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Characterization of Dolomite in Ambar Formation (Cambrian), Peshawar Basin, Khyber Pakhtunkhwa, Pakistan

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Abstract

Ambar Formation (Cambrian) is consists of massive dolomite that is well exposed in Peshawar. The exposed Ambar Formation provides an insight view of Dolomitization. The current study is generally focus on multiphase dolomitization mechanism in Ambar Formation. The objective of the present study has been evaluated on the basis of field observation, petrographic thin section analysis, XRD, and Carbon-Oxygen isotopes analysis. Generally limestone is converted into dolomitized by burial and diagenetic mechanisms. Saddle dolomite, calcite vein, brecciation and stylolization are common features in the studied outcrop. Three phases of dolomitization has been evaluated on the basis of field observation and thin section study which are confirmed by geochemical analysis. The first phase is the replacive matrix dolomite (RMD) phase, where MD-I, MD-II and MD-III has been formed. The pore-filling cementation phase consists of different calcite and saddle dolomite (SD). The dolomite display planner and non-planar texture and fine to medium to coarse crystallinity as well as stylolites and brecciation which is the characteristic of burial dolomitization. The oxygen isotope values of MD-I ranging from -7.64 to -8.13% PDB (Cambrian marine signature with no depletion), that indicate MD-I has been formed at low temperature under burial condition. Whereas MD-II consisting -7.8 to -8.3% PDB, that lies in the same range and MD-III range from -8.4 to -9.31%PDB. It has been concluded that it has been formed at relatively low temperature under burial with no depletion. Stylolization and brecciation is the resultant of short-term shear stresses and pore filling pressure dissolution. A complete continuous dolomitization process which started from the replacive phase and end up at pore filling phase. The C and O isotopic values are in the range of original Cambrian signatures so the dolomitization are possibly take place during Mid or Late Cambrian. The thermal convection induced heat to the trap water in the deep buried Tanawal Formation which comes to the overlaying Ambar Formation and causes dolomitization. Fracture and fault provide path for the dolomitizing fluid and followed by calcitization phase. In this phase white calcite (WC) has been precipitated, that is the last phase of dolomitization.

Keywords: *Cambrian dolomite; Ambar formation; Peshawar basin; O/C Isotopes; Dolomitization.*

1. Introduction

Peshawar basin is a sub-basin of Pakistan that is superimposed on fold and thrust belt at the foothills of Himalaya [1]. The basin comprises of unconsolidated sediments of lacustrine and fluvial environment. Carbonate rocks (Cambrian) are mostly dolomitized [2-3]. Multiphase dolomitization mechanism commonly lead to pervasive dolomitization of carbonate rocks [2, 4-5]. Most of the dolomitization is formed during diagenesis at sediment water interface less than 10m burial depth [6-9]. Dolomite is a carbonate mineral which forms dolostone and is considered as a good reservoir rock in the hydrocarbon field [10-14]. To understand of its formation and conversion of limestone to dolomite in present situation is still a complicated issue. Earlier workers have introduced different dolomitization models on the basis of different digenetic criteria to explain the formation of dolomite as well as the changes that occurs in it after its formation [7, 15-16].

The sections have been exposed at Ambar village and it's surrounding along Swabi-Jehangira road that has been designated as the type section, which lies in the Peshawar Basin. The underlying Tanawal Formation (pre-Cambrian) and the overlying Misri Banda quartzite (Ordovician) represent unconformable contact with the Ambar Formation. The purpose of current study is to evaluate the various macroscopic and microscopic characteristic of Ambar formation. In the study area it has been noticed that diverse varieties of replacive dolomite is present that has been evaluated on the basis of color contrast (MD- 1, MD-2, MD-3). Beside the replacive matrix phase the study area also undergone through cementation phase which comprise white calcite cement and saddle dolomite. Because of these diagenetic modifications the porosity and permeability of the rock is affected. The Main objective of the current study are; 1) to evaluate the characteristics of dolomite and 2) paragenetic sequence of and origin of dolomite. The objectives has been evaluated on the basis of field observation, petrographic thin section study, and C and O isotope analysis.

2. Geological setting

The study area is situated in Peshawar basin, north of MBT (Lesser Himalaya). The lesser Himalayan rocks are thrusted over the Sub-Himalayan sequences of Neogene molass deposit extended southward along the Main Boundary Thrust (MBT) [17]. The Main Boundary Thrust Zone is comprised of a series of parallel or an echelon thrust fault dividing the NW Himalaya sequence into deformed southern zone or Foreland, and a deformed and metamorphosed northern zone or the hinterland [18].

