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Microfacies analysis and depositional environment of the Cambrian Ambar Formation, Peshawar Basin, Pakistan

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Abstract

The Cambrian Ambar Formation is composed of massive dolomite, dolomitic limestone, limestone, quarzitic dolomite, and sandy limestone. It is exposed in the Swabi and Turlandi areas, the northeastern part of the Peshawar Basin. The present study deals with the sedimentological and petrographical aspects of the Ambar Formation. Algal laminated beds, dissolution cavities, chop-board weathering, stylolites, quartz, and calcite filled fractures together with open fractures are prominent in the outcrops. Based on microscopic studies, three microfacies are identified: (1) Siliciclastic Mudstone Microfacies (MF-1), (2) Dolomitic Packstone Microfacies (MF-2) and (3) Dolomitic Packstone-Grainstone Microfacies (MF-3) without taking consideration of the lithofacies in a single outcrop exposed in the studied section. The integration of the outcrop and petrographic observations indicate transitional to inner carbonate shelf setting ranging from supratidal to lagoon during the deposition of the Ambar Formation.

Keywords: Cambrian; Ambar Formation; Microfacies; Inner Shelf

1. Introduction

The stratigraphy of the Peshawar Basin is comprised of Neoproterozoic to Silurvian age rocks. The studied strata are least focused on previous works in the context of sedimentology, biostratigraphy, and sequence stratigraphy (Martin et al., 1962; Stauffer, 1968; Pogue and Hussain, 1986; Shah, 2009). The Ambar Formation exposed in the Peshawar basin has been described in the context of stratigraphy (Stauffer, 1968; Pogue and Hussain 1986; Martin et al., 1962; Shah, 2009). (Stauffer (1968) has briefly explained the lithology of the Ambar Formation exposed near the Turlandi area. Martin et al. (1962) mentioned the outcrop of the Ambar Formation in the "Kala Limestone and Dolomite". According to Shah (2009) and present researchers the studied stratigraphic units are comprised of dolomitic limestone, dolomite, calc quartzite with occasional argillite. Chert is also reported as veinlets and nodules within the formation. Dolomite is characterized by algal laminations and stromatolites at the outcrop level. In Swabi area underlying contact between the Ambar formation and Tanawal Formation is unconformable while the overlying contact of the Ambar Formation is also unconformable with the Misri Banda Quartzite in the form of maroon colour shale. The formation is devoid of fossils except debris of microscopic shells within the pisoliths interstices from the Ambar section (Shah 2009). According to Hussain et al. (1991), the Ambar Formation has been assigned the Cambrian age because of its stratigraphic position. The depositional setting of the Ambar Formation is not addressed by any previous work in the past, so the present research work focused on carrying out detailed petrographic analysis in order to present a reliable depositional setting of the Ambar Formation in the Peshawar basin.

1. Geological Setting

The present study investigates Ambar Formation of Cambrian age exposed in Ambar Village, Swabi area of the Peshawar Basin (latitude 34º 03' 02" N; longitude 72º 24' 46" E; Fig. 1).
The field study describes the stratigraphic unit as dolomitic limestone, dolomite, calc quartzite with minor argillite and chert nodules. The dolomite is associated with algal laminations and stromatolites. So, based on the stratigraphic position the Cambrian age is assigned.

Multiple tectonic episodes can be adopted for stratigraphic succession and sedimentology of the Peshawar basin. Erosion of the Ambar Formation, its deposition as a conglomeratic bed at the base of Misri Banda Quartzite, and siliciclasts of the underlying Tanawal Formation represent the late Cambrian events in the region. Quartzitic lithology of the Misri Banda might characterize the erosional products of plutonic felsic rocks which are associated with intrusion of the Precambrian Mansehra Granite (Le Fort, 1975). Tectonics of the Late Cambrian to Early Carboniferous events tell that the sediments deposited in the Peshawar Basin occasionally from regions to the north and gradually eroded craton to the south.

2. Materials and Methods

Current research is based on the study of laboratory analysis and field work. The variation in color, texture, fossil content and lithology are used to collect rocks samples for petrographic analysis. The stratigraphic thickness of the studied formation is measured as per standard procedure with the help of Jacob's Staff (Prothera and Schwab 2003; Fig. 2). The total thickness of the studied strata is approximately 70 meters (Fig. 2). Besides the measurement of the stratigraphic thickness, the field photographs are taken on a high-quality camera (Plate 1A-H).

