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Diagenetic History and Microfacies Analysis of Upper Permian Wargal Limestone in the Central Salt Range, Pakistan

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Abstract. The present study focuses on the microfacies analysis of Wargal Limestone in Central Salt Range. The Wargal Limestone is composed of thin to medium bedded, light to medium grey, olive grey and brownish grey limestone, dolomite with some marl and chert nodule. Field sampling was carried out on a 49m thick stratigraphic section and 25 samples of limestone were obtained for microfacies analysis. Based on skeletal grains, texture and diagenetic characteristics, seven microfacies namely: brachiopod, crinoidal grainstone (MF1), crinoidal, bryozoan grainstone (MF2), crinoidal sandy limestone (MF3), codiacean, crinoid, brachiopodal grainstone (MF4), codiacean, crinoidal grainstone (MF5), brachiopod, bryozoan, crinoidal grainstone (MF6) and crinoid, brachiopodal grainstone (MF7) have been recognized in the Wargal Limestone. A number of diagenetic features such as stylolite, dolomitization and cements types of equant blocky, syntaxial overgrowth and cavity fill spar were observed in the microfacies. The diagenetic processes have obliterated the grains morphology and rock fabric in some microfacies. The presence of stylolite and recrystallization of grains indicate mechanical compaction during the diagenesis. The microfacies and diagenetic features suggest deposition in warm shallow water conditions on carbonate ramp environment.

Keywords: microfacies analysis, diagenetic processes, Central Salt Range, Wargal Limestone

Introduction

The rapid increase in research on carbonate sedimentary rock was triggered by the discovery of carbonate reservoirs worldwide in the second half of the 20th century. During 1950's and 1960's, modern and ancient carbonate environments, facies model and diagenetic processes and features were remained the focus of research worldwide (Flugel, 2013). The increasing importance of limestones and dolomites as reservoir rocks and use of thin section fossils in subdividing carbonate platform has provided impetus to progress and growth of microfacies research. In Pakistan, carbonate rocks of Permian and Eocene age are acting as reservoir rocks in many oil and gas fields of Indus Basin (Kadri, 1995). The Permian rocks in Pakistan represent a unique opportunity to study both Paleo-Tethys and Gondwana land deposits (Wardlaw and Pogue, 1995). The Permian succession of Indus Basin comprised of siliciclastic rocks of Nilawahan group and carbonate-dominated sequence of Zaluch group. The Zaluch group consists of three formations namely Amb Formation, Wargal Limestone and Chhidru Formation. Excellent outcrops of the well-developed Permian sequence are present in the Salt Range for field studies.

The name Wargal Limestone was introduced by Teichert (1965) for the Middle Productus Limestone of Waagen (1879) that was approved as such by Stratigraphic Committee of Pakistan. Wargal village in Central Salt Range is the type locality of the formation. The Wargal Limestone consist of thin to medium bedded, light to medium grey, olive grey and brownish grey limestone and dolomite with some marl and chert nodule. In the study area, Wargal Limestone has conformable lower and upper contacts with Amb Formation and Chhidru Formation, respectively. The earlier work by Pakistan Japan Research Group (1985) and Mertmann (2003) showed late Murghabian to an early Dzhulfiann age of the formation.

The bulk of studies on Wargal Limestone largely dealt with paleontology and biostratigraphy of the formation (Mertmann, 2000; Okimura, 1988; Grant, 1970; Douglass, 1968). The formation yielded abundant smaller foraminifers that are associated with Colaniella, an upper Permian Index fossil, in the Salt Range (Okimura, 1988). The biogeographical studies (Singh, 1987) suggested tropical climatic conditions in the Salt Range

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during the time of upper Permian. Similar findings by Mertmann (2003) indicate that Wargal Limestone was deposited on a carbonate platform with coral patches and abundant bars of echinodermal debris. The Permian strata of South-East Asia were correlated with the help of Fusulinacea and Brachiopoda due to their extensive development and close zonation (Tazawa, 2002). Studies on microfacies of Wargal Limestone are limited and mostly based on Western Salt Range (Khan *et al*., 2017; Hussain *et al.*, 2015; Khan *et al*., 2014). However, there are no such detailed studies on Wargal Limestone in the Central Salt Range where formation has considerable thickness and good outcrop exposures. The present study aims to address this gap in research on Wargal Limestone in the area and focused on the microfacies analysis and diagenetic history of Wargal Limestone in Central Salt Range.

