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Petrography, Micro facies Analysis and Interrelated Model of Schematic Depositional Environmental of Ambar Formation, District SWABI KPK, Pakistan

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Abstract
The present work mainly focused on petrography of the Ambar formation for the interpretation of depositional modal of Ambar Formation. In the petrographic study, the major minerals observed under microscope are dolomite, calcite, mica (muscovite) and quartz. Similarly, pyrite and magnetite are also observed in the Ambar formation. The most important detrital constituent of Ambar Formation is quartz which ranges up to 70% at different stratigraphic levels. Dolomite rhombs are mostly idiotypic to hypidiotopic which is favored by temperature range 25-50 °C. From the previous work and petrographic study there is gradual change in lithology from the lower part of the formation towards the upper parts. The lower part of the study unit is mostly quartzitic to limy dolomitic with prominent clastic input of siliceous materials as well as is represented by algal lamination and poorly preserved stylolites. The upper part is purely dolomite having butcher chop weathering, dissolution cavities, quartz and calcite filled fractures. The Ambar formation is undergone through various diagenetic episodes. The different diagenetic features are studied in thin sections i.e., stylolites, fractures, joints, mechanical compaction, development of spar and iron leaching in dolomite. As the stylolites, mechanical compaction and bimoldic porosity usually developed at shallow depth and fracturing developed at deeper depth so the presence of poor algal stromatolite, presence of relic features of limestone, chert and selective to pervasive dolomatization indicates secondary nature of Ambar Formation.

Keywords: *Ambar Formation, Dolomite, Stylolite, Bimoldic porosity, Depositional modal.*

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I. Introduction

The Ambar Formation of Swabi area occur along Swabi- Jhangira road and is the part of Peshawar Basin. The study area lies between latitude 34˚03' 02" N and longitude 72˚24' 46" E and at an elevation of 1010 feet. Ambar is a small village in the Swabi District of Khyber Pakhtunkhwa,Pakistan. The Swabi interchange connecting Punjab and Khyber Pakhtunkhwa is also located in Ambar village.

The district Swabi is famous for natural resources and Gadoon Industries which play a vital role in economic growth of Pakistan. The total area of this district is 1,543 square Kilometers and geographically it is bounded by Buner district, Haripur district, Attock district of the Punjab Province, Nowshera and Mardan districts in the North, East, South and West respectively. District Swabi is also famous for two mega hydropower projects i.e. Tarbela dam (one of the biggest dams of the world) and Ghazi Barotha (a foreign funded project). These hydropower projects are the back-bone of Pakistan economy and their canal systems irrigates agricultural lands of surrounding areas.

The stratigraphy of the Swabi and adjacent areas has been subject of consistent research since early sixties. Martin and other (1962) subdivided the rock sequence of the northeastern Peshawar basin into "Swabi-Chamla Sedimentary Group" and "Lower Swat-Buner Schistose Group". Davis and Ahmed (1963) described orthoconic nautiloids from the hills, south of Swabi indicating a Paleozoic age. Teichert and Stauffer (1965) made the first discovery of Siluro- Devonian reef rocks near the town of Nowshera. Stauffer (1968a) described the reef complex and also reported other probable localities of Paleozoic rock from northern Pakistan.

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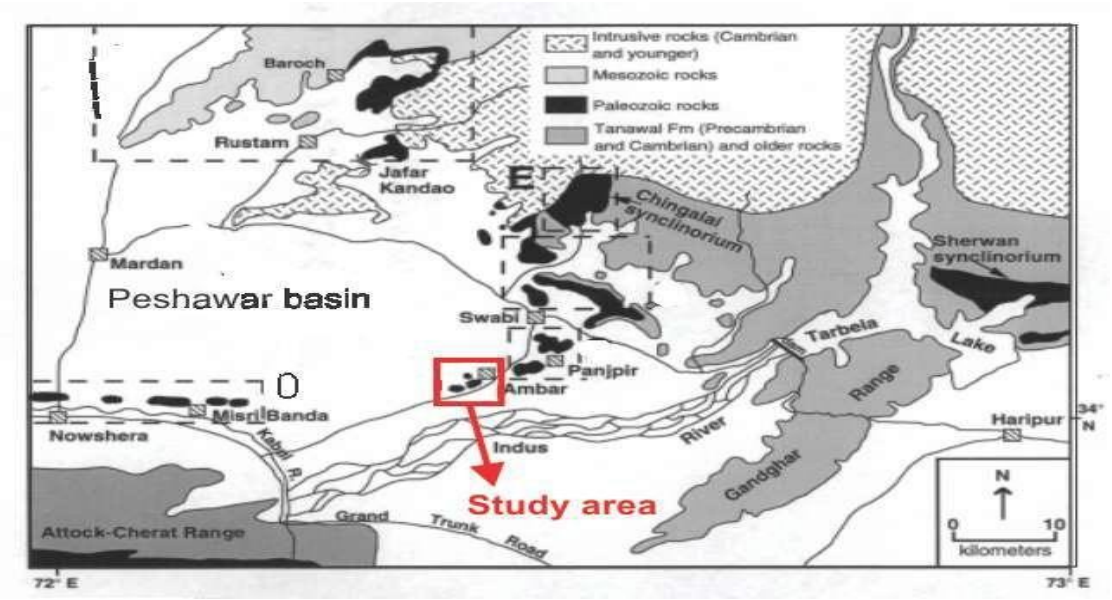


Figure 1. Modified geological map of Eastern Peshawar basin of Northern Pakistan. (Husain et al., 1991) (Box in the map represents the study area).

