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Petrographic and Diagenetic Characteristics of the Dolomites at Um Bogma Formation (Early Carboniferous), West Central Sinai, Egypt

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Abstract: The present work is concerned with the Early Carboniferous succession exposed in west central Sinai. Um Bogma Formation in west-central Sinai displays extensive and pervasive dolomitization. This study is carried out to determine the sedimentary properties of dolomites; microtextural characteristics, diagenetic development and origin of the Um Bogma dolomites. Um Bogma dolomite rock textures can be classified according to crystal size distribution and crystal boundary shape. Size distributions are classified as unimodal or polymodal. Crystal boundary shapes are classified as planar or non-planar. Eight dolomite-rock textures are recognized and classified according to crystal-size distribution and crystal-boundary shape. These are made of unimodal, very fine to fine-crystalline planar-s (subhedral) mosaic dolomite; unimodal, medium to coarse crystalline planar-s (subhedral) dolomite; medium to coarse-crystalline planar-e (euhedral) mosaic dolomite; Medium-crystalline planar-e (euhedral) replacement dolomite ; unimodal, medium to coarse-crystalline non-planar-s-a (subhedral- anhedral) mosaic dolomite; Polymodal, planar-s-e (subhedral-euhedral) mosaic dolomite; Coarse to very coarse-crystalline non-planar-c (cement) saddle dolomite and Polymodal, non-planar-p (porphyrotopic). The studied area reveals the presence of two distinct diagenetic dolomite stages: Early Diagenetic; Selective Dolomite (Type I) and Pervasive Dolomite (Type II). The second stage is Late Diagenetic Dolomite; Pervasive Dolomite (Type III) and Dolomite Cement (Type IV). The first one dolomite (Type I) is confined to the Lower Member of the succession, dolomite ((Type II) of Middle Member; and dolomite ((Types III and IV) is recorded in the Upper Member of the succession. Lower Member Dolomites refer to early diagenetic, fine crystalline dolomites, not associated with evaporites and generally Ca-rich, while dolomites of Upper Member show late diagenetic, coarse crystalline dolomites, generally nearly stoichiometric. Generally, the studied dolomites demonstrate relatively low concentrations in Sr, Na and Mn contents, in agreement with the nearly stoichiometric composition and high ordered. Um Bogma Formation dolomites have been formed as early diagenetic in shallow-marine carbonate environment (tidal-subtidal) within mixed water area at low temperature and as the late diagenetic at the shallow-deep burial depths at high temperatures.

Key words: Carboniferous · Dolomitization · Egypt · Planar · Sinai · Stylolites · Um Bogma · Unimodle

INTRODUCTION

Um-Bogma area locates in the west central part of Sinai, Egypt. The Paleozoic succession in west central Sinai (up to 320 m thick) unconformably overlies the basement complex with a common peneplain and separated from pre-Cenomanian rocks, in many localities, by a basaltic sheet [1]. The Um Bogma Formation is an important rock unit because of the polymetallic mineralization and ores associated with it. Um Bogma Formation unconformably overlies Adadia Formation. It attains maximum thickness of 61m at W. Khaboba in the northwest part of the environs and decreases towards the south and east to a minimum thickness of 2 m at G. Syniea. The formation is mainly composed of grey and pink hard crystalline dolostone beds forming the majority of the lower and upper parts, while the middle portion comprises intercalation of yellow shale, siltstone and marly dolostone with abundant and well preserved fossil remains. Many authors studied the petrography of Um Bogma Formation, such as Soliman [2], El Shahat and Kora [3], El Agami *et al.* [4], Shaaban *et al.* [5] and

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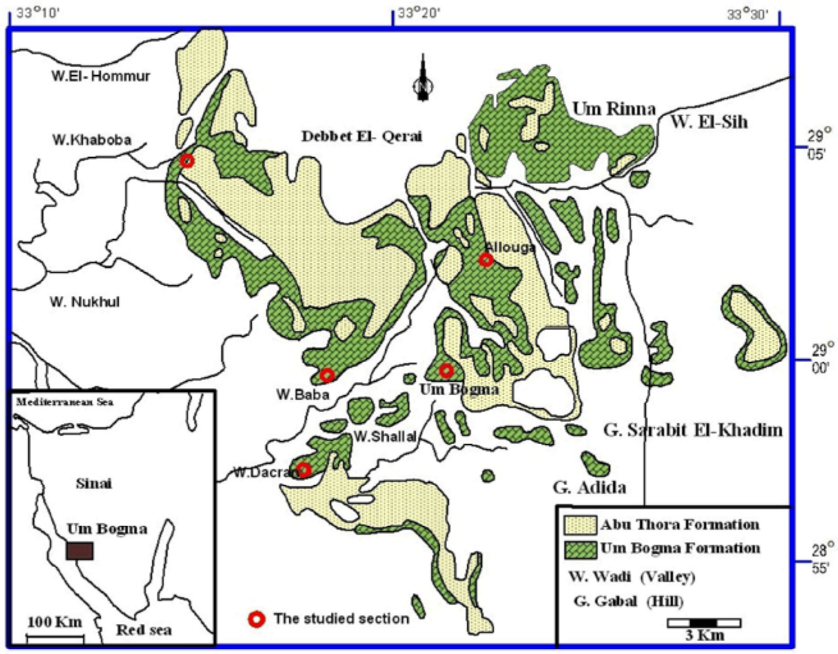


Fig. 1: Map showing distribution of the Lower Carboniferous in the Um Bogma area, west-central Sinai, Egypt according to Kora and Jux [11].

Sobhy and Ezaki [6]. The Um Bogma environs are located to the east of Abu Zeneima town on the east coast of the Gulf of Suez, southwestern Sinai Peninsula. These environs are bounded between Longitudes 33° 10`- 33° 32` E and Latitudes 28° 50`- 29° 05` N (Fig. 1) covering an area of about 700 km^2. This district has been known for its polymetallic mineralization since the Ancient Egyptians especially copper-deposits and turquois. Recently this area became famous for Mn-ores and some industrial minerals such as kaolinite, sand glass and bentonite clays.

Two basic dolomite textures exist in sedimentary rocks-planar dolomite and non-planar dolomite [7]. Planar dolomite crystals have straight boundaries equivalent to idiotopic [8], whereas non-planar dolomite crystals have curved, lobate, serrated, indistinct, or otherwise irregular boundaries and often have undulatory extinction [9] equivalent to xenotopic of Friedman [8]. Occasionally, a rock may be composed of planar or non-planar dolomite. The description of a dolomite may include characteristics of allochems, matrix and void filling. Allochems may be unreplaced dissolved leaving molds, replaced or partially replaced. If they are replaced they may be mimically or nonmimically replaced. Mimic replacement [10] refers to preservation of the form and internal structure of an allochems. Mimic replacement requires abundant of dolomite nuclei unless the allochems being replaced as a single crystal such as an echinoid fragment. Mimic replacement does not require pseudomorphic replacement of the crystals making up the fossil. Nonmimic replacement may preserve the form but not the structure of an allochems. This will occur if there are relatively few crystals replacing the allochems. Void filling includes cement and dolomite that replaced precursor cement. The term void filling is used, therefore, to cover both types of dolomite.

The aim of this study is to determine the microtextural characteristics, diagenetic development and origin of the Um Bogma dolomites. The classification of dolomite rock textures proposed by Sibley and Grigg, [9] is adopted here. Their classification can be interpreted in terms of the parameters that control rates of nucleation and growth.