Location and geology of the study area. The study area lies near Khura village (coordinates 32.3147^0 N, 72.1348^0 E) in the western part of Central Salt Range along Khushab- Sakessar road (Fig.1). Sedimentary rocks of Eocambrian Salt Range Formation to Miocene Kamlial Formation are present in the study area (Table 1). Two important disconformities, one at the base of Permian and other between Cretaceous and Tertiary, exist in the area. The study area has well developed Permian sequence which comprised of siliciclastic rocks of Nilawahan group (Tobra Formation, Dandot Formation, Warcha Sandstone and Sardhai Formation) and dominantly carbonate rocks of Zaluch group (Amb Formation, Wargal Limestone, and Chhidru Formation). The Mesozoic rocks are represented by Mianawali Formation. The Jurassic and Cretaceous rocks are absent in the area and Mianawali Formation has an unconformable upper contact with the Paleocene rocks of Makarwal group. A thick succession of Eocene Nammal and Sakessar Limestone is exposed in the area.

Salt Range is the result of an ongoing collision between Indian and Eurasian plates (Kazmi and Jan, 1997; Lillie *et al*., 1987). It is the most recent and outer expression of Himalayan shortening. Broad shallow folds and gentle monoclines are present on the northern slope of Salt Range while tight folding with faulting is formed on the southern slope. The vertical movement of Eocambrian Salt Range Formation has resulted in the salt diapirism and halo-kinesis in the area. The

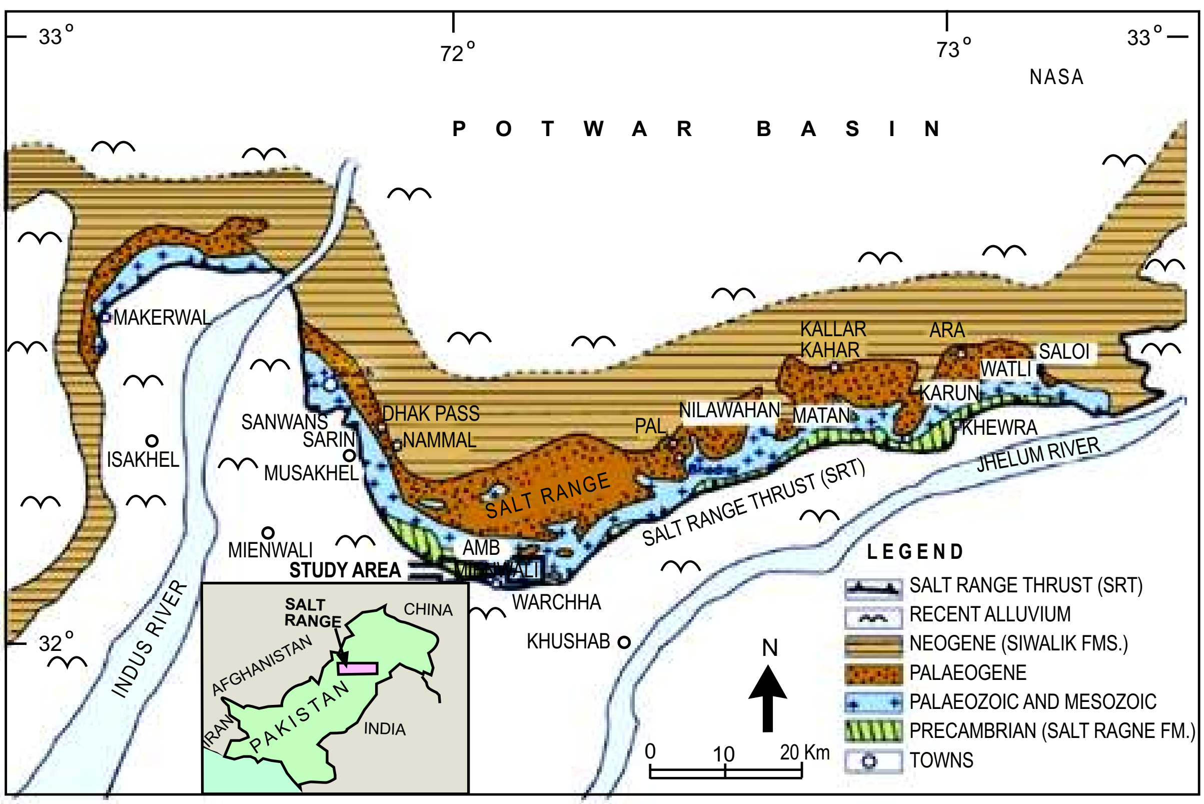

Fig. 1. Location and geological map of the study area (modified after Ghazi and Mountney, 2009).