Ali and Anwar (1969) described the stratigraphy of the Nowshera reef complex. Latif (1970) collected corals from the Nowshera Formation at Pir Sabak hillock and suggested the possibility of Carboniferous age. Fuchs (1975) described the stratigraphy of rocks exposed near Swabi and Nowshera area. Pogue and Husain (1986) established a revised stratigraphy and modified the previous stratigraphic nomenclature of the southern Peshawar basin based on systematic geological mapping and discoveries of trilobite trace fossils of Early to Middle Ordovician age. As a result of their work the revision of stratigraphy of Peshawar basin became apparent. To establish the stratigraphic and structural setup, the area was remapped and fossiliferous horizons were sampled. Bulk samples from the rocks units were also processed for conodonts studies. Davies and Ahmed (1963) reported orthoconic nautiloids from the Kala Limestone to the south of Swabi and assigned it a Silurian-devonian age.

Table 1. Observed stratigraphy of field area.

Rock Formations	Lithology	Description
Amber Formation (Cambrian Age)	Dolomite, dolomitic limestone, calcareous quartzite and subordinate argillite and chert	The dolomite contains algal laminations and poor development of stromatolites. Chert in the form of veinlets, nodules and stringers are found at some places. The formation has not revealed any fossils except microscopic shell debris in the interstices of pisoliths from Ambar section.
Tanawal Formation (Pre- Cambrian Age)	Quartzitic sandstone, quartzitic schist, quartzite and schistose conglomerate.	The quartzitic sandstone, quartzitic schist and quartzite are thin to thickly bed. Occasionally massive beds. Grey, Yellowish brown and pinkish brown and white to cream colours are quite conspicuous. The formation is unfossiliferous

II. Methodology

The methodology for current research comprises of field and laboratory work.

Fieldwork

The field work was conducted to Ambar section of Swabi district. The field work was comprised of logging of section by measuring tape. The sedimentary and field features were covered by taking snaps at different location in the studied area. The selected and representative field photographs are included in this research work for the better understanding of geology of the Ambar Formation.

Laboratory work

Laboratory work comprises of making thin sections from the selected samples taken from the outcrop and detailed petrographic study under polarizing microscope.

Thin Section Preparation Method

The following steps are involved in the preparation method.

Rocks sample collection.

Trimming of rock sample with large diamond saw.

- Cut rectangular slabs with small diamond saw.
- Mark on one side of the rectangular slab and impregnate the other side with epoxy.
- Grind away epoxy with (400) grit.
- Frost the glass slide on one side.
- Stick the slab with the frosted glass slide and put it on the hot plate for few hours.
- Label the unfrosted side of the glass slide with diamond scriber.
- Trimming off the slab from glass slide using chip trim saw.
- Grind the slide to the correct thickness using the grind Machine

