Journal of Himalayan Earth Sciences Volume 47, No. 2, 2014, pp. 49-61

Diagenetic analysis of the Early Eocene Margala Hill limestone, Pakistan: A synthesis for thin section porosity

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Abstract

The diagenetic fabric and its implications for the thin section porosity in carbonate facies of the Margala Hill Limestone in the Haripur area of North Pakistan is documented here. The facies analysis suggests deposition of the unit in a carbonate shelf platform setting having characteristic sediments of the inner shelf lagoon to middle shelf subtidal environments. The diagenetic overprinting of these facies includes micritization, neomorphism (microspar, aragonite calcite transformation, dolomitization) and compaction (disorientation of biocalst, pressure dissolution fabric). The inner shelf facies have an enhanced porosity due to transformation of calcite to dolomite and micritization of skeletal fragments. The occlusion of the effective porosity in the middle shelf and sub-tidal distal shelf facies is related to the stylonodular, stylobrecciated fabric and calcite filled veins. The overall assessment of the unit suggests that the middle part of rock intervals have fair porosity (8-13%), in contrast to the lower and upper part which has negligible porosity (0-5%).

Keywords: Eocene; Diagenetic overprinting; North Pakistan.

1. Introduction

Diagenesis is a sedimentary phenomenon incorporating all physical and chemical changes taking place after deposition and before the onset of metamorphism (Flügel, 2004; Ahr, 2008). Diagenesis generally obscure information about primary depositional features (Boggs, 2009), in some cases, some of the evidences may survive to help interpret pre-diagenetic environments. Major changes in porosity and permeability are known to be associated with diagenesis (Ahr, 2008; Boggs, 2009).

The Kohala-Bala area lies in southern Hazara, situated to the north of Potwar Basin and to the south of Mansehra Metamorphic Zone (Baig and Lawrence, 1987) and is bounded by Panjal Fault in the north and Murree Fault in the south (Hylland and Riaz, 1988; Iqbal et al., 2007; Fig. 1). The southern Hazara is part of the Himalayan Fold and Thrust Belt formed due to collision between Indian and Eurasian plates forming various complex structures including the Lora Synclinorium (Iqbal et al., 2007). The complete stratigraphic succession within the southern Hazara (Fig. 2) ranges in age from Pre-Cambrain to Miocene (Latif, 1970a) but the stratigraphic succession within the studied area starts from Late Jurassic Samana Suk Formation up to Miocene Murree Formation, these rocks are highly deformed, hence, are folded and faulted (Munir et al., 1997). The Jurassic and Cretaceous strata lies in core of anticlines and/or at places thrust over Lower Tertiary succession, which lies in core of synclines or limbs of anticline (Munir et al., 1997).