Geologic Setting: The Paleozoic rocks in the studied area are cut by numerous faults in various blocks with vertical displacement reaching up to 100 m, sometimes forming horsts and grabens. The major faults usually control the location of deep wadis, as well as the landscape [12]. The studied area, among the neighboring ones, is affected by a series of faults of various trends (e.g. NNW-SSE, EW), which belong to successive post Paleozoic tectonics [13]. However, faulting does not control the distribution of Um Bogma dolomites. Permo-Triassic basaltic sills and

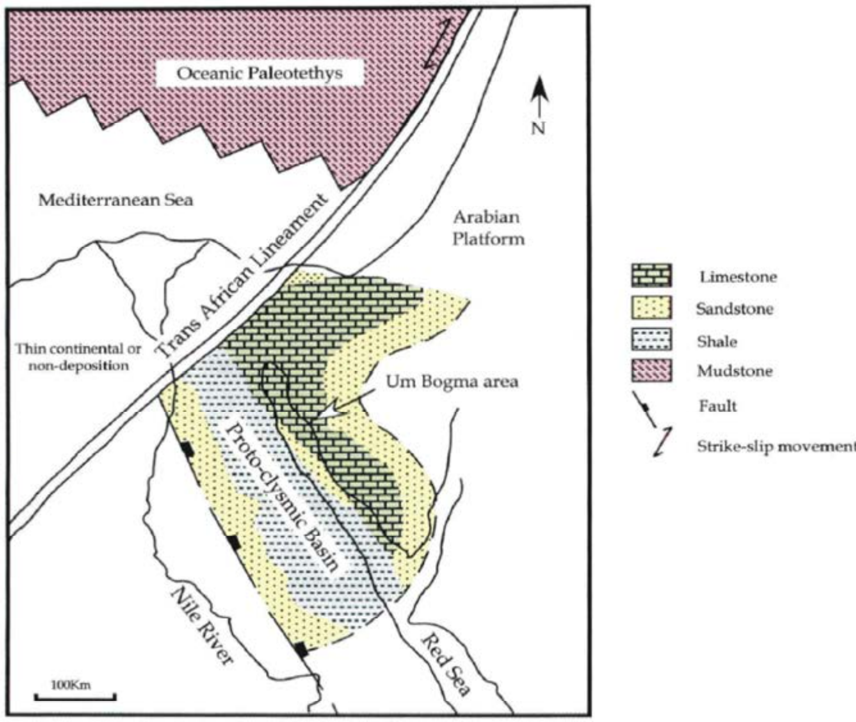


Fig. 2: Early Tournaisian and -mid Permian depositional phase in Northeast Egypt according to Keeley [23].

doloritic and basaltic dikes of post-Miocene age are abundant near the top parts of the Paleozoic rocks [14]. The Um Bogma Formation is economically of further interest because it hosts the economic ferro-manganese ore deposit in Egypt. From the beginning of the twentieth Century, the Carboniferous rocks in the Um Bogma area have attracted the attention of many geologists such as Soliman [2], EI-Shahat and Kora [3], Agami *et al.* [4], Shaaban *et al.* [5], Sobhy and Ezaki [6], Kora [15], Brenckle and Marchant [16], El-Sharkawi *et al.* [17], Kora *et al.* [18], Ahmed and Osman [19], EI-Kelani [20] and Bishta [21]. The Carboniferous deposits of Egypt range from fully marine carbonates, shallow marine clastics, deltaic and continental fluviatile sandstones to lacustrine and fluvioglacial deposits. The main reason for much differentiated appearances of Carboniferous strata (beside eustatic changes) is the structural and tectonic development (Fig. 2), during the Early Carboniferous time characteristic of Egypt [22, 23].In additions, a heterogeneous thickness-distribution pattern of the Um Bogma Formation is noticed allover west-central Sinai. Soliman [2] attributed this heterogeneity to the paleo-topography of the basement highs.

The Um Bogma Formation is underlained by the basal non-marine clastic Cambro-Ordovician Araba, Naqus and Malik Formations, which were deposited on the peneplained surface of the pre-Cambrian basement [24]. Unconformably overlying the Um Bogma Formation are thick (190m) cross-bedded fine-grained sandstones with thin layers of kaolinitic and black shales of the Ataqa (Syn: Abu Thora) Formation. The Cretaceous/Tertiary rocks overlie, unconformably, the Paleozoic rock units. The term Um Bogma Formation has been accepted by most investigators. The Um Bogma Formation is subdivided by most workers into three members [11, 13, 14]. The common subdivisions from base to top are as follow: 1) lower dolomitic, middle dolomitic limestone and upper dolomitic members [25]; 2) lower, middle and upper members [15].

In the study area; the Um Bogma Formation is subdivided into three members (Fig.3); lower, middle and upper members following Kora [15]. The maximum thickness (approximately 40 m) of this formation was recorded at the area between Wadi Khaboba and Gabal Nukhul sections in the northwestern part of the Um Bogma area. Its thickness tends to decrease gradually northeastwards (14m) at Wadi Alluga. The Lower Member consists of a thick succession of sandy dolostone, which is pinkish, porous, hard and cliff-forming. This member reflects a great variation in its lithology. In the west; it is composed mainly of dolostone while in the center and east it is formed of dolostone, siltstone, sandstone and

Mn-Fe ores. The dolomite beds of Lower Member is recorded at Wadi Khaboba, Wadi Dacran and Wadi Allouga, It is represented by rich brown beds which are laterally varies in thickness from 3 to 12 m at Um Bogma section and Wadi Baba the dolomite beds are disappeared. The Middle Member represented by yellow, reddish grey, very hard crystalline rocks of dolostone, marl, siltstone and claystone fossiliferous in some localities. The dolomite beds of the Middle Member are recorded at all studied sections. They were appeared as wavy beds. They were ranged from 1.5 to 9 m in thickness. The Upper Member marked by its yellow to brown or sometimes pink dolomite beds. It is composed of coarse-grained, sometimes sugary dolomite crystals, containing variable amounts of silt-and sand-sized quartz grains to form sandy/silty dolostones and dolomitic sandstones. The dolomite beds are dominant at Wadi Khaboba, Wadi Dacran, Um Bogma and Wadi Baba sections. While, they were disappeared at Wadi Allouga section. They dolostones in hard, compact crystalline, pinkish brown in colour and displaying thick beds. It ranges from 7 to 9 m in thickness.

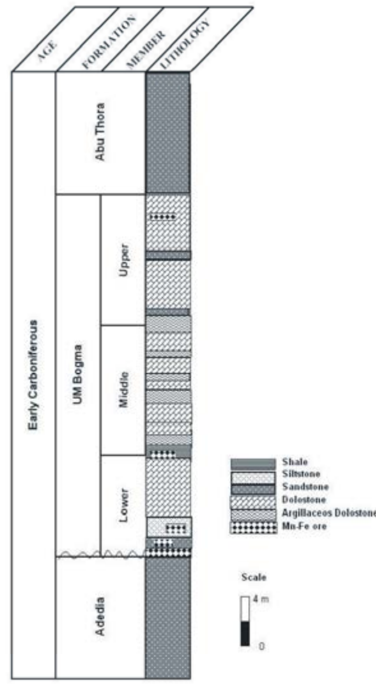


Fig. 3: Composite lithologic log of Um Bogma Formation in the studied area.

MATERIALS AND METHODS

This study used a data-base of 76 samples collected from five measured stratigraphic sections (Wadi Khaboba, Wadi Baba, Wadi Dacran, Um Bogma and Wadi Allouga (Fig. 1). Thin sections were presented and were stained with Alizarin Red-S to distinguish calcite from dolomite [26]. They were carefully examined using a light polarizing microscope and Scanning Electron Microscopy (SEM) at Zagazig University. Representative powdered samples were analyzed by X-ray diffraction to determine carbonate mineralogy and dolomite stoichiometry using a Philips X-ray diffractometer type Pw/1010 Ni- Filter, Cu-K radiation at 50 Kv and 30mA. Ca, Mg, Na, Fe, Sr and Mn elements contents were determined for dolomite samples at Central Laboratories of the Geological Survey in Cairo. The studied dolomite rocks were classified according to Folk [27] size scale and the dolomite textural classification of Wright [28]. Wright's classification combines those of Sibley and Gregg [9] and Gregg and Sibley [29] with the recognition of a transitional texture between planar and non-planar dolomite. The classification has two principal categories: 1) crystal size distribution-unimodal or polymodal and 2) crystal boundary shape-planar or non-planar. Planar crystal boundaries are further subdivided to euhedral (planar-e) or subhedral (planar-s). Planar-c dolomite is cement that lines or fills pores and planar-p dolomite is porphyrotopic. Non-planar dolomite occurs as anhedral dolomite mosaics (non-planar-a), saddle dolomite (non-planar) and porphyrotopic crystals (non-planar-p). In this study; complete textural description was done includes recognizable grains, matrix and cement. The allochems and cements may be unreplaced, partially replaced, or completely replaced. The replacement may be mimetic or non-mimetic.

