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Microfacies analysis and reservoir characters of eocene carbonates of Khair-i-Murat Range, Northern Potwar Deformed Zone (NPDZ), Sub-Himalayas, Pakistan

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Key words: Microfacies, Eocene, Potwar, foraminifera, Tethyan Ocean.

Abstract

Khair-i-Murat Range is a fundamental part of Northern Potwar Deformed Zone (NPDZ), Sub-Himalayas. The geological investigations were carried out to understand the stratigraphy, sedimentology and tectonics of the area. The surface geology of the area is comprised of early Eocene to recent rock units. Eocene rocks namely; Margalla Hill Limestone, Chorgali Formation and Kuldana Formation are exposed along the Khair-i-Murat reverse fault. The petrographic study of Eocene carbonates of Chorgali Formation and Margalla Hill Limestone shows microfacies of various types. The Margalla Hill Limestone comprised of dolomitic, fossiliferous, nodular and fractured packstone to wackestone facies. The Chorgali Formation is dominated by sparsely fossiliferous, dolomitized and micritic limestone. The important microfacies of these carbonates are biomicrite, containing a variety of benthonic forams including different species of Assilina, Nummulities, Alveolina, Milliolids, Soritids and Textularia. The other common microfacies is dolomite. Cementation and supplementary alterations within the carbonate of these formations indicate that these are of early diagenetic origin. The major factor responsible for the development of secondary porosity and permeability in carbonate rocks was the fractures caused by intense structural deformation and development of thrust faults in Khair-i-Murat area. The presence of Eocene benthonic foraminiferal assemblages and dolomitization in the carbonate sequence of Margalla Hill Limestone and Chorgali Formation show the shallow marine, open shelf and intertidal to supratidal environments of deposition. The Early Eocene Margalla Hill Limestone, Chorgali Formation and Middle Eocene Kuldana Formation also indicate different transgression and regression periods of the Tethyan Ocean.

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Introduction

The Khair-i-Murat area is the part of Potwar foreland sub-basin, which is formed by tectonic compression at the northern margin of Indian Plate (Gansser *et al*, 1964: Fig. 1). In Middle to Late Eocene, the uplifting of Himalayan Ranges began due to continent-continent collision (Molnar and Tapponnier, 1975) and collision between the Indian-Eurasian plates cause structural deformation. Structurally, Potwar sub-basin is bounded by Margalla Hills in the north, left lateral Jhelum fault to the east, the Salt Range Thrust to the south and right lateral Kalabagh fault in the west (McDougall and Khan, 1990; Kazmi and Rana, 1982). The rocks of Potwar sub-basin represent thin-skinned compressional deformation. The cover sequence is deformed on the basal decollement of Salt Range Formation (Lillie *et al.,* 1987). The Khair-i - Murat area lies in Northern Potwar Deformed Zone (Jaswal, 1990), and formations exposed in the area are entirely sedimentary in nature. These include Margalla Hill Limestone, Chorgali Formation, Kuldana Formation, Kamlial Formation and Murree Formation. In these formations Margalla Hill Limestone and Chorgali Formation are fossiliferous and contain wide variety of foraminifers. In Khair-i-Murat Range, the carbonates of Chorgali Formation and Margalla Hill Limestone are exposed in the central part of the Khair-i-Murat anticline at Chorgali Pass (Fig. 2). On the basis of accessibility and continuity of exposure, a complete sequence of rocks along the northern limb of Khair-i-Murat anticline was selected for detailed petrographic studies. Chorgali pass is the type locality of Chorgali Formation. According to petrographic studies, the carbonate rocks are mainly composed of micrite, allochems and sparry calcite. Rock types are classified and these rock types are considered as microfacies. Initially Brown (1943) suggested the term microfacies and has been defined as "the total of all the paleontological and sediment logical criteria which can be classified in thin sections, peels and polished slabs". This study is carried out to determine the microfacies and reservoir characteristics of Eocene carbonates (Margalla Hill Limestone, Chorgali Formation) of Khair-i-Murat Range, Northern Potwar Deformed Zone (NPDZ), Sub-Himalayas, Pakistan.

Materials and methods

Field work

The field work was arranged along the northern limb of Khair-i-Murat anticline to collect the samples and to study the exposure of various formations.

