Journal of Himalayan Earth Sciences Volume 52, No. 1, 2019 pp. 106-119

Diagenetic studies of the Cretaceous turbidities, Sulaiman Range, Pakistan: Implications for reservoir quality

Bilal Wadood[1-2]*, Muhammad Awais[1], Suleman Khan[2], Sajjad Ahmad[2], Laeiq Ahmad,[1] Muhammad Muslim[3]

[1]*Department of Geology, University of Swabi, Swabi, KPK, Pakistan*
[2]*Department of Geology, University of Peshawar, Peshawar, KPK, Pakistan*
[3]*National Centre of Excellence in Geology, University of Peshawar, Peshawar, KPK, Pakistan*
**Corresponding authors email: bilalwadood@uoswabi.edu.pk*
Submitted:07/05/2018 Accepted:15/03/2019 Published online:29/03/2019

Abstract

The composite carbonates-clastic succession of the Mughal Kot Formation exposed in Mughal Kot Section, Sulaiman Range is studied in detail in the context of diagenesis and reservoir quality. Both carbonates and clastic rocks have been altered by diagenetic processes in their respective diagenetic environments. The diagenetic processes, noticed in carbonates of the Mughal Kot Formation, includes micritization, dolomitization, iron cementation, cementation (isopach), mechanical compaction, chemical compaction (stylolitization) and fracturing (but most are filled). Similarly, the sandstone of the Mughal Kot Formation exhibit reservoir heterogeneity based on the diagenetic features and overall rock fabric. The sandstones are modified by mechanical compaction, cementation (quartz overgrowth, calcite, dolomite and iron minerals). Such diagenetic alterations control the reservoir properties and quality. In the light of present study, carbonates as well as clastics of the Mughal Kot Formation are poor quality reservoir rocks.

Keywords: Diagenesis, Reservoir, Mughal Kot Formation, Sulaiman Range, Pakistan.

1. Introduction

The type section of the Mughal Kot Formation is designated by Williams (1959) to be in the gorge ~3 miles west of Mughal Kot Post (lat 31°26'52"N.; long 70°02'58"E.; Fig. 1). In this section the Mughal Kot Formation is comprised of 1000m thick monotonous sequence of nodular marl with minor intercalation of graded bedded lenticular sandstone and thick bedded limestone (Khan et al., 2017). The upper part of the Mughal Kot Formation has produced oil seepages along joints, fractures and bedding planes (Williams, 1959). The exposed thickness of the Mughal Kot greatly varies from place to place within the Lower Indus Basin (Shah, 2009). This great variation in thickness of formation may result from the differential tectonics in the region which may have resulted in the bathymetric relief on the same basin margin during the Coniacian–Santonian interval induced significant thickness variations and environmental settings (Smewing et al., 2002; Hedley et al., 2001).

Various geological studies have been undertaken to understand the biostratigraphic ages and depositional environment of the Mugahl Kot Formation e.g. La Touche (1893) described the physiography, stratigraphy, general structural setting, and economic geology of the study area. Marks (1962) have recorded Campanian to early Maastrichtian fossils from the Mughal Kot Formation. Malkani (2010) has assigned shallow marine deltaic depositional environment for the Mughal Kot Formation on basis of facies. Such hyperpycnal deltaic system of the Mughal Kot Formation is supported further by the presence of turbidite sandstone (e.g. William, 1959 and Dorreen, 2010). Khan et al. (2017) has assigned Maastrichtian age to the Mughal Kot Formation and reconstructed paleoceanographic conditions and its effect on the evolution of Maastrichtian planktonic foraminifera.

The Mughal Kot Formation bears a strong potential of hydrocarbon reservoir because such hemipelagic carbonates and turbidite sandstone are reported to be good hydrocarbon reservoirs e.g. the basinal hemipelagic muddy carbonates deposited in slope or toe-of-slope host reservoir quality (Stow, 1994; Krenmayr, 1996). Such deeper carbonate reservoirs share similarities with unconventional siliciclastic and shale reservoirs; however the dimension and the distribution of pores within its matrix indicate one order lower magnitude than high quality reservoir (Loucks et al., 2012). However, the low matrix porosity may play major role for fluid storage (e.g. Motyka et al., 1998). Furthermore, the deep water turbidites also host major world hydrocarbon reservoirs (Pettingill and Paul, 2002). The literature review indicates that diagenetic studies in relation to the reservoir properties of the deeper hemipelagic carbonate and turbidite sandstone of the Mughal Kot Formation are still lacking. The aim of this study is therefore to investigate the diagenesis and reservoir quality of the Mughal Kot Formation and to establish a reliable link between these two parameters of the hemipelagic strata.