RESULTS AND DISCUSSION

Dolomite Petrography and Distribution:

Petrography: Petrographic characteristics of the dolomites were studied in thin section under the polarizing microscope and scanning electron microscopy (SEM). The description of dolomite rocks, including dolomite textural classification, given by Gregg and Sibley [29] and Gregg [30] is shown in Fig. 4. Dolomite rock textures can be classified according to crystal size distribution and crystal boundary shape. The classification scheme presented here is largely descriptive but carries genetic implications because size distribution is controlled by both nucleation and growth kinetics and crystal boundary shape is controlled by growth kinetics. Size distributions are classified as

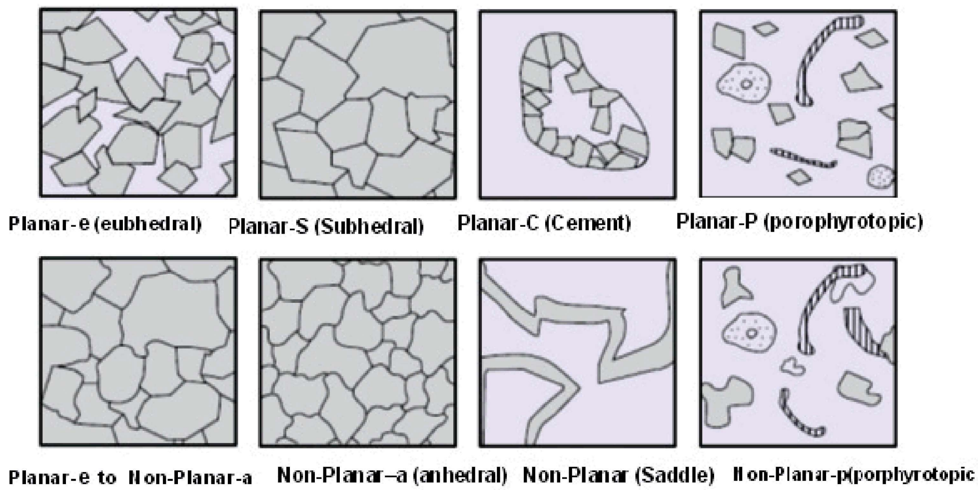


Fig. 4: Dolomite textures and classification combined from Wright [28] after Gregg and Sibley [29] and Sibley and Gregg [9].

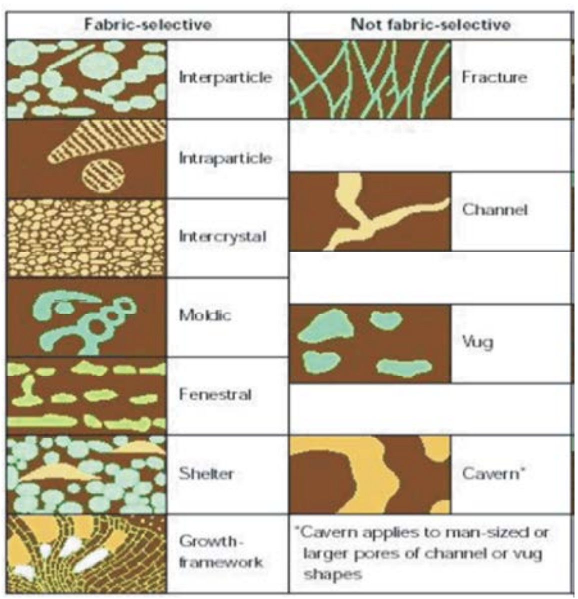


Fig. 5: Classification of carbonate porosity [31]

unimodal or polymodal. Crystal boundary shapes are classified as planar or non-planar. If the evidence permits, a complete classification includes a description of recognizable allochems, matrix and void filling. Allochems and preexisting cements may be unreplaced, partially replaced, replaced mimically, or replaced nonmimically. Allochems may be dissolved, leaving molds. Matrix can be unreplace, partially replaced, or replaced by a unimodal or polymodal size dolomite. Unimodal size distributions generally indicated a single nucleation event on a unimodal substrate. Polymodal sizes can be formed by multiple nucleation events on a unimodal or polymodal substrate or differential nucleation on an originally polymodal substrate. Planar crystal boundaries develop when crystals undergo faceted growth and non-planar boundaries develop when crystals undergo non-faceted growth. Non-planar boundaries are characteristic of growth at elevated temperature (> 50°C) and/or high supersaturation. Both planar and non-planar dolomite can form as cement, replacement of $CaCO_3$, or neomorphism of a precursor dolomite. Meanwhile, terminology of the pore types and their classification are adopted by Choquette and Pray [31] and Pittman [32] (Fig. 5). They are divided into two main groups: (1) fabric-selective porosity, which is controlled by the components of the original rock and (2) non-fabric selective porosity where the pores are developed independent of original textures or fabric. Due to the intensive dolomitization of the Um Bogma Formation the types of porosity are secondary intercrystalline dolomite, moldic pores, fractures, channels and stylolites.

Fabric Selective Porosity:

Dolomite-rock Textures: Eight dolomite-rock textures have been recognized and classified according to the dolomite-rock classification scheme of Sibley and Gregg [9]. In this study, the classification of dolomite-rock textures is based on petrographic analysis of photos. For crystal-size distributions, the apparent maximum dimensions of the dolomite crystals were measured or estimated and subdivided using Folk's [27] size scale. The following dolomite-rock textures have been defined: 1-unimodal, very fine to fine-crystalline planar-s (subhedral) mosaic dolomite. 2-Unimodal, medium

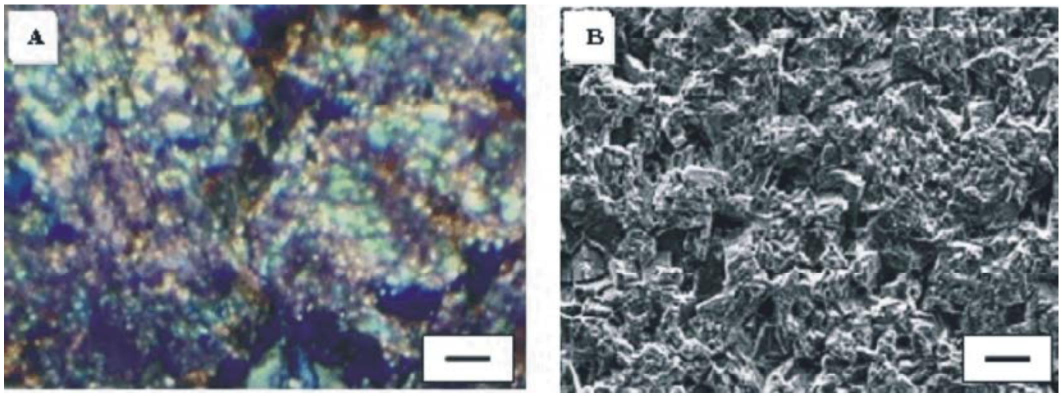


Fig. 6: Dolomite-rock texture 1: unimodal, very fine to fine-crystalline planar-s (subhedral) mosaic dolomite. This type forms dense, dark mosaics of interlocking subhedral to anhedral crystals (A, B). Partially dolomitized with relict crystals interpreted to be inherited from the precursor calcite red color (micrite (A), C.N, Lower Member. Bare scale A=300 µm, B= 20 µm (SEM),

to coarse crystalline planar-s (subhedral) dolomite. 3-Medium to coarse-crystalline planar-e (euhedral) mosaic dolomite. 4- Medium-crystalline planar-e (euhedral) replacement dolomite. 5-Unimodal, medium to coarse-crystalline non-planar-s-a (subhedral-anhedral) mosaic dolomite. 6- Polymodal, planar-s-e (subhedral-euhedral) mosaic dolomite. 7-Coarse to very coarse-crystalline non-planar-c (cement) saddle dolomite. 8-Polymodal, non-planar-p (porphyrotopic) dolomite crystals.

Dolomite Rock-texture 1: Unimodal, Very Fine to Fine-Crystalline Planar-s (Subhedral) Mosaic Dolomite: This type consists mainly of dolomite crystals forming 75-90 % of the rock, forming dense, dark mosaics of interlocking sub to planar-s crystals (20-60 µm (Figs. 6A, B). The dense mosaics show no recognizable allochems and are probably to be enlivened associated with organic matter. Beside microstylolites also is existed in this fine dolomites. Some serrate stylolite planes cut through the rock are enriched with iron oxides (Fig. 6A). The pores are common and especially channel and intercrystalline types forming 4-10 % of the rock mass. Intercrystalline porosity is classically developed in the sucrosic dolomite. Small fractures can be modified and enlarged into macrovugs upon dissolution.This type of dolostones occurs only in the Lower Member at Wadi Khaboba, Wadi Dacran and Wadi Allouga.

Interpretation: The small crystal sizes (<60 µm), the inferred restricted subtidal to supratidal environments [33]. The fine crystal size may be a result of an early replacement of precursor peritidal calcite (lime mudstones) or of neomorphism of a penecontemporaneous or early diagenetic dolomite [33]. Crystal size is controlled by the relation of two rate processes, the rate of nucleation and the rate of growth [33]. Fine particles have a very large surface area in comparision to their volume and, therefore, a rapid nucleation rate. If the nucleation rate is high compared to the growth rate, the resultant crystal size will be small [33]. Experimental data [34] indicate that the induction stage of dolomite formation increased with increasing crystal size. This may explain, among others, the selective dolomitization of finer crystalline calcium carbonate and early dolomitization of subtidal to supratidal lime muds [33].Thus, petrographic data compared with theoretical and experimental considerations allow interpretation of dolomite texture type 1 as early-diagenetic dolomite replacing subtidal to intertidal carbonate muds.