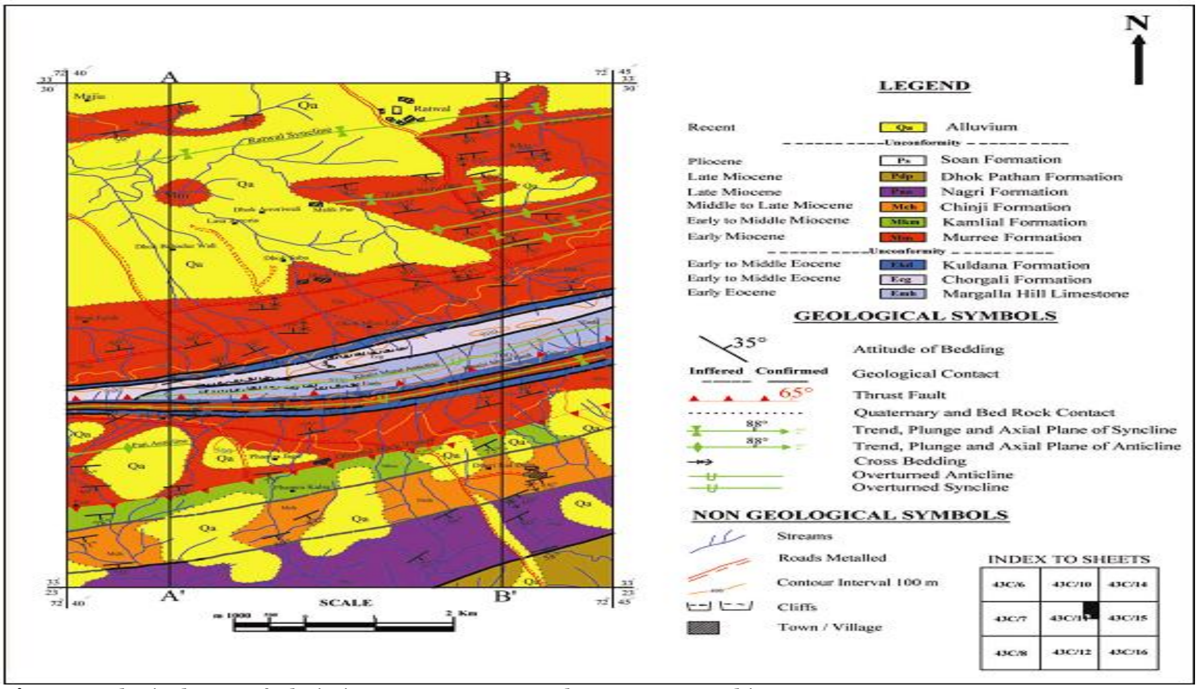

Fig. 1. Geological map of Khair-i -Murat Range, Northern Potwar, Pakistan.

The selected section was measured with the help of tape-compass method and all field features were plotted on the litholog. Various samples of Margalla Hill Limestone and Chorgali Formation were collected for subsequent laboratory study and thin sections of limestone were prepared for detailed petrographic study.

Laboratory work

Thin sections of collected samples were prepared in laboratory to conduct petrographic study by using polarizing microscope. The microphotographs were taken at preferred locations from thin sections by digital camera.

Results and discussion

Margalla Hill Limestone

In Khair-i-Murat area, Margalla Hill Limestone is dominantly grey to dark grey on fresh surfaces while grey to whitish grey on weathered surfaces.

The rock is hard and nodular (Fig. 2). Limestone is medium to thick bedded and fossiliferous. The fossils range in size from 2mm to 41 mm. The rocks of this section are highly jointed, fractured and these fractures are filled by quartz veins and calcite.

Table 1. Modal percentage composition of Margalla Hill Limestone (visual estimate).

Sr. No	Sample No.	Fossils (Bioclasts)	Micrite	Spar	Dolospar	Calcite	Peloids	Intra-clasts	Porosity	Classification	
										Dunham's (1962)	Folk's (1962)
1	DD_{12}	--	35	--	50	10	--	05	--	Mudstone	Dolomicritic Limestone
2	C_{17}	--	25	--	55	10	05	05	--	Mudstone	Dolomicritic Limestone
3	C_{17a}	05	30	--	50	10	--	05	--	Mudstone	Dolomicritic Limestone
4	C_{19}	30	45	--	05	05	--	10	05	Wackestone	Biomicrite
5	Cg	65	20	--	--	10	--	--	05	Packstone	Biomicrite

Petrologic nature

The Margalla Hill Limestone is a benthonic foraminiferal packstone to wackestone. The bio debris is mixed with common *Assilina sp., Nummulites sp., Alveolina sp., Soritida sp.*, sparsely distributed, small *Milliolids* and *Ostracodes* (Kamran *et al.,* 2006). In some thin sections medium size rhombohedral crystals of dolomite occurs showing pervasive dolomitization.

Table 2. Modal percentage composition of Chorgali Formation (Visual estimate).

Sr. No.	Sample No.	Fossils (Bioclasts)	Micrite	Spar	Dolospar	Calcite	Peloids	Intra-clasts	Terri- geneious	Porosity	Classification	
											Dunham's (1962)	Folk's (1962)
1	Pc_4	02	50	10	--	05	20	--	05	08	Wackestone	*Pel bio-micrite*
2	Pd_5	01	55	05	--	05	10	09	05	05	Wackestone	*Pel bio-micrite*
3	Pd_7	05	20	05	05	35	20	05	--	05	Wackestone	*Pel bio-micrite*
4	CG_6	01	40	--	--	20	10	--	04	25	Wackestone	*Pel bio-micrite*
5	Pd_2	01	55	05	--	05	10	09	05	05	Wackestone	*Pel bio-micrite*
6	C_8	--	05	25	40	10	--	05	10	05	Wackestone	*Dolomitic Limestone*
7	Cg_4	03	40	10	25	05	05	02	05	05	Wackestone	*Dolomitic Limestone*
8	CG_{1a}	40	30	--	05	15	--	--	04	10	Wackestone	*Biomicrite*
9	C_{12}	25	30	--	15	05	--	05	10	10	Wackestone	*Biomicrite*
10	CG_{2a}	30	45	--	05	10	--	--	03	07	Wackestone	*Biomicrite*
11	Cg_2	10	60	--	15	05	--	03	05	02	Wackestone	*Biomicrite*
12	Pd_8	01	18	05	25	05	25	05	01	15	Wackestone	*Pel-sparite*
13	Pfc_5	--	45	--	--	40	--	--	05	10	Mudstone	*Micritic Limestone*
14	PC_{11}	--	50	--	--	35	--	--	05	10	Mudstone	*Micritic Limestone*
15	Pc_{13}	02	35	05	--	45	05	--	03	05	Mudstone	*Pel bio-micrite*
16	DM_1	--	60	06	--	20	05	--	05	05	Mudstone	*Pel micrite*
17	Cg_1	--	--	10	70	05	--	--	10	05	Mudstone	*Dolomitic Limestone*
18	C_{15}	02	--	10	80	03	--	--	03	02	Mudstone	*Dolomitic Limestone*