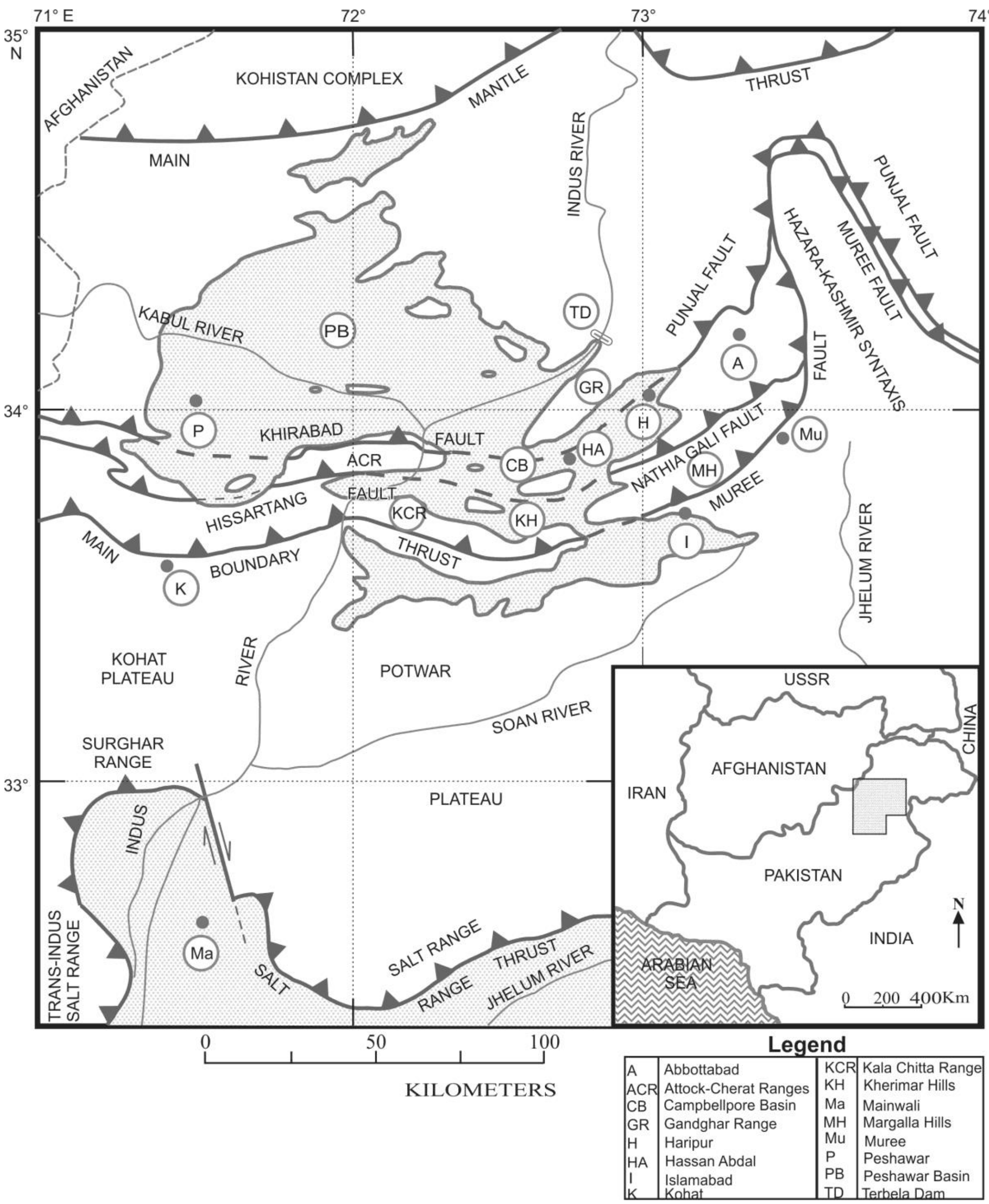


Fig. 1. Tectonic map of Northern Pakistan, Showing major structural boundries (modified after Hylland and Riaz, 1988; Iqbal et al., 2007).

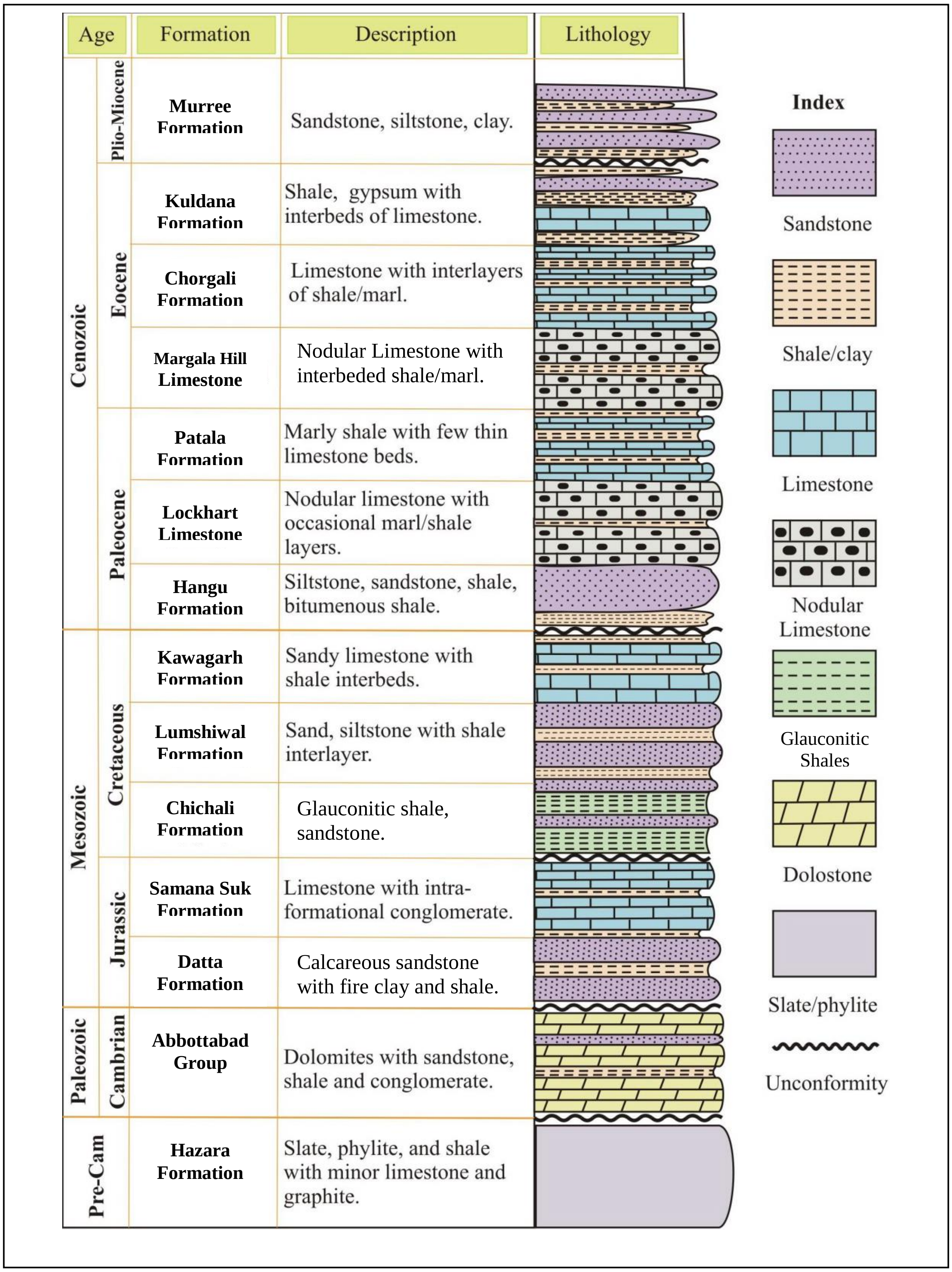


Fig. 2. Generalized stratigraphic column of Hazara area (not to scale), Khyber Pakhtunkhwa, Pakistan (after Latif, 1970a).