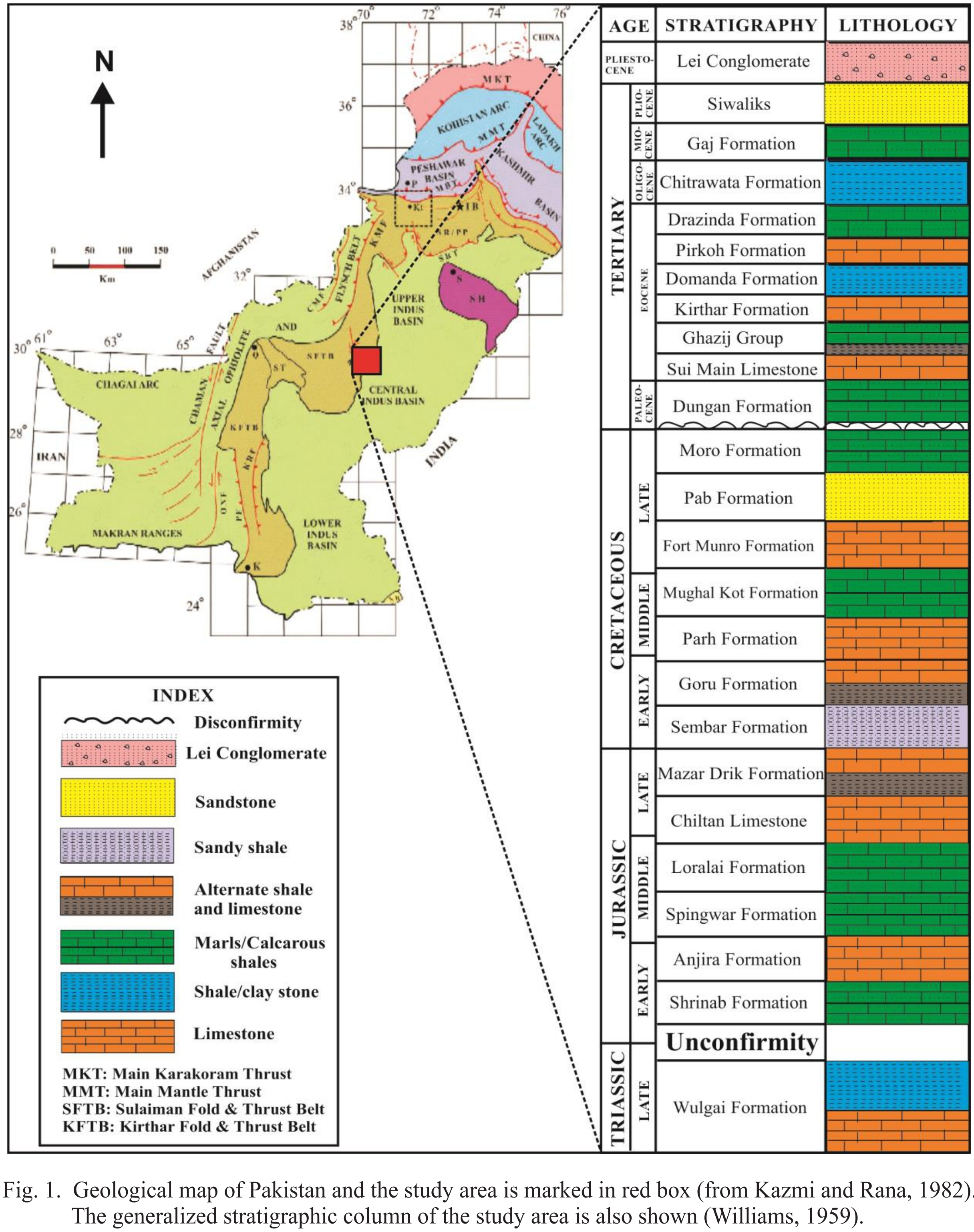


Fig. 1. Geological map of Pakistan and the study area is marked in red box (from Kazmi and Rana, 1982). The generalized stratigraphic column of the study area is also shown (Williams, 1959).

2. General geology of study area

The studied stratigraphic section is located in the Sulaiman Range. This range is an outcome of the complex thin and thick skinned fold-and-thrust resulted from collision along an oblique margin between the Indian and Afghan blocks (Haq and Davis, 2010). The sediments of Mesozoic age were deposited on the northern passive margin of the Indian continent under active tectonic conditions (Hedley et al., 2001). The arcuate shape of the Range is because of the irregular continental block of Katawaz between the strike slip component of the Afghan Block on the west and the Indian to the east (Fig. 1). The Sulaiman Basin is the largest sub-basin of Indus Basin which consists of approximately 170 thousand Km^2 area with more than 40% area of Indus Basin (Malkani, 2010). The Basin is divided into two arc shaped major tectonic zones namely Sulaiman fold belt and Sulaiman foredeep and a monoclinal zone called as the Punjab Monocline.

The Sulaiman Basin is comprised of the rocks ranging from Triassic to recent (Shah, 2009). The oldest known rocks deposits are of Triassic–Jurassic i.e. Ferozabad Group (Anwar et al., 1991) and are platform carbonates formed on a wide north-facing shelf. A disconformity which shows clear evidence of emergence separates these carbonates from the Early–Late Cretaceous succession (Umar et al., 2011). This succession includes dark grey shales of the Sembar Formation, hemi pelagic nodular limestones, marls and shales of the Goru Formation (Shah, 1977) and biomicrite sand marls of the Parh Limestone. These Tethys sediments pass up conformably into the siliciclastic-dominated units of Mughal Kot and Pab formations, comprising of fine to coarse and pebbly sandstones, with subordinate marls and mudstones. These Cretaceous units are succeeded by the Paleocene Dungan Formation, showing deposition of limestone. The Eocene succession is characterized by shales with subordinate sandstones succeeded by limestone. Further subsidence of the margin during the Oligocene provided accommodation space for the sediments to deposit (Khan et al., 2002). During the late Oligocene–Miocene the elimination of the Neo-Tethyan Ocean is evident by the Gaj Formation, which consists of shales, subordinate-sandstones with minor limestones. Gaj Foramtion is separated by angular unconformity from the non-marine clastics of the Plio-Quaternary time (Umer et al., 2011).

3. Materials and methods

The late Cretaceous turbidites in the Mughal Kot Section, Sulaiman Range has been observed, studied, measured and sampled. The overall stratigraphic log of the Sulaiman range is prepared (Fig. 1). A total of 110 samples at different intervals were collected from the Cretaceous turbidite sequence of the Mughal Kot section. Thin sections were prepared from the rock samples to study the diagenesis and reservoir quality using the standard techniques defined by Flügel (2004). Petrographic studies of sandstone and carbonates were carried out and different minerals and features were observed and recorded. Photomicrographs of diagnostic features were taken using petrographic microscope Labomed LB-580 and Olympus DP-12 Camera. To establish possible link between digenesis and reservoir quality, the digenetic model and table for paragenetic sequences of the digenesis were constructed (Fig. 7; Table 1 & 2).The graphics software (Corel draw X7) was used to label the diagrams and construct the daigenetic model and sequences.

4. Results

The detailed description of the diagenetic processes is given below:

4.1. Diagenesis of carbonates of the Mughal Kot Formation

The diagenetic processes, noticed in carbonates of the Mughal Kot Formation, includes micritization, dolomitization, iron cementation, cementation (isopach), mechanical compaction, chemical compaction (stylolitization) and fracturing (but most are filled).

4.1.1. Micritization

In carbonates of the Mughal Kot Formation, micritization is noticed in different forms i.e. as micritized allochems and micrite envelopes. In some cases, middle of the allochem has been micritized. The intensity of micritization varies from curtailed to extreme such that some of the grains have been entirely micritized obscuring the signs of original allochems (Fig. 2A-2D).

4.1.2. Dolomitization

The carbonates of the Mughal Kot Formation have also experienced dolomitization. The noticed dolomitization is selective dolomitization where calcite of allochems is partly replaced by dolomite. Most of the dolomitization is restricted to allochems, however, very less dolomite rhombs are present in the scattered form. Some of the allochems are completely occupied by dolomite while in some cases only small spots are occupied by dolomite. In some dolomitized zones, the dolomite rhombs are brownish red colored and might be implying the presence of Ankerite (Fig. 2E). The dolomite texture is non-planar to planar-e (euhedral) and planar-s (subhedral). The dolomite within the recrystallized allochem implies scattered area of nucleation (Fig. 2E-2J).

4.1.3. Neomorphism

In the Mughal Kot Formation, aggrading neomorphism (Fig. 2K) and recrystallization are noticed (Fig. 2L). The aggrading neomorphism involves the conversion of fine grained micrite to coarse grained spar. Some of the allochems are recrystallized. The unstable/metastable mineral (e.g. aragonite) dissolves out and precipitation of more stable mineral calcite occurs.