The petrographic study delineates three microfacies in Margalla Hill Limestone at Chorgali Pass (Table 1) which are briefly described below:

Mudstone-dolomicritic limestone facies: The samples DD_{12} and C_{17a} are classified as dolomicritic limestone facies (Table 1). The micrite forms the ground mass and ranges from 25-35%. The dolospar is about 50-55%. The dolospar occurs as anhedral-rhomb shaped crystals. Microfractures are also present, which are both calcite filled and quartz filled. The calcite is about 10%. Some bioclasts are also observed (sample no $C_{17\text{-}a}$), which are less than 5% (Fig. 4.1 and 4.2).

Wackestone-biomicrite facies:

The sample C_{19} is classified as wackestone-biomicrite facies (Table 1). The ground mass is mainly micrite (about 45%). The bioclasts are partly fragmented and are about 30% of the rock. The microspar is not very common and is up to 5%.

Fig. 2. Photograph showing folded beds of Margalla Hill Limestone at Chorgali Pass, Potwar Basin.

The calcite is mainly present in the form of well-calcified veins and patches and makes about 5% of the rock (Fig. 4.3).

Packstone-biomicrite facies

The sample Cg is classified as packstone-biomicrite facies (Table 1). The micrite is about 20%. The well preserved bioclasts are about 65% and mainly consists of *Assilina sp., Nummulites sp.* and*, Alveolina sp.* (Fig. 4.4). Both filled and open fractures are present in this microfacies. The calcite filled microfractures make up 10%. Moldic and fracture porosity is present and is about 5% of the rock (Fig. 4.5).

Diagenesis

The digenetic history may be described in the light of compaction, cementation and replacement of the constituents of the rock unit. There are not much imprints of compaction in Margalla Hill Limestone.

It is evident from petrographic study that the bioclasts are mostly intact. However, in some cases the fracture porosity may be attributed to the post-tectonic stresses. Mostly the post consolidation pressure solution including stylolite seams and calcite veins cut across the cement. The stylolite seams occur with clay and hematite.

This implies several episodes of diagenesis. The well-calcified veins cut across one another as well as the other allochems. These calcite veins at places have undergone micritization, which indicates numerous diagenetic processes.

The zoned and euhedral rhombs of dolomite are also present. The zoned dolomite rhombs have micrite core. This implies that the dolomite is mainly neomorphic in origin.

Fig. 3. Photograph showing weathered limestone beds of Chorgali Formation, Chorgali Pass, Potwar Basin.

The cement is mainly composed of micrite. The micrite sometimes seems to be clayey. This may be due to the presence of shale and marl in Margalla Hill Limestone.

In Margalla Hill Limestone the replacement is not well evident. Most likely the replacement commenced in terms of pressure solution and dolomitization.

Porosity

Margalla Hill Limestone display several types of porosity including moldic, vuggy and fracture porosity. Moldic pore types are either open or filled with calcite and authigenic silica.

Fracture and microfracture pores are common in some thin sections, but these are generally filled by anhydrite or dolomite cement (Fig. 4.2).

Fig. 4. Photomicrographs of the carbonates of Margalla Hill Limestone and Chorgali Formation.

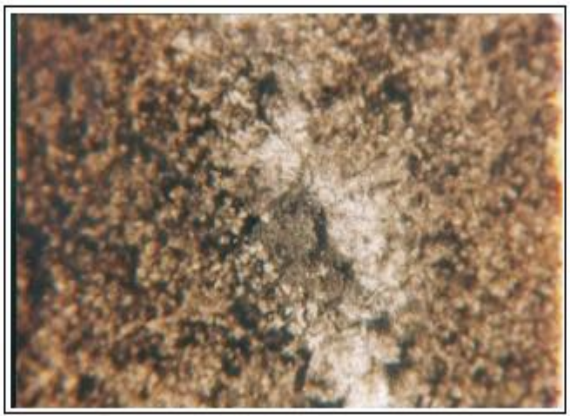

Fig. 4. 1. Photomicrograph of Mudstone-dolomicritic unit of Margalla Hill Limestone (Sample No. C_{17}) showing dolospar and filled pore spaces (Cross Nicol. x10).

Chorgali formation

The chorgali formation mainly consists of dolomitic limestone and shale. The limestone at the base is brownish grey, dolomitic, thin bedded and highly fractured (Fig. 3).

The shale form upper part of the formation and is greenish, yellowish and blackish in color. This shale is soft and calcareous, interbedded with yellowish and greyish limestone.

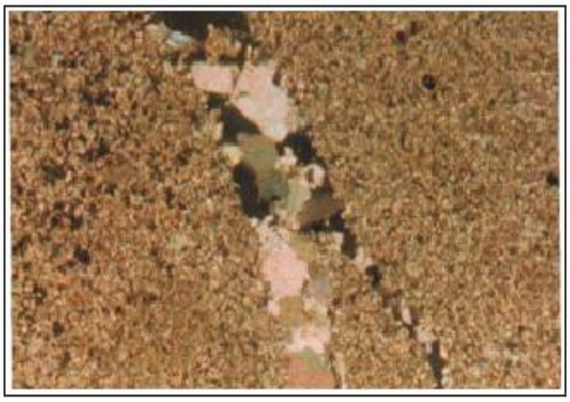

Fig. 4. 2. Photomicrograph of Mudstone-dolomicritic unit of Margalla Hill Limestone (Sample No. C_{17a}) showing neomorphic dolomitic rhombs with micro fractures filled with quartz (Cross Nicol. x4).