Pioneer work on the litho-biostratigraphy of the Bagla-Kohala Bala, Hazara was carried out by Latif (1970b and 1976), who established stratigraphic units and prepared a geological map of the area. The latest work is by Munir et al. (1997) which include the Early Tertiary litho-biostratigraphy, he studied four stratigraphic sections and reported nineteen (19) diagnostic larger benthic foraminiferal species from Lockhart Limestone, Patala Formation, Margala Hill Limestone, Chorgali Formation and Kuldana Formation. This study on Margala Hill Limestone deals with the determination of the diagenetic overprinting of the Limestone for understanding its reservoir characteristics.

2. Materials and methods

The study area is located 42 km SE from Haripur. The Margala Hill Limestone consists of limestone with thin inter-beds of clay/marl and has a conformable lower contact with the Patala Formation of Palaeocene age; the upper contact conformable with Chorgali Formation of the Eocene age is not exposed. The limestone is grey to dark grey, weathering pale yellow, fine to medium grained, nodular, (nodules range from 2-35cm), medium to thick bedded and rarely massive. The marl is grey to brownish grey. The stratigraphic section measured, described and sampled by Swati et al. (2013) were used in this study. In which a total of 136m exposed section was sampled and thirty one thin sections were prepared for detail petrographic studies. The thin sections were photographed by using digital camera fitted Nikon Polarizing microscope at the Department of Geology, University of Peshawar. The allochemical constituents were identified visually in thin sections and the limestone was classified with the help of Dunham (1962) and Flügel (2004).

3. Results

3.1 Diagenetic fabric of the Margala Hill Limestone

Carbonate rocks are particularly susceptible to diagenetic alteration because of their higher solubility in water than many other naturally occurring minerals (Flügel, 2004). The ancient carbonate rocks therefore provide a record of several episodes of dissolution and re-precipitation during their entire history (Tucker and Wright, 1990). The Margala Hill Limestone exhibit variations in faunal assemblage and textures which are used to recognize facies within the shelf, and includes 1) inner shelf facies 2) shallow subtidal distal shelf facies and 3) middle shelf facies interpreted to be deposited under clastic free shallow shelf conditions (Swati et al., 2013; Fig. 3). These facies has also been subjected to a variety of physical changes and chemical alterations, which are summarized below.

3.1.1. Micritization

The term micritization refers to conversion of allochemical constituents of the carbonate rocks into micrite or lime mud through boring activity of endolithic algae (Bathurst, 1966). In the Margala Hill Limestone, the micritized fabric is restricted to shell fragments of benthic organisms specifically gastropods and larger foraminifera of inner and subtidal distal shelf facies (Plate 2C).

3.1.2. Neomorphism

A transformation process by which a mineral crystal forms new shape, within itself or polymorph, which differs from previous one in terms of shape and size, the new crystal, could be smaller or larger one. It does not include pore space filling (Folk, 1965). It includes:

3.1.2a. Microspar

The term refers to fine grained calcite matrix, characterized by rather uniformly sized and generally loaf-shaped, subhedral and euhedral calcite crystals ranging from 5 to > 20μm in diameter (Flügel, 1959). The formation of microspar has been attributed to aggrading neomorphism (Folk, 1965). In the Margala Hill Limestone, conversion of micrite to microspar is a common phenomenon and is characterized by the development of isolated, patches of inequigranular microspar selectively converting high magnesium calcite (micrite) into low magnesium calcite with heterogeneous texture of middle shelf facies (Plate 1C) and inner shelf facies (Plate 2E).

