

Diagenetic setting, dolomitization and reservoir characterization of Late Cretaceous Kawagarh Formation, Khanpur Dam section, Hazara, Pakistan

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Abstract: The Kawagarh Formation is well exposed in Hazara basin in different sections. Due to deep depositional settings, the Kawagarh Formation is least appealing to geologists to investigate it as a hydrocarbon reservoir. In the present study, the diagenetic settings of Kawagarh Formation were chronologically studied to interpret its diagenetic history and the effect of different diagenetic phases on the reservoir potential. The dolomitization is also studied in depth to use it as a key for its reservoir potential. Kawagarh Formation is sampled at Khanpur Dam Section for porosity analysis. The samples were taken from limestone and dolomite facies randomly. The dolomites are in the form of veins and well developed thick size beds. These dolomites are secondary in nature which is hosted by fractures and joints of limestone, which affect about 25% of limestone facies. At outcrop scale different types of dolomites are recognised on the basis of color and texture, yellowish fine-grained, brown blackish coarse-grained in the top portion and saddle dolomites. In petrographic study partial and complete dolomitization are observed. On the basis of crystal sizes and geometry different types of dolomites are recognized which are; (1) fine crystalline planar-euhedral dolomite, (2) medium crystalline planar-subhedral dolomite, (3) medium crystalline non-planar-anhedral dolomite, (4) coarse crystalline planar-subhedral dolomite, (5) coarse crystalline, non-planar-anhedral dolomite and (6) saddle dolomites (SD1). In petrographic study, high inclusions and disturbance are observed at the surfaces of dolomititic rhombs which indicate low Mg replacement or dedolomitization phenomena. On image J porosity analysis, the porosity is found of limestone and dolomititic samples. In limestone facies which is mostly, non-laminated mudstone has very low up to 2 to 3% in the form of vugs and fractures. In dolomititic facies, the porosity is ranging from 5% to 14%. In most of the dolomititic samples, the porosity is round about 5%. From the structural analysis and the study of other carbonate formations, it is concluded that this dolomitization occurs in the Kawagarh Formation along the Khui da Maira fault. Near the fault, the dolomites occur in the irregular pattern, but as we move away from faulted section, the dolomites are converted into horizontal veins and beds. The dolomitization model has been evaluated for better understanding of the phenomenon of dolomitization.

Keywords: Kawagarh Formation, diagenesis, dolomitization and reservoir characterization.

Introduction

The late Cretaceous strata are well exposed in Hazara basin and represented by thick carbonate sequence of Kawagarh Formation. The Kawagarh Formation mainly composed of limestone, dolomites and marl (Rahman et al., 2016). The formation is previously analyzed by many researchers for paleontological and sedimentological interpretations (Rahman et al., 2016; Khan et al., 2010; Rehman, 2009; Ahsan and Chaudhry, 2008). These researches provide information about the depositional environments and their biostratigraphic zone, but there is lack of information about its diagenetic setting. In the present study, the detailed field and petrographic studies of Kawagarh Formation, exposed in Khanpur Dam section of Hazara Basin are conducted to provide information about the diagenetic setting. Likewise, the dolomites are studied in detail in the field and petrographically to determine its nature and origin. Besides, the reservoir characterization has been done

for Kawagarh Formation to find out its reservoir potential.

Geology of the area

The study area lies in Hazara Basin, which is situated in Lesser Himalayas (Gensser, 1964 and Coward et al., 1988). The Hazara Basin, is bounded on the south by a regional tectonic boundary, Main Boundary Thrust (MBT), while in the north by Panjal Thrust (Ahsan, 2008) (Fig.1). Main boundary thrust is the southernmost thrust, which places meta-sedimentary rocks of Lesser Himalayas over the unmetamorphosed clastic rocks of the Himalaya foredeep. As a result of Himalayan orogeny, the area is structurally developed and having a huge number of geological structures: anticlines, synclines and thrust faults. Stratigraphically, the area of south eastern Hazara forms a part of the much larger Kohat Potwar sedimentary basin (Ghazanfar et al., 1990). The study area has thick succession from Precambrian to upper Eocene and Oligocene age (Fig.1). The Precambrian Hazara Slates

are well exposed in Hazara Basin. The Hazara Slates are the oldest sequence in the area. Besides this, the Jurassic Samana Suk, the Cretaceous Chichali, Lumshiwal and Kawagarh, the Paleocene Hungu, Lockhart and Patala, The Eocene Margala Hills Limestone, Chorgali and Muree Formation are well exposed. These lithologies are well exposed along the road cut as well as various geological structures. In the studied section of the eastern bank of Khanpur Dam, the lithology is too much disturbed due to multi faulting and folding. In the section, the Lumshiwal

texture, color, dilute acid reaction and cross cut relation at the outcrop. Overall fifty samples were collected from dolomites and limestone. In Khanpur Dam section, the formation has a thickness up to 250 meters. The formation has planner bedding and light grey in color. The diagenetic features, dolomitic beds and veins were observed in the field for later comparison with the petrographic study. High resolution photographs were taken from the visible diagenetic features. The thin sections were prepared from the samples and studied with the aid of a high

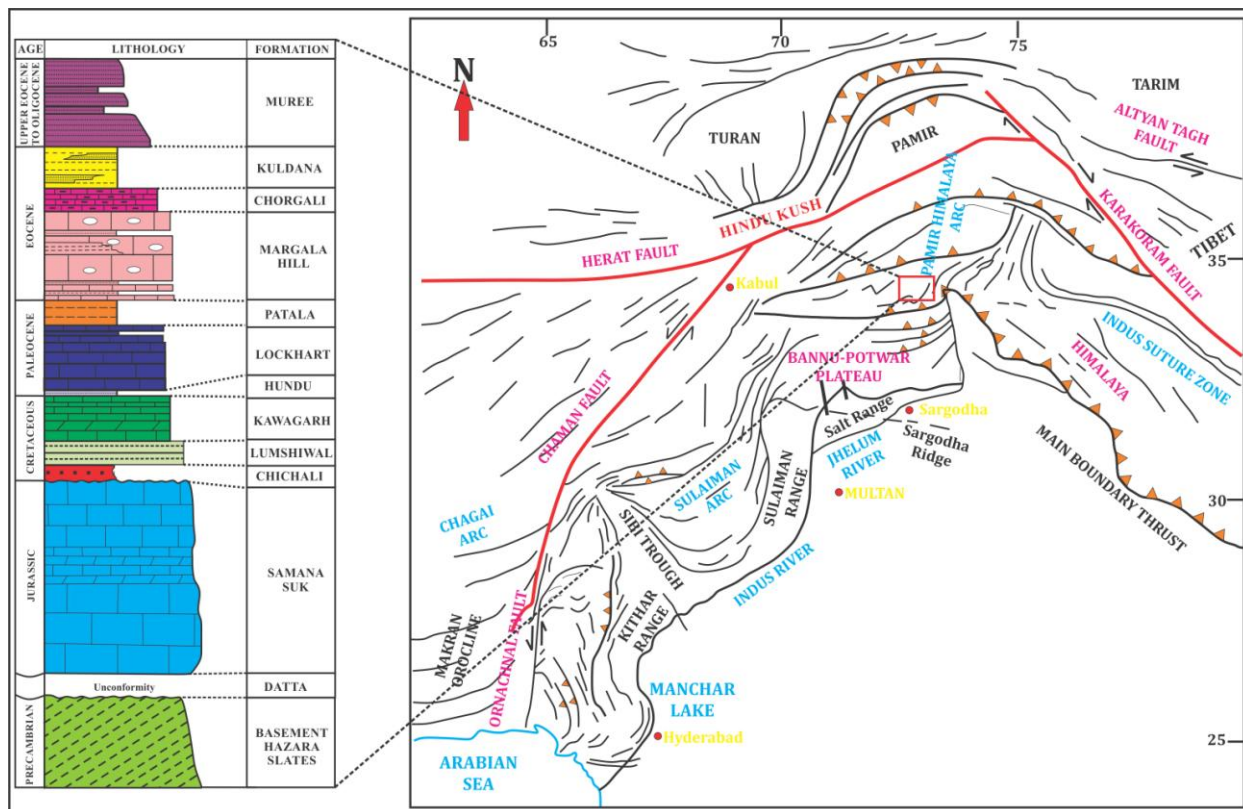


Fig.1 Regional tectonic map of Pakistan and stratigraphic setting of Hazara Basin.

Formation is too thin, which is undividable while the Chichali Formation is missing. The Samana Suk and Kawagarh formations are thickly exposed along Khanpur Thrust and Khanpur Dam Thrust (Fig. 2). The Samana Suk Formation thrusts over Eocene-Paleocene sequence along KT1, and again thrust over on the Cretaceous Kawagarh Formation along KT2. The trending and the nature of KT2 indicate that the KT2 is a splay of KT1 (Fig. 2).