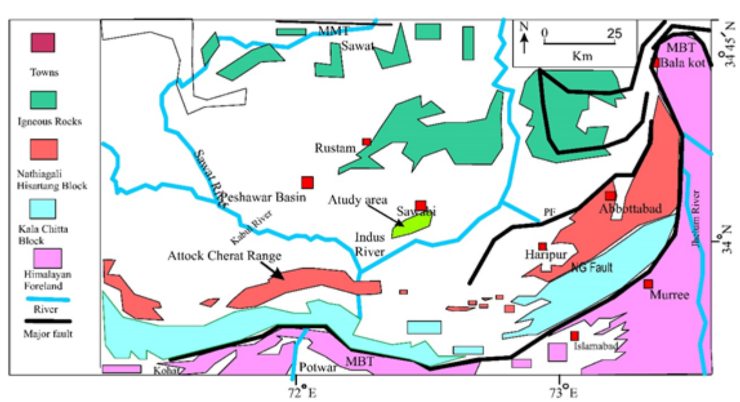

Figure 1 Location of the research area and its relative contacts with the adjacent formations (after Ali *et al.* [29])

From NE to SW, the Main Boundary Thrust is located along the Hazara Kashmir Syntax, northern Potwar and Kohat plateau of Pakistan (Fig.1). The tectonic setting of the Peshawar basin is transitional between a sedimentary fold-and-thrust belt to the south and metamorphic terrain to the north. The pre and syn-rift metasedimentary rocks (eastern Peshawar Basin and Swat) provide evidence of the Late Paleozoic rifting that occurred at the northern margin of the Indo-Pakistan tectonic plate. The pre-Himalayan clastic sedimentation of the Late Paleozoic-Triassic Jafar Kandao Formation specifies the beginning of extensional tectonics. The clastic input was derived from the formerly passive northern margin of the Gondwana Land [19].

Peshawar basin have predominantly unlithified sediments of lacustrine environment including silt with fluvial sand and gravel [20]. The Peshawar basin was formed in Plio-Pleistocene time when more than 300 meters of sediments were deposited in response to ponding of drainage by the rising Attock-Cherat Range [21]. Within the basin the exposure of the Paleozoic and older strata is limited to smaller outcrops. On the south it is bounded by Attack-Cherat Ranges, on East by Gandghar Ranges, and on Western side by Khyber Ranges. On the north and northeast side, the rock strata include metasediments of the Peshawar basin which is intruded by igneous rocks belonging to the marginal masses of Indian Plate.

Ambar Formation is mainly consisting of dolomite, dolomitic limestone argillite and calcareous quartzite (Table 1). At some places chert is also present and dolomite consisting of algal lamination with subordinate stromatolites. Tanawal Formation (Pre-Cambrian) consisting of quartos schist, quartzite, and schistose conglomerate. Misri Banda Quartzite (Ordovician-Silurian) mostly consisting of quartzite of grey to pinkish grey with medium grains quartz and feldspar in calcareous matrix. Nowshera Formation (Devonian) consisting of limestone and dolomite whereas Kashala Formation (Triassic) consisting of brown grey marble with inter bedded calcareous Phyllite.

Table 1. Generalized stratigraphic column of the study area

Age	Formation
Mesozoic	Nikanai Ghar Formation
	Kashala Formation
Late Paleozoic-Triassic	Duma Formation
	Jafar Kandao Formation
Early-Middle Paleozoic	Nowshera Formation
	Panjpir Formation
	Misri Banda Quartzite
	Ambar Formation
Late Proterozoic	Tanawal Formation
Early Proterozoic	Gandaf, Manki and Hazara Formations

3. Methodology

The field excursion has been arranged to the research area. Two sections have been selected for sampling, and studying different sedimentary structures. The purpose of this study is to describe the different digenetic events took place in Cambrian Ambar Formation and also to elaborate the causes of dolomitization. About 50 Samples were collected from the Ambar Formation after 1 meter interval along Sawabi-jehangira road at regular intervals on the basis of change in color, texture, lithology, and other features. Among them 35 samples were chosen for thin section analysis, 15 for C and O isotope analysis, and 8 samples for XRD. For geochemical study samples were powdered in ball mill of tungsten carbide to <200-mesh size. A part of every sample was taken after complete inspection. The pulverized specimen of cement was kept in the impermeable glassware container after soaking at 110°C in an oven. Samples slabs were further processed for polishing, etching, staining (staining of slabs is done with Alizarin Red S and Potassium Ferri-cyanide to distinguished the different types of carbonate rocks and minerals i.e. limestone, Ferron/ non-Ferron dolomite, saddle dolomite and calcite. 15 samples were collected for Oxygen isotope (O^{18}) and Carbon isotope (sigma C^{13}) analysis from Ambar Formation (main type section) of Cambrian age. We use these two isotopes because the most abundant stable isotopes in carbonates are oxygen (O^{16} and O^{18}) and carbon (C^{12} and C^{13}) isotopes. All the experimental work has been performed at Institute of Geology, University of Peshawar, Pakistan.

