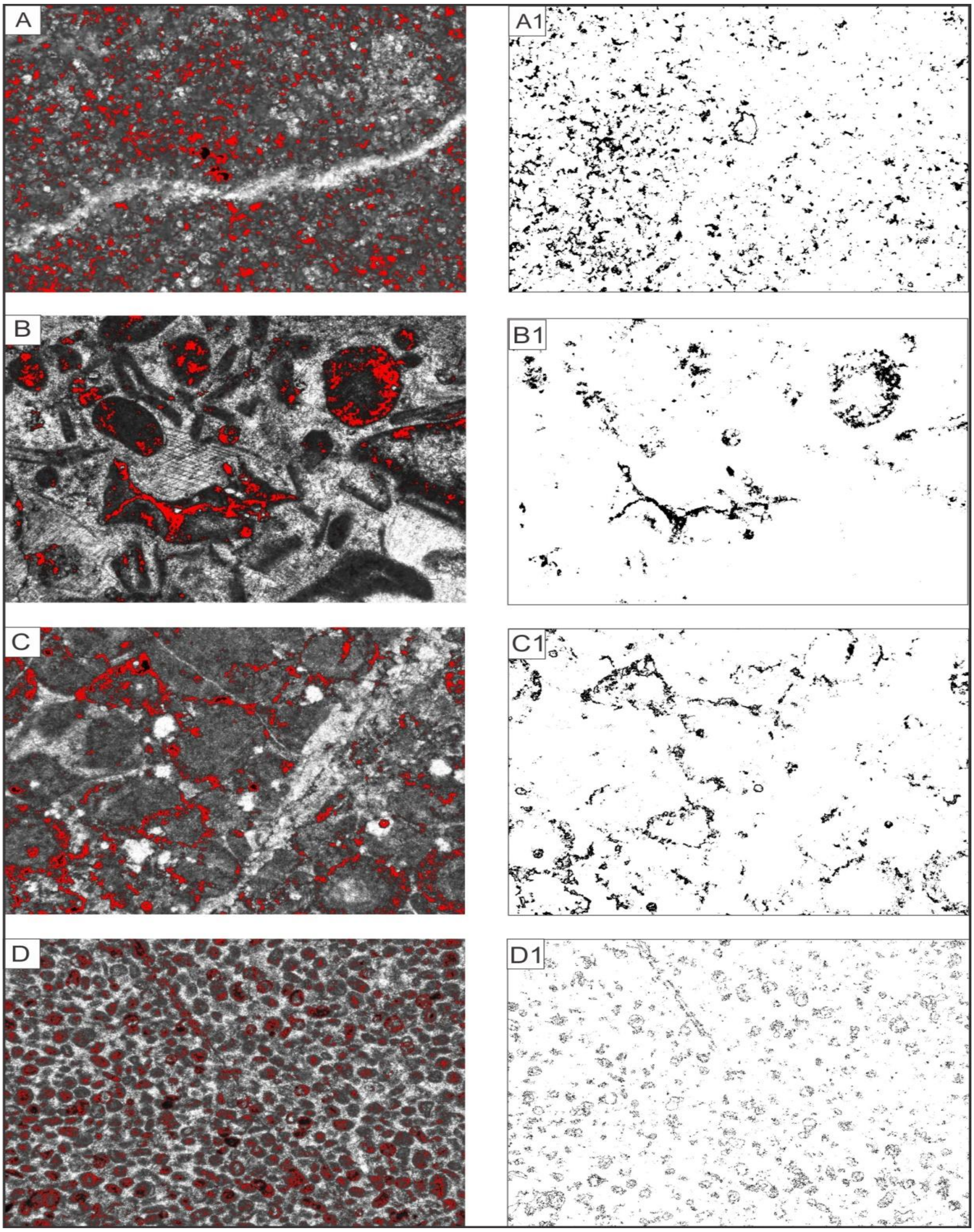

Fig. 12 (A) the threshold color porosity in dolomitic mudstone while (A1) shows porosity framework in dolomitic mudstone facies. (B): the threshold color porosity in intraclastic packstone facies while (B1) shows porosity framework in intraclastic packstone (C): the threshold color porosity in ooidal grainstone facies while (C1) shows porosity framework in ooidal grainstone, (D) the threshold color porosity in peloidal grainstone facies, while (D1) shows porosity framework in peloidal grainstone.