Fig. 4. 3. Photomicrograph of Wackestone-biomicrite unit of Margalla Hill Limestone (Sample No. C_{19}) showing *Assilina sp.* and *Nummulites sp.* in micrite cement (PPL. x2.5).

Petrological nature

The Chorgali Formation is dominantly of dolomitized micrite composition carbonates with varying amounts of bioclasts and intraclasts. In order to study the composition of Chorgali Formation, thirty rock samples were collected. Twenty rock samples were thin sectioned for detailed petrographic analysis (Table 2). The petrographic study delineates the two major microfacies (Dunham, 1962) and seven sub-microfacies (Folk, 1962) in Chorgali Formation. These microfacies are briefly described below:

Fig. 4. 4. Photomicrograph of Packstone-biomicrite unit of Margalla Hill Limestone (Sample No. Cg) showing Equatorial section and meridian section of *Nummulites mamilatus* (Cross Nicol. x4).

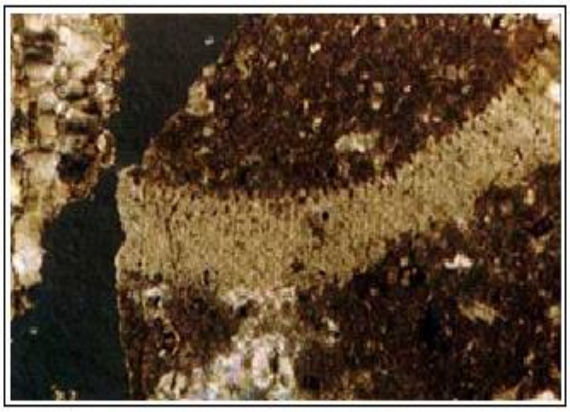

Fig. 4. 5. Photomicrograph of Packstone-biomicrite unit of Margalla Hill Limestone (Sample No. Cg) showing open fracture and calcite filled fracture. Note the cleavage traces of calcite, which is an example of neomorphism. (Cross Nicol. x4).

Wackestone (Pel-bio-micrite, Dolomitic, Biomicrite, and Pel-sparite) Facies: The limestone of Chorgali Formation mainly consists of wackestone facies in which groundmass is mainly micrite, sparite or dolospar and allochems (bioclasts, peloids) are more than 10%. Micrite occurs as matrix in allochems bearing limestone. Spar is carbonate cement and crystals of sparite are coarser than micrite. Due to neomorphism various diagenetic processes of recrystallizaton and replacement, including changes in mineralogy are common in limestone of Chorgali Formation. Due to these processes the crystals of spar developed dolomitic rhombs known as dolospar.

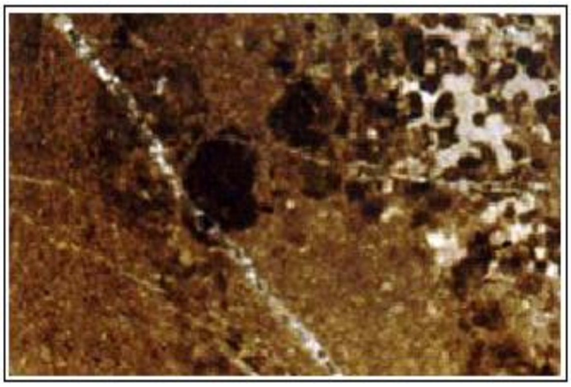

Fig. 4. 6. Photomicrograph of Wackestone Pel-biomicrite unit of Chorgali Formation (Sample No. Pc_4) showing pellets and micro fractures filled with silica/calcite (Cross Nicol. x4).

The dolospar present in this microfacies act as cement. Micritic allochemical limestone and sparry allochemical limestones are subdivided by Folk (1962) on the basis of type and proportion of allochems and given composite names. On the basis of allochems, the wackestone of Chorgali Formation is subdivided into following facies according to the Folk's, (1962) classification.

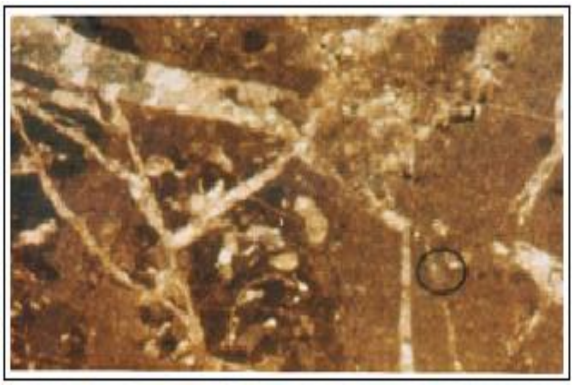

Fig. 4. 7. Photomicrograph of Wackestone Pel-biomicrite unit of Chorgali Formation (Sample No. Pd_7) showing micro fractures filled with silica/calcite (Cross Nicol. x4).