4. Results

4.1. Field observations

The studied Ambar Formation is located at Ambar village along Sawabi Jahangira Road in Peshawar basin. The thickness of the studied section varies from 400m to 450m. During the field different outcrops structures, various types of dolomite and bedding has been observed and captured. The types of dolomite were observed and identified in study area on the basis of variable color and grain size. Matrix dolomites are resulted from the replacement of preexisting limestone.

The various color of matrix dolomite seen during the field are Type -I (MD-I) (Fig. 2a) dolomite, which is dark grey color, Type- II (MD-II) (Fig. 2b) dolomite which are light grey in color, Type -III (MD-III) (Fig. 3a) dolomite having brown color. The size of these dolomites are coarser to fine crystalline. These dolomites are medium to thick, and massive bedded (Fig. 2a, b). They also include saddle dolomite (SD) and calcite cement (Fig. 3c, d). Saddle dolomites (SD) are occurred as veins and pores filling cements within matrix dolomite while replacive matrix dolomites (MD) are formed as a result of early replacement (Fig. 2).

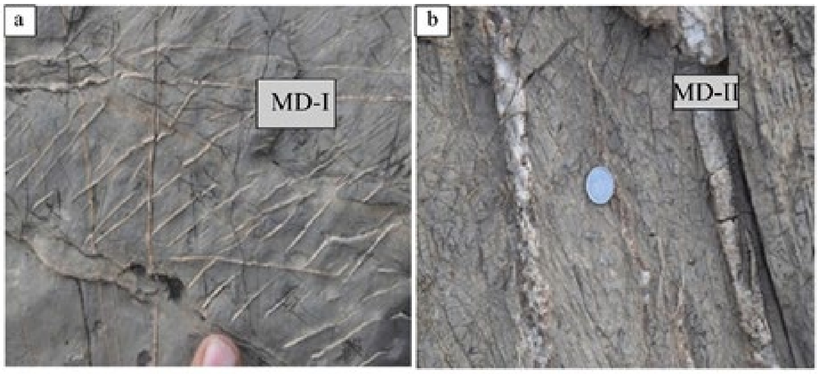

Figure 2. Photographs showing various types of dolomite observed in the study area. a) Shows dark grey dolomite (MD-I) having calcite veins and saddle veins, b) Shows light grey dolomite (MD-II) with calcite veins