Dolomite Rock-texture 2: Unimodal, Medium to Coarse Crystalline Planar-s (Subhedral) Dolomite: This type consists mainly of dolomite crystals forming about 90 % of the rock. This type comprises medium to coarse (200-600 µm) planar-s dolomite (Fig. 7A) that occurs in patches or irregular zones associated with types 1 and forming unimodal mosaics, or filling fractures cutting across type 1 dolomite (Fig. 7 B). Dolomite type 2 is cloudy center and clear rim texture, most dolomite rhombs were coating and void filling with iron oxides along fractures and pores. No allochems were observed. Intercrystalline, fractures and channels pores are common forming 6 % of the rock. Fractures and channels are produced in response to stress. Small fractures can be modified and enlarged into macrovugs upon dissolution

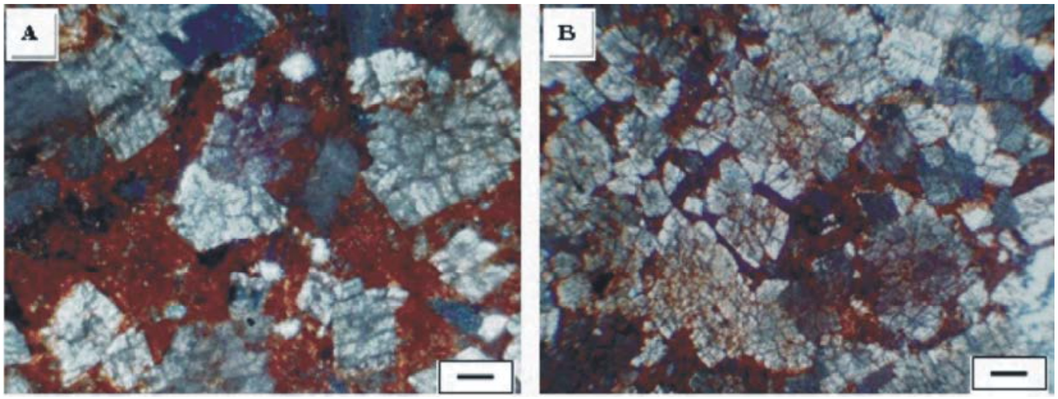


Fig. 7: Dolomite rock-texture 2. Medium to Coarse-crystalline planar-s (subhedral) dolomite. This type forms patches and irregular bands associated with dolomite-rock texture 1. Pore-occluding late dolomite (C.N.), Middle Member. Thin section stained with Alizarin red-S, Bare scale =300 µm.

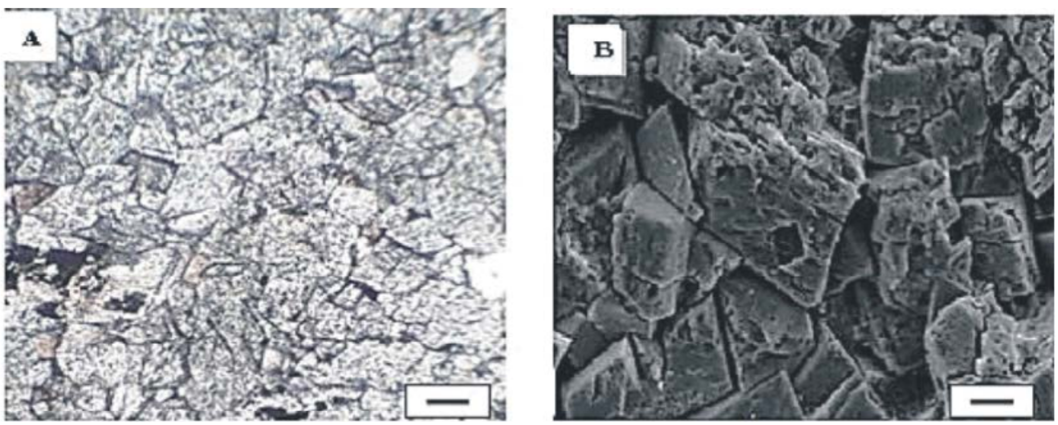


Fig. 8: Dolomite rock-texture 3: medium to coarse-crystalline planar-e (euhedral) mosaic dolomite. This type shows clear and dull euhedral crystals (A, B). This dolomite has intercrystalline porosity and less sparry calcite cement (B), Upper Member. Thin section stained with Alizarin red-S, Bare scale A =300 µm, B =10 µm.

or remain tight linear and/or irregular especially in dense dolomites (Fig. 7 B). This type of dolostones occurs in the Middle Member at all the studied sections.

Interpretation: Dolomite type 2 occurs together with dolomite type 1. Paragenetic relationships indicate that dolomite 2 is later than dolomite 1. Based on paragenetic relationships dolomite type 2 is interpreted to represent an intermediate to late-diagenetic replacement dolomite. The preservation of original depositional textures and the coarse crystal size suggest a major, probably long lasting, dolomitization event. This type compares in part to dolomite type 3 of Lee & Friedman [35] and compares to the dolomite type 2 of Murray and Lucia [36] and Amthor & Friedman [33], which they interpreted as of late burial origin. Characteristic for dolomite type 2 is the cloudy core, clear rim texture, which is common in rocks of all ages [33, 36, 37]. Cloudy cores represent replacive dolomite, whereas the clear rims are zoned dolomite cements, which occlude intercrystalline porosity [33]. That means that host-phase dissolution of calcite and precipitation of dolomite must occur simultaneously along a thin solution film [33, 38-42]. This type includes dolomite cement and dolomite replacing precursor cement. The term void-filling dolomite [9] is employed for this type, because it is often not possible to differentiate between dolomite cement and dolomite replacing precursor cement.

Dolomite rock-texture 3: Medium to Coarse-crystalline Planar-e (Euhedral) Mosaic Dolomite: It consists of coarse dolomite rhombs forming about 90 % of the total rock. The dolomite crystals are observed, it is consisting of planer-e euhedral to subhedral crystals (580-1000µm) showing mosaic textures. Mosaics of mostly planar-e, medium to coarse crystalline dolomite make up this

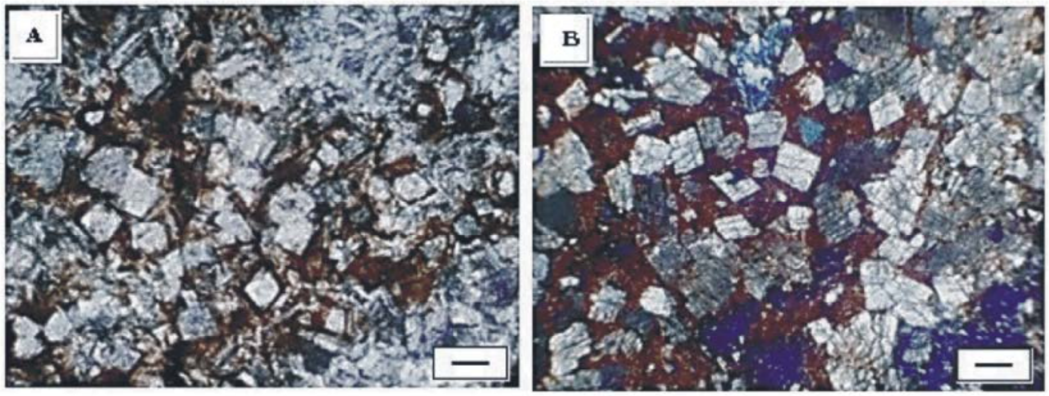


Fig. 9: Dolomite rock-texture 4: medium-crystalline planar-e (euhedral) dolomite. This type shows clear and dull euhedral crystals (A, B). This dolomite has intercrystalline porosity cement (A (PPL) and B (C. N.), lack of any compaction fabric dominance of euhedral planar crystal boundaries and relatively intercrystallie porosity. Upper Member. Bare scale =300µm.

dolomite type (Fig. 8 A&B). The crystals are clear or cloudy textures. The relatively coarse crystals commonly have a cloudy core (euhedral or irregular) with a clear rim exhibiting straight to embayed crystal faces dolomite crystals commonly display a sharp extinction under cross-polarized light. The dolomite crystals commonly have a cloudy core (subhedral or petal-like) with a clear rim. This type of dolomite is characterized by unimodal (bimodal locally and occurs as sucrosic mosaics/patches in the matrix of the host carbonate rocks. Abundant intercrystalline pore spaces are present and are partially filled with iron oxides. No replacement textures can be observed. Intercrystalline areas are either porous or filled with intercrystalline material. In other cases are partly to completely heal by progressive dolomitization events. No intracrystalline truncation features are observed. In part, corrosion and dissolution of outer zones, however, are present commonly where crystals face line pore spaces. It shows that euhedral dolomite rhombs were developed in the medium to coarse grained dolomites (Fig. 8 B). This type of dolostones occurs in the Upper Member at Wadi Khaboba, Wadi Baba, Wadi Dacran and Um Bogma.