Materials and Methods

The Kawagarh Formation was measured and sampled in Khanpur Dam Section Khui Da Maira Village (Fig. 1). The samples were collected randomly based on lithological variations from the fresh and compacted surfaces in stratigraphic order. The outcrop was also covered horizontally to encounter the diagenetic changes. The limestone and dolomite facies are differentiated from each other on the basis of the

magnification polarising microscope. During the petrographic study, the microphotographs were taken of the diagnostic diagenetic fabric and different variations in dolomites. The petrographic and field observations were compared in the light of existing literature on diagenesis. From the field and petrographic observations (cross cut relations of diagenetic features), the diagenetic model was constructed and evaluated. The diagenetic model displays the early to the late diagenetic fabric in chronological sequence with the effect on porosity. The dolomites were studied in depth to find out its geometry, size, and nature of crystals as well as other petrographic properties using dolomite classification by Sibley and Gregg (1987). From the field petrography and previous tectonic literature, dolomitization model is suggested and the reservoir characterization has also been done. For the reservoir characterization, the Image J software is used in order to find out the porosity in different thin sections. The

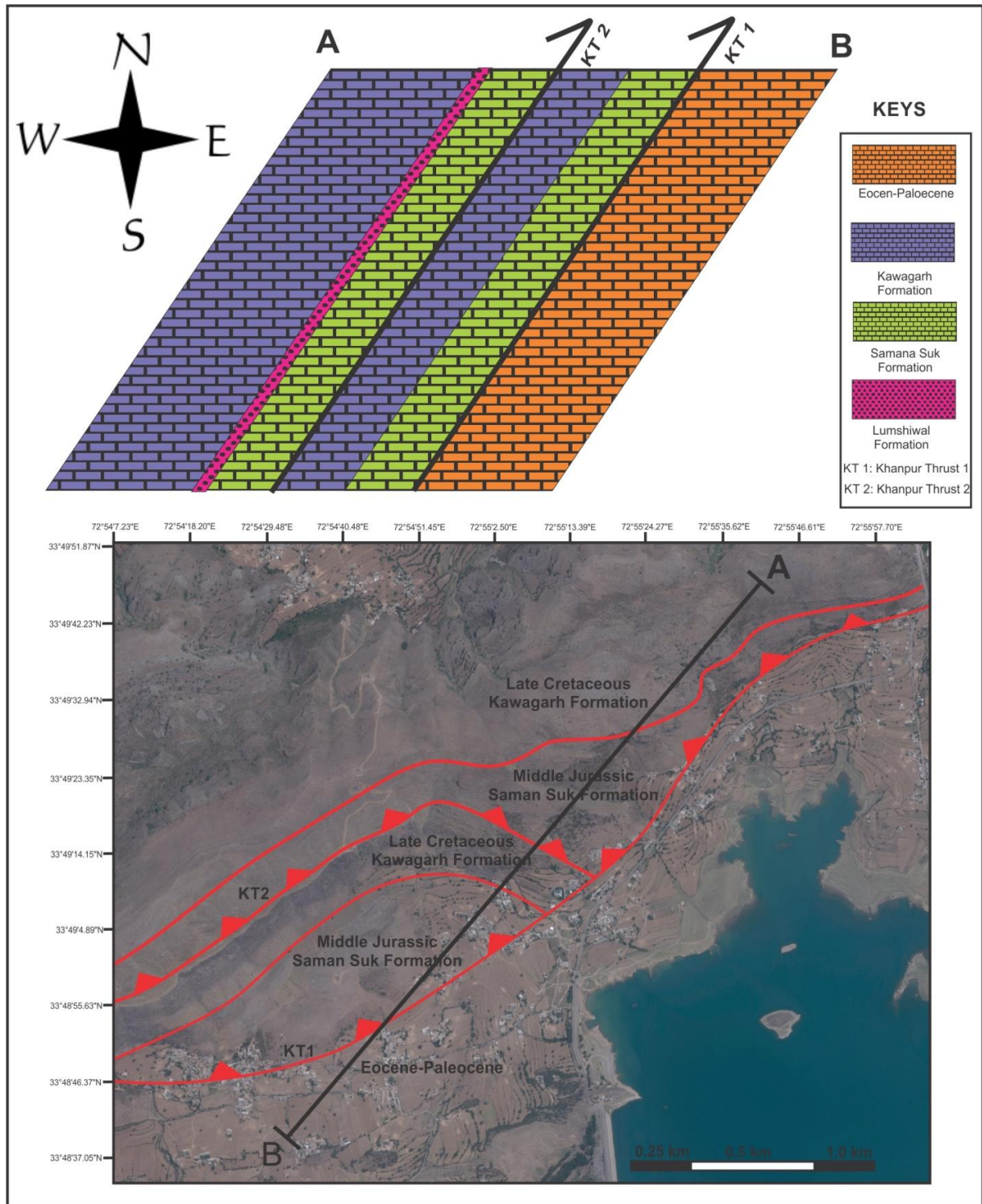


Fig. 2 Structural setup of the Khanpur Dam section.

methodology is inspired from by (Hayat et al., 2016, Grove et al., 2011; Haeri, 2015). Image J porosity analysis is fresh computerised methodology. The image J are operating on Javascript and calculating the pores spaces in microphotographs. This software needs high-resolution microphotographs.

The microphotographs will be converted to 32-bit type (black and white colour) to eliminate the different

colour complexities. After that, the threshold (Color threshold) will apply. In threshold box, the “Dark background” is marked because the threshold colour will only cover the background which is the pore spaces behind the allochems and cementing materials. Subsequently the threshold adjustment, the analysed particles command will apply. The analysed particles commands have different calculations, in which one is “percent area”. By applying this command the covered

percent area is displayed, which is the percent porosity. Likewise, the snapshots were taken from the porosity traces/shadow to find out its nature and effect on permeability. The porosity of limestone and dolomites were compared with each other to find out the effect of dolomitization on the porosity. For the better understanding of the relation between limestone and dolomitic porosity, the cross plots were drawn.

Results and Discussion

Diagenetic setting of Kawagarh Formation

The diagenetic fabrics of the Kawagarh Formation have been studied in order to find out its diagenetic

is the product of early stage marine diagenesis.

Sparitization

Folk (1959) introduced the term “Micro-spar” for the fine-grained size inorganic calcite crystal, grain size ranging between 4 to 30µm (mostly 5-15µm). It is obvious that micro spar, typically showing mosaic-like texture, due to this texture it must have diagenetic origin. Petrographically, approximately in every sample/thin-section of Kawagarh Formation, the small white spot are observed which is recognised as a micro spar. The micro spars are too much common, especially in the basal and in the middle part of the Kawagarh Formation. In some portion of the thin-

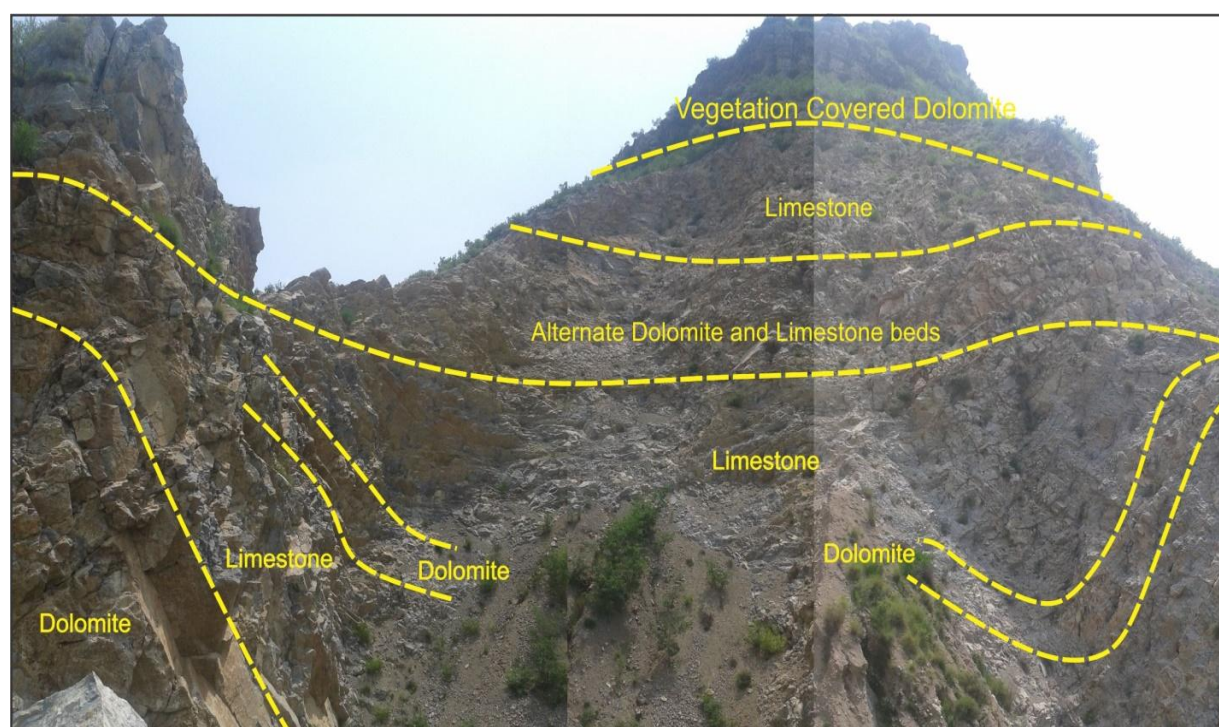


Fig. 3 The outcrop view of Kawagarh Formation showing limestone and dolomitic facies.

setting and the effect of the diagenetic phases on the reservoir potential. The base for the chronological sequence of diagenetic phases is the cross cut relation. Each diagenetic fabric is discussed in detail below.