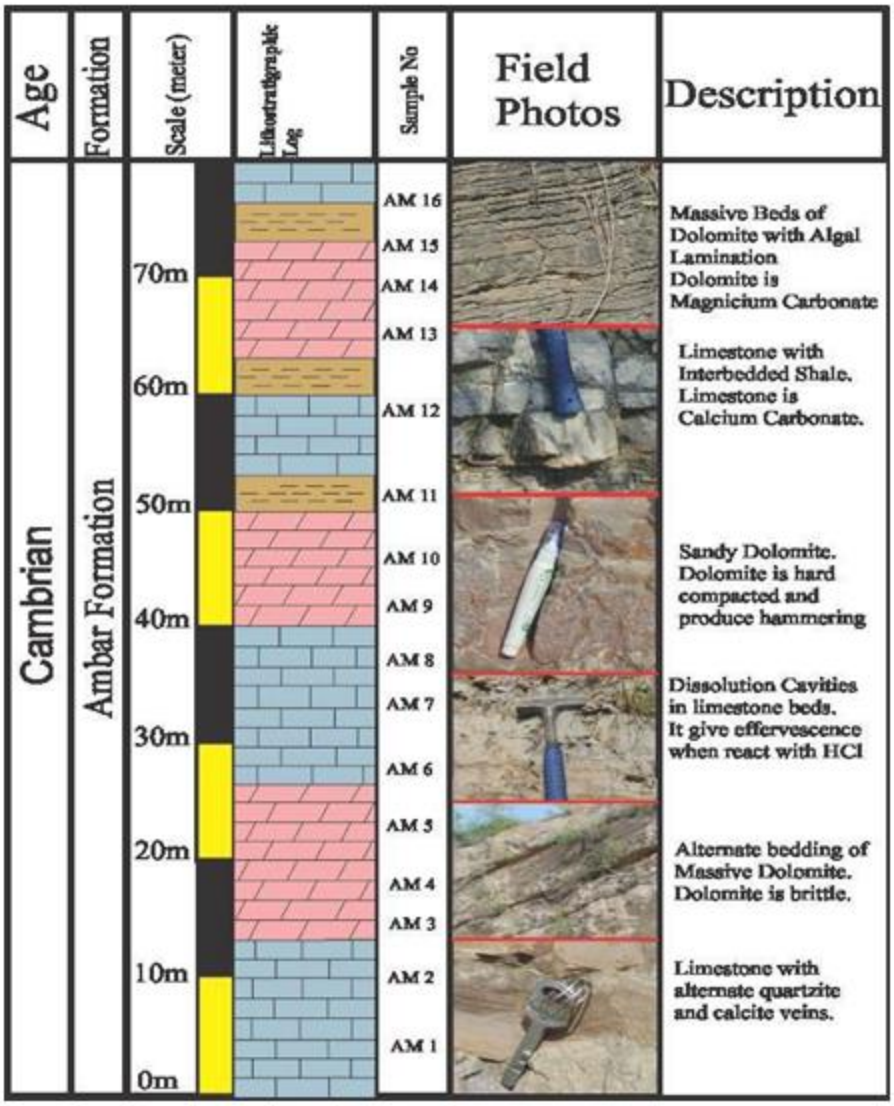


Figure 2. Lithological log of Ambar Formation (Peshawar Basin)

Section Measurement

This part of study is important to get information about the thickness of different beds of the Ambar formation in selected geological section (Ambar Village). The methods employed in measuring section in sedimentary rocks were determined by standard procedure mentioned in literature. Details of the various procedures are given by Compton (1986) and Tucker (2003). Regarding this a total of 70 meter section of Ambar Formation was measured through measuring tape along the metallic road to the main campus of University of Swabi and 16 rock samples were collected.