Table 1. Generalized stratigraphy of study area in Central Salt Range, Pakistan

Age	Group	Formation	Lithology
Miocene	Rawalpindi	Kamlial Fm	Sandstone, mudstone, conglomerate
Eocene	Chherat	Sakesar Limestone Nammal Fm	Limestone, marl, chert Limestone, shale, marl
Paleocene	Makarwal	Patala Fm Lockaart Limestone Hangu Fm	Shale, limestone Limestone Sandstone, shale
Triassic	Musa Khel	Mianawali Fm	Limestone, shale, sandstone
Late Permian	Zaluch	Chhidru Fm Wargal Limestone Amb Fm	Limestone, shale, sandstone Limestone, marl, shale Shale, dolomite, limestone
Early Permian	Nilawahan	Sardhai Fm Warcha Sandstone Dandot Fm Tobra Fm	Shale, siltstone, sandstone Sandstone, mudstone Sandstone, siltstone, shale Sandstone, conglomerate, shale
Cambrian	Jhelum Group	Baughanwala Fm Jutana Dolomite Kussak Fm Khewra Sandstone	Siltstone, sandstone, shale Dolomite, limestone Sandstone, shale Sandstone, shale
Precambrian	--	Salt Range Fm	Salt, marl, gypsum, dolomite

superimposition of salt diapirism along the southern scarp has created north-south salt-cored anticline (Gardezi and Ashraf, 1974).

Materials and Methods

A stratigraphic section near Khura village on Khushab-Sakessar road (coordinates 32.3147^0 N, 72.1348^0 E) was measured using Brunton compass, tape, and Jacob staff. Five lithofacies were recognized based on the outcrop appearance of the formation. Field sampling was carried out on a 49 m thick stratigraphic section and 25 samples of limestone were obtained for thin section studies and microfacies analysis. Thin sections were also stained with a mixed solution of potassium ferric cyanide and Alizarin Red-S. Thin sections were studied by using the standard petrographic polarizing microscope with a DP12 camera fitted at Petrography Laboratory of the Pakistan Museum of Natural History, Islamabad.

Results and Discussion

Lithostratigraphic units of Wargal Limestone. The detailed outcrop studies of Wargal Limestone showed five distinct lithostratigraphic units in the study area of Central Salt Range (Fig. 2).

Unit 1. It consists of medium to thick bedded limestone of 14m thickness. Some patches of dolomitization and shale were observed in the unit (Fig. 2B). Mainly crinoid's fossils were witnessed on the weathered surfaces. Stylolites are parallel to bedding with few suture type stylolite normal to bedding were present. The unit is conformably underlain by Amb Formation.

Unit 2. It consists of a 15m thick sequence of massive bedded limestone. Some diagenetic features like stylolites and fracturing are present (Fig. 2C). Fractures are difficult to distinguish from bedding planes as they run parallel to bedding. An increase in carbonate grains can be observed with the help of hand lens. The layer thickness increases towards the top of the unit.

Unit 3. It is approximately 13m of thickness and comprised of nodular limestone. Shale and marl partings were also observed in the unit. Crinoids are abundant in the basal part while Productus dominate the upper beds of the unit (Fig. 2D). The shale beds of the unit are highly fossiliferous and yield Productus, Crinoids and Bryozoans fauna.

Unit 4. It is only one-meter thick dolomite bed which shows the abundance of recrystallized shells of brachiopods (Fig. 2E).

Unit 5. It is the topmost unit of the Formation and 5m thick. It comprised of highly fractured medium to thick bedded, light grey to yellowish grey limestone. Fractures run perpendicular to the bedding. The limestone contains abundant brachiopods (Fig. 2F). The unit has a conformable upper contact with Chhidru Formation.

Microfacies of Wargal Limestone. Based on the thin section studies, seven microfacies (MF) have been recognized in the Wargal limestone

(*MF1*)-*Brachiopod crinoidal grainstone.* This facies is bioclastic grainstone and consists of brachiopod shells, bryozoans, ostracods, gastropods, crinoids and mollusks (Fig. 3A). Crinoids is present in high number as compared to other fauna. The percentages of brachiopods and crinoids are 30% and 60%, respectively.

Diagenetic features such as dolomite, micritization, and cementation are observed in thin section. Dolomite is fine to coarse, rusty brown and is present in the form of individual dispersed crystals. Replacement of some skeletal grains with dolomite was also seen in the microfacies. Slight micritization of crinoids were evident along the grains margins (Fig. 4D). The cement type in