At the basal part of the outcrop, the limestone facies is present, which is followed by dolomitic facies. Initially the dolomite less affected by dolomitization, while on further moving to the middle and top portion, it becomes strong. At basal part, dolomites are in the form of thin veins, which is difficult to recognise in hand specimen but in the middle and upper portion dolomites are in the form of thick beds and veins. Saddle dolomites are also recognised in various parts of outcrop which are rich in middle (Fig. 7 D).

Limestone facies

On the basis of field observations like texture, color and grain size, two types of limestone have been recognized. These are light grey and dark grey (Fig. 7, 8). Petrographically limestone facies have five different microfacies. These microfacies are intraclastic Packstone microfacies, mudstone microfacies, ooidal grainstone microfacies, pellet peloidal grainstone microfacies and ooidal peloidal grainstone microfacies. On the basis of microfacies analysis, the depositional environments are ranging from inner ramp lagoon to middle ramp setting. The limestone of ramp/shelf setting is a good reservoir. The limestone facies are volumetrically about 60% out of the whole composition. The limestone facies are dominantly composed by pellet peloidal grainstone microfacies. The limestone facies are highly jointed, fractured and having filled and unfilled fractures. The pyrite crystals and stylolites have also been recognised.

Dolomitic facies

In Samana Suk Formation dolomites are about 40% volumetrically. These dolomites are hosted by limestone in fractures and joints. Dolomites are in various size and shape of beds, veins and spots (Fig. 8). On color and textural variations four kind of dolomites were recognized, brown (DI), dark brown (DII), yellow (DIII) and saddle dolomites (Fig. 7, 8). From field and petrographic signatures, it is concluded

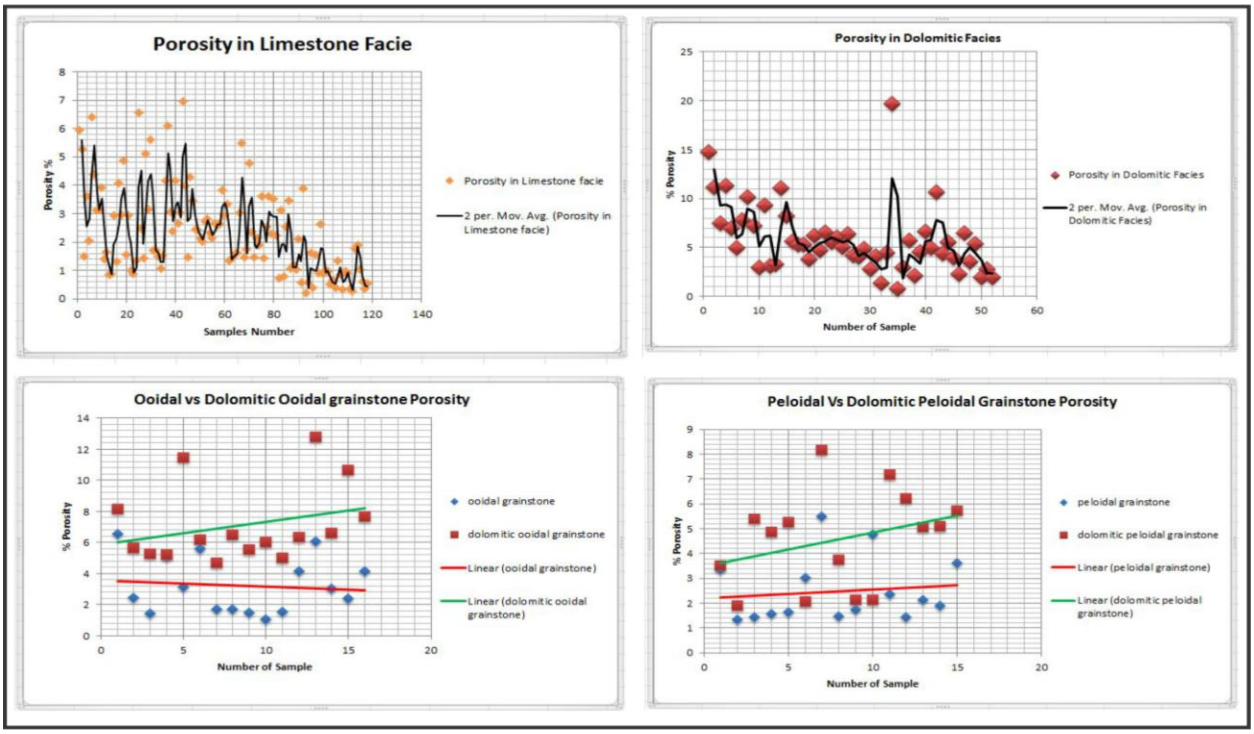

Fig. 13 Shows the porosity in different limestone and dolomitic facies.