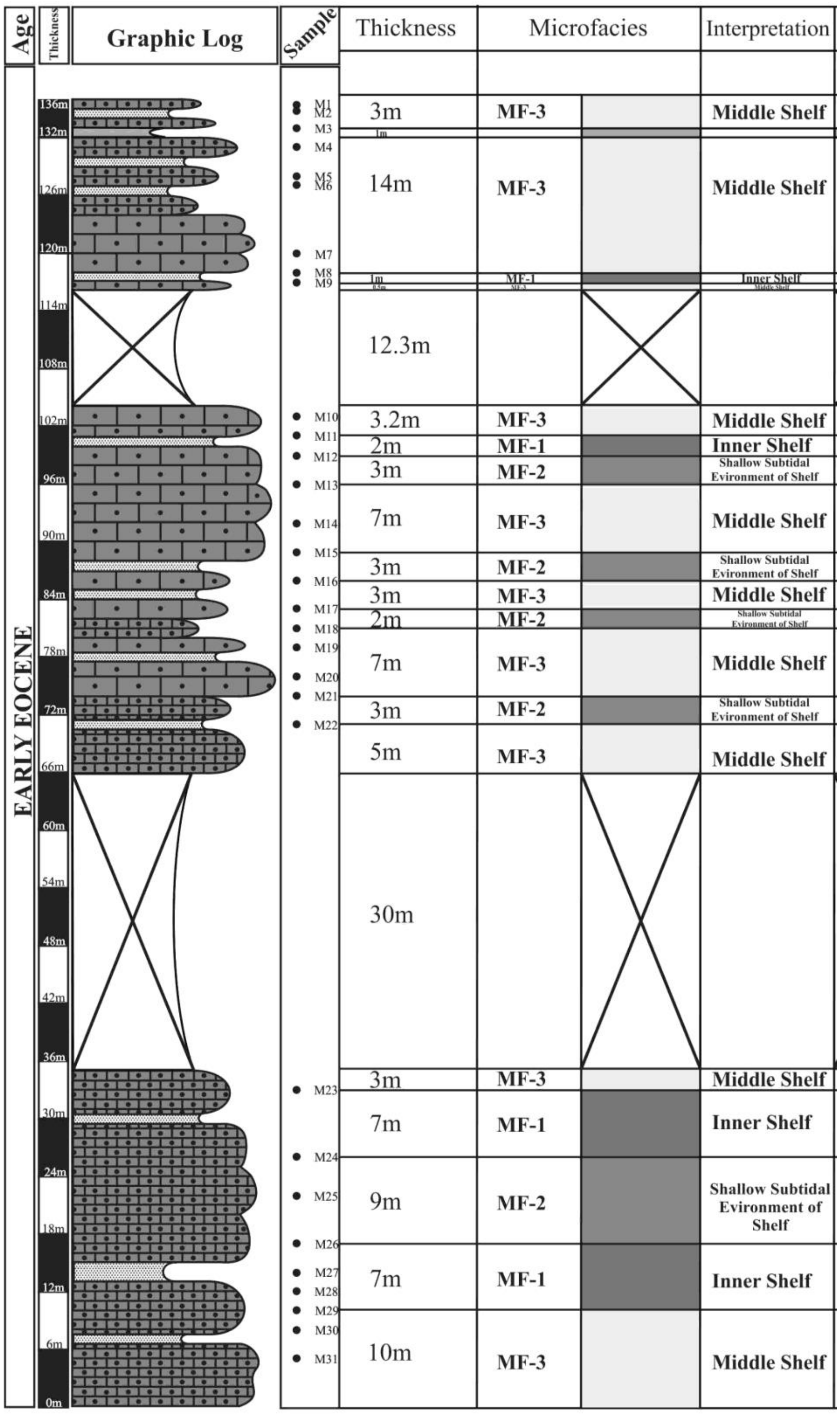


Fig. 3. Stratigraphic Section of Margala Hill Limestone showing Facies distribution (after Swati et al., 2013)

3.1.2b. Aragonite to calcite transformation

The Margala Hill Limestone predominantly displays wacke to packstone textural types with an appreciable amount of lime mud matrix as shown by middle shelf facies. The allochemical constituents include a wide assemblage of larger foraminifera with dominantly low magnesium calcite skeletal composition. However, fragments of gastropods with original shell mineralogy of aragonite are specifically transformed into low magnesium calcite during diagenesis (Plate 1A).

3.1.2c. Dolomitization

The dolomitization is confined to the inner shelf facies (Plate 3B). It is coarse grain to sub-euhedral texture in all the section rightly called as pervasive dolomitization. The dolomitization process occurs in low temperature at near surface (Osborn, 2007), which is the case within inner shelf facies. However, it is obvious in the section that there are some inner shelf limestone facies that do not contain dolomitization. This is might be due to location of inner shelf limestone facies that is close to the surface, where there is less mixing of fluids (Osborn, 2007).

3.1.3. Compaction

The compaction refers to changes in original fabric of the rocks under shallow to deep burial conditions as a result of overburden pressures. The compaction features recognized in the Margala Hill Limestone include the followings;

3.1.3a. Mechanical compaction

The mechanical compaction is typically associated with larger foraminifera, middle shelf facies (Plate 3C) and involves localized fracturing without any appreciable dislocation along closely associated fractures. Crushed foraminiferal test is generally the victim of physical compaction caused by bioclast to matrix contact (Flügel, 2004). Differences in rigidity of bioclast and matrix caused breakage of test associated with relatively shallow burial (Flügel, 2004).

3.1.3b. Chemical compaction

The chemical compaction is also called as pressure dissolution fabric resulting in the formation of various types of stylolites and solution seams developed under deep burial conditions (Carrozi and Bergen, 1987; Flügel, 2004). In the Margala Hill Limestone, a number of stylolitic features have been recognized within subtidal distal shelf and middle shelf facies. The features include;

3.1.3b(i). Sutured seams

These are low amplitude stylolite to stylolitic swarms and/or irregular stylolite, solution seams are isolated or swarm-like partings characterized by thin seams, often with accumulations of insoluble residues (Logan and Semeniuk, 1976). The subtidal distal shelf as well as middle shelf facies have the concentration of insoluble residue occurring along stylolite surfaces are mostly clay minerals and iron oxide (Plates 1C-1F, 1H, 2B and 2D).

3.1.3b(ii). Stylobrecciated fabric

The stylobrecciated fabric is a type of fabric also referred to as condensed fabric (Logan and Semeniuk, 1976). The fabric develops by the intersection of multiple sets of low amplitude stylolites in three dimensional frameworks enclosing a relatively rigid grain. The resulting feature called as iden, which is densely packed and bounded by irregular to anastomising microstylolites, formed by selective pressure dissolution of grains (Logan and Semeniuk, 1976). In Margala Hill Limestone, benthonic foraminifera of middle shelf facies are bounded by microstylolites (Plate 1G).

3.1.3b(iii). Stylolaminated fabric

The stylolaminated fabric is characterized by a set of closely spaced, straight, low amplitude, stylolites separated by seams of rectate, the iron oxide residue. It is formed when clay content is high then 10% (Logan and Semeniuk, 1976). In the Margala Hill Limestone, this type of fabric found within middle shelf facies, seems to be the result of continuous dissolution of texturally homogenous limestone with appreciable quantity of uniformly distributed, clay minerals or iron oxide insoluble residue (Plate 1H).