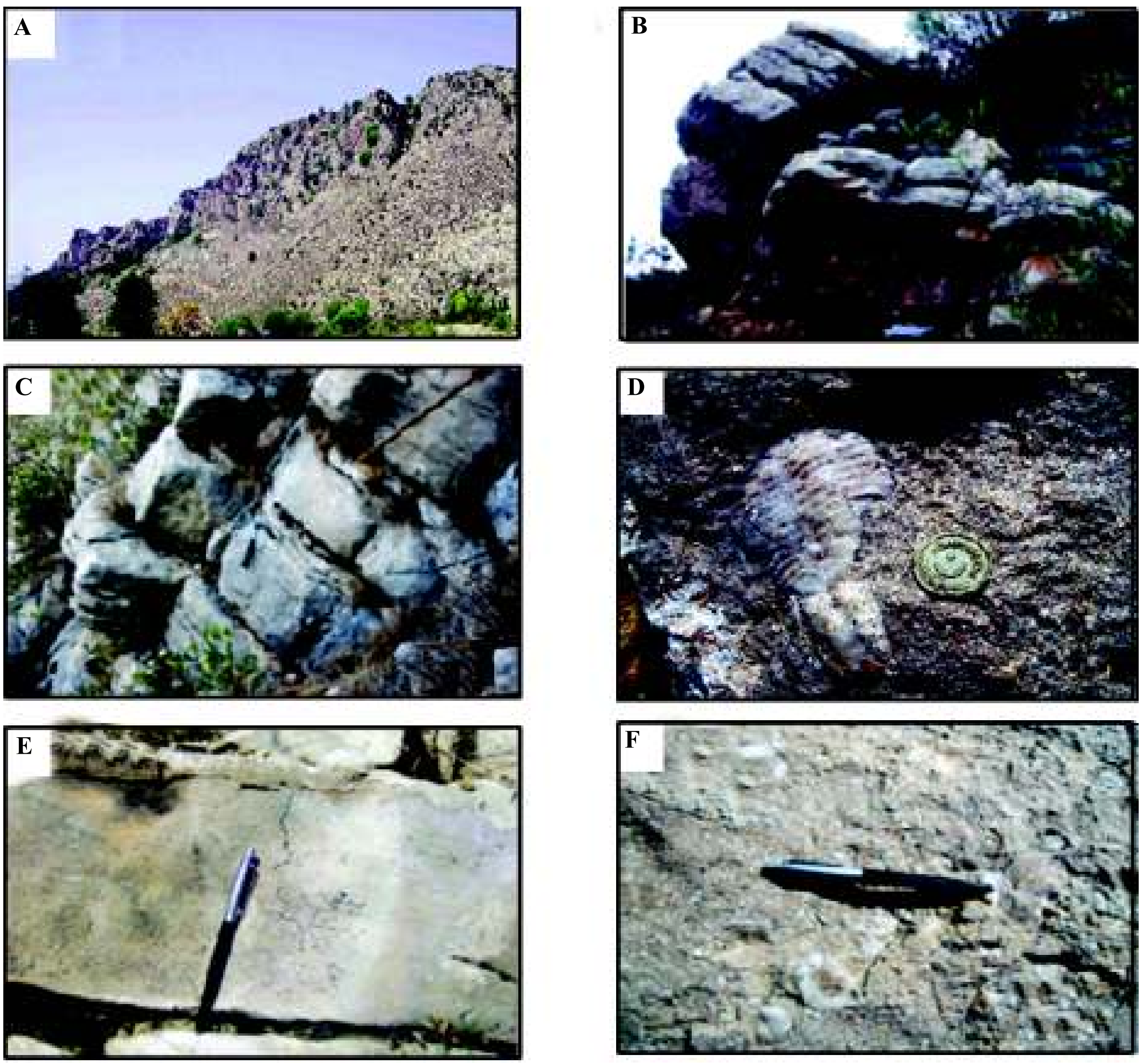

Fig. 2(A-F). Field photographs of Wargal Limestone showing (A) overview of measured section, (B) lithostratigraphic unit 1 (C) lithostratigraphic unit 2 (D) Productus in unit 3 (E) lithostratigraphic unit 4 and (F) lithostratigraphic unit 5.

microfacies is equant blocky and cavity filling spar cement which can readily be recognized under the microscope.

Interpretation. The presence of abundant bryozoans, ostracods, gastropods, crinoids, and brachiopods in the microfacies suggest deposition in well aerated, oxygenated shallow marine conditions (Draper, 1988). The diversity of fauna indicates middle to inner ramp environment with tropical climatic conditions favorable for organisms' growth (Blendinger, 1992). During the upper Permian, Indian plate was part of Gondwanaland and marine deposition was occurring at the passive margin of Tethys Ocean (Kobayashi, 1999). The low influx of terrigenous sediments helped in carbonate