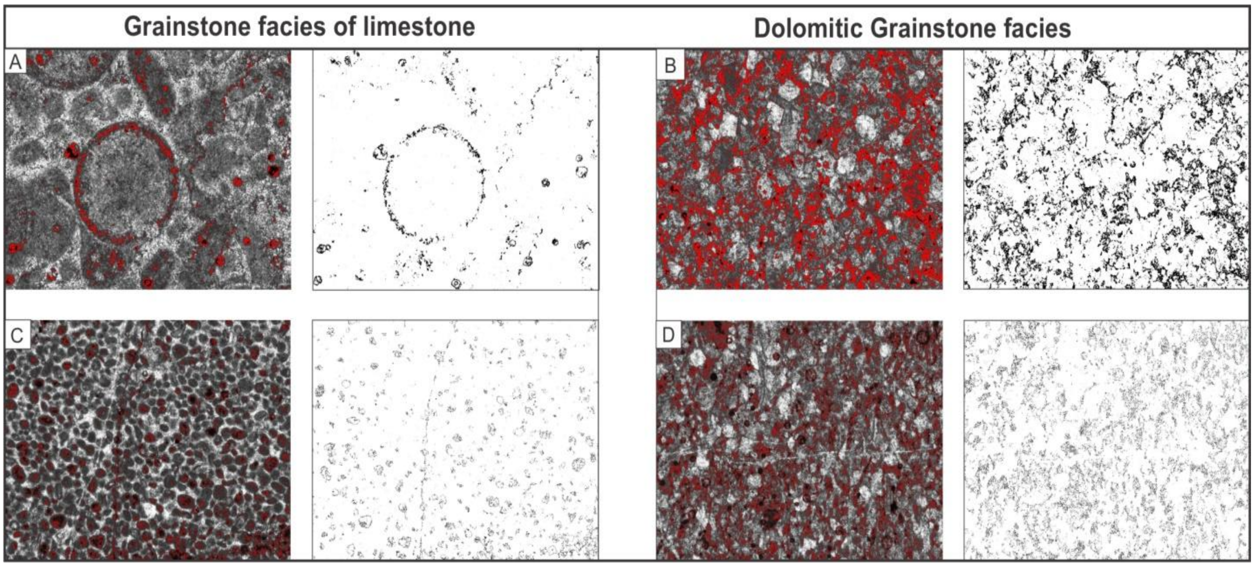

Fig. 14 (A) Shows the porosity and porosity framework in ooidal grainstone facies, (B) shows the porosity and porosity framework in dolomitic ooidal grainstone facies (C) shows the porosity and porosity framework in peloidal grainstone facies, while (D) shows the porosity and porosity framework in dolomitic peloidal grainstone facies.

that these dolomites are secondary in nature.

Petrography of dolomites

The petrographic study has been performed to find out the different sedimentological, digenetic and petrographic properties of the dolomites. In the petrographic study, the size of crystals, shape of crystals, quantity of replacement, natures of occurrences, extinction, cleavages and inclusions are studied.

Types on the basis of crystals geometry and size

The dolomites in Samana Suk Formation are formed as replacement phase (RD), because it obliterated primary limestone facies. Based on crystal size, crystal geometry (planar or non-planar; Sibley and Gregg, 1987) six textural types of dolomite were distinguished. These are (1) fine crystalline planar-E & S dolomite (RD1), (2) fine to medium crystalline non-planar-A dolomite (RD2), (3) medium crystalline planar-E dolomite (RD3), (4) coarse crystalline planar-S dolomite (RD4), (5) coarse crystalline non-planar-A dolomite (RD5), (6) saddle dolomites (SD1).

disturbed and jointed due to ongoing tectonic processes (Fig. 2). The thickness of the strata is up to two meters. Petrographically, the RD1 dolomites are associated with mudstone microfacies. RD1 dolomites are composed of planar euhedral, subhehdarl and non-planner anhedral textured crystals. The sizes of the crystals vary from 40 µm to 80 µm, but some of the crystals are up to 100 µm. These dolomitic crystals are surrounded by the dull colour matrix, which is lime mud (micrites). The crystals have inclusions in middle of the crystal and inclusions are low-Mg calcite relicts of precursor limestone (Kırmacı, 2013). Besides inclusion, some part of the section gives the cloudy appearance. The boundaries of the crystals are clear while not clear in anhedral crystals that shows high extinction under the crossed light. These dolomites crossed cut by the calcite-filled veins, vary in thickness from 10 µm to 110 µm. (Fig. 11 A, B, C).