A total of sixteen thin sections were prepared and analyzed under a polarizing microscope. The studied samples are classified according to the standard classification schemes of Dunham (1962) and Sibley and Gregg (1987). The developed local microfacies types are compared with the standard works of Wilson (1975) and Flugel (2004).

3. Results and Discussion

Three microfacies e.g., siliciclastic mudstone microfacies (MF-1), dolomitic packstone microfacies (MF-2), dolomitic packstone-grainstone microfacies (MF-3) in the Ambar Formation are recognized.

3.1. Siliciclastic Mudstone Microfacies (MF-1)

3.1.1. Outcrop Description

The MF-1 represents the basal part of the Ambar Formation. This thick-bedded limestone is characterized by fractures and rusty appearance on weathered exposure whereas light to dark grey colour on a fresh outcrop. Similarly, pressure dissolution results in solution cavities within the limestone unit. The limestone units appeared in outcrops as fine to medium grained. The bedding is rarely showing any sort of sedimentary structure, fossils assemblages, and other depositional or paleo-climatic indicators (Plate 2A-B, Fig. 2).

3.1.2. Petrographic Description

Lime mud is present as cementing materials which range in percentages from 60-70% while some of the micrites are converting into

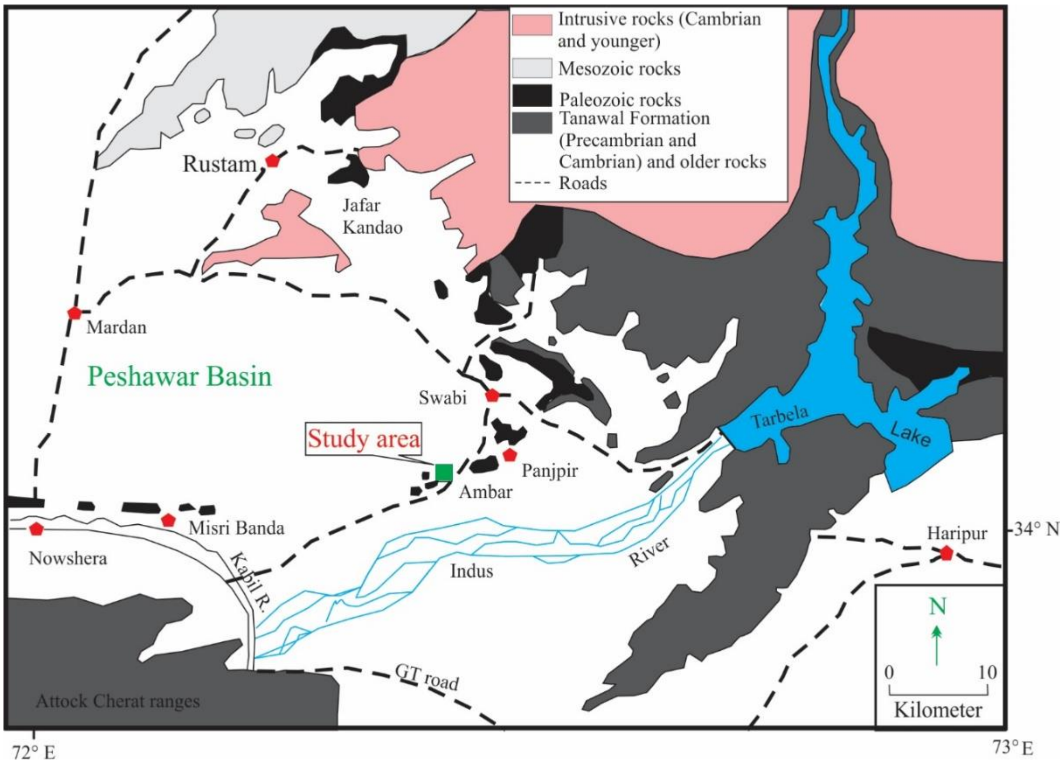

Fig. 1: Generalized geological map of eastern Peshawar Basin, northern Pakistan (Hussain et al., 1991). The study area is marked with a green square.