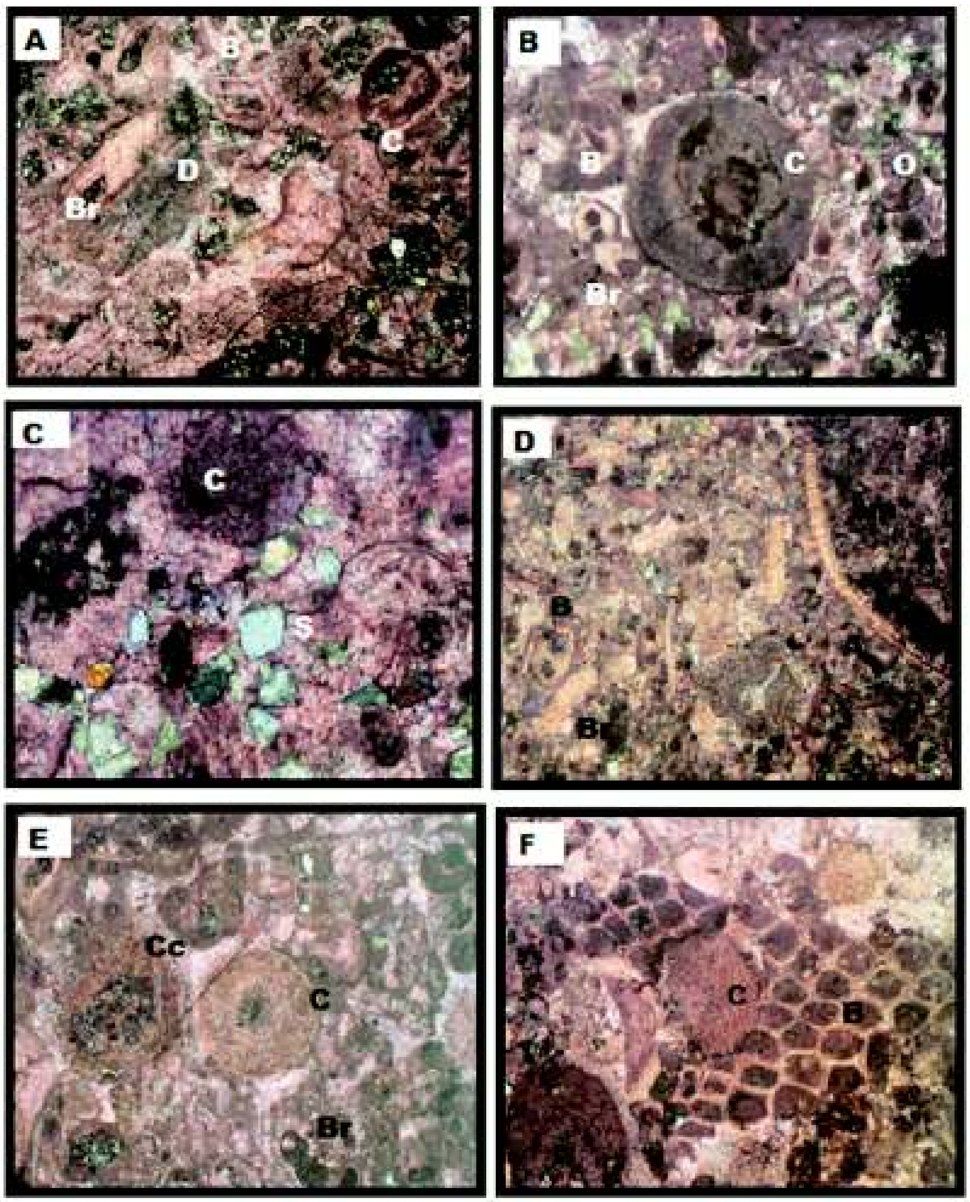

Fig. 3(A-F). Microphotographs of microfacies in Wargal Limestone showing (A) microfacies MF1 (B) microfacies MF2 (C) microfacies MF3 (D) microfacies MF4 (E) microfacies MF5 and (F) microfacies MF6. Whereas brachiopod (Br), crinoid (C), bryozoan (B) siliciclastic grains (S), ostracod (O) algae (A), circumgranular cement (Cc) and dolomite (D).

deposition in the form of Zaluch group (Mertmann, 2003). The presence of cavity spar and equant blocky cement suggest role of meteoric water during burial (Bjørlykke, 2014).

(MF2)-Crinoidal bryozoan grainstone. MF2 comprised of bioclastic grainstone (Fig. 3B). Like MF1, it also includes skeletal detritus of bryozoan, crinoids, ostracods and brachiopod shells. Bryozoans are approximately 40% while crinoids makeup 30% of skeletal grains. Terrigenous as well as non-skeletal carbonate grains were absent in the microfacies. Some shells of bryozoan show deformation effect possibly arise by mechanical compaction. The types of cement are cavity filled spar and blocky with occasional occurrence of syntaxial overgrowth.

Interpretation. Bryozoan marine species tend to live in a warm tropical neritic environment (Draper, 1988). Bryozoans are static species and generally found on the hard natural stone like shells, rocks, and grains (Mertmann, 2003). The presence of crinoids, ostracods, and bryozoan indicate the diversity of fauna that is characteristics of inner to middle shelf environment of the carbonate platform.

(MF3)-Crinoidal sandy limestone. It consists of skeletal grains of crinoids and siliciclastic terrigenous sediments (Fig. 3C). Approximately 60% grains are composed of crinoid shells. The composition of most detrital terrigenous grains is quartz and plagioclase. Few skeletal grains of bryozoan were also observed in the microfacies. In MF3, some dolomitization were seen as replacement of fine grained micrite. The dolomite crystals are mostly dispersed and rusty brownish in colour (Fig. 4C).