Interpretation: Dolomite type 3; medium to coarse crystalline, planar-e selective replacive dolomites are generally replaced selectively fine-crystalline calcium carbonate [33, 34]. Fine particles have a very large surface area in comparison to their volume and, therefore a rapid nucleation rate. If the nucleation rate is high compared to the growth rate, the resultant crystal size will be small. The medium to coarse size formation in these dolomites suggests fine calcite and/or dolomite replacement originated from shallow-medium burial late diagenetic processes. The preservation of original depositional textures and the coarse crystal size suggest a major, probably long lasting, dolomitization event, which they interpreted as of late burial origin [33]. The paragenetic relationships indicate an intermediate to late-diagenetic origin for this type, which is also related to the presence of significant intercrystalline porosity.

Dolomite Rock-texture 4: Medium-crystalline Planar-e (Euhedral) Replacement Dolomite: Dolomite crystals forming 80% of the rock. This type of replacive dolomite has a planar-e texture. Typically the dolomites consist of scattered rhombs of 500-700 µm in diameter in dolomicritic matrix (Fig. 9A&B). The cores of the rhombs are cloudy and they have a clear an outer zone (first generation). Some of the rhombs show intercrystalline truncation features (Fig. 9A&B). Dolomite filling fractures cutting across this type. The second generation of dolomite is between (80-200µm) in size. It shows planer crystals. This phase may have been subjected to extensive digenetic processes which resulted in the recrystallization of the precursor calcite. The dolomite rhombs are well developed and zoned with thick iron oxides coating along fructures and pores; indicating an increase in Fe substitution during crystal growth (Fig. 9A). No allochems were observed. Intercrystalline pores and channels are common forming 4-6 % of the rock. Particully they are filled with iron oxides. Intercrystalline porosity is the most common type. However, high and effective porosity is found to be associated with fine and/or medium crystalline dolostone classes of planar-e to planar-s type (9 B). This type of dolomite rhombs floating

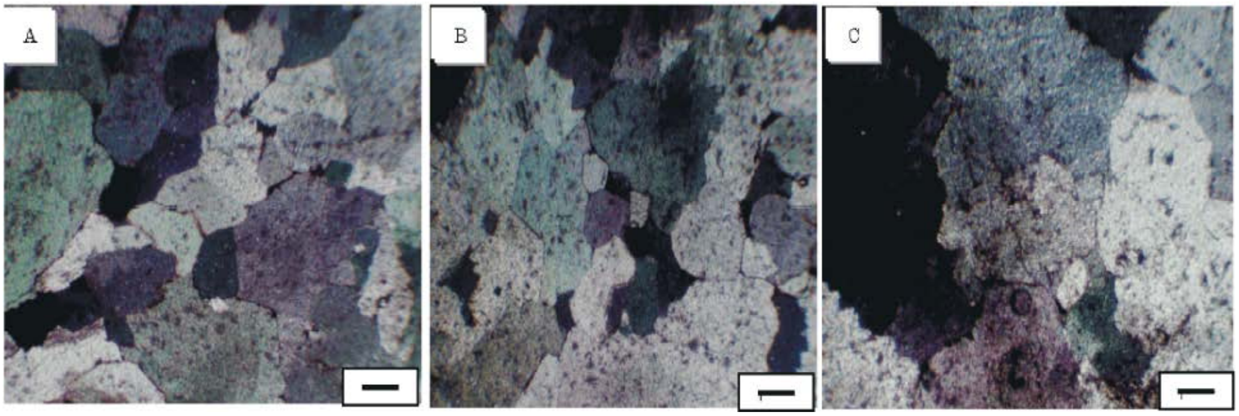


Fig. 10: Dolomite-rock texture 5: unimodal, medium to coarse-crystalline non planar-s-a (subhedral to anhedral) mosaic dolomite (A, B, C). Note dolomite crystals are truncated by microstylolites (8c), dolomite crystals have irregular boundaries and they have undulatory extinction, crystals are anhydral closely pack (8B), C.N., Lower Member, Bare scale =300 µm

in few dolomite matrix.Beside microstylolites also is existed in this medium to coarse crystalline dolomites. This type of dolostones occurs in the Upper Member at Wadi Khaboba, Wadi Baba, Wadi Dacran and Um Bogma section.

Interpretation: Characteristics of dolomite type 4 are the cloudy core, clear rim texture, which are common in rocks of all ages [33, 37]. Intercrystalline truncation in the dolomite rhombs are indicated dissolution later than dolomitization. Late diagenetic filling crack dolomites are occurred at elevated temperatures (burial origin). The fracture filling which cuts dolomite rhombs in medium-crystalline planar-e (euhedral) replacement dolomites of late diagenetic stage indicates that the formation at elevated temperatures (burial origin). The euhedral form of the dolomite rhombs is suggestive of formation at temperatures below 50-100°C (critical roughening temperature), since higher temperatures favour anhedral forms [9, 43]. As well as, chemical compaction might have concentrated the planar dolomite crystals along the solution seams.

Dolomite Rock-texture 5: Unimodal, Medium to Coarse-crystalline Non-planar-s-a (Subhedral-anhedral) Mosaic Dolomite: This dolomite crystals forming 75-90 % of the rock.This type forms dense, tightly packed mosaics of subhedral to anhedral planar-s crystals (600 µm), that are pinkish brown, clear, or have a cloudy texture (Fig. 10A, B). Microstylolitic porosity was also determined in this type of dolomites (Fig. 10C). Dolomite is in the form of non-planer, medium in size (350 µm). Few planer dolomite rhombs are well developed around cavity. The dolomite crystals have a cloudy appearance may be due to crystallization from precursor calcite. The crystals have irregular, serrated, curved or otherwise indistinct boundaries. Preserved crystal faces are rare or absent. The crystals are rimed by iron oxides; some serrate stylolite planes cut through the rock are enriched with iron oxides. The pores are common and especially channel and stylolite types forming 4-10 % of the rock mass. Stylolites are another secondary fabric independent of porosity types, which are developed in homogenously dolomitized rocks (Figs. 10 A, B and C). The uniform and tight texture of the sucrosic dolostone units seems to assist in the development of these deep-burial dissolution features (Fig. 10C).These secondary porosity features, with their linear and zigzag pattern connecting isolated pores. This type of dolostones occurs only in the Lower Member at Wadi Khaboba, Wadi Dacran and Wadi Allouga.

Interpretation: Non-planar-s-a (subhedral-anhedral) mosaic dolomite-occurs as replacement of a precursor limestone or dolostone. This type of replacement usually obliterates all original depositional textures [33]. This dolomite type corresponds to the xenotopic-a dolomite as defined by Gregg and Sibley [29] and Sibley and Gregg [9]. They propose that the xenotopic dolomite texture resulted from the replacement of limestones by dolomite or by neomorphic recrystallization of a pre-existing dolomite at elevated temperatures. Folk [44] recognized non-planar-a dolomite replacing a precursor limestone in a burial environment.

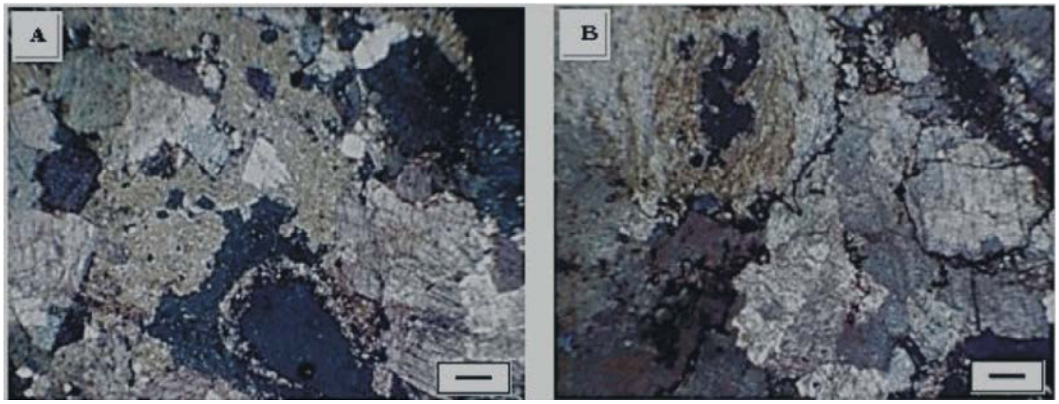


Fig. 11: Dolomite-rock texture 6 Polymodal, planar-s (subhedral) dolomite with nonmimically partially replaced foram molds (dark) and void- filling dolomite and they have undulatory extinction. Crystals are rimmed in many cases by a thick iron oxide rim some serrate microstylolite plans cut through are enriched with iron oxides the rock Note dolomite crystals are truncated by stylolites, C.N. Lower Member. Bare scale =300µm

Such a replacement took place only in certain zones, which were characterized by original high porosity and permeability. This coarse, non-planar dolomite cement is usually termed saddle dolomite [33, 45]. Almost all of this dolomite has been interpreted as having formed at elevated temperatures (60-150°C; Radke & Mathis [45] and from high-salinity brines. Analyses of homogenization temperatures from fluid inclusions of Ellenburger Group saddle dolomites by Lee and Friedman [35], who used the same cores for their study, gave average temperatures as high as 220°C [33]. So far, no conclusive evidence has been provided that saddle dolomite can form at low temperatures from marine or hyposaline water [33].