3.1.3b(iv). Stylonodular fabric

The stylonodular fabric, results from swarms of stylolites, enclosing relatively rigid residual idens (Logan and Semeniuk, 1976). The size of the nodules varies from millimeter to centimeter while the shape of the nodules varies from highly irregular to round to ellipsoidal or lenticular. This type of fabric is the most common one and occurs throughout the middle shelf facies (Plate 1H).

3.1.4 Calcite-filled microfractures

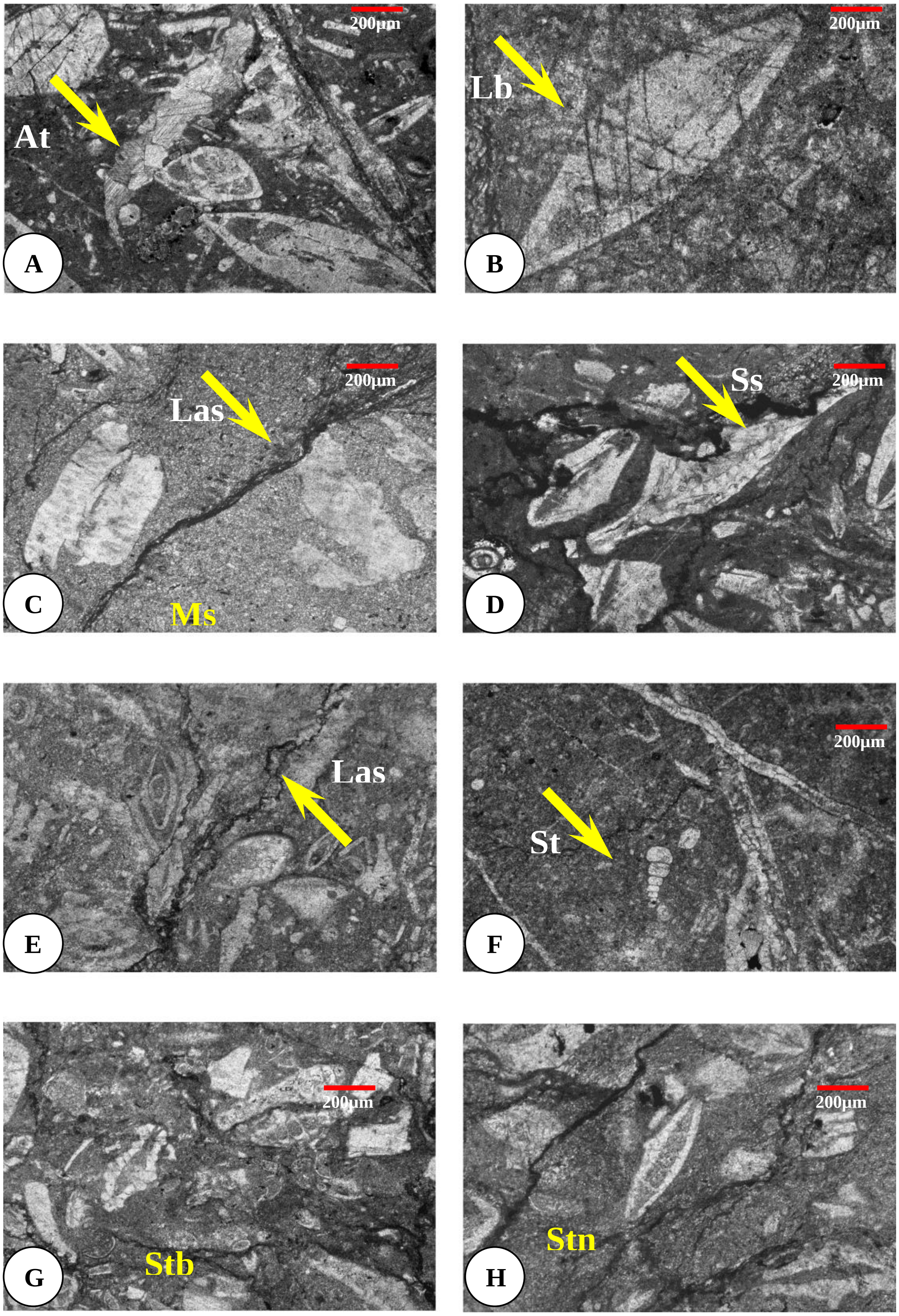
Fractures in carbonate rocks are usually important secondary features formed by either compaction or develop in response to regional tectonic regime (Tucker and Wright, 1990; Flügel, 2004). They vary in width from hairline to several cm. These fractures are later filled with coarse spary calcite and are termed as calcite veins. A wide variety of calcite veins and veinlets are present in all the three micorfacies of Margala Hill Limestone. These include, single to multiple, intersecting, large to small veins displaying a wide range of thicknesses from few mm to several cm (Plates 2B, 2D, 2F and 3A).