Interpretation. Crinoids live as an attached object to floating driftwood which sometimes becomes waterlogged and present at the base with crinoids (Tucker and Wright, 2009). The presence of terrigenous grains indicate slight fall in sea level and influx of land sediments. The dolomite crystals show subtidal to intertidal zone of deposition with frequent episodes of flooding (Kobayashi, 1999).The diagenetic products of microfacies such as Ferron dolomite and spary calcite cementation indicates replacement during the burial diagenesis.

(MF4)- Codiacean crinoid brachiopodal grainstone. Skeletal grains of brachiopods, codiacean green algae, crinoids and few benthic foraminifera are present in MF4 (Fig. 3D). The proportion of brachiopods, crinoids and bryozoans is 38%, 32% and 28%, respectively. The grains are not easily recognizable under thin section due to overprinting by diagenetic processes. Effects of micritization and minor recrystallization can be seen in some skeletal grains. The cementation is in the form of syntaxial overgrowth and cavity filling spar cements in the microfacies (Fig. 5C). Skeletal grains in the microfacies show little to no effect of mechanical or chemical compaction.

Interpretation. The deposition of MF4 microfacies possibly taken place in the inner ramp to lagoonal conditions of the shallow marine environment. Warm shallow water is considered suitable for growth of benthic foraminifera, brachiopods, and bryozoans while green algae exist in the shallow lagoon or lacustrine setting (Flugel, 2013). The cementation processes might be influenced by meteoric and groundwater circulation during deposition and diagenesis (Tucker and Wright, 2009).

(MF5)-Codiacean Crinoidal grainstone. MF5 consists of crinoids, brachiopods, codiacean green algae, sponges and benthic foraminifer (Fig. 3E). Crinoids dominate the skeletal grains of microfacies and approximately 60% of skeletal grains. Codiacean green algae are approximately 25%. The microfacies show circumgranular cementation and grain dissolution and recrystallization (Fig. 4E). Some grains have straight contacts which indicate effects of mechanical compaction in the facies (Fig. 5D). The MF5 facies also shows slight micritization of skeletal grains.

Interpretation. The skeletal grains of microfacies MF5 indicate deposition in a warm shallow tropical condition suitable for carbonate deposition. The carbonate sedimentation possibly occurred on middle to inner ramp environment of carbonate platform as suggested by the presence of crinoids, benthic foraminifers, and brachiopods (Okimura, 1988). The presence of codiacean green algae and sponges in microfacies point to stable physical conditions with very little energy (Draper, 1988). The sutured contacts of grains are caused by mechanical compaction during burial (Flugel, 2013). The facies also show signs of phreatic water activity during diagenesis.

(MF6)-Brachiopod bryozoan crinoidal grainstone. MF6 is also grainstone composed of skeletal grains of bryozoans, crinoids, mollusks, and brachiopods (Fig. 3F-4F). Bryozoans and crinoids are present in greater number as compared to other types of skeletal grains. Crinoids and bryozoans comprise 50% and 35% of the skeletal grains. Matrix is sparse. Mechanical and