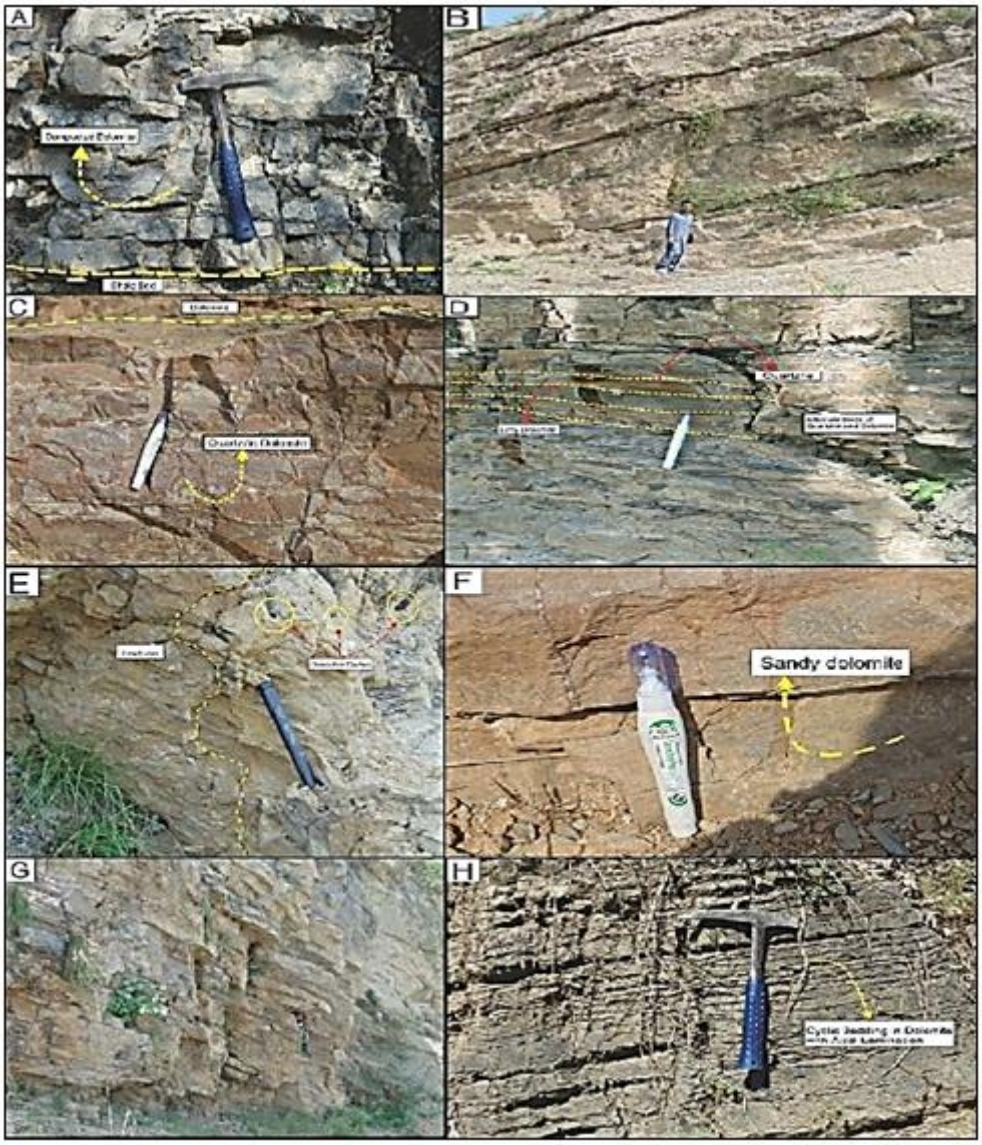


Figure 3. Field photograph showing (A) Hard and compacted dolomite with shale beds (Geological hammer for scale). (B) Field photograph showing field view of sandy part of Ambar formation. (C) Massive beds of hard and compacted quartzitic dolomite (white marker for scale). (D) Alternate beds of quartzite and limy dolomite (white marker for scale). (E) Fractures and dissolution cavities in dolomite. (marker for scale). (F) Sandy dolomite (lower part of Ambar formation). (white marker for scale). (G) Measured section of Ambar formation. (H) Cyclic bedding in dolomite with algal lamination. (Geological hammer for scale).

Microacie Analysis of Ambar Foramation

Dolomite and dolostone, the words used synonymously is a mineral chemically between calcite ($CaCO_3$) and magnesite ($MgCO_3$). Dolomite is a pure carbonate mineral forming through different mechanism like primary precipitation from marine water, diagenetic or by hydrothermal replacement but all these requires sufficient supply of magnesium, permeability and also the mechanism which facilitates the fluid flow as well. In past it was the concept about dolomite that this mineral precipitates in metamorphic conditions but extensive study throughout the world proved that dolomite is formed and deposited in sedimentary environments. The distribution of dolomite is uneven i.e. abundant in Pre-Cambrian and decreases gradually from Paleozoic through Cenozoic (Chilingar , 1956; Ronov, 1964).

The story of understanding dolomite in carbonate rocks is very complex due to the wide variation of dolomitization in the stratigraphic record, but two major types of dolomite; primary and secondary are known because of their diagnostic criteria on both outcrop level and petrographic study. Dolomite may form in a variety of depositional environments like marine, lacustrine, lakes and on or beneath the shallow sea floor. In such settings the bacterial metabolism may precede the process of precipitation where sulfate reducing bacteria

flourish and microbial activity may control primary precipitation in some hypersaline anoxic lake settings (Warren, 2000). For detailed interpretation of depositional environment, the study of size and shape of carbonate grains constituents, cementing material, allochems and fauna and flora types is very important through petrographic investigation.

In case of dolomite, there are number of crystal forms, fabrics and mosaic like pattern, but most of the time diagonostic forms also occur like pseudomrphs of calcite and aragonite. Dolomite may be destructive to retentive and selective to pervasive. Some of the factors involved are; original mineralogy, crystal size and timing of dolomitization and nature of dolomitizing fluids (Tucker, 1990).

III. Results

Sixteen (16) numbers of thin sections were studied in detail from Ambar Formation, Ambar near M1 motorway Swabi interchange exit. The thin sections having similar features like allochems, diagenetic features, cementing materials, shape, size and crystals of dolomite and micritization were grouped in one microfacie. The standard classification of Wright 2004, Dunham 1962, Folk 1959 and Sibley & Gregg 1987 were used for the classification of the studied thin sections.

Microfacies of the Ambar Formation

Following the above methodology, 16 selected thin sections from Ambar Formation of Cambrian age exposed in the north-eastern Peshawar basin were studied in details for petrographic investigations. The following microfacies in Ambar Formation (MAF) are identified;

- MAF-1 Fractured, silicified, Micritized Mudstone Microfacie
- MAF-2 Dolomitized, Peloidal, Ooidal Packstone Microfacie
- MAF-3 Laminated Sandy Dolomitic packstone-grainstone Microfacie

MAF-1 Fractured, silicified, Micritized Mudstone Microfacie

Outcrop Description

This Microfacie is comprised of massive limestone representing the lower part of Ambar Formation. This unit is highly fractured and has rusty color on weathered surface while light grey to dark grey color on fresh surface. The dissolution phenomenon is very common in the form of solution cavities. Using hand lens, the grain size ranges from fine to medium grained.

Petrographic Description

In this Microfacie angular to sub angular grains of quartz occur disseminated in the rock constituting~ 3% of constituent grains. Partial to complete silicification have been observed represented in the form of micro and macro quartz. Furthermore, mud is present as a cementing material which constitutes 60-70% of this Microfacie which is later on converted into microsparite. The phenomenon of Micritization is common as well on allochems which is manifested by the alteration of allochems into fine micrite through the boring activity of endolithic algae (Flugel, 1982). Similarly, fractures filled with spary calcite are also dominated in this Microfacie. On the basis of the high amount of mud as a cementing material, according to Dunham 1962 and folk 1959 this Microfacie is named as Fractured, silicified, Micritized Mudstone Microfacie.

Environmental Interpretation

Due to devoid of fossils e.g. benthonic and planktonic, it is suggested that the Microfacie is deposited in the low energy condition e.g. lagoonal setting. This argument is further supported by the micritization in mud; the micritization is mostly take place in low energy condition. In micritization, the algae boring on the surface of allochem which is later on filled by lime mud. So on the bases of these petrographic features and after comparison with standard Microfacie of

Flugel and Wright 2004, this Microfacie is same like SMF 23 and RMF 19 and the environment is suggested as low energy conditions i.e. Lagoonal setting.