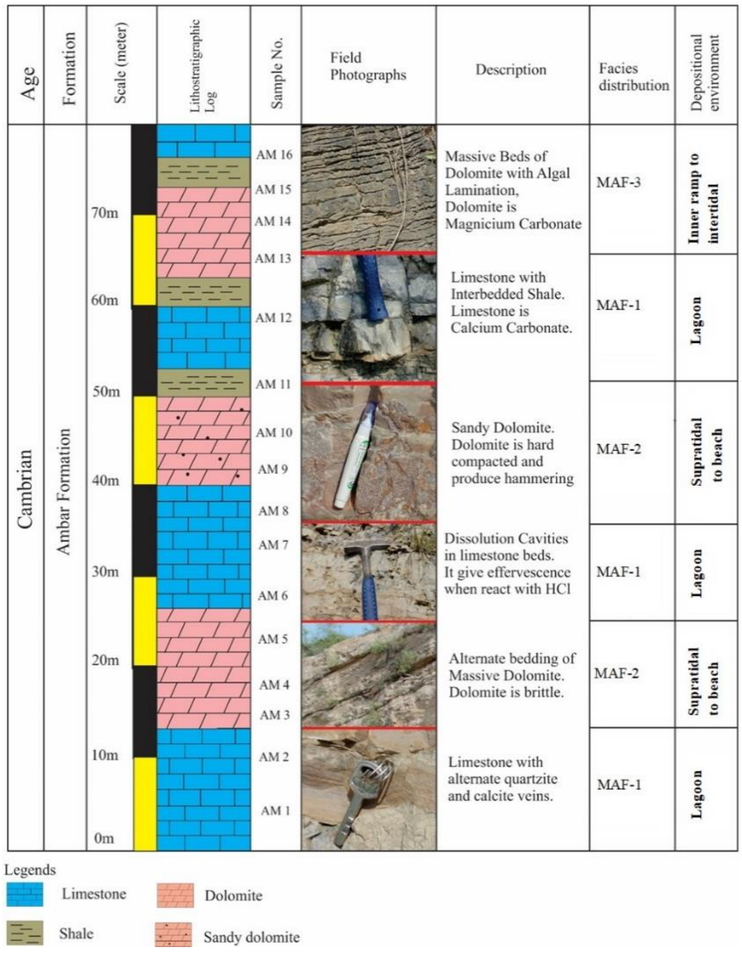

Fig. 2: The lithological log of the Ambar Formation in the Peshawar Basin.