Pel-bio-micrite

The samples Pc_4, Pd_5, Pd_7 and CG_6 are recognized as Pel-bio micrite facies according to Folk's (1962) classification (Table 2). This microfacies is defined as the carbonate rock type containing pellets 10-20%, bioclasts 1-5% and micrite 20-55%. Bioclasts are mostly represented by fossil fragments of foraminifers. Pellets are rounded, spherical to elliptical and devoid of any internal structure and indicate faecal origin. Prominent lamination is also observed in one rock sample (Pc_4) of this microfacies. These laminas probably represent sediments deposited by tidal currents (Fig. 4.6 & 4.7).

Fig. 4. 8. Photomicrograph of Wackestone dolomitic unit of Chorgali Formation (Sample No. Pd_2) showing calcite crystals, some pellets and dolospar crystals at upper right (Cross Nicol. x4).

Dolomitic Facies

The samples Pd_2, C_8 and Cg_4 of Chorgali Formation are recognized as dolomitic facies. Dolomite occurs as a fabric or mosaic of crystal forms and is produced due to the replacement of preexisting calcite.

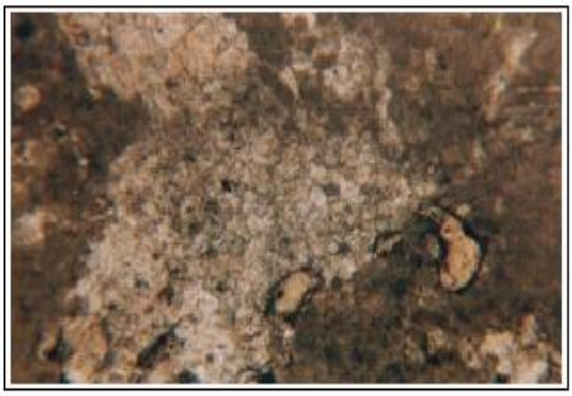

Fig. 4. 9. Photomicrograph of Wackestone dolomitic unit of Chorgali Formation (Sample No. C_8) showing pores filled by dolomite. (PPL. x10).

The shapes of dolomite crystals vary from anhedral to euhedral rhombs. Most of the dolomite crystals have light brown cloudy centers with clear rims. The process of dolomitization has completely destroyed the fabric information of the precursor sediments (Fig. 4.8 & 4.9).

Biomicrite

Four rock samples (CG_{1-a}, C_{12}, CG_{2a} and Cg_2) of Chorgali limestone are recognized as biomicrite facies (Table 2). This facies is the most abundant microfacies of Chorgali limestone and contain 10-40% fossils of shallow marine benthonic environment in micrite cement (30-60%). Many recognizable foraminifers are present in this microfacies including *Nummulities sp., Assilina sp., Milliolids sp., Soritids sp., Alveolina sp.* Clasts of Ostracodes, Pelecypods and Gastropods are also present having different shapes like elongated, lenticular and rounded (Fig. 4.10, 4.11 & 4.12). In some thin sections, bioclasts are represented by molds, filled by sparry calcite or authigenic silica.

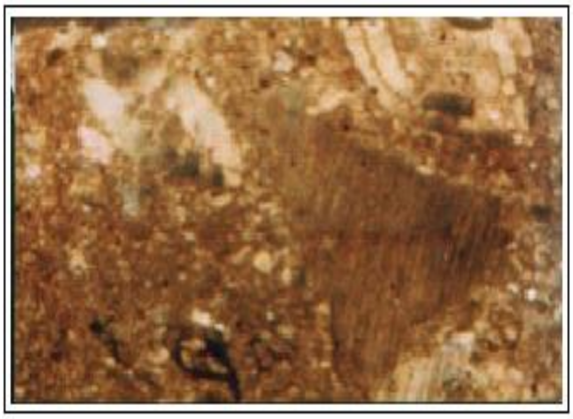

Fig. 4. 10. Photomicrograph of Wackestone-biomicrite unit of Chorgali Formation (Sample No. CG_{1-a}) showing calcite crystals and bioclasts of Nummulities embedded in micrite cement (Cross Nicol. x4).

*Pel-sparite***:** Sample Pd_8 is recognized as Pel-sparite facies. This facies consists of 25% pellets, 30% spar and 18% micrite. Pellets vary in shape from spherical to elliptical, and have irregular boundaries, indicating recrystallizaton of spar spreading from the cement into the pellets. Spar / dolospar forms as a simple, primary pore filling cement in this microfacies (Fig. 4.13).

Mudstone (Micritic, Pel-micrite, Dolomitic) Facies:

Six samples (Pfc_5, PC_{11}, PC_{13}, DM_1, Cg_1 and C_{15}) are classified as mudstone facies (Table 2). In this type of microfacies allochems are less than 10% and matrix is mud supported i.e probably micrite or spar.

On the basis of allochems, the mudstone facies of Chorgali Formation is subdivided into following sub-facies (Folk's, 1962).

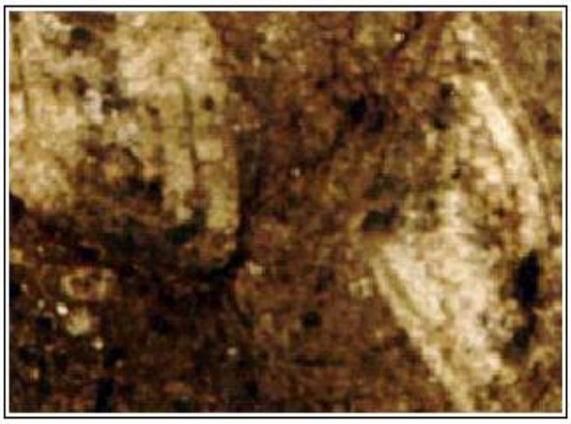

Fig. 4. 11. Photomicrograph of Wackestone biomicrite unit of Chorgali Formation (Sample No. C_{12}) showing *Nummulites sp.* embedded in micrite. (Cross Nicol. x4).