4.1.4. Cementation

The carbonates of the Mughal Kot Formation are cemented by calcite, dolomite (Fig. 3B), Ankerite (?) and iron minerals. Isopachous cement type is identified (Fig. 3A). Some of the allochems have been recrystallized (Fig. 3A). The microvugs and micromolds are filled with calcite (Fig. 3C). Cements have mostly occupied the fractures and zones of dolomitization (Fig. 3D).

4.1.5. Dissolution

Dissolution features are not noticed in the Mughal Kot Formation. However, some of the microvugs are occupied by cements, which were initially formed by dissolution and then occluded by the precipitation of cements (Fig. 3C).

4.1.6. Compaction

The carbonates of Mughal Kot Formation show two types of compaction i.e. mechanical and chemical compaction.

Mechanical/Physical compaction

The mechanical compaction is interpreted based on the presence of bioclastic debris (Fig. 3E), however, it can also be produced by reworking. Similarly, at very local scale tight fabric is also observed, which might be due to the mechanical compaction.

Chemical Compaction

The chemical compaction is evident by the formation of stylolites (Fig. 3F and 3G). The intensity of stylolitization is variable. In some cases, stylolites are generated in the middle of the allochem while in some cases they are present as small discontinuous lines reflecting chemical compaction on a very local scale. The stylolites morphologies includes sutured and smooth. The compaction has less affected the carbonates of the Mughal Kot Formation. It can be due to two possible reasons; (1) the carbonates have not experienced shallow and burial diagenesis for considerable period of time; and (2) the carbonates are dominated by mud-supported fabric so the overburden stresses are absorbed by the fabric of the rock. This happened due to the much closed fabric which is caused by the increase in total-overburden pressure.

4.1.7. Micro-fracturing

The carbonates of the Mughal Kot Formation are deformed by the generation of different fractures. Two episodes of fractures are demarcated while at one area (Fig. 3H), fracture splays are formed (Fig. 3I). At an instance, fractures are displaying fault like relative movement (Fig. 3J). Almost all of the fractures are occupied by cements. These fractures seem to be formed by tectonic stresses.

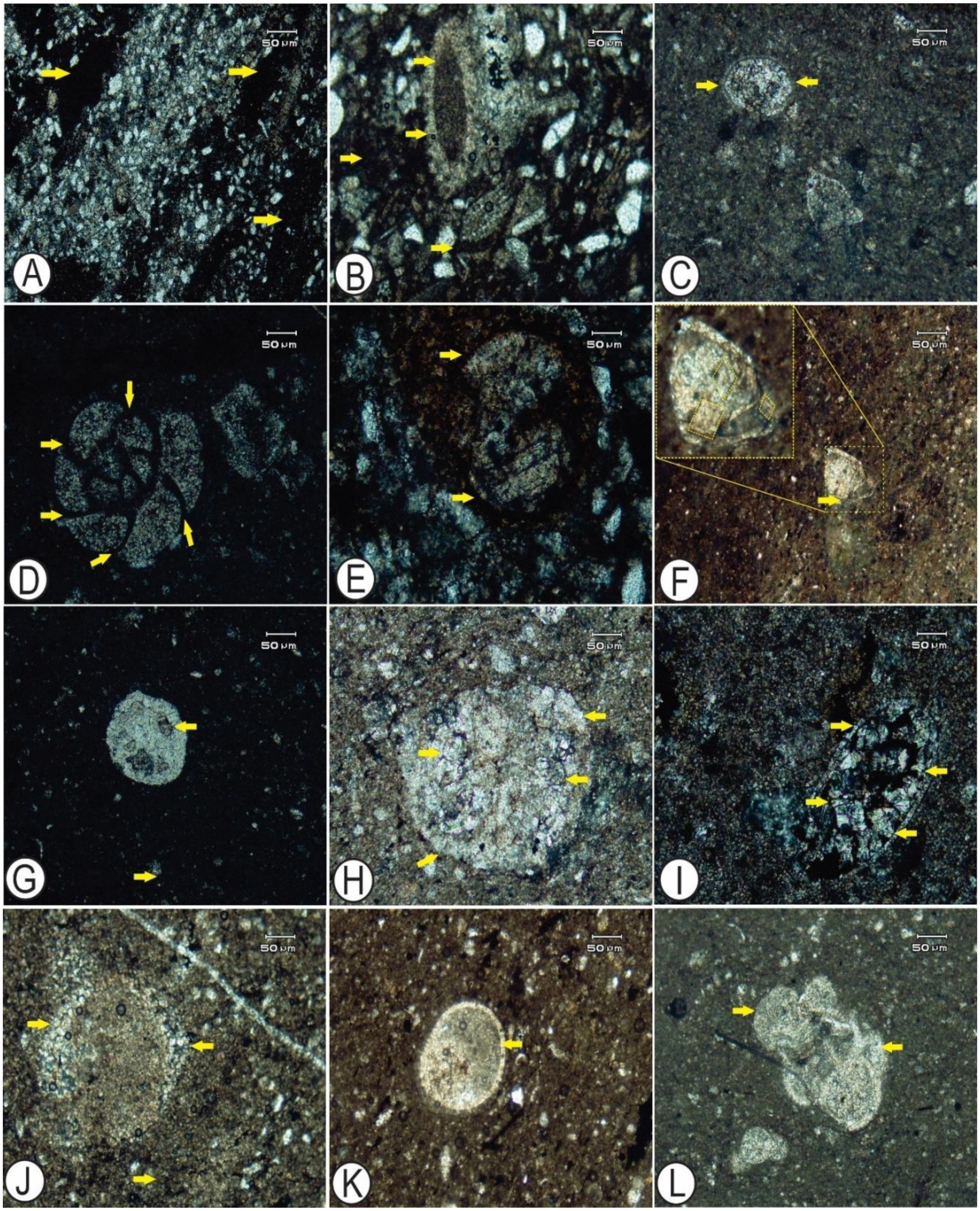


Fig. 2. Diagenetic fabric of the Mughal Kot Formation carbonates: (A) Micrite (marked by arrowhead), (B) Micritized allochem, (C) Micrite envelope, (D) Micrite envelopes at the periphery of fossil chambers/along septa, (E) Dolomitization within the allochem, (F) Dolomite within the recrystallized allochem, (G) Dolomite, having few zones of nucleation, within the recrystallized allochem, (H) and (I) Pervasive dolomitized allochem, (J) Partially dolomitized allochem, (K) Aggrading neomorphism, and (L) Recrystallized allochem.