Cementation

Cementation is the basic element of the early stage of diagenesis, in which the unconsolidated loose particles become consolidated through the infilling of the cementing materials in the pore spaces between these loose particles (McLane, 1995; Bathrust, 1982). The Kawagarh Formation in the study area forms elevated ridges because it is well cemented (Fig. 3). Due to high cementation, it shows high resistance to physical and chemical weathering. Petrographically, different thin sections were studied. In all thin sections, micritic mud is recognised as cementing materials (Fig.5A), which

section, sparites fill the dissolution cavities (Fig. 5B).

Pyritization

The term pyritization is referred to the process of the formation of different crystals of pyrite. Generally, the pyrite is formed under reducing condition, probably promoted by the decay of organic matter, which in turn is induced by anaerobic bacteria or solution of sulphate by reducing bacteria (Hudson, 1982). At outcrop, the pyrite crystals were not observed. It may be due to their small size, not visible to the naked eye. Petrographically, the black blank space is recognised as pyrite crystal. These crystals exhibit cubic and euhedral geometry. Approximately, in all sections, the pyrites were recognised (Fig. 5C). The sizes of the crystals are too small which may be the reason for their non-availability at the outcrop. The High quantity of

pyrites indicates the reducing deep marine depositional environment.

Fractures

Due to secondary porosity and permeability mainly attributed to deformational fractures in carbonate rocks, The carbonate reservoirs contain some 50–60% of the world's oil and gas reserves (Garland et al., 2012). The term fracture is generally used for the naturally occurring planar discontinuity in the rock due to deformation or physical diagenesis (Nelson,

ions replace the half of Calcium (Ca) ions in limestone the phenomenon is called dolomitization. Dolomitization can cause an overall contraction of the rock by as much as 13% (Chilingar and Terry, 1964). At outcrop, the dolomites were recognised as thin to thick beds and small beds (Fig. 3). At the basal part of the outcrop, the dolomitic beds are thin, while in middle and upper portion it is medium and thick bedded respectively. The saddle dolomites are common at outcrop (Fig. 4D). Petrographically, euhedral, subhedral and anhedral rhombs were

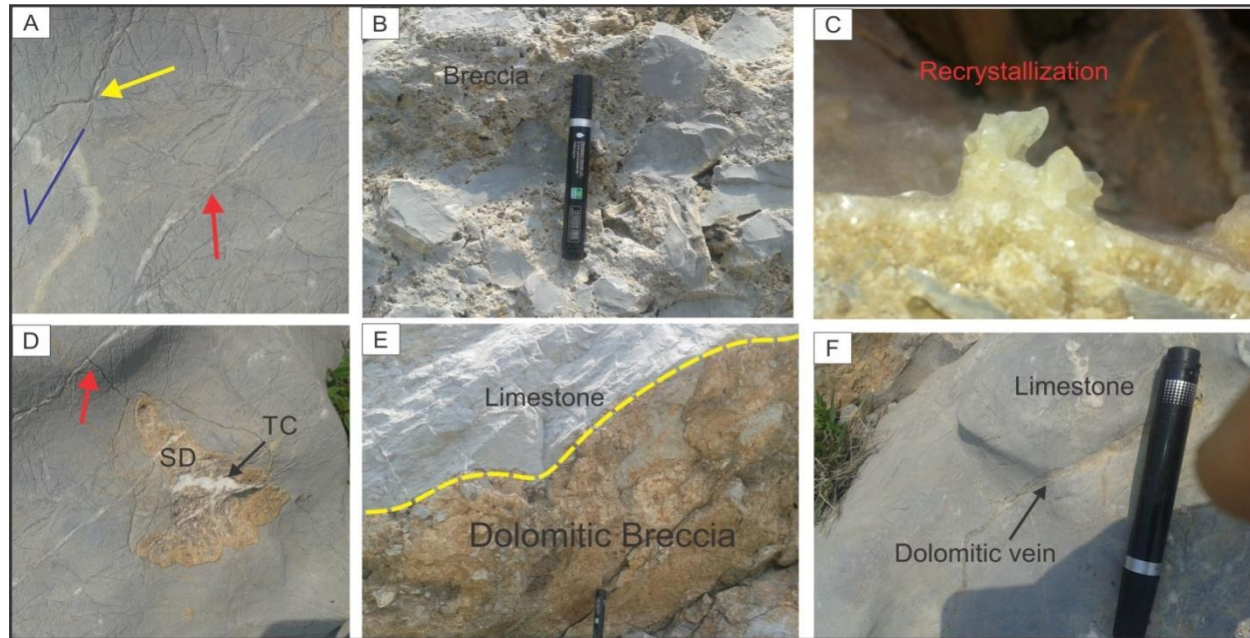


Fig. 4 Diagenetic fabric at outcrop of Kawagarh Formation. A) the red arrow show filled fractures while yellow arrow show fracture which make displacement in bed, indicated by blue mark. B): Show Breccia. C) show Recrystallization in dolomitic bed. D) Show Saddle dolomite (SD) in limestone bed and telogenetic calcite (TC), and red arrow show filled and unfilled veins cross cut. E) Show a clear boundary between limestone and dolomitic breccia. F) show dolomitic vein in limestone bed.

2001). The fractures system occurs in the carbonate rocks at various stages of sedimentation and diagenesis. The calcite-filled veins are due to brittle failure and tectonic fracturing of lithified carbonate rocks caused by stress and shear displacement. Likewise, extensional movements and natural hydraulic fracturing are also responsible for the formation of micro-fractures (Sibson, 1975). At outcrop, filled and unfilled both fracturings are recognised (Fig.4A), but the ratio of fractures is low as compared to the other carbonates in Khanpur Dam Section. The reason for the low amount of the fractures is may be due to the low amount of allochems and high amount of mud. Petrographically, filled and unfilled fractures were recognised. The fractures host calcite and dolomites. These fractures cross cut allochems and other fractures which indicate it is multistage of occurrences (Fig. 5D).

Dolomitization

Post-depositional process in which Magnesium (Mg)

recognised as dolomitic crystals. The rhombs sizes are varying from 100 to 350-400 micrometres (Fig. 5E).

Brecciation

Brecciated rock textures are common and may be associated with in situ deformation of rock (e.g., from hydrofracturing), cataclastic deformation in tectonic shear zones, mass flow deposits such as landslides or rock falls, and various other causes. At outcrop, the breccia is recognised in a dolomitic portion which indicates that may have been caused by the dissolution of the dolomitic fluids (Figs. 4B, 4E).

Recrystallization

At a late stage, in deep burial diagenesis due to high pressure and temperature condition primary fabrics of the rock recrystallized into new fabrics. At outcrop, many portions were highly crystallised due to which the recognition of primary sedimentary features is not possible. In recrystallized portions, well-developed crystals are present. Recrystallization is common in

limestone facies (Fig. 4C). Petrographically, high recrystallization is identified, due to which the allochems are difficult to recognize (Fig. 5F).