Dolomite Rock-texture 6: Polymodal, Planar-s (subhedral) to Planar-e (Euhedral) Mosaic Dolomite: Dolomite crystals forming 75-90 % of the rock. This type of replacive dolomite has a planar-e to planar-s texture. Crystal size distribution is polymodal and ranges between 100 and 600µm (Fig. 11 A, B). The cores of the rhombs are cloudy and they have a clear an outer zone (Fig. 11 B). Some of the rhombs show clear sucrosic features (Fig. 11A) and some of the rhombs are cutting across by microstylolite (Fig. 11 B). Stylolites are secondary fabric independent of porosity types, which are developed in this type (Fig.11 B). Nonmimically dolomite rhombs are partially replaced foram molds and void-filling dolomite and they have undulatory extinction (Fig.11 A) Moldic pores are the voids left by removal, usually through dissolution, of original carbonate grains. Shapes of the original grains especially bioclastic are preserved and help in identifying the original components. Moldic porosity is common in dolostone rock types of the early diagenetic origin (11 A& B). Polymodal size distributions may develop from a heterogeneous distribution of nucleation sites, multiple periods of nucleation, or variations in the local growth rate [9]. If a rock has a high porosity and planar crystals, the crystal will tend to be euhedral. This texture is referred to as planar-e (Fig. 11 B). If a rock has a low porosity and planar dolomite, the crystals will be subhedral to anhedral and referred to as planar-s [9]. This type of dolostones occurs only at the Lower Member from Wadi Khaboba, Wadi Dacran and Wadi Allouga.

Interpretation: This type of dolomite is a polymodal, planar-s dolomite with mimically and non-mimically replaced fossils and a unimodal matrix [9]. If the dolomitizing solution is somewhat less supersaturated with respect to dolomite, the matrix may be dolomitized, but the fossils may remain undolomitized [9]. The fossils remain undolomitized because at the lower saturation state very few dolomite nuclei form on the coarser calcite. If these fossils remain as calcite, the resultant rock will be a unimodal, planar-s dolomite with unreplaced allochems [9]. If the allochems that resisted dolomitization are later dolomitized above the critical roughening temperature or above the critical saturation, the resultant texture may be polymodal with a planar-s matrix and non-mimically replaced allochems with non-planar dolomite [9]. A third possibility is that the unreplaced fossils will dissolve either during or after dolomitization, leaving molds [9]. If the undolomitized matrix and allochems dissolve, the resultant dolomite would be a unimodal, planar-e dolomite. This is the category of dolomites that is

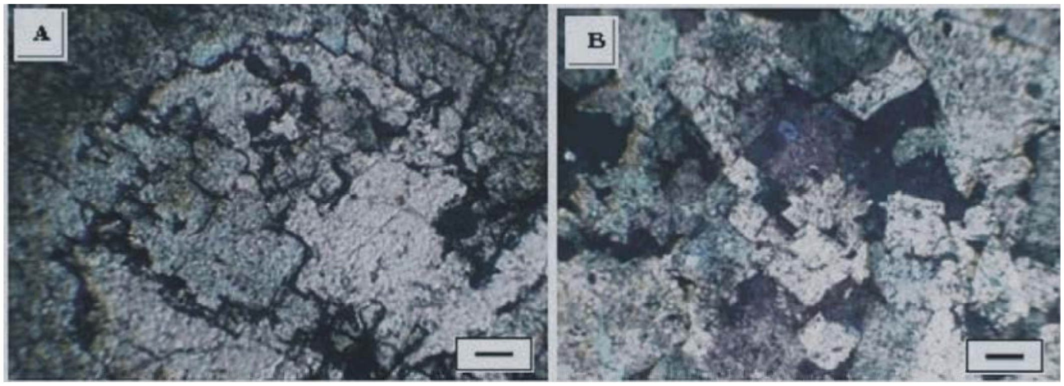


Fig. 12: Dolomite rock-texture6: Coarse to very coarse-crystalline non-planar-c (cement) saddle dolomite. Dolomite crystals have curved; lobate, serrated or irregular boundaries (A). This type shows clear saddle dolomite shape in void (B). A (PPL) and B (C.N.), Upper Member. Bare scale =300 µm

commonly referred to as sucrosic. A situation similar to that depicted by Sibley and Gregg [9] may occur but the dolomite may continue to grow until it completely fills the space [9], resulting in a unimodal, planar-s dolomite.

Dolomite Rock-texture 7: Coarse to Very Coarse-crystalline Non-planar-c (Cement) Saddle Dolomite: Dolomite crystals forming 80-90 % of the rock. Coarse to very coarse-crystalline (500 -1000 µm) dolomite cement makes up this dolomite type (Fig. 12A, B). They have curved or lobate crystal faces and sweeping extinction under crossed polars is most characteristic. Under plane light triangular surface irregularities (defects) may be visible, as well as curved crystal faces. Planar-c dolomite lines vugs and fractures and occurs as major void-filling dolomite and is thus responsible for occlusion of pore spaces and fractures. This type includes dolomite cement and dolomite replacing precursor cement. The term void-filling dolomite [9] is employed for this type, because it is often not possible to differentiate between dolomite cement and dolomite replacing precursor cement. This type of dolostones occurs in the Upper Dolomite Member at Wadi Khaboba, Wadi Baba, Wadi Dacran and Um Bogma.

Interpretation: In the light of this evidence the non-planar-c dolomite is also interpreted as having formed at elevated temperatures from brines with higher salinities than seawater [33]. Polymodal size distributions may develop from a heterogeneous distribution of nucleation sites, multiple periods of nucleation, or variations in the local growth rate [9]. If a rock has a high porosity and planar crystals, the crystal will tend to be euhedral. This texture is referred to as planar-e. If a rock has a low porosity and planar dolomite, the crystals will be subhedral to anhedral and referred to as planar-s [9]. To show how textures can be classified and interpreted, Sibley and Gregg [9] was illustrated with a hypothetical wackestone. First, assume that matrix and fossils are both composed of low-Mg calcite and the matrix is more finely crystalline than the fossils. If this wackestone is dolomitized with a solution that is very highly supersaturated with respect to dolomite, dolomite may nucleate in the matrix and fossils [9]. The fossils are composed of relatively large calcite crystals, so dolomite nuclei in the fossils are likely to be rather far apart, leading to non-mimetic replacement.

Dolomite-rock Texture 8: Polymodal, Non-planar-p Porphyrotopic Dolomite: Dolomite crystals forming 85% of the rock. The final dolomite is finely to very coarse crystalline, polymodal, planar-p dolomite replacing decimicron-size neomorphic calcite crystals. The dolomite crystals are cloudy due to abundant inclusions and predate fractures in the rock. It is composed of dolomite rhombs forming about 80 % of the rock. The dolomite rhombs are non-planer-a anhedral to subhedral-s ranging in size from 50 to 750 µm and show in-equigranular texture (Fig. 13A). Some dolomite rhombs have thin disseminations of iron oxides along rhombohedral cleavage (Fig. 13B). Many cavities lined by coarse crystalline dolomite were observed. The fine grained dolomite forming grumose texture (Fig.13B). Both matrix and grains are affected by this type of dolomitization, which shows low intensity in a relatively dense limestone. Fracture porosity is the common porosity type. The fine crystalline dolomite in this texture is frequent by formed after fine crystalline calcite which may point to