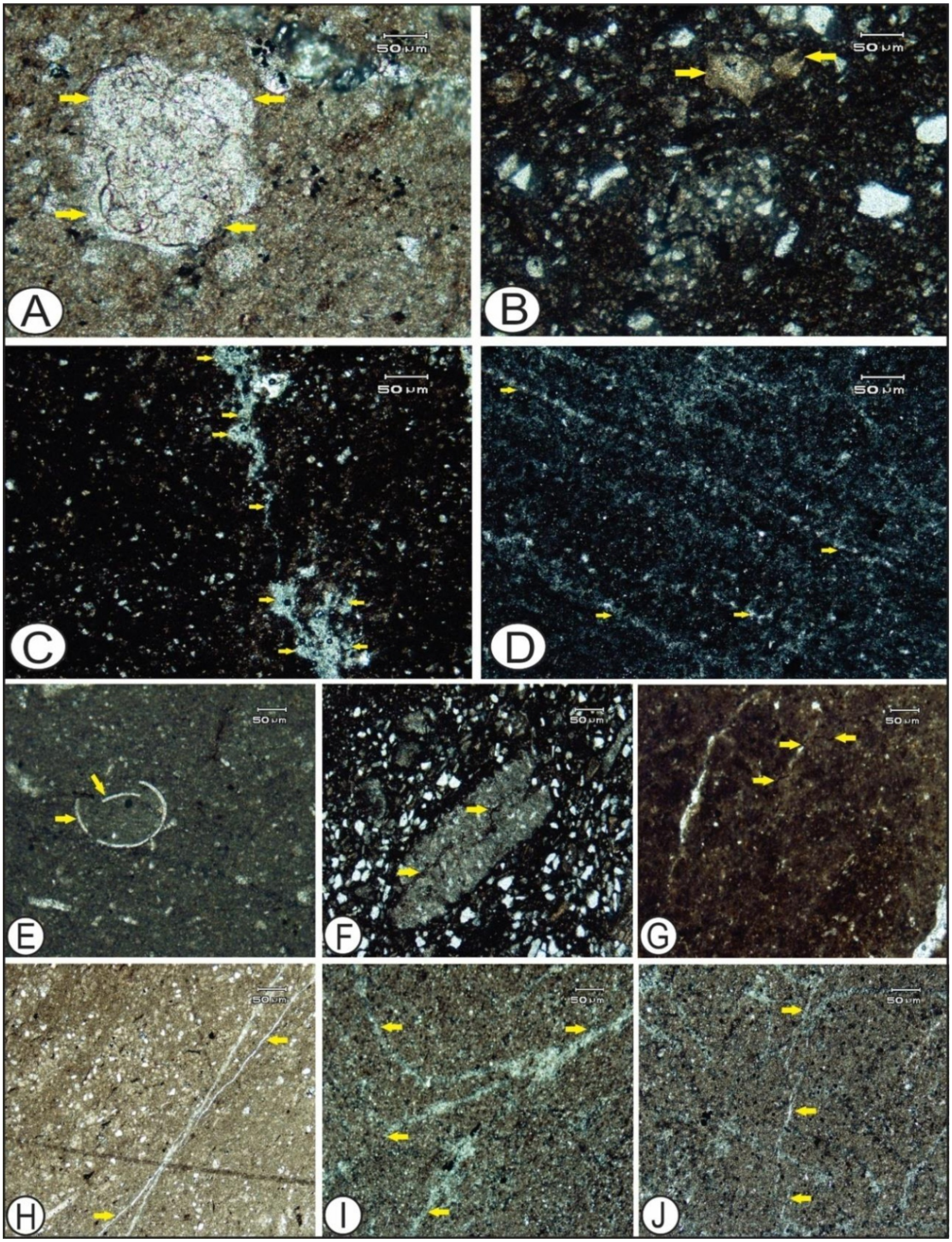


Fig. 3. Diagenetic fabric of the Mughal Kot Formation carbonates: (A) Isopachous cement at the periphery of recrystallized allochem, (B) Dolomite cement, (C) Calcite cement in the microvugs, (D) Calcite cement in fractures, (E) Bioclastic debris (marked by arrowhead), (F) Stylolite within the allochem, (G) Stylolite, (H) Two episodes of fractures, (I) Fracture splays, and (J) Fracture showing displacement.