Stylolites

According to Buxton and Duncan (1981), stylolites are the product of physiochemical process induced by the burial compaction and tectonic compression. The surfaces of stylolites are characterised by well-

pronounced roughness with teeth or pen-like geometries. At outcrop, the identification of the stylolites is difficult because it has the stylolites, but too much thin sized which is difficult to differentiate from thin fractures. Petrographically, the wavy structure like ECG shape is recognised as stylolites. The stylolites in Kawagarh Formation cross cut all the diagenetic fabric evenly cut the calcite-filled veins which indicate its late stage of occurrences (Fig.5G,

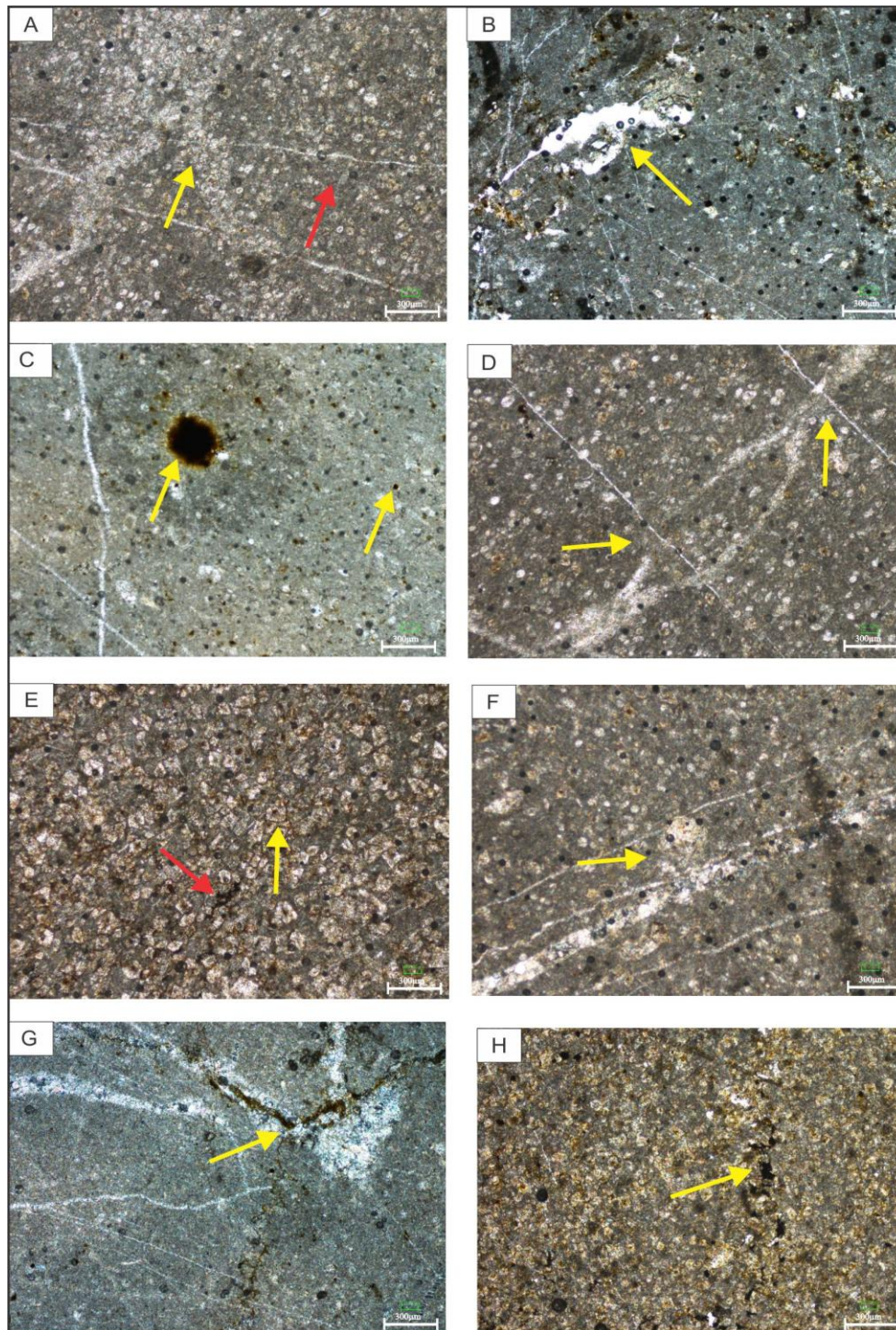


Fig. 5 Different petrographic views of diagenetic fabrics of Kawagarh Formation. A) red arrow shows cementing materials, while yellow arrow shows Planktonic forams/allochems. B) yellow arrow shows sparite. C) yellow shows large and small crystals of pyrites. D) yellow arrow shows crosscut filled veins. E) yellow arrow shows dolomitic rhombs while red arrow shows inter crystalline pores. F) yellow arrow shows recrystallized fossils and calcite. G) yellow arrow shows stylolite crosscut the filled fracture. H) yellow arrow shows the stylolite in dolomitic facies.

5H).

Evolution of diagenesis

- After the deposition, the cementation occurred at the early stage of marine diagenesis, because all the allochems are well cemented.
- Pyritization occurs at early burial stages (Larsen and Chilingar, 1979). Pyrites are abundantly present in Kawagarh Formation.
- Fracture occurs in carbonates rocks at various stages (Sibson, 1975). In Kawagarh Formation, the filled fractures are abundantly present (Fig. 5D).
- Dolomitization occurs at a late stage because it affects all the depositional and diagenetic fabrics (Fig. 5E, 5H).
- After or during the time of dolomitization, brecciation takes place because when fluids are injected into carbonates it causes dissolution, which may lead to brecciation or due to the replacement of the Ca by Mg resulting in dolomitization may have led to collapse and ultimately to collapse breccia.
- Some parts of the Kawagarh Formation show recrystallization. In recrystallized portion, whole the fabric is missing, which indicates that it occurred at the late stage of diagenesis.
- Stylolite is formed at the time of burial or due to the tectonic compaction (Buxton and Duncan, 1981).

From petrographic observation, it is noted that it is post diagenetic feature as it cross-cuts all fabrics.

Dolomitization

Host Rock

Late Cretaceous Kawagarh Formation is well exposed in Khanpur Dam section. The Kawagarh Formation is lithologically limestone, which has different impurities at different locations like marl and sandy particles. In the study area, the Kawagarh Formation has two different facies limestone and dolomites (Fig. 3). The limestone facies have further four different microfacies. These microfacies are foraminifera mudstone, mudstone, radiolarian wackestone and foraminifera wackestone microfacies. From microfacies analysis, the outer ramp to the deep marine setting is suggested for the deposition of Kawagarh Formation. The formation is highly micritized and dominated by mudstone facies.

Outcrop

In the study area, the Kawagarh Formation is thickly exposed (Fig. 3). It has medium to thick beds which conformably overlies on each other. On weathered surface, the color is light grey while some beds give light yellowish color; color is changing from weathered to afresh surface. The grain size is very fine, while due to recrystallization in some places grain size is fine to medium. The dolomitization has been recognised at the outcrop in the form of thick beds and veins (Fig. 4F). Round about 25% of the limestone

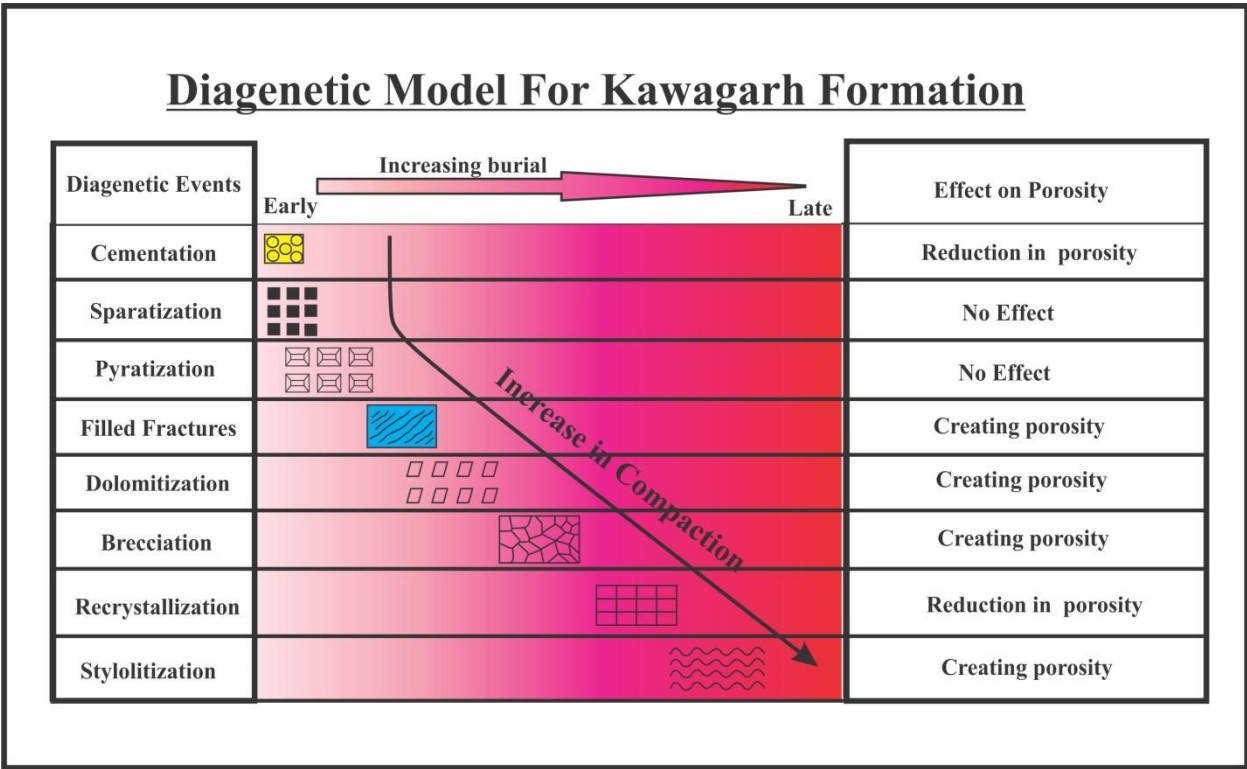


Fig. 6 The diagenetic model for Kawagarh Formation, Khanpur Dam section.

facies is affected by dolomitization. Saddle dolomitization is common in the basal part of the formation (Fig. 4D). A thick dolomitic bed was recognised at the top of the outcrop which is brownish to blackish in color (Figs. 3,7). From field observation, it is recognised that these dolomites are secondary in nature as they cross cut the entire primary structures of limestone. Near the Khui Da Maria Thrust, the dolomitic veins and beds are in their regular pattern

and cross cut limestone beds but as moving away from fault zone the dolomitic beds become parallel to the limestone beds. At the different parts of the Kawagarh Formation the dolomitic breccia has been observed (Figs. 4B, 4E).