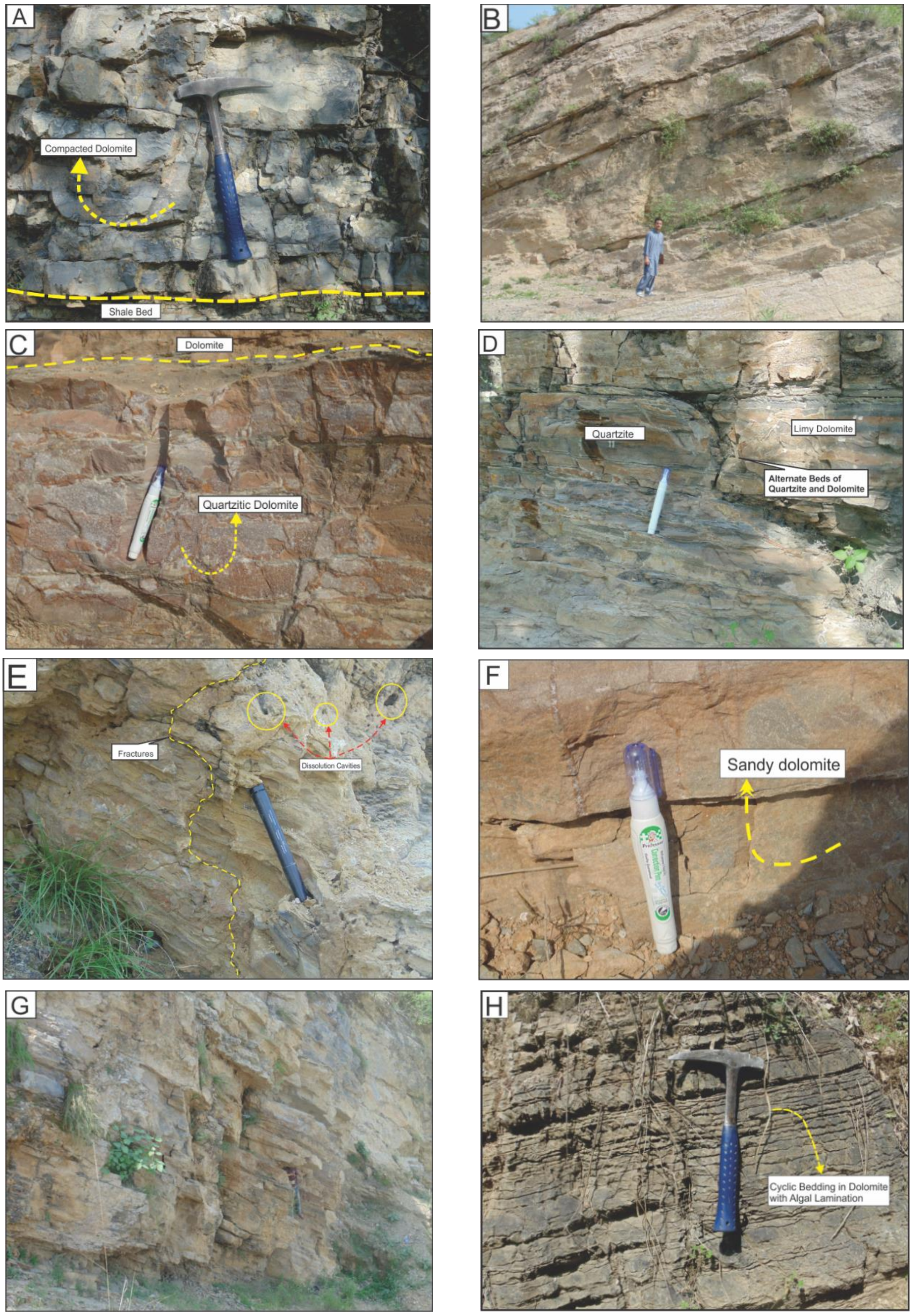

Plate 1: Field photographs show (A) Compact dolomite having interbedded shale (geological hammer for scale); (B) Sandy part of the Ambar Formation; (C) Massive bedded and compact quartzitic dolomite (whitener for scale); (D) Alternate beds of limy dolomite and quartzite (whitener for scale) (E) Meso-fractures and solution cavities within dolomite (a marker for scale); (F) Sandy dolomite beds (lower part of the Ambar Formation), whitener for scale; (G) Measured outcrop of the Ambar Formation; and (H) Rhythmic/Cyclic bedding in dolomite with algal laminations (geological hammer for scale).

microsparites (Plate 2A). The lime mud shows internal arrangements in the form of lamination. Besides this, quartz occurs as angular to sub-angular disseminated grains which constitute ~3% of the rock volume. Further, partial-complete silicification has been noted in the form of micro quartz (Plate 2B). The micritization phenomenon is common which is revealed by the modification of carbonate components (allochems) into micrite through endolithic algae (Flügel, 1982). On the basis of the presence of mud, these microfacies are named siliciclastic mudstone microfacies.

3.1.3. Environmental Interpretation

The MF 1 is devoid of known skeletal and non-skeletal allochems, while a low percentage of detrital grains are present. The absence of allochems, the presence of micritization, and internal lamination indicate a low-energy restricted condition of the high saline geochemical setting. Micritization is the process associated with the boring activity of algae on the allochem surface which is later on filled by lime mud. This phenomenon mostly takes place in low-energy conditions. So, based on these microscopic features, the interpreted depositional settings are low energy lagoons. The lagoon setting is also supported by the microfacies correlation with Standard Microfacies (SMF) 23 of Wilson (1975) and Flügel (2004).

3.2. Dolomitic Packstone Microfacies (MF-2)

3.2.1. Outcrop Description

In outcrop, the MF-2 is dominantly composed of massive beds of greyish dolomite. The dolomite is showing a rhythmic appearance of quartz veins and argillaceous materials (Plate 3A-D; Fig. 2).

3.2.2. Petrographic Description

MF-2 is a mostly prevailing dolomitization phenomenon. Dolomite crystals are fine to medium grained, anhedral-subhedral, and have suture contacts (Plate 3A). Occasionally, the dolomite rhombs have been micritized and devoid of internal structure (Plate 3A, B). The elongated muscovite flakes are distributed randomly throughout thin sections which indicate the continuous clastic input. Peloids are ~0.5mm to 1mm in size and constitute 40 to 45% of this microfacies (Plate 3D). Approximately uniform grain size and partially preserved structures within the peloids show that they are fecal in origin.