Fine to medium crystalline non-planar-A dolomite (RD2)

RD2 dolomites occur in Samana Suk Formation at the middle part. At the outcrop, the yellowish color bed is present which is highly crystallised and the grain size

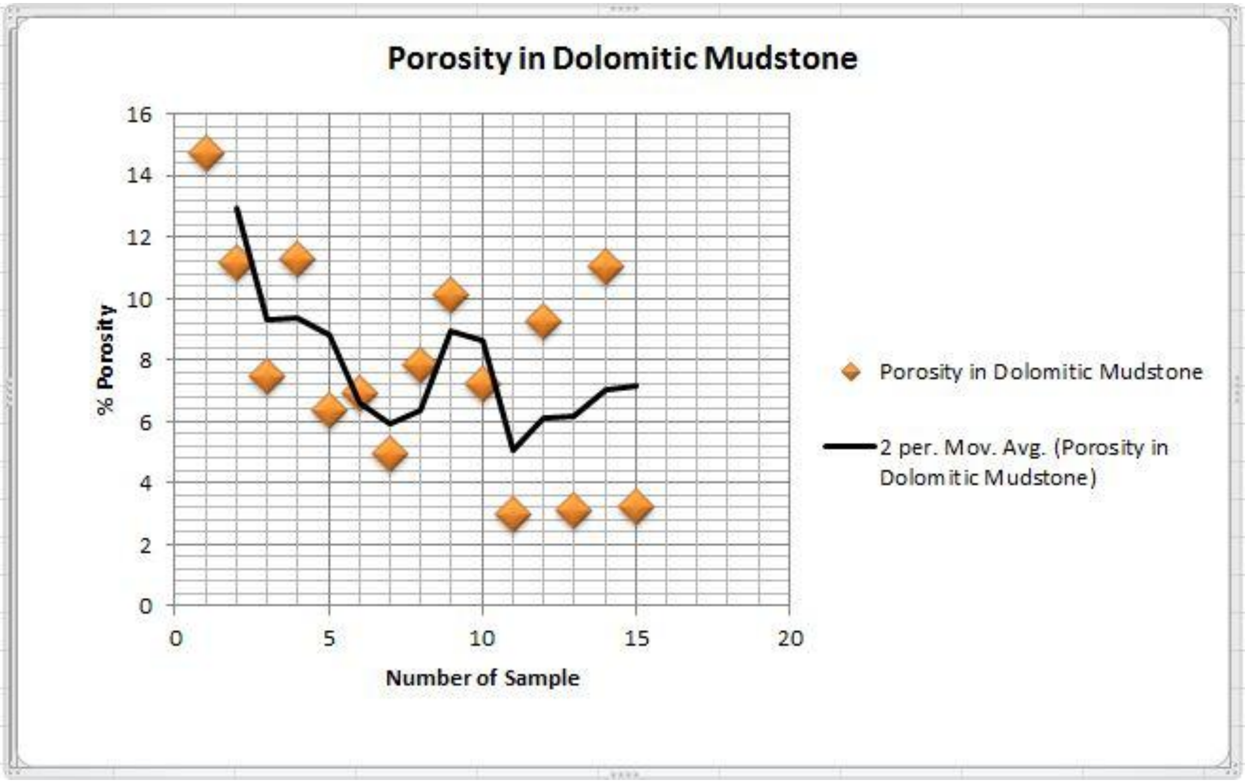

Fig. 15 Shows the porosity in dolomitic mudstone facies.

Fine crystalline planar-E, S and Non-planner A dolomite (RD1)

RD1 dolomites are present in the Samana Suk Formation in basal part. At the outcrop, the strata are marly at the weathered surface, while show yellowish-brown color on the fresh surface. The grain size in hand specimen is very fine. The strata are highly

is fine to medium. In petrographic view, RD2 dolomites have bright yellow color. The dolomitic crystals are cloudy, the boundaries between crystals are not clear due to which it cannot be easily separated. The crystal size is ranging from 100 µm to 350 µm. The crystal surfaces have visible cleavages and some crystals have inclusions. These crystals give strong extinction under the crossed light. In some part of section the sparry calcites are present with dolomitic crystals (Fig. 9 D, E, F).