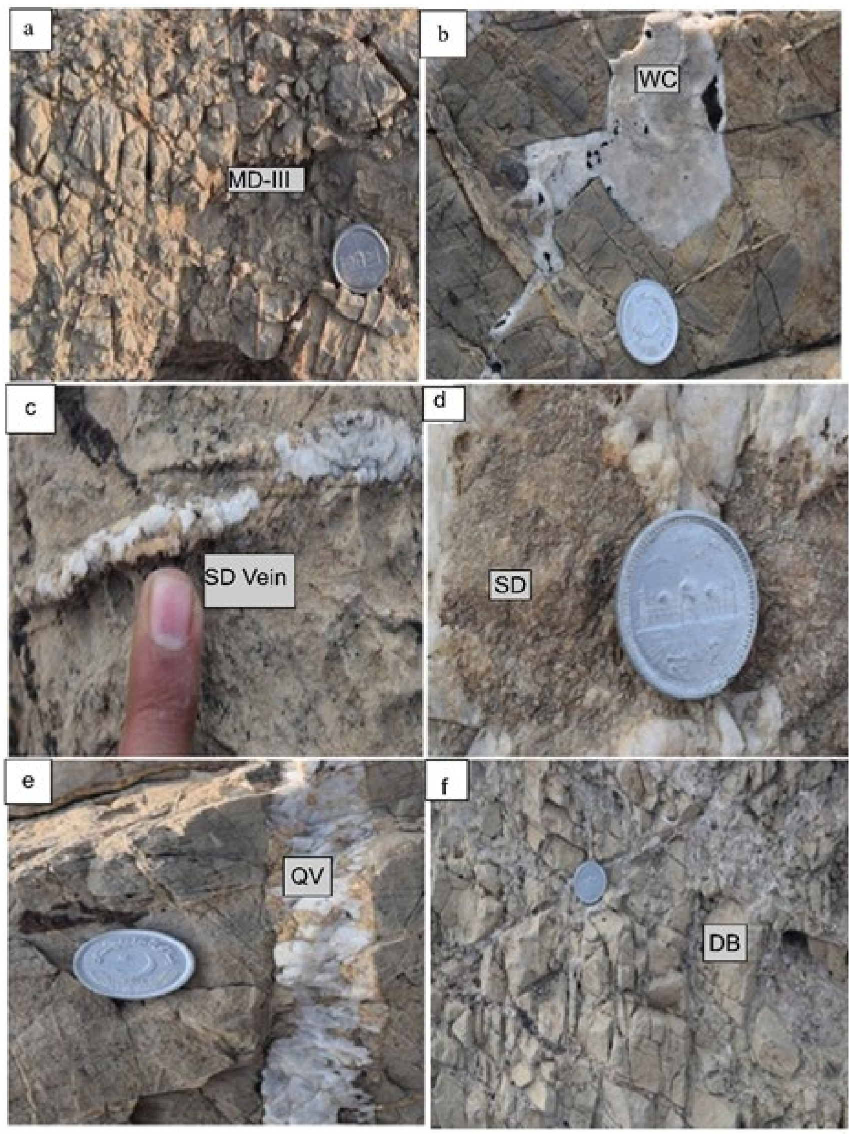

Figure 3. Photograph showing a) chop board weathering in dolomite (Ambar formation), b) White calcite intrusion in dolomite, c) saddle dolomite vein in dolomite, d) saddle dolomite and white calcite, e) Quartz vein in dolomite, f) bedded dolomite

4.2. Petrography

The petrographic studies of samples show that the main constituent of these samples is dolomite and calcite with minor Ferron calcite. The analyzed samples of the study area contain fine to medium crystalline anhedral dolomite, saddle dolomite, and pore-filling calcite.

The crystal size varies from fine to medium and medium to coarse. The study rocks also contains three types of dolomites which show a different phase of dolomitization and change in mineralogy with varigated colors. The pores filling saddle dolomite are also present. Besides the other diagenesis processes includes calcitization, stromatolites, stylolization, and dedolomitization are also recognized (Fig. 4; Fig. 5).