Ooids are the third dominant constituents that make up ~15% of the total rock volume and have been micritized up to some extent. Stylolites are also observed which are filled by iron oxides (Plate 3B). In some cases, the documented stylolite is characterized by the precipitation of authigenic minerals (iron oxides) forming stylolitic seams (Plate 3B). This Chemical compaction process causes a strong reduction in rock bulk volume, the thickness of sediments, porosity, and permeability (Wong and Oldershaw 1981; Tucker and Wright 1990 and Flugel 2004).

3.2.3. Environmental Interpretation

This microfacie represents the feature of high energy conditions such as siliciclastic input and ooids. According to Flugel (2004), ooids are important ancient environmental proxies for marine water energy, hotness/warmness, salinity, and water depths. The formation of ooids needs a high-level super-saturation with respect to Ca and CO_3 ions, the presence of nuclei, and high energy agitated conditions (Flugel, 2004). A close relationship existed between ooids formation and water depth. The ooids are formed in shallower water having a higher level of agitation (Jon, 2007). It is commonly believed that most ooid deposits originate in shallow water conditions which are regularly disturbed and agitated over a long time by tides, waves, and/or currents (Flugel, 2004). The presence of siliciclastic input and non-skeletal allochems ooids represent high energy conditions dominated by strong agitated waves and currents. While the existence of dolomite and associated peloids represents a supratidal condition. So, the interpreted geologic setting is shallow ranges from supratidal to beach area.

3.3. Dolomitic Packstone- Grainstone Microfacies (MF-3)

3.3.1. Outcrop Description

The MAF-3 is represented by samples AM 14, 15, and 16. While at the outcrop level these microfacies are dominated by grey coloured sandy dolomite with regular bedding of limestone. The dissolution cavities and butcher chop weathering are well documented in the Ambar Formation. Fractures observed in the studied rocks represent tectonic deformation in the region (Plate 3 A-B; Fig. 2).

3.3.2. Petrographic Description

The MAF-3 is represented by detrital sedimentary particles and the presence of pervasive dolomitization. Detrital sediments are represented by quartz and micas (Plate 4A). The quartz grains are anhedral to sub-hedral (Plate 4A, B) and constitute approximately 5 to 8%. Besides detrital grain and dolomite crystals, thin mud lamination is also noted in this microfacies. The mud is silty and fine grained in nature. Muscovite flakes are present

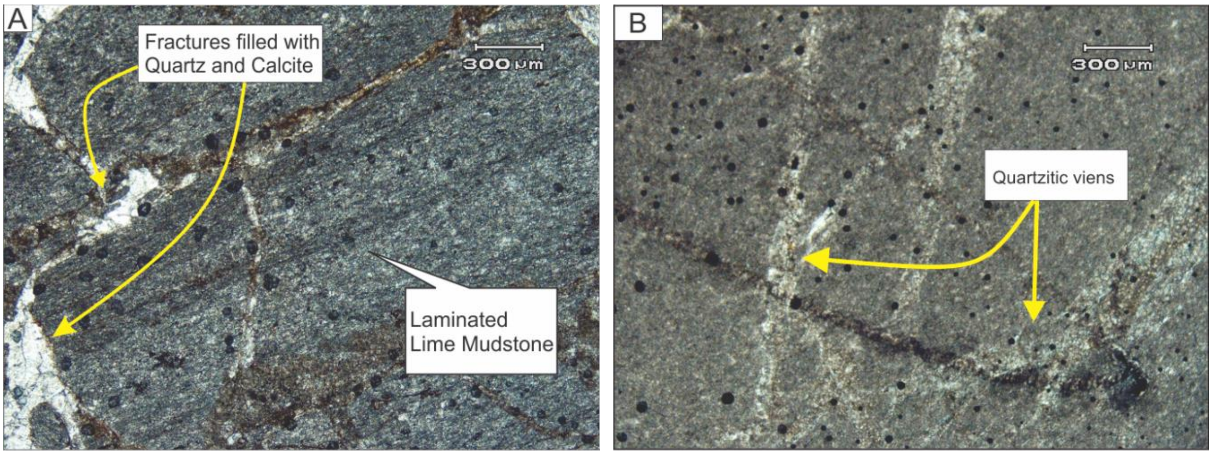

Plate 2 (A-B): Photomicrographs illustrating the details of Siliciclastic Mudstone Microfacies (MAF-1); (A) Fractures are filled with quartz and sparry calcite while the groundmass contains the laminated mud; and (B) Multiple quartz filled fractures (cross-polarized light).