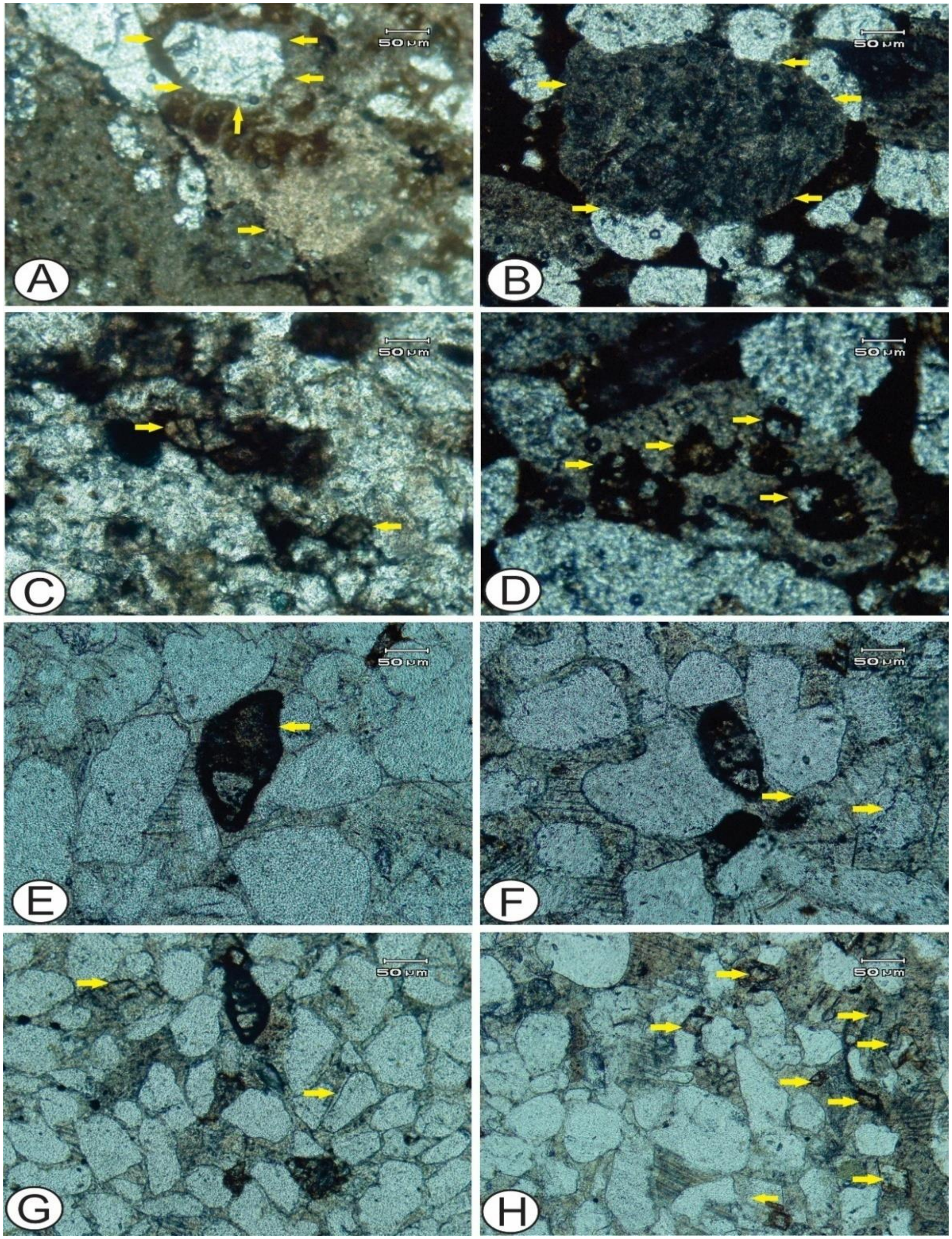


Fig. 4. Diagenetic fabric of the Mughal Kot Formation sandstone (A) Micrite envelope, and (B) Micritized allochem, (C) Dolomite cement, (D) Dolomitized allochem with few nucleation sites, (E) Dolomite within a allochem, (F) Calcite Cement, (G) Calcite and dolomite (marked by arrowhead) cements. Quartz overgrowth is also marked by arrowhead, and (H) Planar-e rhombs of dolomite as cement.

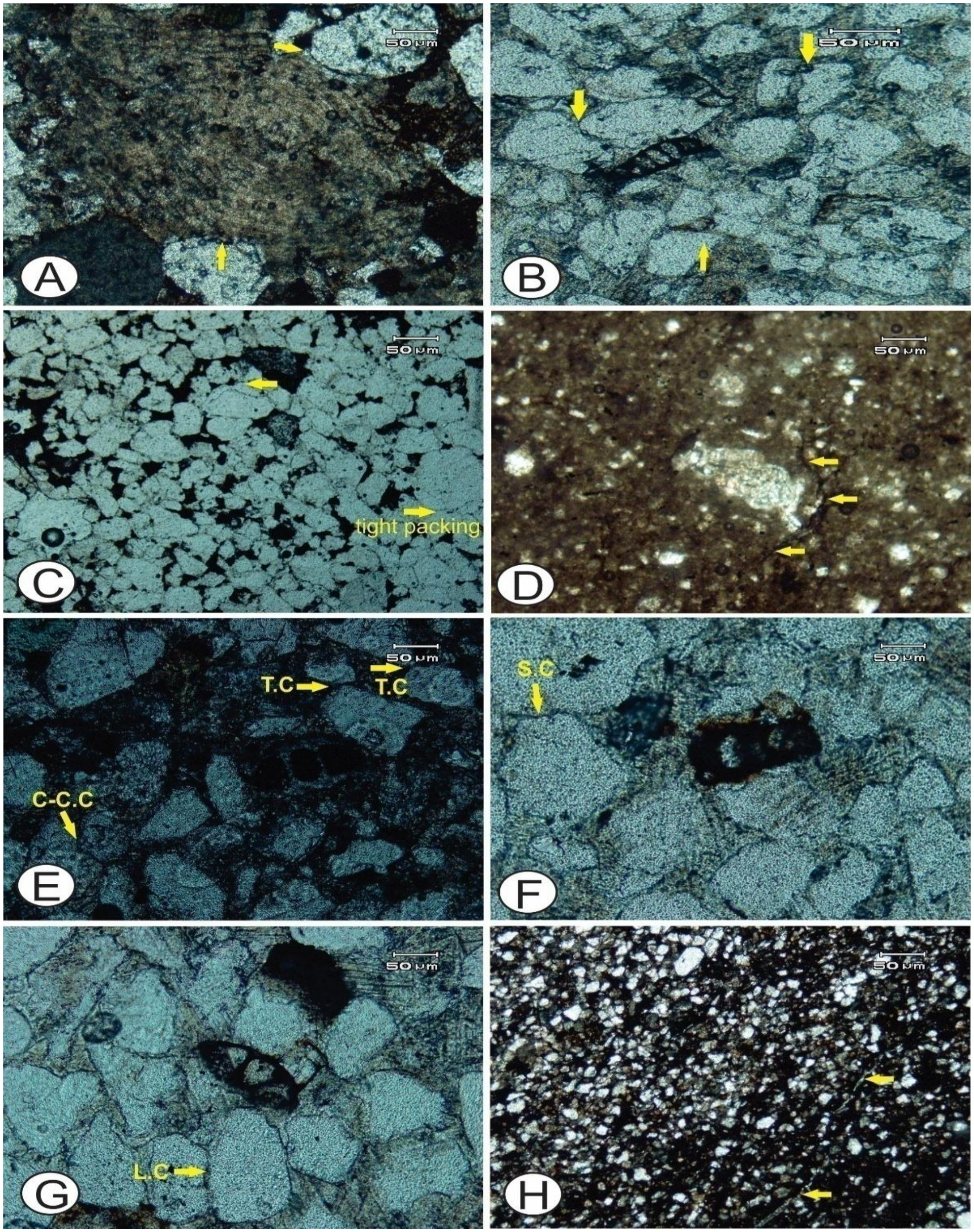


Fig. 5. Diagenetic fabric of the Mughal Kot Formation sandstone: (A) Quartz grains penetrated into the allochem, (B) Grain breakage, (C) Tight packing and quartz overgrowth (marked by arrowhead), (D) Stylolites, (E) Tangential (T.C) and concavo-convex contacts (C.C.C), (F) Suture contact (S.C), (G) Long contact (L.C), and (H) Fracture within the clayey zone of the sandstone.

4.2. Diagenesis of sandstone of the Mughal Kot Formation

The sandstone of the Mughal Kot Formation exhibit reservoir heterogeneity based on the diagenetic features and overall rock fabric. The sandstones are modified by mechanical compaction, cementation (quartz overgrowth, calcite, dolomite and iron minerals).Glauconite is also present.

4.2.1. Micritization

In sandstones of the Mughal Kot Formation, certain allochems are also incorporated which are micritized. The intensity of micritization varies from micrite envelopes to complete micritization of allochems (Fig. 4A and 4B).

4.2.2. Cementation and dolomitization

The sandstones of the Mughal Kot Formation are cemented by variety of cements such as calcite (Fig. 4F), dolomite (Fig. 4C), quartz overgrowth (Fig. 4G) and iron minerals cementation. The sandstones of the Mughal Kot Formation are dolomitized in different forms. The dolomite is present as cement (Fig. 4C). In some cases, dolomitization is restricted to allochems (Fig. 4D and 4E).