Petrographic observation

In the Khanpur Dame Section, the upper and middle



Fig. 7 shows the top most dolomitic bed of Kawagarh Formation.

part of Kawagarh Formation (volumetrically about 25%) is completely or partly dolomitized (Fig.8). These dolomites were formed as replacement phase (RD). 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 dolomite (RD1), (2) medium crystalline planar-s dolomite (RD2), (3) medium crystalline non-planar-a dolomite (RD3), (4) coarse crystalline planar-s dolomite (RD4), (5) coarse crystalline non-planar-a dolomite (RD5) and (6)

Saddle dolomites (SD1).

Fine crystalline planar-e dolomite (RD1)

The RD1 type dolomites are present at the lower part of Kawagarh Formation. At outcrop, the medium to thick bed is present which is light yellowish in color, while at fresh surface color is yellow. The recrystallization is observed (Fig. 3, 4C). The grain size is fine to medium. Petrographically, the fine crystalline planar-e dolomitic crystals are recognised.

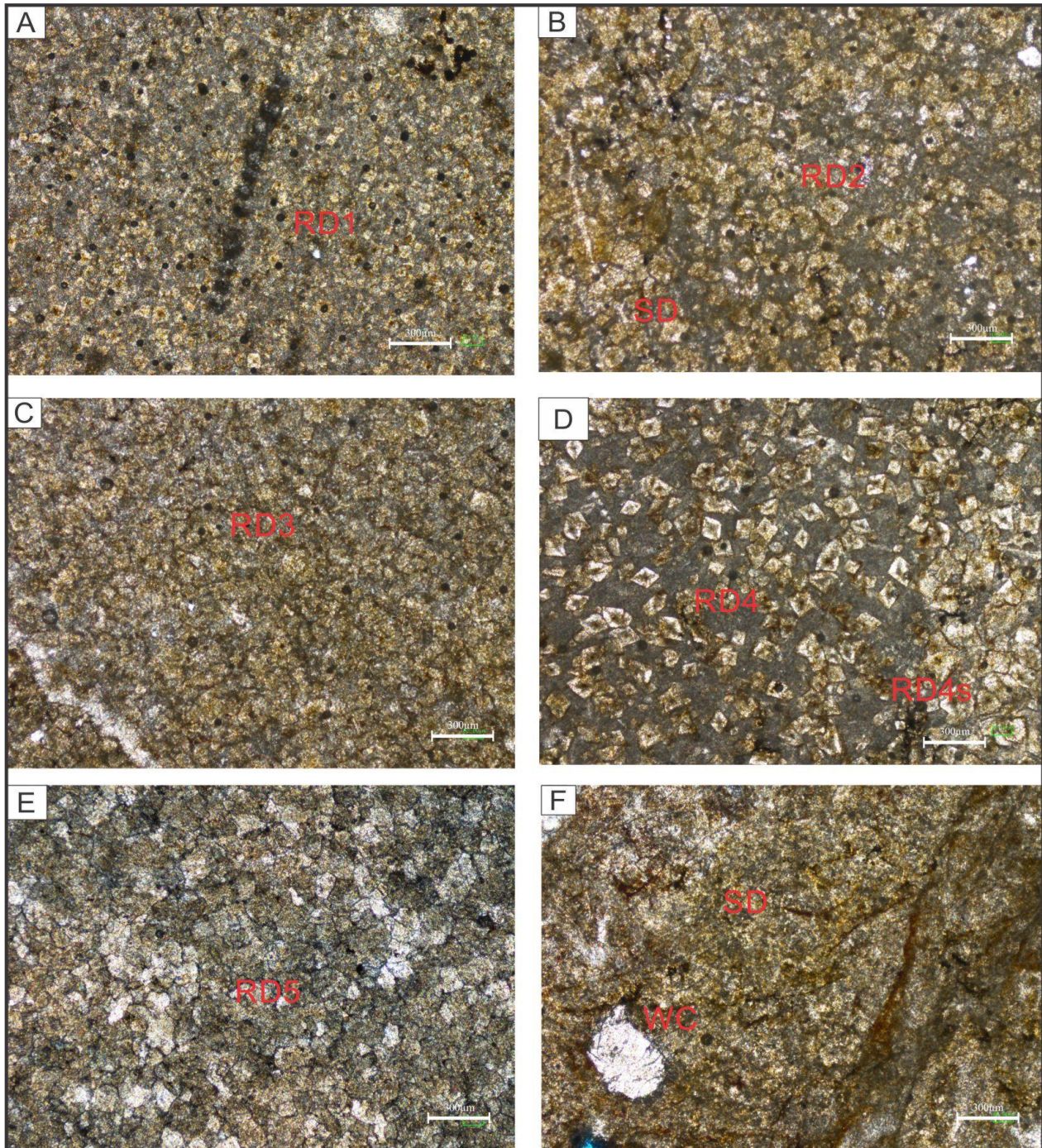


Fig. 8 Shows different types of dolomites on the basis of the crystals geometry and nature e.g. euhedral, subhedral and anhedral. RD1, RD2, RD3, RD4, RD5 and saddle dolomites (SD1) in Kawagarh Formation, Khanpur Dam Section. (D) RD4 subhedral (RD4s). F) Saddle dolomite (SD), white calcite (WC).