4. Discussion

4.1 Diagenetic history of Margala Hill Limestone

The Margala Hill Limestone is typically characterized by nodular bedding in the studied section as well as adjacent area. The individual nodules are highly irregular and are attributed to chemical compaction of an alternating sequence of thin bedded limestone and marl. The abundant bedding parallel, stylolites and solution seams in limestone strongly support this interpretation. The diagenesis occurs in three main environments namely: (a) marine, (b) burial and (c) meteoric classified into various steps. To begin with the history of diagenesis, the first would be micritization of carbonate grains, a slow process, generally takes place in a low energy, restricted environments or shallow environment within photic zone (Tucker and Wright, 1990). The process of conversion varies from partial to complete obliteration of original depositional fabric. The next step is neomorphism which takes place in the form of aragonite to calcite transformation, aragonite is unstable mineral and it changes to low magnesium calcite (LMC) along with the aggrading neomorphism (recrystallization of calcite), which is common in muddy shelf sediments, occurs typically in shallow environment by moving of super saturated $CaCo_3$ water especially in meteoric diagenetic environment (Heckel, 1983). In the dolomitization process, variety of diagenetic environments affects formation of the dolomites; however, it is understood that dolomitization indicates early diagenesis based on the evident low energy microfacies. The abundance of styloites and other compaction related features ares indicative of burial diagenesis. The Fracture system in carbonate rocks can be formed at various stages of diagenesis as well as is associated with brittle failure and tectonic fracturing of lithified carbonate rocks caused by stress and shear displacement. Extensional movements and natural hydraulic fracturing is also responsible for the formation of microfractures (Longman, 1985; Lucia, 1999). Detailed studies of fractures are important in defining tectonic history, fluid migrations, diagenetic history, reservoir potential and the mechanical properties of carbonate rocks. The fracture formation in studied area could be related to brittle failure of rocks on active tectonic platform. The fractures later filled by calcite suggesting late burial diagenesis (Osborn, 2007), hence, formation of fracture could be predated to burial diagenesis on active tectonic setting.

Plate 1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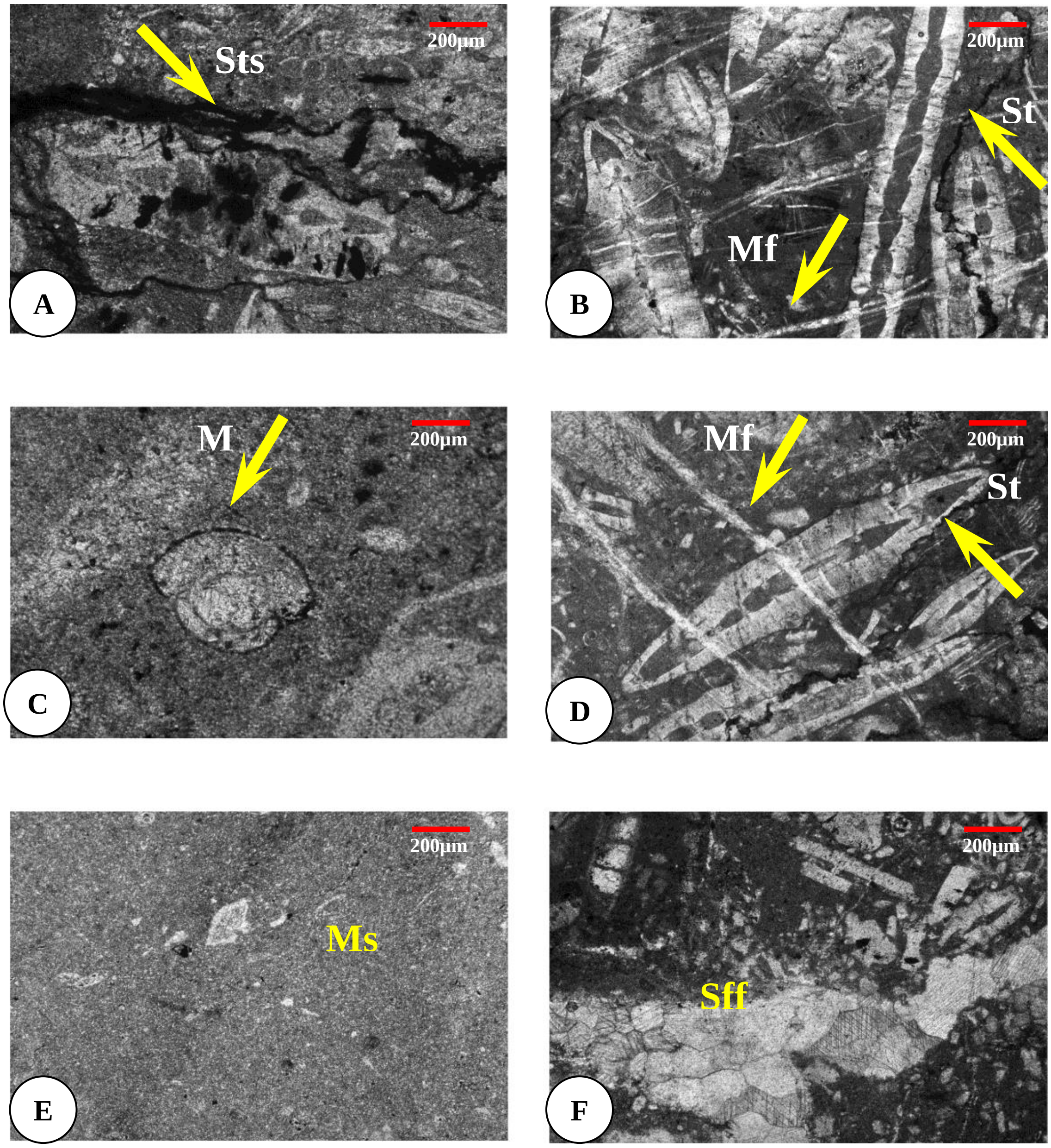
A. Photomicrograph showing coarse spar replaced bioclast of originally aragonitic mineralogy, indicated by middle shelf facies (At: Aragonite transformation; PPL, Mag. x4; 200µm).
B. Photomicrograph showing localized brecciation of skeletal grain of middle shelf facies (Lb: Localized brecciation; PPL, Mag. x4; 200µm).
C. Photomicrograph displaying non-sutured low amplitude stylolite formed during pressure dissolution. The micritic matrix of the rock has been transformed into microspar during aggrading neomorphism, indicated by middle shelf facies (Las: Low amplitude stylolite; PPL, Mag. x4; 200µm).
D. Photomicrograph showing middle shelf facies. Note selective dissolution of part of the *Ranikothalia* sp. (in the middle of the photo) along microstylolitic seams (Ss: Stylolitic Swarm; PPL, Mag. x4; 200µm).
E. Photomicrograph displaying network of low amplitude microstylolite randomly oriented with iron oxide residue in the subtidal distal shelf facies (Las: Low amplitude stylolite; PPL, Mag. x4; 200µm).
F. Photomicrograph showing two different types of diagenetic overprinting on the Margala Hill Limestone, marked by i) development of microspar at the expense of micrite matrix ii) microstylolite pre-dating coarse spar filled calcite veins, developed during tectonic deformation (St: Stylolite; PPL, Mag. x4; 200µm).
G. Photomicrograph of foraminiferal middle shelf facies displaying microscopic scale stylobrecciated fabric developed during burial diagenesis (Stb; Stylobrecciated; PPL, Mag. x4; 200µm).
H. Photomicrograph displaying stylonodular fabric formed by nodules and lenses of limestone. The nodules are bounded by low amplitude microstylolites. A local shearing with the rock is visible in stylolaminated zone in stylolitic swarms (Stn: Stylonodular; PPL, Mag. x4; 200µm).