Micritic Limestone

Two samples (Pfc_5 and Pc_{11}) are recognized as micritic limestone (Table 2). This microfacies mainly consists of micrite (45-50%) with less than 1% allochems. The rock is highly fractured and the fractures are filled with sparry calcite (35-40%). A few partially open fractures are also present. Stylolite seams are present.

Fig. 4. 12. Photomicrograph of Wackestone biomicrite unit of Chorgali Formation (Sample No.CG_{1-a}) showing meridian section of *Nummulites mamilatus.*

The stylolite seams and calcite veins cut across the cement. The stylolite seams are highlighted by clay and hematite. This microfacies is almost devoid of bioclasts and exhibit low energy environment (Fig. 4.14 & 4.15).

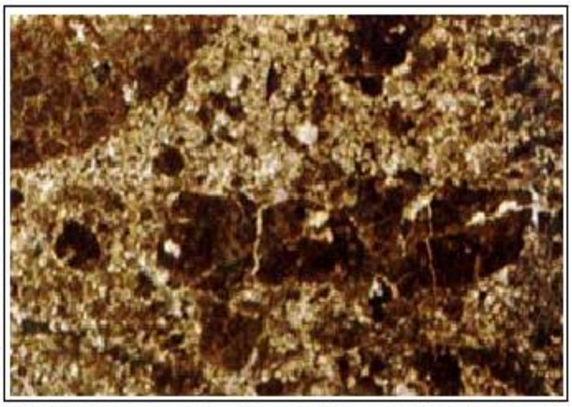

Fig. 4. 13. Photomicrograph of Wackestone-Pel-sparite unit of Chorgali Formation (Sample No. Pd_8) showing varying size of pellets and sparry calcite. (Cross Nicol. x4).

Pel-micrite

Samples Pc_{13} and DM_1 of Chorgali Formation are recognized as Pel-micrite facies. This microfacies in defined as the carbonate rock type containing 35-60% micrite with subordinate pellets (less than 10%) and bioclasts 2%. The rock here is highly fractured due to the presence of Khair-i-Murat fault in the area. The microfractures are well developed and filled with sparry calcite. Some microfractures are filled with authigenic quartz crystals (Fig. 4.16).

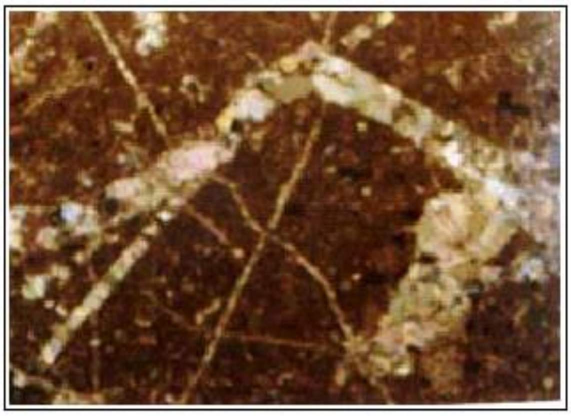

Fig. 4. 14. Photomicrograph of Mudstone-micrite unit of Chorgali Formation (Sample No. Pfc4) showing micro fractures filled by calcite. (Cross Nicol. x4).

Dolomitic limestone

Two samples (Cg_1 and C_{15}) are recognized as dolomitic limestone having 70-80% dolospar crystals. Calcite is present in microfractures and is about 3-5% of the rock.

The dolomite rhombs vary in shape from anhedral to euhedral and also have light brown cloudy centers with rhombs. (Fig. 4.17 & 4.18).

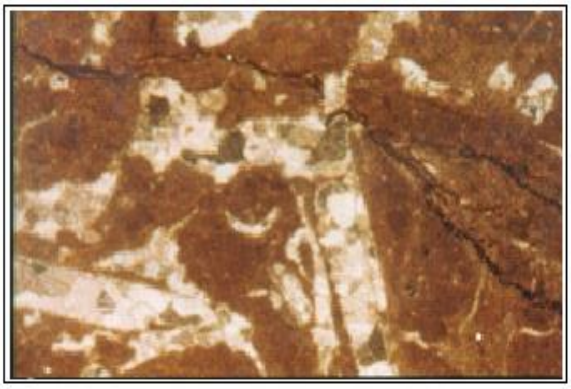

Fig. 4. 15. Photomicrograph of Mudstone-micrite unit of Chorgali Formation (Sample No. Pc11) showing Stylolites veins highlighted by hematite and micro fractures filled by calcite cement (Cross Nicol. x4).

Diagenesis

The diagenetic history of carbonate of Chorgali Formation includes micritization, multiple episodes of cementation, dolomitization, mechanical and chemical compaction (pressure dissolution), recrystallizaton and dissolution.

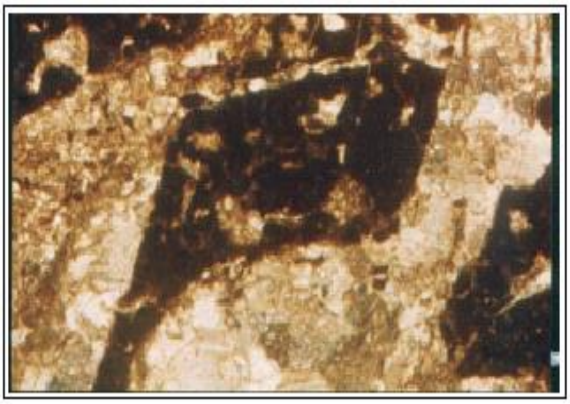

Fig. 4. 16. Photomicrograph of Mudstone-Pel-micrite unit of Chorgali Formation (Sample No. Pc_{13}) showing pellets and fractures filled with dolomite/calcite (Cross Nicol. x4).