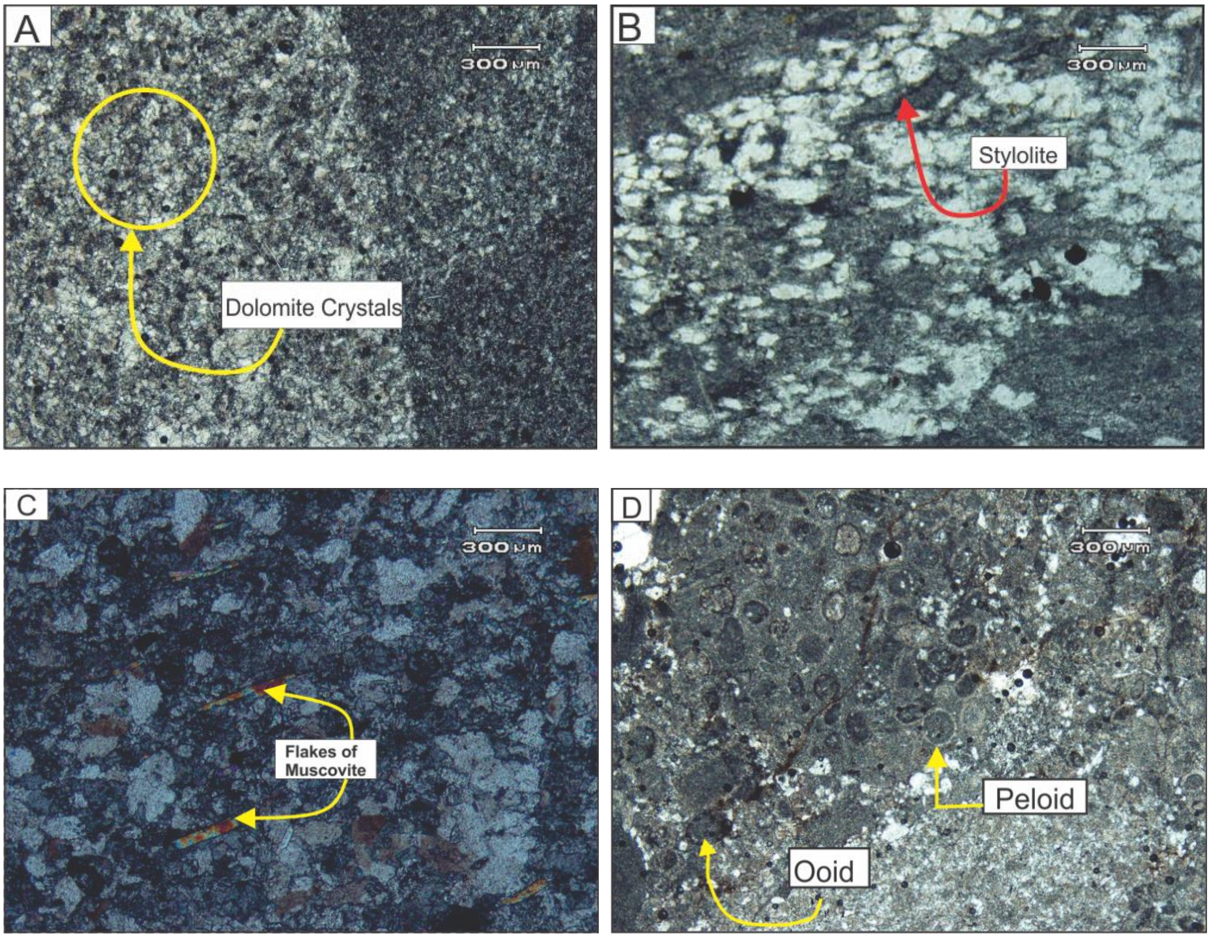

Plate 3 (A-D): Photographs illustrating Dolomitized, Peloidal, Ooidal Packstone Microfacies (MAF-2); (A) Dolomite crystals having suture contacts (Cross Polarized Light); (B) Muscovite flakes showing detrital nature; (C) stylolite; and (D) Ooid and Peloid.

and randomly disseminated throughout the exposed unit of the Ambar Formation (Plate 3C). Further, the iron leaching observed under the polarizing microscope shows oxidizing geologic conditions due to sub-aerial environmental exposure.