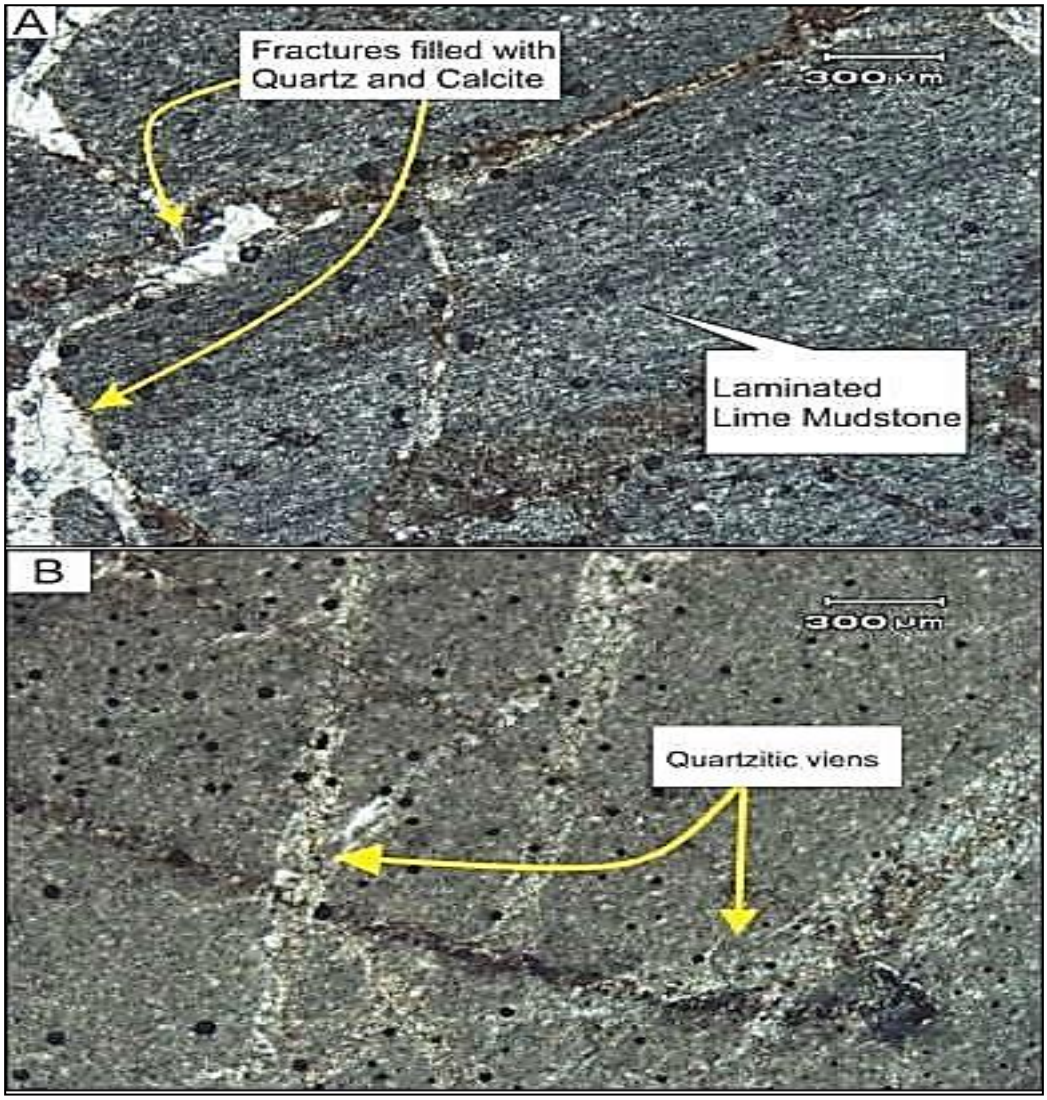


Figure 4. Showing the details of Fractured, silicified, micritized Mudstone Microfacie (MAF-1) (A) Fractures filled with quartz and spary calcite. The laminated Mud is present in the ground mass. (B) Multiple fractures filled with quartz. The iron leaching phenomenon is also seen across the vein. (XPL)

MAF-2 Dolomitized, Peloidal, Ooidal Packstone Microfacie

Outcrop Description

In outcrop this Microfacie is dominated by massive beds of dolomite greyish in color.

Similarly, quartz veins and argillaceous dolomite are present in cyclic sequence in Ambar Formation in this portion.

Petrographic Description

The phenomenon of dolomitization is very common in this Microfacie. Dolomite grains are fine to medium grained, anhedral to sub-hedral (hypidiotopic), having suture as well as point to point contacts. In some places the rhombs of dolomite have been micritized lacking internal structure. The elongated flakes of muscovite are randomly distributed throughout thin sections which show the continuous clastic input. Peloid constitute 40 to 45% of this Microfacie ranging in size from 0.5mm to 1mm. Uniformity in grain size and and partially preserved internal structures indicate that these peloids are fecal in origin. T he third dominant constituent after dolomite and peloid are ooids which constitute~15% of the rock and have micritized up to some extent. The pressure dissolution phenomenon is well displayed in the form of stylolites which are filled with iron oxdes. Moreover, some of these stylolites are characterized by the accumulation of authegenic mineral which forms the stylolitic seams. These stylolites resulting from pressure solution process causes a strong reduction in a rock bulk volume which finally resulted loss in porosity due to diagenetic phenomenon of

cementation (Wong and Oldershaw 1981).