Medium crystalline planar-E dolomite (RD3)

RD3 dolomites are present in Samana Suk Formation in the basal part. These dolomites are associated with mudstone facies. At outcrop, thick weathered beds represent RD3 dolomites. Petrographically, the crystals are well-developed and have clear boundaries. The sizes of the crystals vary from 200 µm to 350 µm and few are exceeding. These crystals have inclusion on their surfaces and lack cleavages. It gives strong extinction under the crossed light. The micrite matrix occurs in the surrounding of the crystals (Fig. 9F, G, and H).

Coarse crystalline planar-S dolomite (RD4)

RD4 dolomites are present in the middle part of the Samana Suk Formation. These dolomites are associated with mudstone and packstone microfacies. At outcrop, a massive bed of mudstone hosts these thin dolomitic beds. These beds have light yellowish color on the weathered surface while dark yellow at the fresh surface. The grain size is medium. The strata are highly recrystalized at different places. Petrographically, the well-developed rhombic crystals are present which have subhedral geometry. The boundaries of the crystals are clear but in some crystals the boundaries are disturbed. These rhombic crystals have cleavages and inclusions on their surfaces. The sizes of crystals are ranging from 300µm to 600µm. Calcite-filled fractures are also present (Fig. 10 A, B, C).

Coarse crystalline non-planar-A dolomite (RD5)

RD5 dolomites are present in the Middle Jurassic Samana Suk Formation in the basal part. These dolomites are associated with packstone and mudstone microfacies. At outcrop, a massive bed hosts these dolomites in the form of thin interbeds. The color of the bed at the fresh surface is brownish. The grain size is fine to medium. Petrographically, these dolomites are non-planar anhedral. The boundaries of the rhombs are not too much clear but the rhombs are recognisable. The size of crystals is varying from 250 µm to 400 µm while some crystals are exceeded. The surfaces of the crystals are rich by inclusion and cleavage which make it dull under the microscope. It gives high extinction under the crossed nicols (Fig. 10 D, E, F).

Saddle dolomites (SD1)

Saddle dolomitization common (Fig. 7D) at outcrop which can also be seen in petrographic observation. Saddle dolomites take place as a cement phase. Saddle dolomites have irregular shape and size (Fig.10 G, H, I). The sizes of SD1 dolomites are ranging from 4 mm to 100 mm. SD1 dolomites indicate high-temperature conditions (Spotl and Pitman, 1998).

Origin of fluids and dolomitization model

Dolomitization in the limestone is considered a secondary phenomenon (Land, 1985), and therefore may be the result of different parameters. It has been observed that dolomitization is mainly caused by evaporation, hydrothermal fluid, burial completion and Kohout convection. In the present study, the suggested origin for the fluid migration is due to the overburden pressure, which has forced the fluids to move along the weaker horizon faulted surfaces. It has been observed that the area has a complex structural setting, due to severe intensity of deformation and the lithological units are considerably disturbed. In study area, the Hazara slates are under the Samana Suk Formation with limited fluid concentration in slates. Thus, it is interpreted that probably Chichali and Lumshiwal formations with a clastic nature may be the major source of the fluid for the dolomitization. The fluid sink nature of Chichali and Lumshiwal formations, which have high porosity, might have expelled the reservoir fluid in them during faulting producing overload pressure by crustal thickening. This interpretation is consistent with the Khui Da Maira faults (KT1 and KT2), which thrusted Samana Suk Formation over the Kawagarh Formation (Fig. 11). The argument is further supported by the dolomitization at the same section in Kawagarh (Rahman et al., 2016 a).

Reservoir characterization and the effect of dolomitization on the porosity

The term "*microporosity"* refers to very small pores that can be recognised only with the aid of a high-powered binocular microscope or thin-section (Choquette and Pray, 1970; Pittman, 1971). Micropores may also be known as pinpoint pores. It represents different shapes and sizes (1) birds eye pores in tidal flat deposits, (2) intraparticle pores within small particles, (3) intercrystalline pores between dolomite crystals or between calcite cement crystals, (4) intercrystalline pores within the nuclei or cortices of oolites, or (5) intra-crystalline pores within individual dolomite or calcite cement crystals. In many circumstances, whereas matrix microporosity may not be very permeable for oil, it very well may be permeable enough for natural gas (Roehl, 1985; Ruzyla and Friedman, 1985). In the Samana Suk Formation, in analyzed samples under polarised microscope and porosity analysis, intercrystalline porosity are observed in dolomitic facies (Fig. 12 A), while intraparticle, inter-particles, moldic, fracture, burrows and vuggy porosities are observed in limestone facies (Fig. 12 B, C, D). In the Samana Suk Formation, 75% facies are grainstone, composed of well-rounded ooids and peloids. The well-rounded shape and well-sorted nature of sediments result in an overall increase in porosity and permeability (Fraser, 1935, Rogers and Head, 1961; Pryor, 1973; Beard and