These diagenetic processes occurred in the three-principle environment: the marine, near surface meteoric and burial environment. The uplifting phase of the region cause fracturing and other changes related to tectonic. The process of dissolution in chorgali formation is widely observed. Dissolution can leave a variety of distinctive and interesting textures in a limestone. The important dissolution feature is stylolite, which are common in Chorgali Formation. These structures are jagged, irregular seams dividing the limestone into two parts that interpenetrates. Each side of the seam has tooth like projections that fit into the cavities of the opposite side.

Fig. 4. 17. Photomicrograph of Mudstone-dolomitic unit of Chorgali Formation (Sample No. Cg1) showing well developed lamination. (PPL. x10).

These structures are highlighted by a residue of insoluble opaque minerals (such as hematite) or organic matter, which shows that much limestone has been dissolved to leave so many residues behind. Stylolites are formed by pressure solution. When limestone undergo pressure during burial, they first dissolve rather than deform.

The direction of pressure is usually perpendicular to the plane of stylolite. The well-calcified veins cut across one another as well as the other allochems.

In chorgali formation the process of replacement is described in term of pressure solution and dolomitization. In the Chorgali Formation replacement involves the simultaneous dissolution of original material and precipitation of a new mineral while preserving the original form. Many fossils or ooids can be replaced while all the fine details still intact. The process of cementation is very common in Chorgali limestone. Molds, vuggs and fractures filling cements have also been observed in some of the limestone samples (Fig. 4.7 & 4.14).

Fig. 4. 18. Photomicrograph of Mudstone-dolomitic unit of Chorgali Formation (Sample No. C_{15}) showing dolospar and filled pore spaces. (PPL. x10).

Dolomitization is the process by which calcium carbonate rock alters into dolostone. This process obscures the original texture, which makes classification and genetic interpretation difficult. Dolomites of Chorgali Formation can be fabric destructive, fabric retentive or act as cement to fill fractures etc. The impact of compaction in Chorgali Formation is not too much and it is evident by studying the fossils, which are mostly intact.

Porosity and Reservoir Characters

The limestones of Chorgali Formation generally are tight but in thin sections, open pore spaces are also noticed. No preserved primary porosity is seen, however, all the existing open pore spaces are secondary in origin. Out of the major porosity types described by Choquette and Pray, 1970, the Chorgali Formation contains five porosity types: 1) fenestral, 2) moldic, 3) vuggy, 4) intercrystalline and 5) fracture. Moldic pore types are either open or filled with calcite or silica (Fig. 4.7). Fenestral pore spaces are mostly filled with carbonate cement. Vuggy pores are common and filled with dolomite cement (Fig. 4.8).

Inter crystalline pore spaces are filled. However, open intercrystalline pores are also present. Fracture and microfracture pores are common in thin sections of Chorgali Formation, but these are generally filled with dolomite or calcite cement (Fig. 4.14).

Inter crystalline, moldic, vuggy and fracture porosity associated with dolomite form important pore system for a large number of carbonate field worldwide (Roehl and Choquette, 1985). In north-eastern Potwar sub-basin, the Chorgali carbonate act as a best reservoir rock. It is generally characterized by finely crystalline dolomite with locally moderate to high permeability due to the inter-connected pore network of solution cavities, vuggs, fractures and intercrystalline pore spaces.

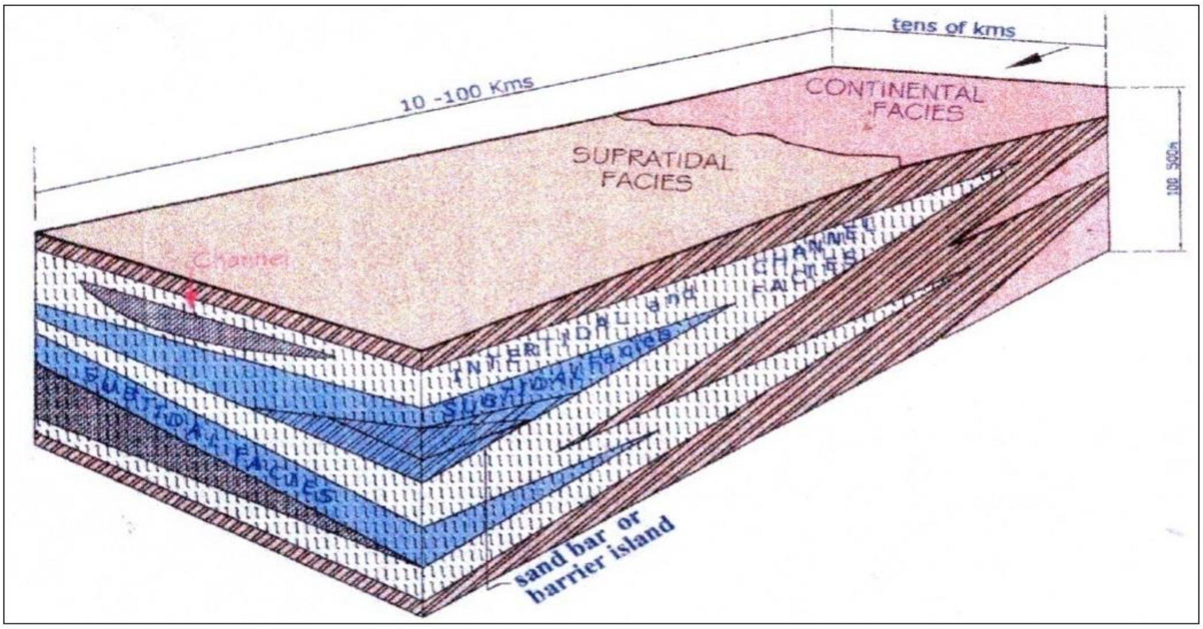

Fig. 5. Idealized tidal flat model for carbonate environment of deposition.