Environmental Interpretation

This Microfacie is represented by abundance of siliclastic input which manifests high energy condition dominated by strong agitated waves and currents. Such discussion leads to the inner ramp settings which is the initial stage providing Mg rich solution for dolomitization. According to the depositional environment for dolomite deposition supratidal to subtidal setting is more appropriate for this Microfacie.

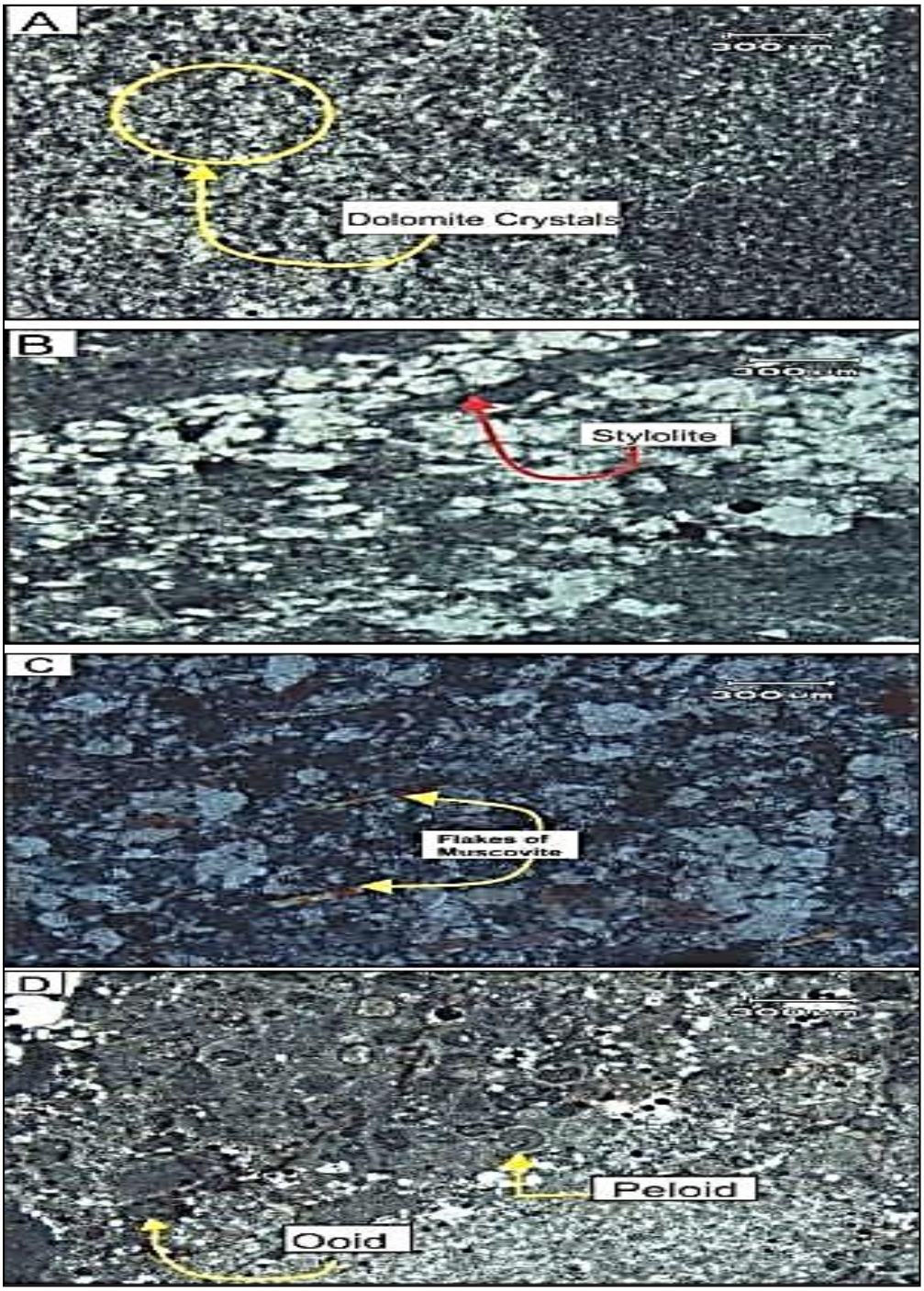


Figure 5. Photograph showing Dolomitized, Peloidal, Ooidal Packstone Microfacie. (A) Crystals of dolomite having suture and point to point contacts (XPL). (B) stylolite (C) Flakes of muscovite showing detrital nature (D) Ooid and Peloid

MAF-3 Laminated Sandy Dolomitic Packstone-Grainstone Microfacie

Outcrop Description

In outcrop this Microfacie is dominated by grey color sandy dolomite with continuous rhythmic bedding of limestone. Butcher chop weathering is well displayed on the exposed outcrop in Ambar Formation. The fractures are preserved in the rocks represents the tectonic deformation in the area.