4.2. Thin section porosity

Reservoir characterization or reservoir quality includes two properties of rock, i.e., porosity and permeability and is a product of texture and composition of original sediment, which are modified by the diagenesis processes such as compaction, burial and deformation (Slatt, 2006). The Reservoir characterization can be determined by various techniques which includes; visual methods, laboratory techniques to Petrophysical measurements.

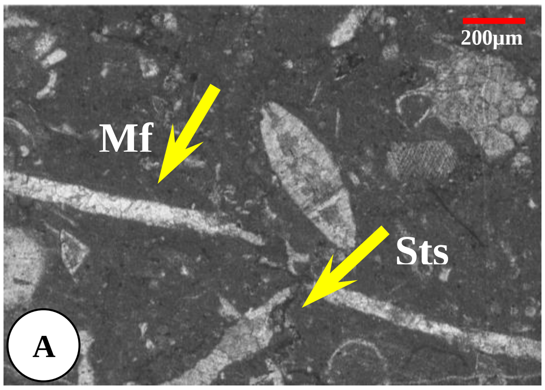
In the present study, the reservoir characterization of the Margala Hill Limestone for its thin section porosity is estimated visually. The reservoir characterization of Margala Hill Limestone of the inner shelf facies, which is mud supported have fair porosity (10-15%), it contains transformation of calcite to dolomite that increase the porosity up to 13% (Selley, 2000) along with micritization, which further increases the porosity caused by boring activity of algae within skeletal grains of carbonate, besides, dolomitization and micritization there is neomorphism (microspar appearance) and microfractures which retard the porosity, however, confined to one place maintaining the overall quality to fair porosity (10-15%). The subtidal facies, which is grains supported, contains poor porosity (5-10%). Although the subtidal facies contain micritization of skeletal fragments yet contains stylolites. Stylolites prevents fluid movement because it contains clay minerals or iron oxide insoluble residue, similarly, the same effect can be expected from calcite filled fractures which retard the porosity and permeability. The middle facies, which is grains supported, contains negligible porosity (0-5%), this microfacies has neomorphism (aragonite to calcite transformation, generation of microspar) along with stylonodular and stylobrecciated fabric. This fabric changes involve either physical breakdown of constituent grains or chemical dissolution at along grain boundaries, stylonodular and stylonuduar fabric results in reduction of effective porosity. Then the fabric is cross cut by calcite filled fractures. These entire features can destroy the porosity and permeability in any rock. There is a fluctuation of microfacies within Margala Hill Limestone (Fig. 3) based on which the porosity changes as we move upward in the section. There is negligible porosity (0-5%) at the top and bottom of the section, in the middle of the section where inner shelf facies along with subtidal facies lies contains fair porosity of (8-13%).