3.3.3. Environmental Interpretation

The occurrence of flaky mineral and clastic quartz shows the fluvial input, supplemented by alternate layers of silty material in this rock. On the basis of these results and rounded behaviour

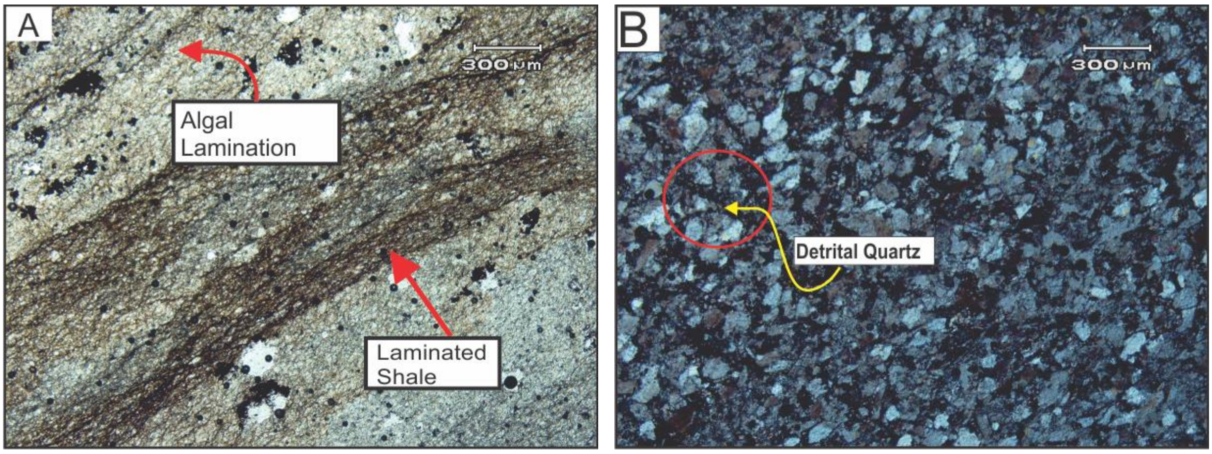

Plate 4 (A-B): Photomicrographs showing Laminated, Sandy Dolomitic Packstone-Grainstone Microfacies (MAF-3); (A) Algal lamination and laminated shale representing clastic input; and (B) Detrital quartz grains having rounded to sub-rounded nature (Cross Polarized Light).