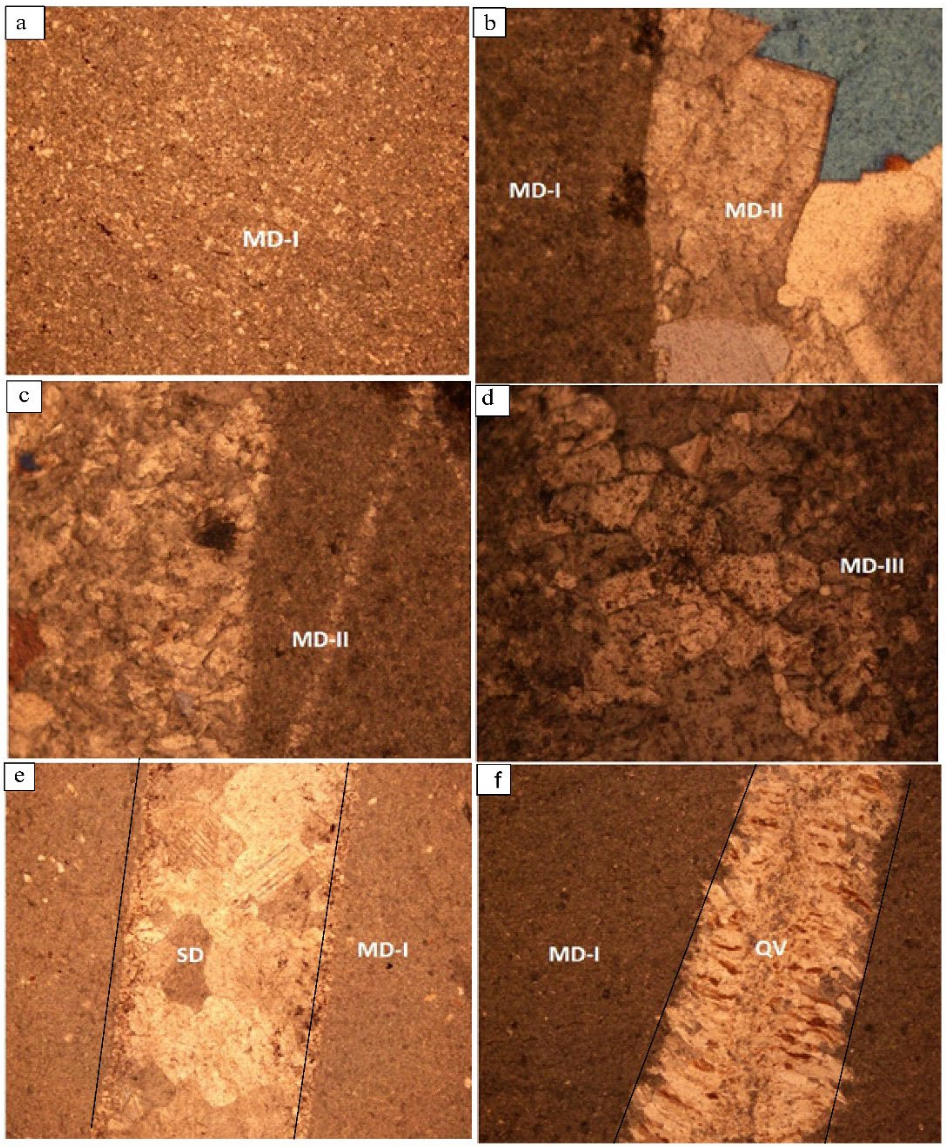

Figure 4. Photomicrographs of different dolomites. a) Fine anhedral non-planar crystalline dolomite. b) Sharp contact between MD-I and MD-II. c) Medium non-planar anhedral crystalline dolomite MD-II. d) Medium non-planar anhedral to subhedral crystalline dolomite MD-III. E) Clear contact between dolomite (MD-I) and Saddle dolomite (SD) having undulate extension on rotating the stage. F) Contact between quartz veins (QV) and dolomite

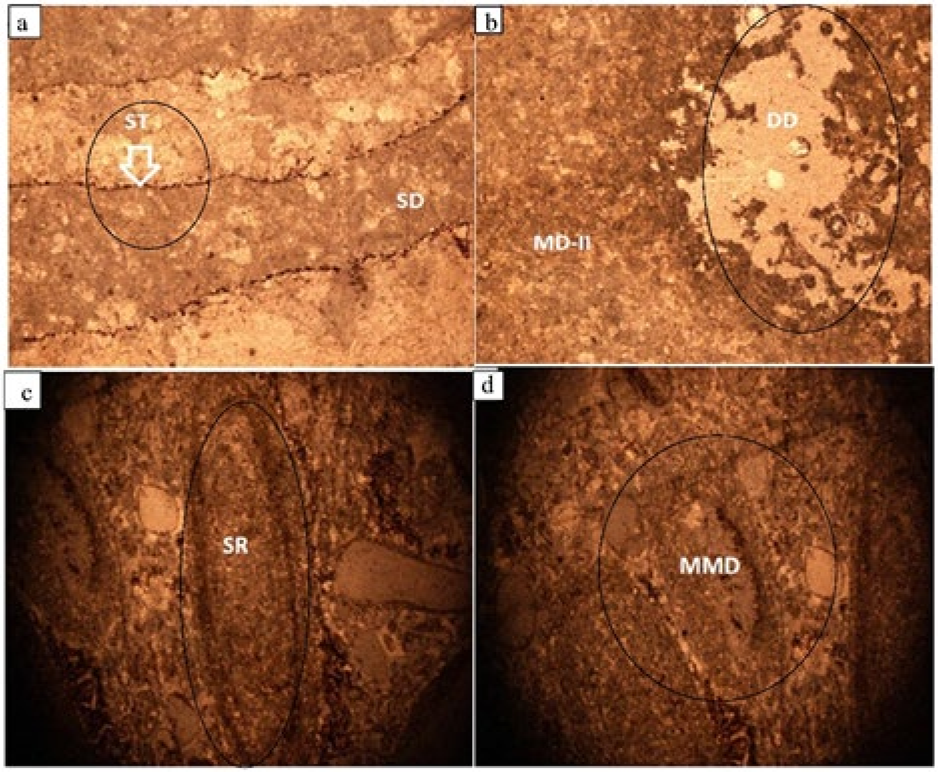

Figure 5. a) Stylolization (ST) in dolomite. b) Calcitization or Dedolomitization in medium crystalline dolomite MD-II. c) & d) photomicrographs of dolomite having dolomitized Stromatolites. The circle shows the preservation of the stromatolite outlines. It also shows mimic dolomites

4.2.1. Non-planar anhedral fine dolomite (MD-I)

Non-planar dolomite having anhedral crystal morphology has been observed under thin sections. Non-planar dolomites have irregular, nonlinear crystal boundaries between crystals. Preserved crystal face junction is rare, crystal often show undulatory extinction under cross polarized light [10] (Fig. 4a, b, e, f).