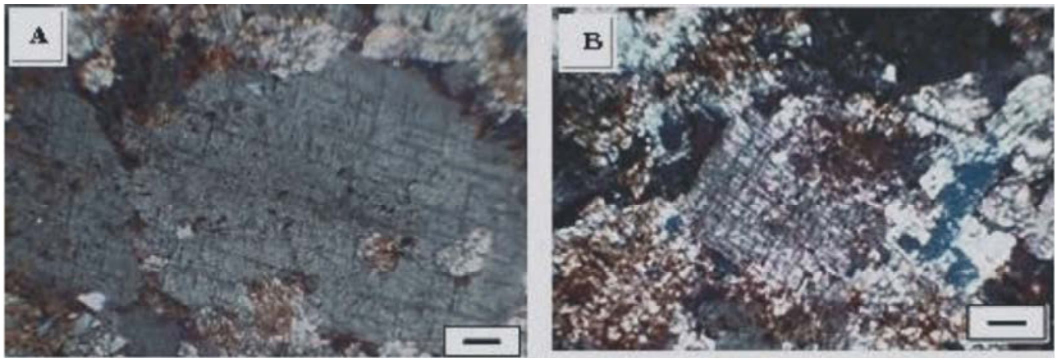


Fig. 13: Dolomite-rock texture Polymodal non planar porphyrotopic coarse to very coarse non- planar-a anhedral (A), fine crystalline dolomite surrounded by coarse dolomite forming grumose texture (B) C.N., Lower Member, Bare scale =300 µm

the original fabric of the rock voids and pore-spaces form about 5% of the total rock of intercrystalline and channel types. This type of dolostones occurs at the Lower Member from Wadi Khaboba, Wadi Dacran and Wadi Allouga.

Interpretation: Polymodal size distributions may develop from a heterogeneous distribution of nucleation sites, multiple periods of nucleation, or variations in the local growth rate [9].The fine crystalline dolomite in grumose texture is formed after fine crystalline calcite which may refer to the original fabric of the rock. Where inclusions of calcite are present, a replacive origin is indicated, a conclusion supported by the single crystal nature and pseudomorphic form of dolomite. The texture of type 8 dolomites consists of larger dolomite crystals with increasing non-planar crystal boundaries, suggesting that this dolomite formed at higher temperatures [9, 46, 47].

Results of Mineralogy and Geochemical Analyses: X-ray diffraction analyses were accomplished on 13 Dolomites samples as well as twenty samples were selected and analysed for their elemental composition. The main results are summarized in Tables 1 and 2. Trace-element concentrations are useful in distinguishing and characterizing various dolomite phases from a single formation [48].

Bulk mineralogy and Stoichiometry: The XRD is often used to determine the Ca/Mg ratio by precise measurements of the position of the *d*104. The Ca excess was calculated by the equation of Lumsden [49]:

$CaCO_3$ mol% = $333.33 * d_{104} - 911.99$

Where d_{104} is the position of the peak in angstrom units.

Stoichiometry have been used to outline three dolomite groups [50, 51]: (1) late diagenetic, coarse crystalline dolomites, generally nearly stoichiometric; (2) early diagenetic, fine crystalline dolomites, associated with evaporates and nearly stoichiometric; (3) early diagenetic, fine crystalline dolomites, not associated with evaporites and generally Ca-rich. X-ray diffraction analyses were accomplished on 13 dolomites samples (Table 1). The patterns obtained exhibit sharp diffraction peaks and reveal minor remnants of the precursor calcite quartz in dolomite samples of Middle Member. The sharpness of the peaks indicates an almost perfect and ordering of the crystalline lattice of the studied dolomites. The X- ray of the studied dolomite (Table 1) showed that the diffraction maxima range from 2.876A° to 2.88A° for the lower Member dolomite samples. The shift from stoichiometric dolomite (2.886A°), expresses deviation of composition from a 1:1 molar $CaCO_3$:$MgCO_3$ ratio to slightly Mg-rich dolomite ranging between 46.66 and 48.00 mole percent $CaCO_3$. The middle Member dolomite samples showed that the differaction maximum ranges from 2.879 A° to 2.885A° which is relatively around stoichiometric. The shift expresses deviation of composition from a 1:1 molar $CaCO_3$:$MgCO_3$ ratio to slightly Mg-rich dolomite ranging between 47.66 to 49.66 mole percent $CaCO_3$ slightly increase than the lower Member. At the Upper Member dolomite samples showed that the diffraction maximum ranges from 2.880 A° to 2.889A°. These d-spacing indicate the dolomite is around the stoichiometric composition, where the mole percent $CaCO_3$ reveals that dolomite of this member has values ranging between 48 and51 mole percent $CaCO_3$. The dolomite of the three members

Table 1: Minerals identified by XRD and mole percent $CaCO_3$ in the some studied dolomite samples.

Formation	Member	Sample No.	Locality	Minerals identified	dA^0	Mole % $CaCO_3$	Mole% $MgCO_3$
Um Bogma	Upper	13	Khaboba	Dolomite and Quartz	2.885	49.66	50.34
		12	Dacran	Dolomite	2.88	48	52
		11	Um Bogma	Dolomite	2.88	48	52
		10	Um Bogma	Dolomite	2.88	48	52
		9	Sidri	Dolomite	2.889	51	49
	Middle	8	Khaboba	Dolomite, Quartz and Calcite	2.88	48	52
		7	Dacran	Dolomite and Quartz	2.881	48.33	51.67
		6	Um Bogma	Dolomite and Quartz	2.88	48	52
		5	Allouga	Dolomite and Quartz	2.879	47.66	52.34
		4	Sidri	Dolomite	2.884	49.33	50.67
	Lower	3	Khaboba	Dolomite	2.88	48	52
		2	Dacran	Dolomite	2.878	47.33	52.67
		1	Allouga	Dolomite	2.876	46.66	52

Table 2: $CaCO_3$, MgCO3, $FeCO_3$ and elemental concentrations for some studied dolomite rocks.

Age	Formation	Member	$CaCO_3$ mole %	$MgCO_3$ mole %	$FeCO_3$ mole %	Na ppm	Mn ppm	Sr ppm
Early carboniferous	Um Bogma	Upper						
		N=6	49.3- 51	49 -52	3-7.5	204-275	95-120	33-40
		Average	49	51	3.5	207	106	35
		Middle						
		N=8	47.6 -49.6	50.4-52.4	3.9-6.6	314-380	60-75	42-57
		Average	48.6	51.4	2.2	320	63	43
		Lower						
		N=4	46.6- 48	52- 53.4	0- 3.9	365-420	32-40	69-89
		Average	47.4	52.6	2.98	375	33	71

showed that the lower and upper members are stoichiometric dolomite, while the middle one is relatively around stoichiometric. The investigated samples here have a nearly stoichiometric composition, which fits with group (1) and group (3) dolomites [50, 51]. In conclusion, the analyzed samples belong to group (1) dolomites, which are thought to result from slow crystal growth, possibly aided by elevated temperatures.

Minor Element Geochemistry: Sr, Na and Mn contents were analyzed on 18 selected dolomite samples (Table 2). The dolomites display relatively low concentrations of these minor elements, in agreement with the nearly stoichiometric composition and the high ordered.

Strontium: Most of the dolomite samples have Sr concentrations between 33 and 89 ppm (Table 2). As a general rule, early diagenetic dolomites have higher Sr contents than late diagenetic ones [52, 53]. This is consistent with a general conclusion that late diagenetic, coarse-grained dolomite has lower Sr^{2+} concentrations than early-stage, fine-grained dolomite [54]. Dolomites directly precipitated from seawater typically have Sr contents of several hundred ppm [55] higher contents are typical for dolomites precipitated in evaporitic environments [56]. The Sr contents measured in the studied samples are comparable with those indicative of burial diagenetic dolomites (e.g. Mattes and Mountjoy [57], Morrow *et al.* [58], Barnaby and Read [59] and Nielsen *et al.* [60]. The low Sr contents of studied dolomites may be referred to its Sr depletion during diagenetic evolution [52]. The dolomite of the Lower Member is relatively rich in Sr^{2+} (average 71ppm) when compared with those of the middle and upper members. However, Sr^{2+} is comparable to that of other ancient dolomites and is much lower than Sr concentrations in typical modern marine dolomites (~ 500.800 ppm) [53].

Sodium: Sodium contents in the studied dolomite samples range between 204 and 420ppm (Table 2), means that the Na contents of dolomites is even lower. Early diagenetic dolomites have higher Na contents than late diagenetic ones [52, 53]. Land and Hoops [61] reported 1000-3000 ppm Na^+ in modern dolomites from Florida, Bahamas, Arabian Gulf and Baffin Bay, whereas late burial dolomites typically contain only a few hundred ppm Na [57, 60]. Na^+ concentrations in dolomite generally increase with salinity of dolomitizing fluids and decrease with stoichiometric enhancement [62]. However, Na^+ does not readily co-precipitate with Ca^{2+} and Mg^{2+} because of their differences in ionic charge and because a good deal of Na+ in dolomite may occur as fluid or solid halite inclusions [63]. In addition, it is unknown whether the amount of non-lattice Na^+ is affected by brine salinity and/or kinetic effects. Therefore, the low Na contents measured in studied samples bear out a late burial origin for the studied samples. The difference in Na concentration among studied dolomites reflects relatively high salinity fluid in the dolomite types of lower and middle members than the upper one.