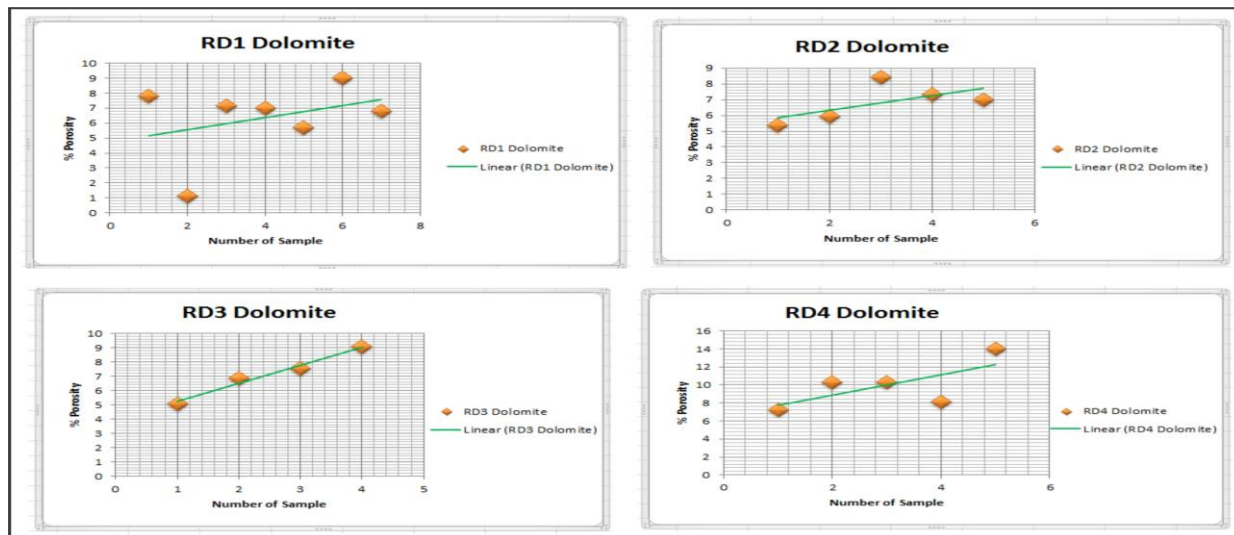


Fig. 9 Shows the Image J porosity in RD1, RD2, RD3 and RD4 dolomites

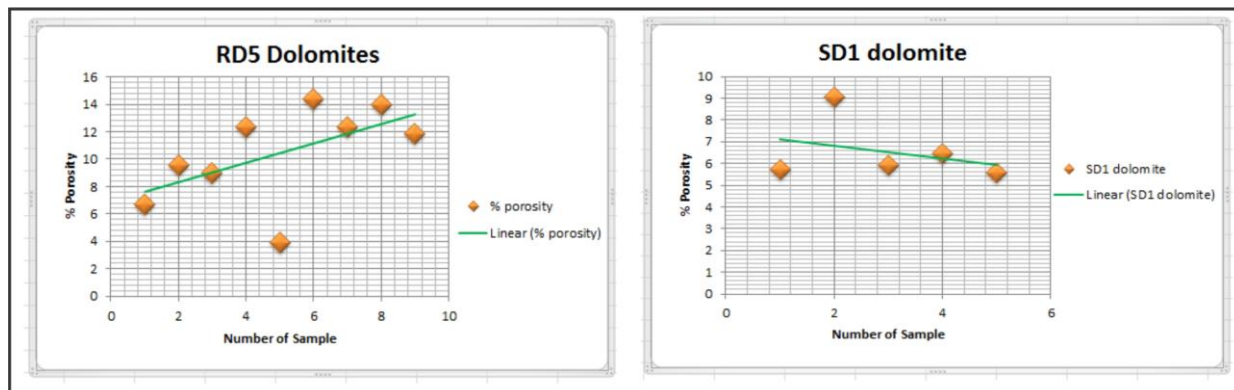


Fig. 10 Shows the Image J porosity in RD5 and saddle dolomites (SD1).

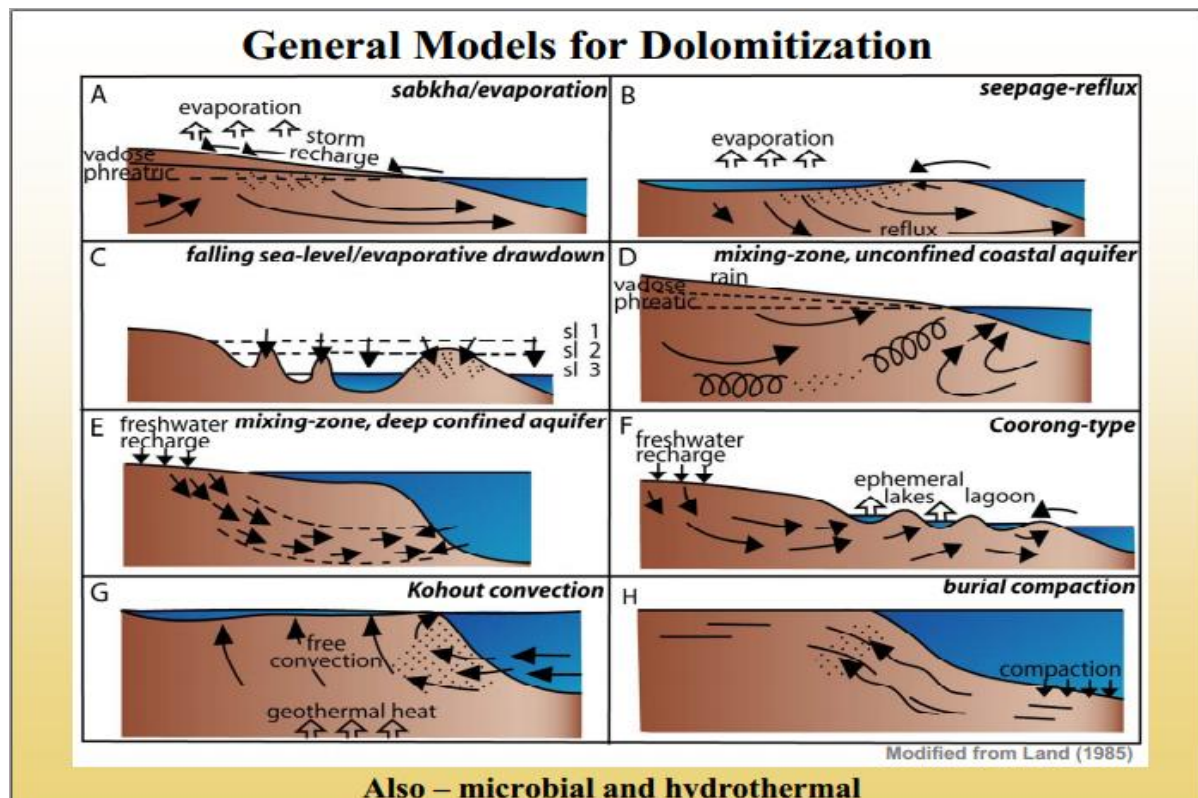


Fig. 11 shows different modes of dolomitization (modified after Land, 1985).

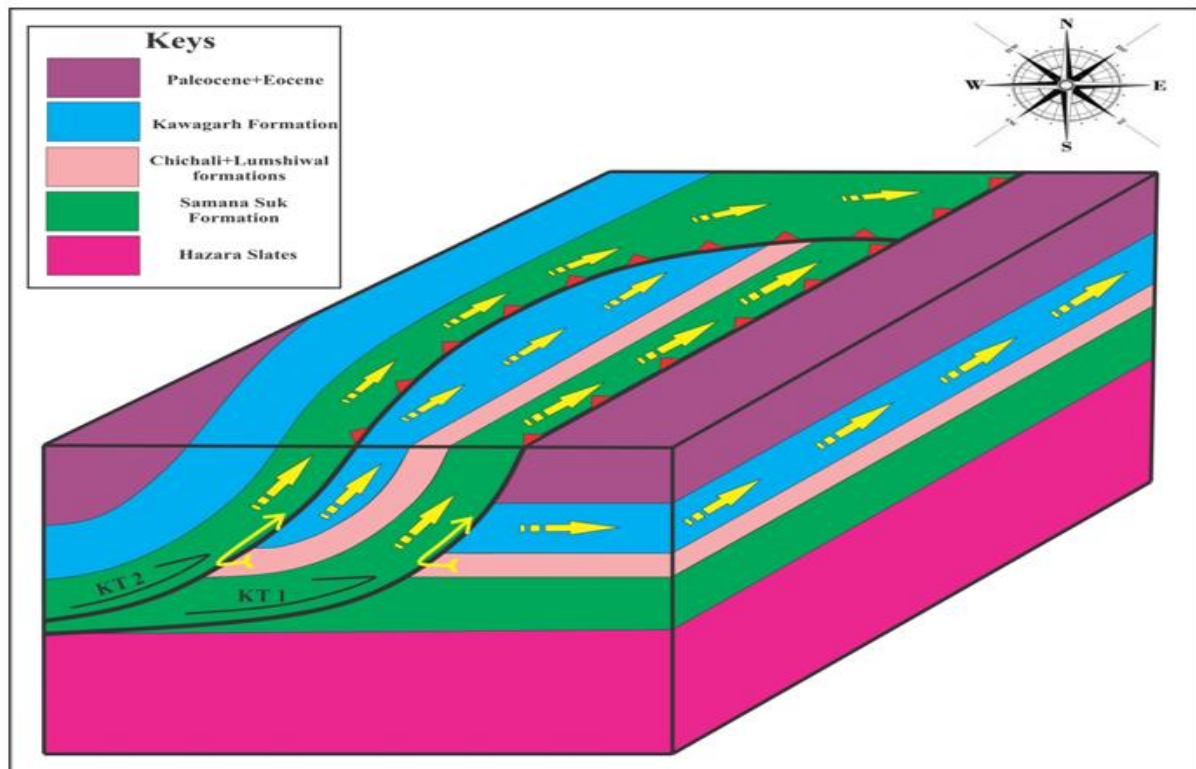


Fig. 12 Dolomitization model for Kawagarh Formation in Khanpur Dam Section, Hazara Basin, KP, Pakistan.