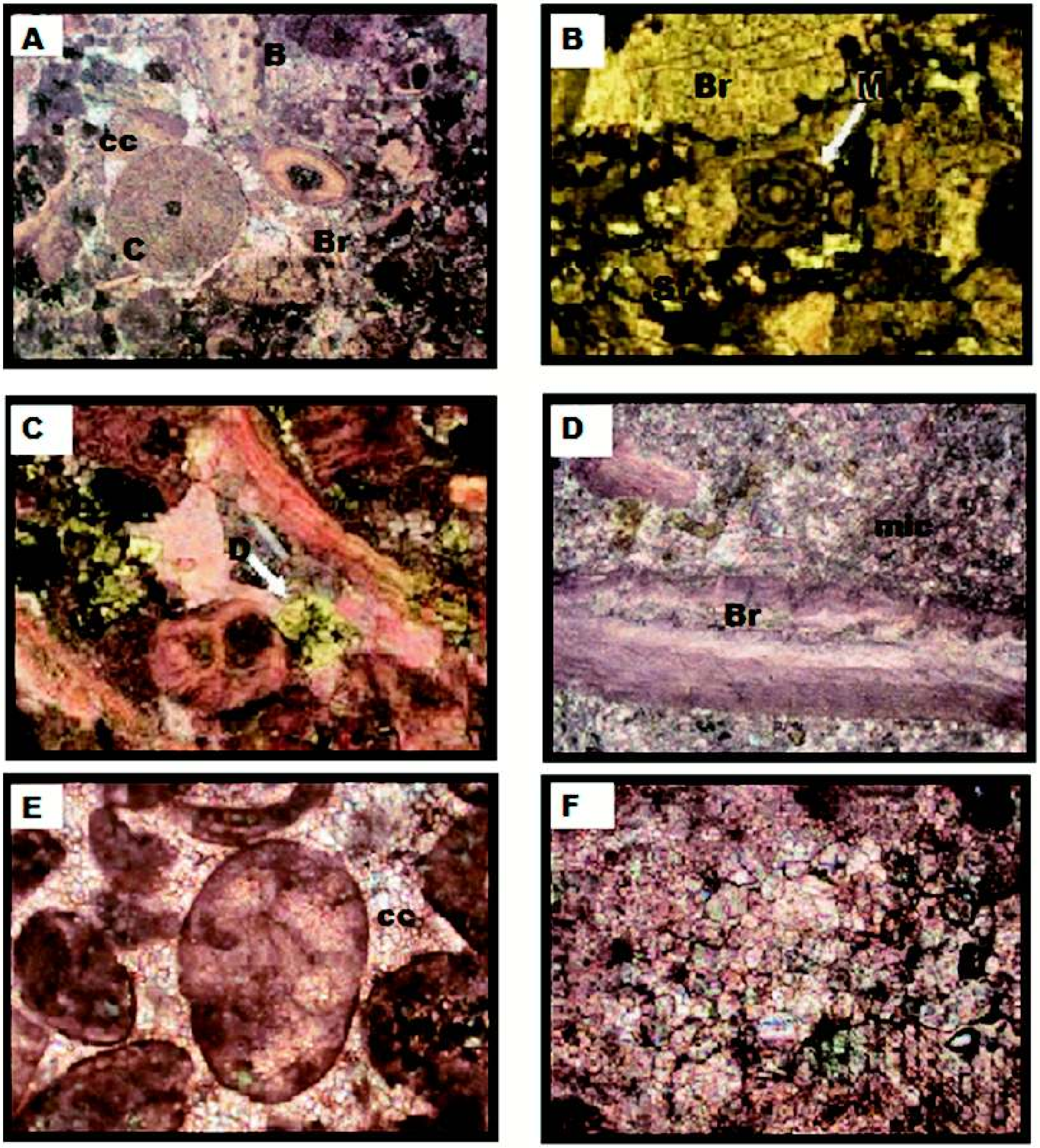

Fig. 4(A-F). Microphotographs of microfacies in Wargal limestone showing (A) microfacies MF7 (B) chemical compaction in MF7 (C) dolomite crystals in MF3 (D) micritization along skeletal grains in microfacies MF1 (E) circumgranular cements in microfacies MF5 and (F) equant blocky cement in microfacies MF6. Whereas brachiopod (Br), crinoid (C), miliolid (M) bryozoan (B) stylolite (St), circumgranular cement (Cc) and dolomite (D).

chemical compaction has resulted in broken and deforms shells. The cavity filling spar is the dominant cement type in microfacies. Syntaxial growth along some crinoid grains can be seen in the microfacies (Fig. 5A).

Interpretation. The MF6 microfacies is deposited in inner to middle ramp environment of shallow marine settings. The skeletal grains of brachiopods, crinoids, bryozoans indicate normal salinity waters with good