4.2.3. Compaction

The sandstones of the Mughal Kot Formation are compacted physically and chemically. The compaction is evident by the penetration of quartz grains into the fossils (Fig. 5A). The physical/mechanical compaction is evident by the brittle discontinuities in some of the quartz grains (Fig. 5B). Such discontinuity is called as Grain fracture (Shanmugam, 1985). According to Shanmugam (1985), grain fracture is formed by overburden stresses and tectonic origin for such fractures is not uncommon. Tight packed sandstone is also noticed implying the impression of compaction (Fig. 5C). Chemical compaction is present in the form of stylolites, however, lengths of stylolites are very limited (Fig. 5D). There is difference in the strength of components of rocks i.e. grains and matrix and hence the compaction caused by overburden pressure is limited to certain specified zones within the rock.

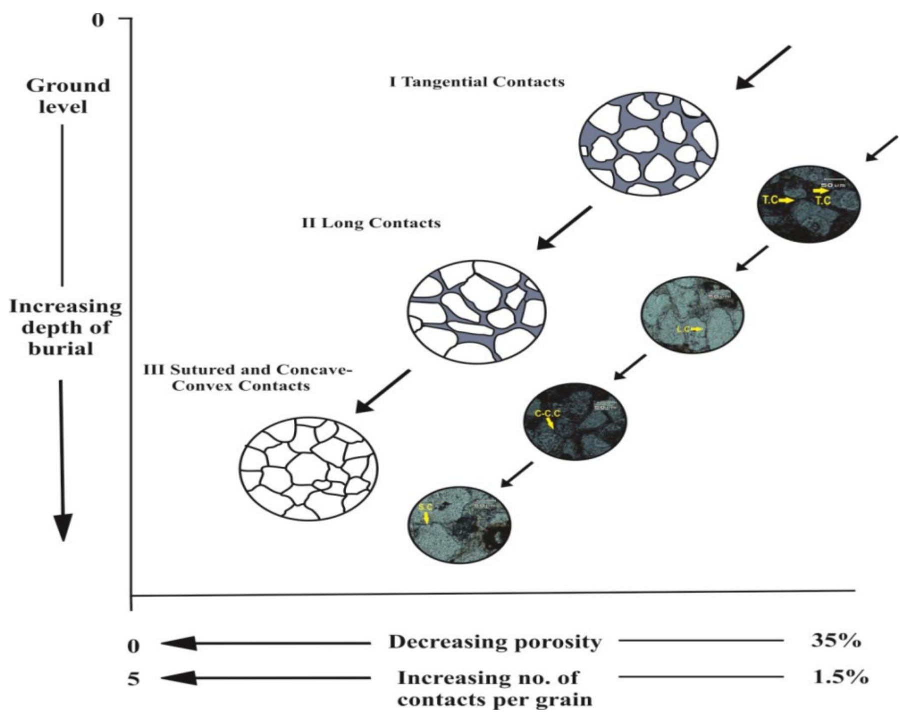


Fig. 6. The destruction of porosity in sandstones with increasing depth (modified after Selley, 2000). Grains contacts in sandstones of the Mughal Kot Formation. T.C for tangential contact; L.C for long contact; C-C.C for concavo-convex contact and S.C for sutured contact.

4.2.4. Grain Contacts in sandstones (Fig. 6)

There are different types of contacts i.e. tangential, sutured, long and concavo-convex contact in sandstone (Selley, 2000). These contacts reflect the loss of porosity with increasing depth of burial and compaction. Such contacts are marked within the sandstone of the Mughal Kot Formation negatively affecting the reservoir potential (Fig. 5E-5G).

4.2.5. Micro-Fractures

The sandstones of the Mughal Kot Formation are fractured but the fractures are very narrow and occluded by cements (Fig. 5H). The fractures are concentrated in fine grained clayey zones of sandstone. According to Shanmugam (1985), "fractures that cut through several grains is called as rock fracture; they are caused by tectonic stresses". In this connection, it is imperative to call fractures noticed in the Mughal Kot Formation as rock fractures.

5) Discussion

5.1. Diagenetic environments

The Mughal Kot Formation shows modification of carbonates and sandstone in four different diagenetic environments/settings i.e. marine phreatic, mixed marine-meteoric, burial and meteoric (Fig. 7). The micritization of rock unit occurred in the marine phreatic settings. Micritization of sediments may occur by endolithic algal borings (Bathurst, 1966; Fig. 7). The dolomitization may take at the mixing of marine and fresh water whereby the water is oversaturated with respect to dolomite and calcite concentration is very low (Badiozamani, 1973; Fig. 7). Similarly the meteoric phreatic environment is represented by neomorphism, cementation and dissolution. The dissolution activities may form soon after the deposition or later on when limestone is uplifted (Tucker and Wright, 1990). The sluggish water (supersaturated with respect to calcium carbonate) of meteoric conditions causes aggrading neomorphism (Heckel, 1983; Fig. 7).

The compaction (both mechanical and chemical) likely to occur in burial diagenetic environment. The carbonates of the Mughal Kot Formation are believed to have experienced shallow and deep burial due to the mechanical compaction (grain to grain suture contact) and the chemical compaction (stylolites). However, scale of compaction is very restricted (Fig. 7).

5.2. Paragenetic sequence of diagenetic processes

5.2.1. Carbonates paragenetic sequence

Based on detailed petrographic studies, the carbonates of the Mughal Kot Formation indicates modifications in four main diagenetic environments. The elementary diagenetic environment is marine environment. After marine diagenesis, dolomitization occurred in marine-meteoric mixing conditions. It is then followed by meteoric diagenesis leading to neomorphism and cementation. At last the Mughal Kot carbonates have undergone burial settings. The paragenetic sequence of different diagenetic stages is shown in table 1.

5.2.2. Clastic rocks paragenetic sequence

The sandstones of the Mughal Kot Formation have experienced early and late diagenesis. During early diagenesis, micritization of allochems and compaction prevailed and then followed by cementation (i.e. quartz overgrowth, calcite, dolomite and iron minerals cements). The paragenetic sequence of different diagenetic stages is shown in table 2.

5.3. Diagenetic controls on reservoir quality

The diagenetic alteration in Mughal Kot Formation has caused modification in their reservoir quality. In carbonates of the Mughal Kot Formation, dolomitization, dissolution and fracturing are such phenomenon enhancing the reservoir quality; however, the dolomitization is dominant with very minor later features. The reservoir quality can be enhanced by dolomitization (by creating intercrystalline porosity). The calcite to dolomite conversion increases the porosity by 13% which is very good for the storage of petroleum (Chilingar and Terry, 1964). In case of Mughal Kot Formation, negligible intercrystalline porosity has been generated by dolomitization, thereby not positively affecting the reservoir property. Also dolomitization is restricted merely to the allochems and at certain spots. In addition, dissolution is negligible in carbonates and clastics of the Mughal Kot Formation. Similarly, the Mughal Kot Formation is fractured; however, all of the fractures are occupied by calcitic cements thereby affecting the reservoir quality unconstructively. Although, the microfractures are the alleyways which can aid in fluids flow and can append to the porosity/permeability the Mughal Kot Formation, provided they are opened by tectonic stresses (Fig. 3H-3J and Fig. 5H).