Weyl, 1973).The grainstone facie of carbonates are known as carbonates sandstone. The carbonate grainstone have a good inter granular porosity and permeability. In Samana Suk Formation the limestone facies have good porosity and permeability framework (Fig. 12 B1, C2, D2). In the present analysis, the limestone has up to 6% porosity (Fig. 13). In grainstone facies, it is 5 to 6 %, while in mudstone it is 3 to 4%. The dolomitic facies has porosity from 4 to 14% (Fig. 13). On comparative analysis, it is noted that the porosity in ooidal grainstone facies is 5% while in dolomitic ooidal facies it increased up to 8% to 10% (Fig. 13). The porosity and permeability are clearly increased by dolomitization (Fig. 14 A, B). In peloidal grainstone facies, the porosity is from 2 to 3%, while in dolomitic Peloidal grainstone facies the porosity is 4 to 6% (Fig. 16). The porosity framework is developed by dolomitization process (Fig. 14 C, D). Likewise, the porosity in dolomitic mudstone is 8 to 14% (Fig. 15). The diagenetic phases like fracturing, brecciation and dolomitization increased the porosity and permeability. Over all, the diagenetic process and especially dolomitization increased porosity and permeability. Overall, the porosity is increased up to 8 to 10%. It is thus, concluded that Samana Suk Formation in the study area has good reservoir potential.

The studied section is subjected to multi phases of diagenesis from fresh marine diagenesis to deep burial diagenesis. In the present study the interesting diagenetic phase is deep burial diagenesis which disturbed the reservoir potential. The deep burial diagenesis (monogenetic) environment is broadly documented by geoscientists (Bathurst, 1980, 1986; Scholle and Halley, 1985; Choquette and James, 1987; Halley, 1987; Mazzullo and Harris, 1989; Moore, 1989). The deep burial diagenesis is known to reduce in porosity by the compaction as well as cementation, while the increase in porosity results by the dissolution and increasing the pre-existing pores or creating new pores by fracturing. Such diagenetic changes can be connected transiently and spatially to the burial depth, temperature-hydrologic history of sedimentary basin sand to their hydrocarbon maturation migration-destruction history (Moore and Druckman, 1981; Foscolos, 1984, Burrussad, 1985; Druckman and Moore, 1985; Crossey et al., 986; Edman and Surdam, 1986; Spirakis and Heyl, 1988; Hutcheon, 1989; Mazzullo and Harris, 1989). During the deep burial diagenetic phases the overall reservoir potential is improved by fracturing, brecciation and especially by dolomitization. The dolomitization is studied in depth. The increasing interest in dolomitization is due to the fact that many oil and gas reservoirs are located in dolomitized carbonates successions (Purser et al., 1994; Braithwaite et al., 2004). The dolomitization increased the overall porosity round about 8 to 10%. Pervasive dolomitization can occur in the diverse geological environment and timing (from early to burial diagenesis) and during orogenic thrust belt evolution (Warren, 2000; Machel, 2004). The dolomitization occurred in the section at deep burial diagenesis during the Himalayan orogeny. During the Late Cretaceous to early Paleocene collision, the area was subjected to multi tectonic activities which resulted in the form of folds and faults, and due to this faulting system the fluid migrated and caused dolomitization.

Conclusion

Petrographically, the Samana Suk Formation has abundant composition as peloidal grainstone and ooidal grainstone microfacies, which lead to high inter grain porosity. The secondary dolomitization occurred in Samana Suk Formationm, which led to high increase in the porosity, which is round about 10%. From porosity shadows, it is concluded that the dolomitization not only improved the porosity, but also increased the permeability. The diagenetic phases like fracturing, brecciation and especially dolomitization improved the reservoir potential of the Samana Suk Formation and make it an effective reservoir. The dolomitization occurred in Samana Suk Formation along the Khui Da Maira faults (KT1 and KT2).

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