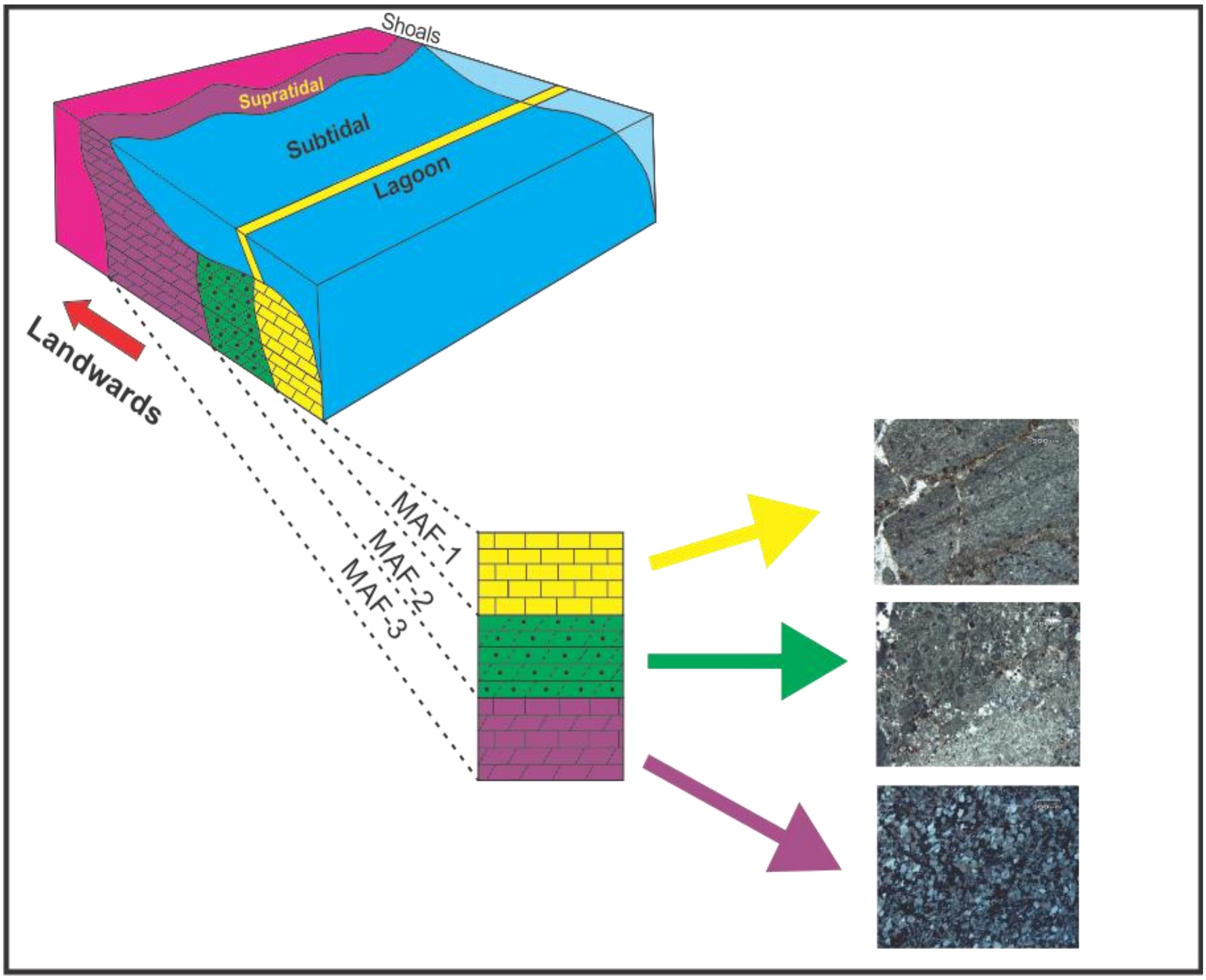

Fig. 3: Schematic depositional model for the Ambar Formation showing sub-environments with their respective microfacies.

of quartz grains, high energy near shoreline marine setting is interpreted as the depositional environment (Boggs 1995), while the presence of algal lamination and silty grain may range from subtidal (inner ramp) to intertidal settings (Scholle and Ulmer-Scholle 2003).

3.4. Depositional Model

The depositional model representing depositional setting for the Cambrian Ambar Formation is comprised of transitional to nearshore inner shelf environment. This interpretation is grounded on microfacies studies under the polarizing microscope and their vertical continuation at the outcrop level. The lagoonal environment is designated by the limited flora and fauna, which is further supported by micritization that occurs mostly in the low energy environment. Similarly, the supratidal-subtidal depositional environment is suggested by siliciclastic input that demonstrates a highly agitated situation and proceeds to inner ramp condition. The transitional marine condition is characterised as a supratidal environment supported by flaky mineral and clastic quartz, with alternating layers of silty material assisting the process. In such carbonate-dominated settings local changes in topogeography, dissolution cavities, microstylolites, micritization, quartz and calcite veins are common phenomena. The stratigraphic differences from mudstone to packstone, as well as textural variations along constituent grains in various microfacies, reveal changes in energy settings (Fig. 3). The depositional model in current research is compared with the depositional model of Middle Cambrian Lower Zhangxia Formation, Xiaweidian, North China, and Middle Cambrian of Iran (Bayet-Goll et al., 2015; Zhang et al., 2020) showing almost the similar setting of shallow marine environments.

3.5. Conclusion

The detailed analysis from the petrographic characteristics and microfacies analyses leads to the important conclusion of samples from the Ambar Formation.

- In the current study, three microfacies are identified i.e. (1) Siliciclastic mudstone microfacies (2) dolomitized, peloidal, ooidal packstone microfacies (3) Laminated sandy dolomitic packstone-grainstone microfacies.
- The Ambar Formation is inferred to have formed in a carbonate-dominated, transitional to nearshore inner shelf marine, based on the microfacies identified.
- Dissolution cavities, calcite and quartz filled fractures, micritization, stylolites, dolomitization, and silicification are among the digenetic changes documented in the dolomite.

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