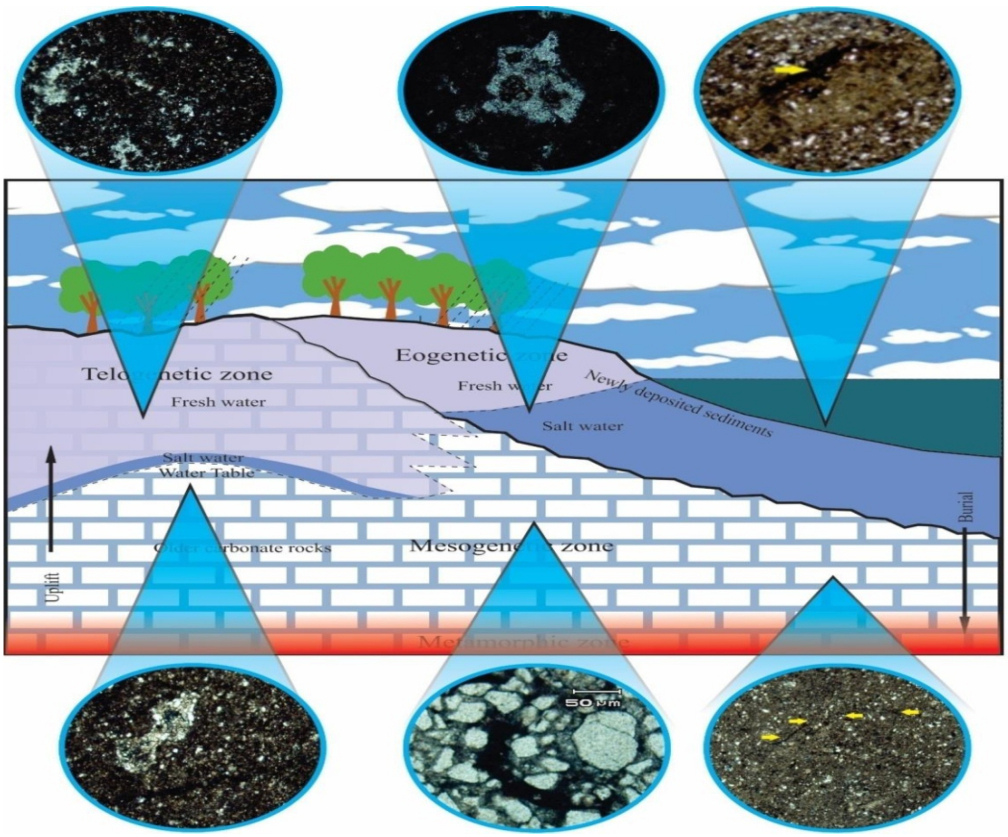
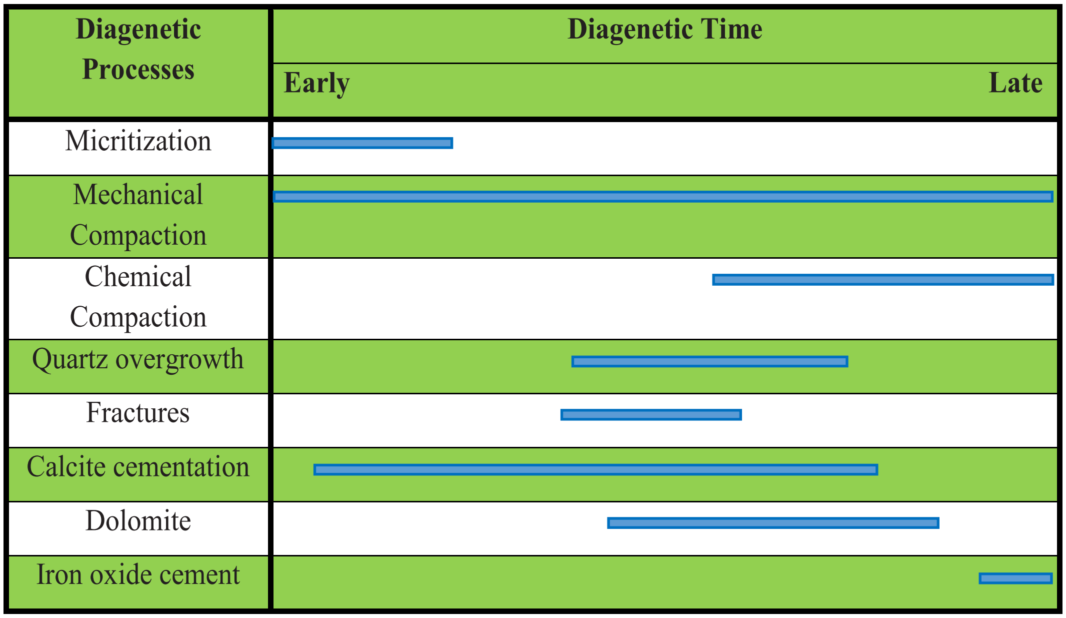


Fig. 7. Diagenetic regimes with their respective diagenetic features noticed in carbonates of the Mughal Kot Formation (modified after Mazzullo, 2004).

Table 1. Paragenetic sequence of diagenetic processes of the Mughal Kot Formation carbonates.

Diagenetic Processes	Diagenetic Time	
	Early	Late
Micritization		
Dolomitization		
Dissolution		
Neomorphism		
Cementation		
Mechanical Compaction		
Chemical Compaction		
Fracturing		

Table 2. Paragenetic sequence of diagenetic processes of the Mughal Kot Formation sandstones.



6. Conclusions

- Both carbonates and clastic rocks have been altered by diagenetic processes in respective diagenetic environments.
- The diagenetic processes, noticed in carbonates of the Mughal Kot Formation, includes micritization, dolomitization, iron cementation, cementation (isopach), mechanical compaction, chemical compaction (stylolitization) and fracturing (but most are filled).
- The diagenetic settings of the carbonates include marine, mixed marine-meteoric, meteoric and burial diagenetic settings. Micritization occurred in marine, dolomitization took place in mixed marine-meteoric while neomorphism and cementation occurred in meteoric conditions. Likewise, compaction occurred in the burial diagenetic settings.
- The sandstone of the Mughal Kot Formation exhibit reservoir heterogeneity based on the diagenetic features and overall rock fabric.
- The sandstones are modified by mechanical compaction, cementation (quartz overgrowth, calcite, dolomite and iron minerals).
- Based on the present study, carbonates and clastics of the Mughal Kot Formation are interpreted as poor quality reservoir rocks.

Acknowledgement

The authors are thankful to Department of Geology, University of Peshawar for providing the facilities of petrographic studies.