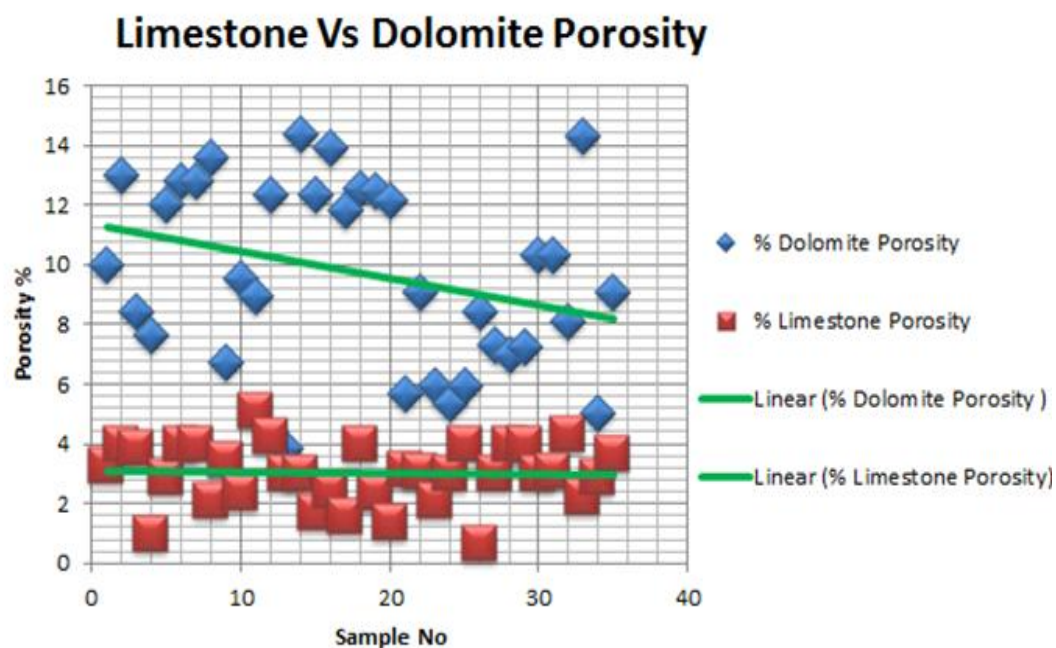


Fig. 13 shows the porosities of limestone and dolomite.

These crystals have 40 μ m to 80 μ m size, while some are ranging up to 110 and 120 μ m. The boundaries of some crystals are clear but mostly not clear but the original shape of the crystals is well preserved (Fig. 8A). Most of the crystals have inclusion on their surfaces; inclusions are low-Mg calcite relicts of

precursor limestone (Kırmacı, 2013). The dolomitic crystals are cross cut by the filled fractures and stylolites (Fig. 5H). On image J porosity analysis the percentage of porosity in RD1 dolomites are ranging from 1 to 9% (Fig. 9).

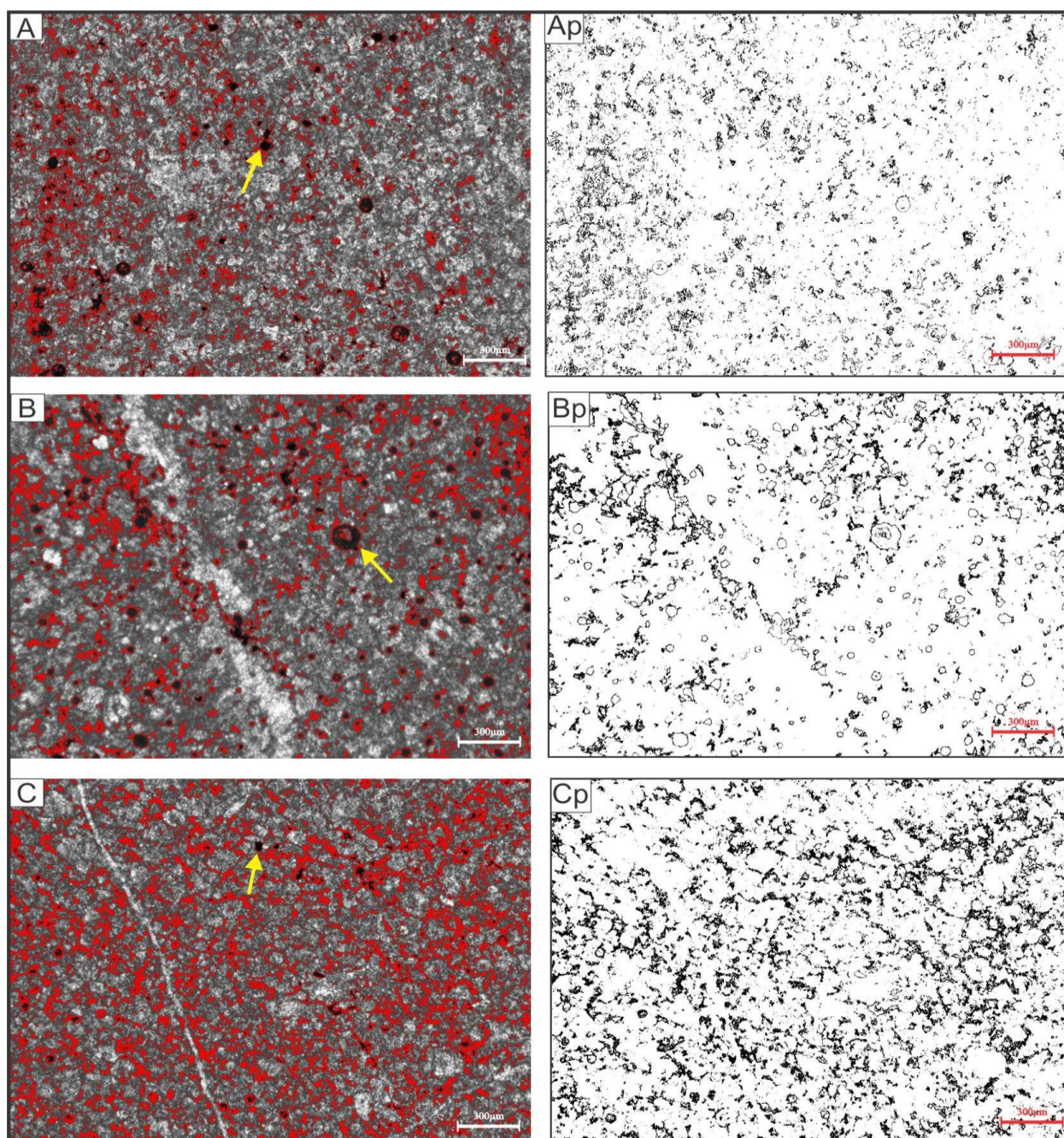


Fig. 14 shows the red color porosity in dolomites while yellow arrow shows air bobbles and pyrites. A) porosity in RD1 dolomite Ap) shows the interconnection of pores in RD1. B) porosity in RD2 dolomite. Bp) shows the interconnection of pores in RD2. C) porosity in RD3 dolomite Cp) shows the interconnection of pores in RD3.

Medium crystalline planar-s dolomite (RD2)

Just above the lower contact of the Kawagarh Formation, the mudstone bed is present; over this mudstone bed, the dolomitic bed is present which have medium planar-s dolomite crystals (Fig. 3). The crystals have planar subhedral nature according to the dolomites classification of Sibley and Gregg (1987). The crystal size is ranging from 120µm to 200µm while some crystals are ranging up to 300µm. The boundaries are not too much clear (Fig.8B). The image j analysis porosity is ranging in RD2 dolomites from 5 to 8.5% (Fig.9).

Medium crystalline non-planar-a dolomite (RD3)

RD3 type dolomites are associated with RD2 type dolomite. The field features like grain size and color are same up to some extent but petrographically both have different properties. RD3 dolomites are anhedral in nature. The boundaries between crystals are not too much clear, difficult to separate different crystals from each other. The crystals are cloudy and have cleavages on their surfaces. The inclusions are also clear on the surfaces of the crystals, where inclusions give brownish appearance on yellowish dolomitic crystals. The dolomitic crystals give selective extension under