4.2.2. Fine to medium crystalline non-planar dolomite (MD-II)

Fine to medium crystalline dolomites are present which is studied under the thin sections (Fig. 4b, c; Fig. 5b). There is distinct contact between non-planar crystals.

4.2.3. Medium to coarse crystalline non-planar dolomite (MD-III)

Medium to coarse crystalline dolomite having non-planar anhedral crystal morphology (Fig. 4d). Besides these three types of dolomite have been studied and noticed veins in dolomite, dolomite cement, saddle dolomite, calcitization, dedolomitization, stylolization, stromatolites feature and mimic crystalline dolomite (MD).

4.2.4. Veins in dolomite

Various dolomite veins have been observed in the studied thin sections, as shown in the fine-grained crystalline dolomite (Fig. 2a; Fig. 3c, e; Fig. 4c).

4.2.5. Saddle dolomite

Typical selective fabric has curved crystal faces, a cloudy appearance (due to abundant fluid and mineral inclusions) and undulate extinction (Fig. 4e; Fig. 5a). Most part is precipitated from hydrothermal brines at temperature above 60°C (commonly up to 150°C) commonly in association with metallic sulfide ores, barite, fluorite, and or hydrocarbons. Deformation of the crystal lattice results from the substitution of up to 15mol% Fe and other cations.

4.2.6. Calcitization phase

Calcite is present in the form of pore-filling calcite cement that has been observed in thin sections of various samples. It shows unit extension with rotating the stage under microscope (Fig.4c).

4.2.7. Dedolomitization

Dedolomitization has been observed in medium crystalline dolomite (Fig. 5b).

4.2.8. Stylolization

Chemical dissolution takes many forms in carbonate rocks, and stylolites are the most readily identifiable in the outcrop. The stylolite (zigzag appearance), present here is studied in thin section under microscope (Fig. 5a).

4.2.9. Stromatolites (ST)

Stromatolites outlines has been observed and identified in various studied thin sections (Fig. 5c, d). Its size ranges from centimeters to meters in height. Laminae are mm to cm in size. It has an abundance of trapped grains, especially pellets/peloids but also clastic terrigenous materials in many cases. Stromatolites are mostly present in limestone whereas in dolomite it is sparsely present due to digenetic events [22].

4.3. Isotope analysis

15 samples were selected for oxygen isotopeO^{18} and carbon isotope sigmaC^{13} analysis (Fig.6). The sample consists of various digenetic phases of calcitization and dolomitization. The oxygen isotope values of MD-I dolomite ranging from -7.64 to -8.13% PDB which lies in the range of original Cambrian marine signature and show no depletion. It is reasonable to suggest that MD-I dolomite formed at low temperature under burial.

The stable oxygen isotope values for MD-II dolomite is -7.8 to -8.3% (Table 2) PDB that also lies in the range, and shows no depletion from original marine Cambrian signature. It's concluded that it formed at relatively low temperature. The oxygen isotope values for MD-III dolomite range from -8.4 to -9.31%PDB (Table 2) (Fig. 6), which lies in the range of original Cambrian marine signature (6l80= -5% 0 PDB; [23] and shows no depletion. It is reasonable to suggest that MD-III dolomite formed at low temperature under burial. The original Cambrian marine signature for C isotope value is range from 0 to -2 and O value is -7.5 to -10.