Author's Contribution

Bilal Wadood, proposed the main concept and involved in write up and geological field work. He also finalized the figures, plates and final draft of manuscript. Muhammad Awais was involved in write up, microscopic studies and interpretation of diagenetic processes. He also assisted in preparation of figures and tables. Suleman Khan supervised the geological field work, collected field data and helped in the finalization of manuscript. He also did technical review before submission. Sajjad Ahmad and Laeiq Ahmad did provision of relevant literature, review and proof read of the manuscript. Muhammad Muslim, helped in geological field work and also collected field data.

References

Anwar, A., Fatmi, A., Hyderi, I., 1991. Revised nomenclature and stratigraphy of Ferozabad, Alozai and Mona Jhal Groups of Balochistan (Axial Belt), Pakistan. Acta Minerologica Pakistanica, 5, 46-61.

Awais, M., Hanif, M., Khan, M. Y., Jan, I. U., Ishaq, M., 2018. Relating petrophysical parameters to petrographic interpretations in carbonates of the Chorgali Formation, Potwar Plateau, Pakistan. Carbonates and Evaporites. Pp 1-15. DOI: 10.1007/s13146-017-0414-x)

Badiozamani, K., 1973. The Dorag dolomitization model--application to the Middle Ordovician of Wisconsin. Journal of Sedimentary Research, 43(4).

Bathurst, R., 1966. Boring algae, micrite envelopes and lithification of molluscan biosparites. Geological Journal, 5(1), 15-32.

Chilingar, G. V., Terry, R., 1954. Relationship between porosity and chemical composition of carbonate rocks. Petroleum Engineer, 26(10), B53-B54.

Dorreen, J., 1974. The western Gaj river section, Pakistan, and the Cretaceous-Tertiary boundary. Micropaleontology, 178-193.

Flügel, E., 2004. Microfacies Data: Fabrics Microfacies of Carbonate Rocks. Springer, 177-242

Haq, B.S., Davis, M.D., 2010. Oblique convergence and the lobate mountain belts of western Pakistan. The Geological society of America.

Hassan, H. M., 2007. Stylolite effect on geochemistry, porosity and permeability: comparison between a limestone and a dolomite sample from Khuff-B reservoir in Eastern Saudi Arabia. Arabian Journal for Science and Engineering, Section B: Engineering 32(2A), 139-148

Heckel, P. H., 1982. Diagenetic Model for Carbonate Rocks in Mid-Continent Pennsylvanian Eustatic Cyclothems. AAPG Bulletin, 66(5), 580-580.

Hedley, R., Warburton, J., Smewing, J., 2001. Sequence stratigraphy and tectonics in the Kirthar Fold Belt, Pakistan. Geology and climate of the Arabian Sea region.

Kazmi, A. H., Rana, R. A., 1982. Tectonic map of Pakistan, scale 1:2000000, 1st edition, Geological Survey of Pakistan, Quetta.

Khan, A., Kelling, G., Umar, M., Kassi, A., 2002. Depositional environments and reservoir assessment of Late Cretaceous sandstones in the south central Kirthar foldbelt, Pakistan. Journal of Petroleum Geology, 25(4), 373-406.

Khan, S., Wadood, B., Ahmed, S., Khan, A., Ahmed, F., Khan, H., 2017. Evaluating paleoceanographic and planktonic foraminiferal diversification from the Cretaceous Mughal Kot Formation, Mughal Kot Section, Lower Indus Basin, Pakistan. Journal of Himalayan Earth Science, 50(2).

Krenmayr, H. G., 1996. Hemipelagic and turbiditic mudstone facies associations in the Upper Cretaceous Gosau Group of the Northern Calcareous Alps (Austria). Sedimentary Geology, 101(3-4), 149-172.

La Touche, T. D., 1893. Geology of the Sherani Hills. Indian Geological Survey Recordings, 26 (3), 77-96.

Loucks, R. G., Reed, R. M., Ruppel, S. C., Hammes, U., 2012. Spectrum of pore types and networks in mudrocks and a descriptive classification for matrix-related mudrock pores. American Association of Petroleum Geologist, bulletin, 96(6), 1071-1098.

Malkani, M. S., 2010. Updated stratigraphy and Mineral Potential of Sulaiman Basin, Pakistan. Sindh University Research Journal-SURJ (Science Series), 42(2).

Marks, P., 1962. Variation and Evolution in Orbitoides from the Cretaceous of Rakhi Nala, West Pakistan. Geol. Bull. Punjab Univ, 2, 15-29.

Mazzullo, S., 2004. Overview of porosity evolution in carbonate reservoirs. Kansas Geological Society Bulletin, 79(1/2), 20-28.

Motyka, J., 1998. A conceptual model of hydraulic networks in carbonate rocks, illustrated by examples from Poland. Hydrogeology Journal, 6(4), 469-482.

Pettingill, H. S., Weimer, P., 2002. Worlwide deepwater exploration and production: Past, present, and future. The Leading Edge, 21(4), 371-376.

Selley, R. C., 2000. Applied Sedimentology. Second edition, 368: Academic Press.

Shah, S., 1977. Stratigraphy of Pakistan: Geological Survey of Pakistan Memoir, 12.

Shah, S.M.I., 2009. Stratigraphy of Pakistan. Memoir of the Geological Survey of Pakistan, 22, 1-381.

Shanmugam, G., 1985. Types of porosity in sandstones and their significance in interpreting provenance Provenance of arenites, Springer, 115-137

Smewing, J. D., Warburton, J., Daley, T., Copestake, P., Ul-Haq, N., 2002. Sequence stratigraphy of the southern Kirthar fold belt and middle Indus basin, Pakistan. Geological Society, London, Special Publications, 195(1), 273-299.

Stow, D., 1994. Deep sea processes of sediment transport and deposition. Sediment transport and depositional processes, 257-291.

Taghavi, A. A., Mørk, A., Emadi, M. A., 2006. Sequence stratigraphically controlled diagenesis governs reservoir quality in the carbonate Dehluran Field, southwest Iran. Petroleum Geoscience, 12(2), 115-126.

Tucker, M. E., Wright, V. P., 2009. Carbonate sedimentology: John Wiley & Sons.

Umar, M., Friis, H., Khan, A. S., Kassi, A. M., Kasi, A. K., 2011. The effects of diagenesis on the reservoir characters in sandstones of the Late Cretaceous Pab Formation, Kirthar Fold Belt, southern Pakistan. Journal of Asian Earth Sciences, 40(2), 622-635.

Williams, M. D., 1959. Stratigraphy of the Lower Indus Basin, West Pakistan. Paper presented at the 5th World Petroleum Congress.

Wilson, M.D., Stanton, P.T., 1994. Diagenetic mechanisms of porosity and permeability reduction and enhancement.