Petrographic Description

Quartz is the major proportion of this Microfacie showing undulose extinction in cross polars. The quartz grains are detrital in nature having anhedral to sub-hedral shape constitutes

approximately 5 to 8% of the rock volume. The grains of dolomite are unzonned and showing pervasive dolomitization. The grains of dolomite have sharp grain to grain contacts. Laminated mud is recorded in this Microfacie showing the silty nature which is very fine grained. Muscovite is present as elongated flakes randomly distributed throughout this rock unit of Ambar Formation. The presence of iron leaching indicates the scenario of sub-aerial exposure to the oxidizing environment.

Environmental Interpretation

The presence of micaseous mineral (muscovite) and detrital quartz (rounded to sub rounded) indicates the fluvial influx which is further encouraged by the alternate layering of silty material in this rock. Based on these observations and rounded nature of quartz grains high energy near shore transitional marine setting is interpreted in the form of supra-tidal environment.

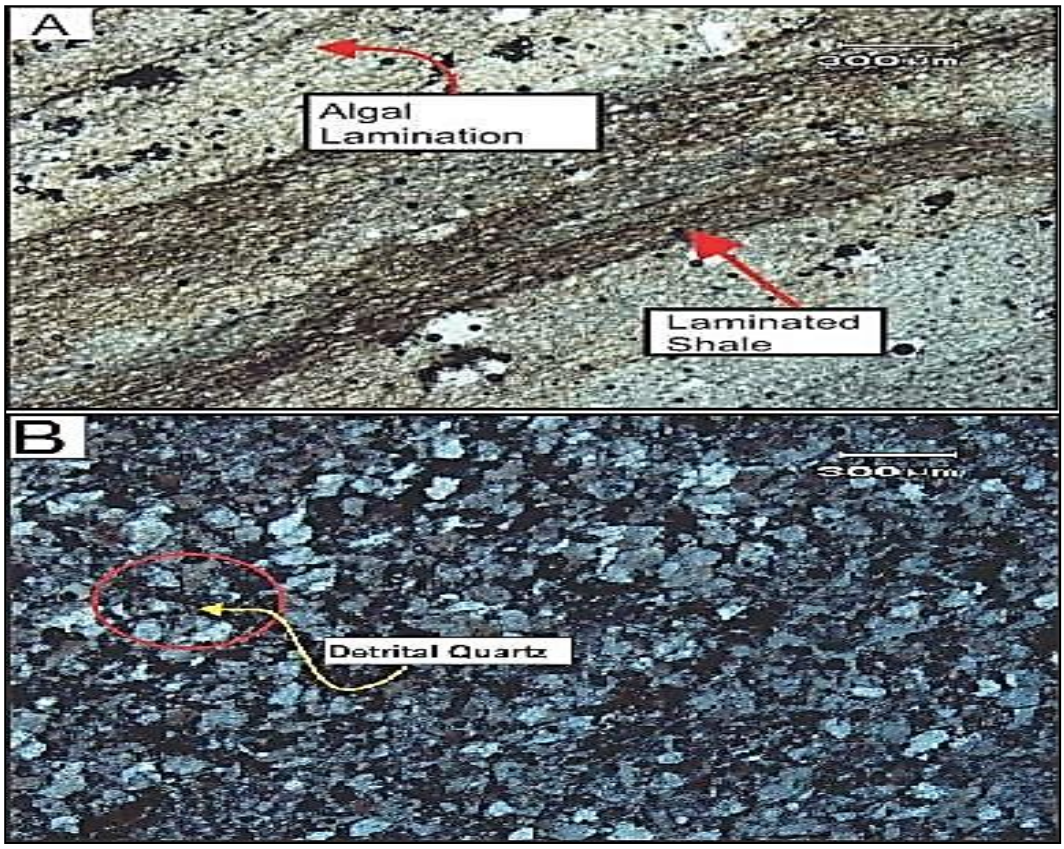
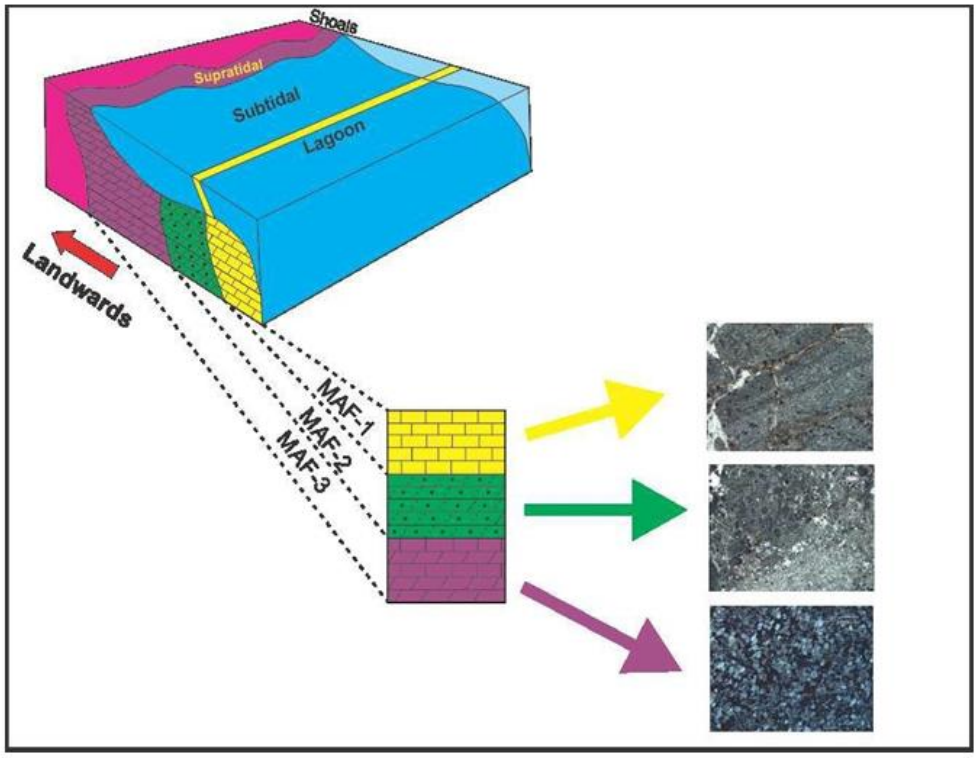