Table 2. O/C isotope results of selected samples from the studied section

S No	Sample name	$\delta\ O^{18}$	$\delta\ C^{13}$
1	A-2	-8.13	-1,75
2	A-3	-9.18	-2.00
3	A-7	-7.64	-1.63
4	A-10	-7.92	-4.68
5	A-13a	-8.01	-1.53
6	A-4	-7.71	-1.80
7	A-5	-7.78	-2.23
8	A-6	-7.85	-1.69
9	A-8	-7.98	-1.93
10	A-9	-8.04	-2.10
11	A-11	-8.09	-2.30
12	A-12	-8.34	-2.76
13	A-14	-8.73	-2.13
14	A-15	-8.81	-1.90
15	A-16	-9.03	-2.10

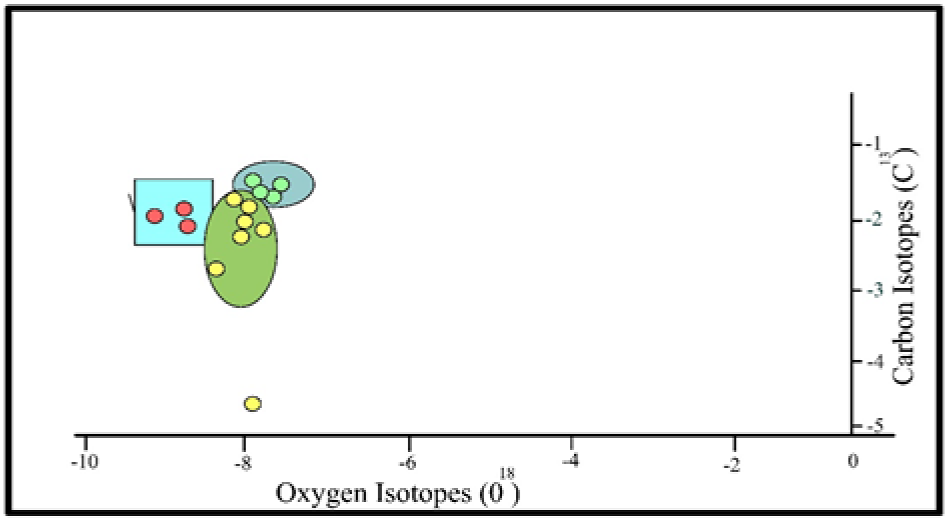

Figure 6. Carbon/Oxygen isotope results of selected samples from the studied section that depict to interpret the origin of dolomite

5. Discussion

On the basis of petrography and geochemical analysis three different phases of digenetic events were recognized which comprise 1) dolomitization, 2) saddle dolomite and quartz vein, and 3) calcitization. Overall formation consisting of dolomite and calcite that has been confirmed by thin section analysis (Figs. 4 & 5) and by XRD analysis (Fig. 7). At first stage the limestone of Ambar Formation was deposited which was followed by dolomitization and as a result of non-planner fine crystalline MD-I was formed, which were followed by non-planar fine to medium crystalline dolomite MD-II and finally non-planar medium to coarse crystalline MD-III gets precipitated. The end of dolomitization phase is signified by the formation of course and non-planar saddle dolomite (SD) and quartz veins. After that a major cataclastic deformation and dissolution took place, than can enhances the pores and fracture. These pores and fractures were filled by SD and quartz which is the second phase of digenetic events. In this phase the reservoir characteristics of MD dolomite are greatly changed. In the last phase again cataclastic deformation took place which results into the formation of fracture and dissolution. Later on, these pore spaces and fracture were filled by white calcite (WC) which is the third phase of diagenetic events (Fig. 3b). Dolomitization mechanism took place in multiple-phases that has been formed by fabric destructive and fabric preserving dolomites.

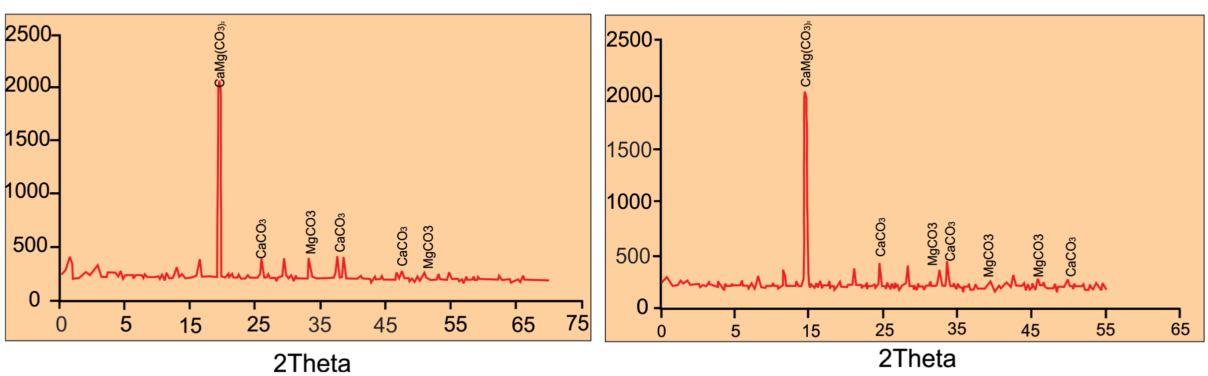

Figure 7. XRD data shows dolomite is the dominant mineral with subordinate calcite