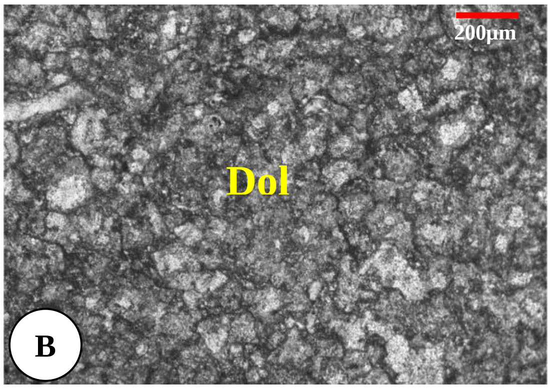
Plate 2

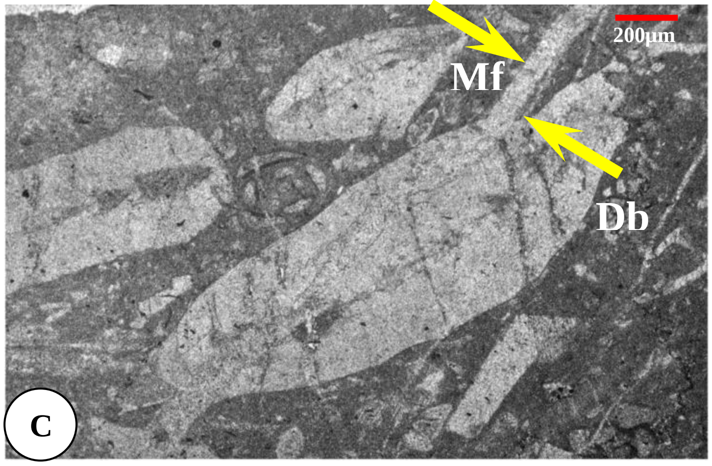


A. Photomicrograph of larger foraminifer (*Assilina granulosa*) has been partially micritized by solution passing through fractures associated with limestone. In the photomicrograph the thick stylolitic swarm is visible in addition to various hairline stylolites (Sts: Stylolitic seams; PPL, Mag. x4).
B. Photomicrograph displaying parallel to sub-parallel sets of intersecting hairlines microfractures filled with calcite and intersecting partially aligned fossils. The microfractures are cross cut by laterally formed stylolite at the right side of the photomicrograph (Mf: Microfracture, St: Stylolite; PPL, Mag. x4).
C. Photomicrograph displaying micritization as indicated by inner shelf facies (M: Micritization; PPL, Mag. x4).
D. Photomicrograph displaying middle shelf facies having partial dissolution of the micrite matrix as well as *Assilina spinosa.* Superimposed on this fabric are late stage parallel fracture, development and coarse spary calcite filling (Mf: Microfracture, St: Stylolite; PPL, Mag. x4).
E. Photomicrograph showing conversion of micrite of matrix into microspar formed as a result of aggrading neomorphism, indicated by inner shelf facies (Ms: Microspar; PPL, Mag. x4).
F. Photomicrograph displaying irregular spar filled veins (Sff: Spar filled fracture; PPL, Mag. x4).

Plate 3







A. Photomicrograph displaying middle shelf facies having *Assilina* sp. (middle), echinoderm (with well-developed rhombic cleavages) and unidentifiable skeletal debris. Diagenetic overprints are evident in the form of microstylolitic seams and coarse spary veins. Note the displacement of the vein along stylolite seams imply stylolite formation as the lastest diagenetic event (Mf: Microfracture, Sts: Stylolitic seams; PPL, Mag. x4).
B. Photomicrograph showing pervasive dolomitization of inner shelf facies (Dol: Dolomite; PPL, Mag. x4).
C. Photomicrograph displaying disorientation of bioclast of middle shelf facies (Mf: Microfracture, Db: Disorientation of bioclast; PPL, Mag. x4).

This can be seen by estimating the percentage of facies distribution within the section, given in the Fig. 4. Combining both the MF1 and MF2 represent 27% of the total rock and is almost more than half of the MF3 which is 41%, while the rest of 32% of the rock unit is covered, hence, it is not used for porosity estimation. Thus the middle part of the Margala Hill Limestone has fair chances of porosity about (8-13%).

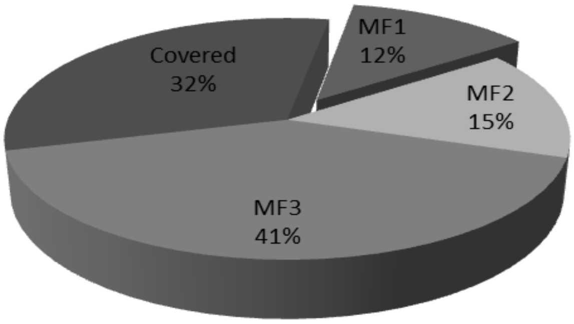


Fig. 4. Percentage of facies distribution within Margala Hill Limestone: a comparison.

5. Conclusions

The Margala Hill Limestone comprises of light to dark grey nodular limestone with clay/marl interbeds and is 136m thick at the Kohala Bala, which contains three Microfacies identified as *1) inner 2) subtidal distal shelf and 3) middle shelf facies* respectively (Swati et al., 2013). The presence of several diagenetic features indicate that the Margala Hill Limestone of the studied area has been subjected to various post-depositional alterations ranges from meteoric to deep burial diagenesis. These diagenetic changes includes micritization, neomorphism (microspar, aragonite calcite transformation, dolomitization), compaction (disorientation of biocalst, pressure dissolution fabric), nature and origin of calcite filled microfractures. The Margala Hill Limestone as analyzed through diagenetic history and its assessment for the thin section porosity (visual estimation) suggested that it contains a negligible porosity (0-5%) at the top and bottom of the section, in the middle of the section where inner shelf facies along with subtidal facies lies contains fair porosity of (8-13%).

6. Suggestions and recommendations

The Margala Hill Limestone studied in this paper is an initial and quick understanding to its thin section porosity. The thin section porosity estimated is the visual estimation without using laboratory method (like blue die, Scanning Electron Microscopy: SEM, core and plug porosity) or other petro-physical parameter such as wireline logs. It is understood that the visual estimation of porosity in thin section has twice high values from laboratory estimated values. Therefore, in order to find the exact laboratory estimated values, it is suggested and recommended that the petrographic data must be synchronized with other data such as SEM (Scanning Electron Microscopy), core and plug porosity along with wireline logs (for subsurface correlation purpose) in future study to have good insight of porosity as well as permeability of the rocks.

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