Figure 6. Photomicrograph showing Laminated, Sandy Dolomitic packstone-grainstone Microfacie (A) Algal lamination and laminated shale representing clastic input. (B) Detrital quartz grains having rounded to sub-rounded nature (XPL).



Depositional Environments of Ambar Formation

The study rocks, representing part of the Cambrian Ambar formation elucite deposition in a carbonate dominated, transitional to inner shelf environment. The interpretation is based on Microfacies identification and their vertical succession in the study outcrop. The lagoonal setting is indicated by the presence of restricted faunal and floral assemblages, which is further supported by micritization in mud which take place in low energy condition. The supratidal to subtidal setting is supported by siliclastic input which manifests high energy condition, which leads to the inner ramp setting. The transitional marine setting is interpreted in the form of supratidal environment is supported by micaceous mineral and detrital quartz further encouraged by the alternate layering of silty material. In such a carbonate setting local variation in topography, dissolution cavity, stylolites, micratization, quartzitic and calcitic veins is a common phenomenon. The changes in energy conditions are marked by stratigraphic variation from mudstone to packstone, textural types along with constituent grains in various microfacies. (Figure 3.4) Figure 3.4 Schematic depositional model for Ambar formation showing sub-environments with their respective microfacies.

IV. Discussion

The Cambrian age has been assigned to the Ambar Formation by Pogue and Hussain (1986) which as declared its stratigraphic position in the Peshawar Basin. The present work is mainly focused on petrography of the Ambar formation for the interpretation of Ambar Formation. In the petrographic study major minerals observed under microscope were dolomite, calcite, mica(muscovite) and quartz. Similarly pyrite and magnetite are also observed in the Ambar formation. The most important detrital constituent of Ambar Formation is quartz which ranges up to 70% at different stratigraphic levels. Dolomite rhombs are mostly idiotopic to hypidiotopic which is favored by temperature range 25-50 °C (Sibley & Greeg, 1987). From the previous work and petrographic study there is gradual change in lithology from the lower part of the formation towards the upper parts. The lower part is mostly quartzitic to limy dolomitic, with prominent clastic input of siliceous materials. The lower part of the study unit is represented by algal lamination and poorly preserved stylolites. The upper part is purely dolomite having butcher chop weathering, dissolution cavities, quartz and calcite filled fractures. The Ambar formation is undergone through various diagenetic episodes. The different diagenetic features are studied in thin sections i.e, stylolites, fractures, joints, mechanical compaction, development of spar and iron leaching in the diagenatic sequence of dolomite, the stylolites, mechanical compaction and bimoldic porosity usually developed at shallow depth and fracturing developed at deeper depth (Loucks and Longman, 1982). The presence of poor algal stromatolite, presence of relic features of limestone, chert and selective to pervasive dolomatization indicates secondary nature of Ambar Formation.

V. Conclusion

- This study is based on field and petrographic data obtained along M1 motorway Swabi interchange, which provide limited exposure of the Tanawal quartzite (Pre-Cambrian) and extensive Ambar dolomite (Cambrian) respectively.
- A stratigraphic section of 70 meters of Ambar formation is studied in detail during the current research.
- Ambar dolomite is composed of light grey, medium to massive bedded dolomite, dolomitic limestone, sandy dolomite and lack flora and fauna.
- In this study, three microfacies identified include, (1) Fractured, silicified, Micritized Mudstone Microfacie (2) Dolomitized, Peloidal, Ooidal Packstone Microfacie (3) Laminated Sandy Dolomitic packstone-grainstone Microfacie
- The Ambar dolomite is interpreted to have been deposited in a carbonate dominated, transitional to inner shelf environment.
- The digenetic changes recognized in the dolomite include calcite to aragonite transformation, dissolution cavaties, calcite filled fractures and quartz filled fractures, stylolites, micritization, dolomitization and silicification.

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