The fabric dolomite has been formed by early diagenetic processes under near-surface settings [2]. The continuous transition of dolomite can be explained by early diagenetic dolomitization which led two different textures. The genesis of fabric-preserving and fabric-destructive dolomites can be explained by significantly various rock physics (porosity) and chemical characteristics (mineralogy) of the ancestor carbonate, or by other mechanism of the same carbonate platform [22,24]. The planar to non-planar anhedral crystals with fine texture dolomite (MS-II) also formed near-surface at low temperature, shallow burial conditions [10,25]. Medium to coarse nonplanar anhedral MD-III dolomite, generally associated along fractures and cavities (Fig. 4d), indicates crystallization at elevated temperature and, possibly, at a greater burial depth [26-27]. MS-I and MS-II dolomite also showing neomorphism by gradual transitions from MS-I and MS-II to MS-III dolomite and relics of earlier phases.

Whereas destructive MS-I cement dolomite generally postdates the preserving I and II matrix dolomite but predates the III dolomite and calcite cement. It has been concluded that intermediate to deep-burial environment and elevated formation temperature [27-28]. The key controlling factor during the formation of the destructive dolomites may be advective fluid flow, evidenced by their preferred occurrence in fractures and cavities. Calcitization has been formed at later diagenetic stage, whereas fractures, solution holes at postdate (Fig.8). Fractures and solution holes filled by calcite cement that reducing the rock physics characteristics.

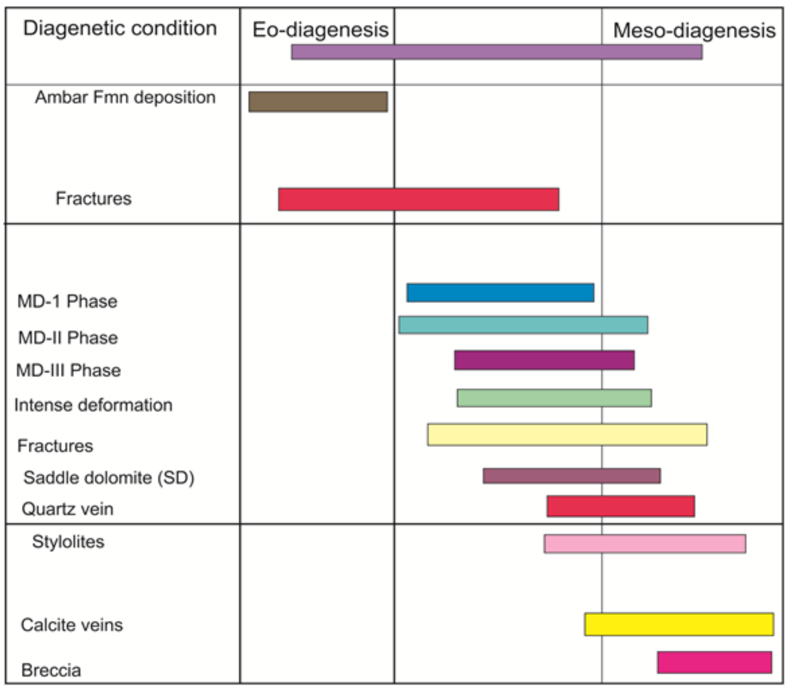

Figure 8. Detailed paragenetic history of the dolomite genesis in Ambar formation

6. Conclusions

Field observation, petrographic study, and geochemical investigation of Ambar Formation reveal that four stages of dolomitization occurred during progressive burial which are MD-I, MD-II, MD-III and saddle dolomite SD. A paragenetic sequence is established which briefly explain the various digenetic events.

MD-I and MD-II dolomite are non-planar anhedral crystalline formed at early diagenetic stage. It has been forms due to seepage-reflux. MD-III dolomite formed due to tectonic squeeze, while the saddle dolomite (SD) formed due to thermal convection. The quartz vein present postdates saddle dolomite, formed after burial.

Fractures filled by calcite and silica rich fluids. The calcitization is also present which postdate quartz veins. The other late stage of digenetic phases is brecciation, and stylolization. From the stable isotope analysis of oxygen O^{18} signature, the obtained values show no depletion or show little depletion from the standard Cambrian isotope signature, suggesting dolomitization mechanism taken place at low temperature for dolomite.

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