Depositional Environment of Carbonate Rock

Carbonate sediments accumulate in many differing environments including shallow marine to deep marine environment. Shallow marine environment is itself complex and includes tidal and supratidal flats, more extensive shelf and bank areas, marginal reefs and back-reef lagoons. Each environment leaves its own imprint on the textures and structures of the accumulating carbonates.

The brief description of depositional environment of these carbonates on the basis of detailed petrography and field observations is given below.

Margalla Hill Limestone: Petrographic study delineates that the Margalla Hill Limestone is composed of two internal units such as dolomitic limestone unit and biomicrite unit (Table 1). These two units correspond to the different environment of deposition.

The dolomitic limestone unit is composed of anhedral and rhomb-shaped crystals containing micrite core. The inclusion of calcite in the dolomite rhombs is also present. Moreover it is evident that the dolomite postdates the micrite. From these evidences it is quite apparent that the dolomite is secondary and replacive. The biomicrite unit predominantly composed of micrite with benthonic foraminifers. Hence it is evident that the unit was accumulated in a low energy level and shallow areas of open shelf. Thus it may be suggested that the Margalla Hill Limestone was deposited in shallow marine environment. The shift of environment of deposition may be attributed to the uplifting of the area due to tectonic events.

Chorgali Formation

Chorgali Formation mainly consists of dolomite and biomicrite microfacies. These microfacies indicate that the Chorgali Formation was probably accumulated in intertidal to supratidal environment which is a part of prograding Sabkha Complex (Mujtaba, 1999). Tidal flats are areas regularly to rarely cover by water, dominated by currents and wave action. They are developed extensively upon epeiric platforms and they occur along the shorelines of low energy shelves and ramps, typically behind beach barriers and around lagoons (Fig. 5).

Petrographic study shows that Chorgali Formation mainly consists of wackestone and mudstone microfacies. The mudstone represent probably progradation of the terrestrial sediments into the depositional basin during regression. The original mineralogy of the faunal components (benthonic forams) in the Chorgali sub tidal limestones has been prominently high-Mg calcite.

Thus it can be suggested that deposition of Chorgali Formation took place on a shallow, partially restricted, sub tidal to supra tidal, low energy ramp type of setting in a moderately arid climate. Chorgali Formation indicates restricted diversity of fauna including foraminifers and ostracodes. Thin to coarse layers of sub tidal skeletal grains may occur, transported onto the tidal flat by storms. Algal mats and stromatolites are typical of tidal flat deposits, which are present in Chorgali Formation at Chorgali pass.

Conclusion

In northern Pakistan, the Khair-i-Murat range is a part of the active thrust belt and foreland-fold of the Himalayas. The collision of Indian and Eurasian plates causes the development of Potwar sub-basin. The Khair-i-Murat range contains sedimentary rocks of marine and terrestrial origin ranging in age from Eocambrian to recent. The exposed sedimentary rocks consist of Chorgali Formation, Margalla Hill Limestone, Murree Formation, Kuldana Formation of Early Eocene to Miocene age. Carbonates of Chorgali Formation and Margalla Hill Limestone present different types of microfacies and lithofacies. The Margalla Hill Limestone comprised of nodular, dolomitic, fossiliferous and fractured packstone to wackestone rock unit. The Chorgali Formation dominantly consists of shale and limestone. The upper part mostly contains shale, while the lower part is dolomitized, sparsely, fossiliferous and micritic limestone. The carbonate of Margalla Hill Limestone has been classified into two microfacies while that of Chorgali Formation has been classified into seven microfacies on the basis of petrographic studies.

The biomicrite microfacies is the most abundant rock type, which contains a variety of benthonic forams including *Assilina*, *Nummulities, Alveolina, Milliolids, Soritids* and *Textularia*. The second most common microfacies is dolomite.

The diagenetic effects on these carbonates show that these are of early diagenetic origin. No preserved primary porosity is seen. Therefore, all the existing open pore spaces are secondary in origin. The secondary porosity in the carbonate rocks has developed due to the fractures and these fractures enhance the porosity and permeability of carbonate rocks. These fractures were developed due to intense deformation and uplifting of Khair-i-Murat Range along Khair-i-Murat reverse fault.

The uplifting of Himalayas changed the environment of Potwar sub-basin during early Eocene from open marine to shallow marine. Therefore, in Khair-i-Murat range, in Eocene time the deposition occurred in setting type of shallow, low energy ramp and in moderately arid climate. It is depicted by the existence of low diversity of benthonic forams.

The increase of orogenic uplift stopped the deposition of carbonate at the end of early Eocene period. This tectonic activity produced major unconformity on the top of early-middle Eocene carbonate and clastic sediments of Kuldana Formation.

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