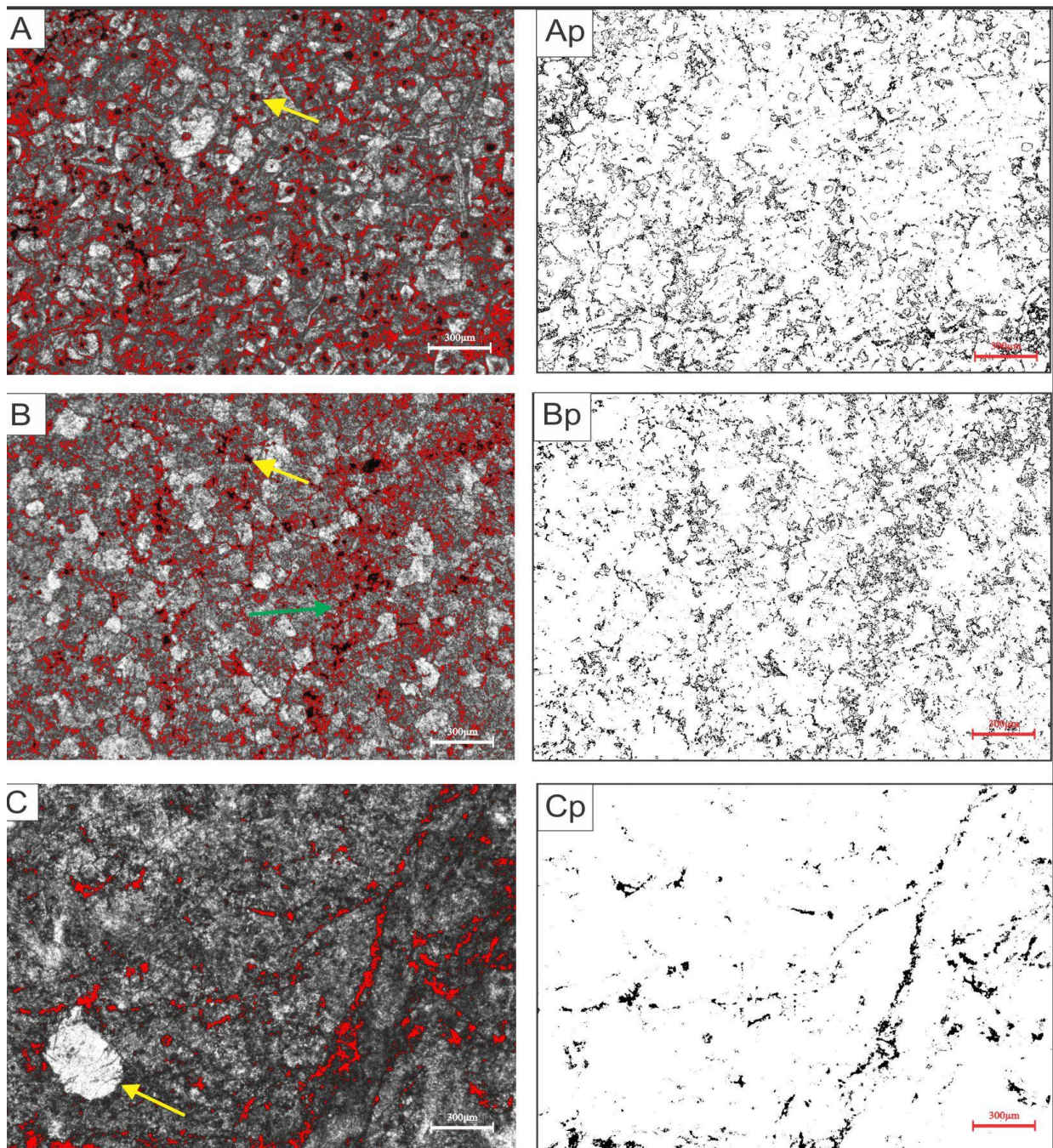


Fig. 15 shows the red color porosity in dolomites, yellow arrow show air bobbles and pyrites and blue arrow show stylolite. A) porosity in RD4 dolomite, Ap) shows the interconnection of pores in RD4. B) porosity in RD5 dolomite, Bp) shows the interconnection of pores in RD5. C) porosity in SD 1 dolomite while yellow arrow shows calcite crystals, Cp) shows the interconnection of pores in SD1.

the crossed nicols through polarizer microscope. The dolomitic crystals are cross-cut by calcite-filled veins. The crystals sizes are ranging from 150µm to 250µm (Fig. 8C). The image J porosity is ranging from 5 to 9% (Fig. 9).

Coarse crystalline planar-e dolomite (RD4)

At the upper part of Kawagarh Formation, a massive dolomitic bed is present with variable thickness from place to place. The color on the weathered surface is

brown to blackish. The grain size is fine to medium. This dolomitic bed is bounded below by foraminifera wackstone facies. Petrographically, the crystals size varies from 250µm to 400µm. The crystals are euhedral in nature and have clear boundaries. These crystals have a sharp zone at the middle part of the crystal it may be the product of low-Mg calcite relicts of precursor limestone. In some part of the thin section, the dolomites nature is subhedral, give extension under the cross-polarised light (Fig. 8D). In RD4 dolomites, the image J porosity is ranging from 7 to 14% (Fig. 9).

Coarse crystalline non-planar-a dolomite (RD5)

RD5 dolomites are associated with RD4 dolomites. At outcrop scale, texturally it has a little difference but petrographically has different nature of crystals geometry. RD5 dolomites have anhedral crystals geometry. The crystal size is difficult to measure but approximately same like RD4 e.g. 250µm to 400µm. RD5 dolomites are cross-cut by veins, give selective extension under the cross-polarised light (Fig. 8E). The porosity is ranging from 7% to 14% (Fig. 10).

Saddle dolomite (SD1)

Saddle dolomites indicate the high-temperature environment (Spotl and Pitman, 1998). In Kawagarh Formation, the saddle dolomites are abundantly present in middle and lower parts of outcrop (Fig. 4D). SD1 dolomites at outcrop are present in dolomitic beds as well as in limestone beds. Petrographically, the saddle dolomites are recognised as large irregular crystals (Fig. 8F). In SD1 dolomites, the porosity is ranging from 5 to 9% (Fig. 10).

Dolomitization model and origin of fluids

The secondary dolomitization in limestone is caused by different parameters. For the dolomitization, the Mg-rich fluids are necessary to cause dolomitization. In Figure 11, different eight (A to H) dolomitization models are presented which demonstrate different origins of dolomitization. In the present study, in the light of the present petrographic analysis and field observation/structure analysis model "H" with modification with thrust fault is suggested for dolomitization in Kawagarh Formation. In the study area, the thick stratigraphic sequence is present which have burial pressure/ compaction. Hence, the Hazara Slates, Samana Suk, Chichali and Lumshiwal formations are under the Kawagarh Formation. The Chichali and Lumshiwal formations have clastic nature, which is favorable to contain fluids in their pores. As the burial pressure and tectonic pressure was already exerted on the stratigraphic sequence, so the fluids from these formations are expelled and migrated to Kawagarh Formation and caused dolomitization.

The dolomitization occurred after the deposition of - Kawagarh Formation and before the deposition of the Palaeocene rocks because such dolomitization is so far not reported from other young carbonates of Palaeocene Lockhart Formation and other Eocene carbonates. Hence, there are two possibilities for the dolomitization fluid migration, that the fluids move along the normal fault as the area was subjected to extensional tectonics and later on invert into compressional tectonics due to Himalayan orogeny (Burge, 2006). The argument of the compressional tectonic/thrust fault is supported by the same dolomitization in the middle Jurassic Samana Suk Formation. The Khui Da Maira Thrust (Khanpur

Thrust 2) (Fig. 2) is suggested as a pathway for fluid migration because along the same fault at the same section, the same dolomitization is observed in Samana Suk Formation (Rahman et al., 2009, 2015). In the area, the middle Jurassic Samana Suk Formation thrust over on the Late Cretaceous Kawagarh Formation along Khui Da Maria Fault (KT2). So, the possible pathway for the Mg-rich fluid movement is Khui Da Maira Fault, which makes the sequence in such manner that neither the original sequence disturbed and nor the pathway and fluid donor lithology location (Fig. 12). It is notable that the dolomitization occurred all along the faulted zone, the KT2 is a major fault in the area along which possibly the dolomitization takes place at subsurface.

Reservoir characterization and the effect of dolomitization on porosity

The term micro-porosity 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). The carbonates have porosity in the form of intra-particles, inter-particles, vuggy pores, inter and intra-crystalline in dolomites. The Kawagarh Formation has deep marine origin due to which the allochems and borrows like shelf/ramp carbonates are not too much common. Most of the composition is mudstone, which is non-laminated and non-borrowed. In limestone facies of Kawagarh Formation, the porosity is ranging from 2 to 3% (Fig.13), which is in the form of unfilled micro fractures and vuggy porosity. The dolomitic facies of Kawagarh Formation has good porosity. The overall porosity in dolomites is ranging from 5 to 14% (Fig. 13), which in most of the samples is generally 5%. The porosity in RD 4 and 5 dolomites ranges from 5 to 14%. In saddle dolomite and other dolomites, it is 5 to 9%. These microporosities with the addition of other diagenetic and tectonic porosities (major and minor fractures, joints, breccia) the overall porosity will be more effective. The interconnection of the pore spaces is good in dolomitic facies, as shown in the pore spaces shadow analysis (Figs. 14, 15), which makes it well permeable and an effective reservoir. Thus, the Kawagarh Formation in Khanpur Dam Section (Khui Da Maira Section) is not the best reservoir but has the potential to be a good reservoir.

Conclusions

- Composition wise and by deposition, the nature of the Kawagarh Formation is the poor reservoir because it has the deep marine depositional setting and abundantly mudstone composition, but the later diagenetic process makes it a good reservoir.
- Kawagarh Formation passes from marine to deep burial diagenetic phases, during these diagenetic phases the reservoir potential of the formation is highly disturbed. In many phases, the porosity reduced and increased, but the overall reservoir capability has increased.

- From image J porosity analysis, it is concluded that the dolomitization process increases the porosity up to 10%, which is a good result.
- From image J porosity shadow analysis, it is concluded that the interconnection of pores in dolomitic facies is good, which will make it as an effective reservoir.
- From the above analysis, it is concluded that in the studied section the reservoir potential of the Kawagarh Formation is good, which may have good reservoir potential at subsurface.

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