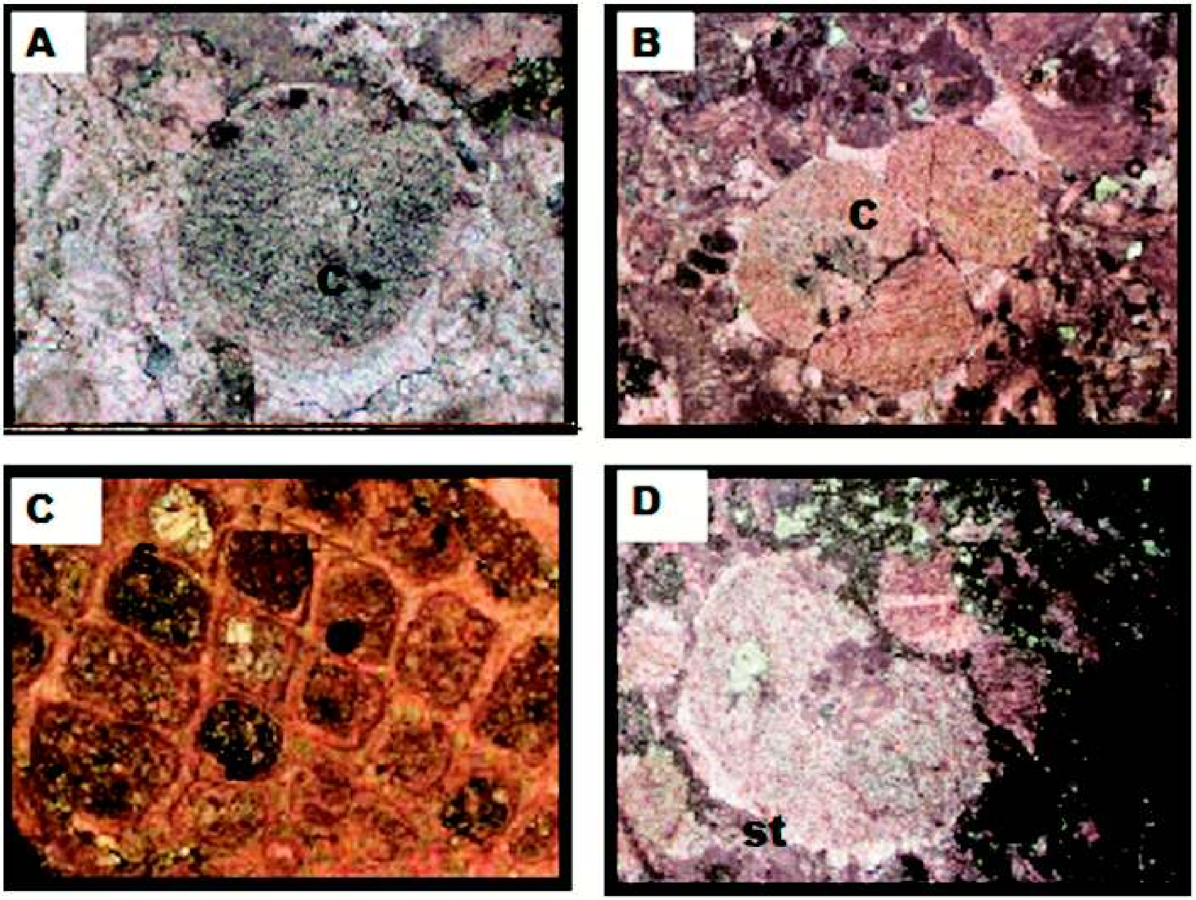

Fig. 5(A-D). Microphotographs of microfacies in Wargal limestone showing (A) overgrowth along crinoids grains in microfacies MF6 (B) deformed and broken shell of crinoids with straight contacts in MF7 (C) cavity filling spar in MF4 (D) stylolite caused by chemical and mechanical compaction in MF5. Whereas crinoid (C), bryozoan (B) stylolite (St) and cavity filling Spar cement. (S).

circulation (Flugel, 2013; Blendenger *et al*., 1992). The low percentage of the matrix also suggest deposition on high energy environment of shelf edge to barrier/shoal settings where wave energy limit deposition of carbonate mud (Krystyn *et al*., 2003). The presence of cavity filling spar and equant blocky types of cement in skeletal grains point to groundwater/meteoric water activity during burial and diagenesis of sediment (Tucker and Wright, 2009).

(MF7)-Crinoid brachiopodal grainstone. Microfacies MF7 is grainstone and consists of skeletal grains of crinoids, brachiopods, and bryozoans (Fig. 4A). The brachiopods grains are in higher numbers and make up 40-45% of total skeletal grains. The percentage of crinoids in microfacies is approximately 30%. Some fractured grains were also observed indicating compaction effects (Fig. 4B-5B). The slight micritization on edges of crinoid's grains is visible. The identification of matrix type is difficult because of dolomitization of the matrix in the microfacies.

Interpretation. The deposition of MF7 microfacies possibly taken place in the middle to outer ramp settings of the shallow marine environment as suggested by skeletal grains of crinoids, brachiopods, and bryozoans (Okimura, 1988). Relatively small percentage of the matrix in the microfacies results in deposition in high water energy environment close to carbonate barrier or shelf edge (Krystyn *et al*., 2003). However, the water depth is not greater than 150-200m as organisms activity drastically reduces in deeper water. The broken shells and straight contacts of skeletal grains are possibly caused by mechanical compaction during burial (Flugel, 2013). The microfacies also show cavity filling spar and syntaxial overgrowth in skeletal grains that point to groundwater/meteoric water activity during burial and diagenesis of sediment (Tucker and Wright, 2009).

Conclusion

In the study area of Central Salt Range, five lithological units and seven microfacies in the Wargal Limestone were identified. The microfacies analysis of Wargal Limestone showed that Limestone formation is of skeletal grainstone. The major skeletal grains in Wargal Limestone are bryozoans, crinoids, brachiopods and green algae. Diagenetic products such as micritization, cementation, chemical compaction and dolomitization were observed in the formation and point toward the role of groundwater and meteoric water during the burial of sediments. The microfacies association of Wargal Limestone suggest deposition in warm shallow water conditions of inner to middle shelf settings. These environmental settings were prevalent on northern margin of Gondwanaland at the passive margin of Tethys Ocean during late Permian which caused deposition of Wargal Limestone in shallow marine condition.

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