Manganese: The investigated dolomites show variable contents of Mn, its concentration ranges between 32 and 120ppm (Table 2). During diagenesis, Fe and Mn contents are both known to increase in carbonates [52]. Reducing conditions favor the concentration of Fe and Mn in natural fluids. Consequently, early dolomites precipitated from near surface oxidizing fluids commonly have very low Fe and Mn contents, whereas burial dolomites have higher Fe and Mn contents because most subsurface fluids are reducing [53, 54, 59]. In conclusion, the Fe and Mn contents reported for the studied dolomites suggest that they formed in a burial, reducing environment.

Diagenesis Dolomitization Mechanism: The only major source of magnesium for pen-contemporaneous and shallow-burial dolomitization may be seawater [35]. Magnesium for deep-burial conditions can be supplied from (1) connate waters (trapped seawater); (2) dissolution of unstable original minerals; (3) pressure solution (stylolitization); (4) compaction of underlying shales; and (5) basinal brines [35]. If thermodynamic and kinetic considerations are combined, the following conditions and environments are considered chemically conducive to dolomitization: (1) environments of any salinity above thermodynamic and kinetic saturation with respect to dolomite (i.e. freshwater/seawater mixing zones, normal salina to hypersalina subtidal environments, hypersaline supratidal environments, schizohaline environments); (2) alkaline environments (i.e. those under the influence of bacterial reduction and/or fermentation processes, or with high input of alkaline continental groundwaters); and (3) many environments with temperatures greater than about 50°C (subsurface and hydrothermal environments) [64]. The meteoric-marine mixing-zone model has been popular for cases where there are no evaporites associated with the dolomites, subtidal facies are dolomitized and the dolomitization event was relatively early (i.e. near-surface, before any compactive fracture of grains). Mixing-zone dolomites can be expected to develop extensively during major regressive periods, when platform carbonates are being deposited. Seaward progradation of a carbonate shoreline will be accompanied by a progradation of the meteoric-marine mixing zone [48]. Active circulation and pumping of water through the carbonate sediments are important and these will be determined to a large extent by the climate. Groundwater circulation will be more active under a humid climate with strong seasonal rainfall, than under a more arid climate [48]. These features of Um Bogma Formation dolomites suggest that the formation were in the early diagenesis in shallow-marine carbonate environment (tidal-subtidal) within mixed water area at low temperature and shallow to relatively deep burial condition (high temperatures). The degree of dolomitization is controlled by the rate of fluid flux, the Mg^{2+} concentration of the fluids and porosity and permeability of the precursor limestone [65, 66]. They showed that the dolomitization is part of a long diagenetic history of four different stages of which dolomitization produces varieties of dolomitic fabrics having taken place at a moderate burial depth. Sadooni and Al-Sharhan [67] classified the dolomite types into two major groups: (1) selective dolomitization, which includes post-fracture, post-stylolite, local source, water controlled types and (2) extensive dolomitization, which includes aphanitic, limpid and saddle types. This classification is generally adopted here with considerable modification.

Early Diagenetic Dolomite

Selective Dolomite (Type I): Selective dolomitization affects all types of percourcer carbonate and both matrix and grains. Dolomite usually occurs as disseminated floating rhombs of 20-60 µm size with variable. It is similar to the floating rhombs fabric of Gregg and Sibley [29] and Randazzo and Zakhos [68], or the porphyrotopic type of Sibley and Gregg [9]. This type is interpreted to represent an early stage of dolomitization [9, 68, 69] and represented by dolomites of Lower Member for Um Bogma Formation.

Pervasive Dolomite (Type II): This dolomite is represented by the extensive and pervasive dolomite mosaic of different fabrics and crystal sizes of shallow burial but post-dates submarine cementation. Generally the crystal size ranges from 1000 to >100 µm and planar-e to planar-s morphology. The mosaic has unimodal distribution and usually retains a uniform intercrystalline pore network. This type of dolomite is equivalent to the sucrosic texture of Sibley [37], or the sutured mosaic of Randazzo and Zakhos [68]. It is believed that these dolomites were developed after considerable burial and is of early diagenetic origin replacing subtidal to supratidal mudstones to wackestones [7], possibly during mixing of a meteoric phreatic wedge with marine waters [69].

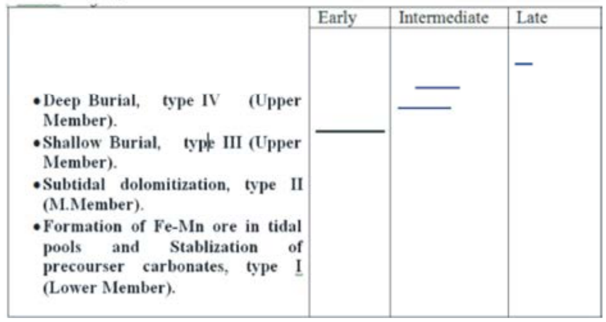
Late Diagenetic Dolomite:

Pervasive Dolomite (Type III): This type is characterized by a coarsely crystalline dolomite mosaic of planar-e, to planar-a fabrics. Original fabric is usually destroyed and occurrence of crystals possess a cloudy-centered clear rim textures may indicate the late replacive nature of dolomitization event. This type of dolomite, however, may occlude intercrystalline porosity [33]. In some cases it occurs as non-planar-a crystals, which usually display an interlocking fabric with coarsely crystalline mosaic. In this case it retains ghosts of the original fabric, which may indicate that dolomitizing fluids are Mg^{2+} deficient to complete dolomitization [33, 69]. The paragenetic relations of this type of dolomite and its association to the surrounding rocks indicate late diagenetic processes [33, 37].

Dolomite Cement (Type IV): This is a late diagenetic dolomite with localized occurrences and commonly reported as vein filling, or fracture healing or pore fillings after late diagenetic calcite cementation. It is common as pore lining or filling with euhedral, equant, coarse dolomite crystals, which increase in size inwards. Other types of this dolomite cement include saddle dolomite of late diagenetic origin. The coarsely crystalline fabric, the microfracture healing and the moldic pore filling nature of this dolomite all indicate a late diagenetic event in a deep-burial environment [33, 69]. The dolomite types of the Lower Member contain relatively higher Sr^{2+} and Na^{+} concentrations and lower Fe^{2+} and Mn^{2+} concentrations compared with those dolomite types of the Middle and Upper members.

Four associated dolomite types are recorded at dolomites of Um Bogma Formation; they are differing in their petrographic and geochemical characteristics. The dolomite of the first (dolomite type I) started since the stablization of precourser carbonates (Lower Member). Fabrics of this type are dominance of medium to fine in size, non-planar crystal boundaries and presence of stylolites. Dolomite type (II) subtidal dolomitization of dolomite; it is setting at Middle Member. The phase of this type (II) has replaced lime mud, which provided suitable template for dolomitization to proceeds, it supported by the absence of any allochemical ghost. Dolomite types (III and IV) are located at Upper Member. The lack of any compaction fabrics, the dominance of euhedral planar crystal boundaries and the relatively high intercrystalline porosity. From data of the studied dolomites a paragenetic sequence of the diagenetic events has been constructed (Table 3).

Table 3: Diagenetic evaluation of studied dolomites.



In trying to evaluate depositional environments of Um Bogma dolomites (Early Carboniferous), it is imperative that the Lower Member of Um Bogma Formation was deposited in intertidal to shallow subtidal environments. The middle member was deposited in an open platform environment followed by shallow subtidal facies of the Upper Member [70]. Um Bogma Formation was possibly deposited in shallow-marine carbonate platform environment. The presence of green algae and benthic foraminifer fossils are determined that this formation is deposited in the shallow-marine carbonate platform (intertidal-subtidal) environment [6].

CONCLUSIONS

Eight dolomite-rock textures are recognized and classified according to their crystal-size distribution and crystal-boundary shape. Unimodal, very fine to fine-crystalline planar-s (subhedral) mosaic dolomite is interpreted as early-diagenetic dolomite replacing the subtidal to intertidal carbonate muds. Unimodal, medium to coarse-crystalline planar-s (subhedral) mosaic dolomite is interpreted to represent an intermediate to late-diagenetic replacement dolomite. Medium to coarse-crystalline planar-e (euhedral) mosaic dolomite; occurs as matrix and forming mosaics. This type of dolomite is characterized by unimodal (locally bimodal) and occurs as sucrosic mosaics/patches in the matrix of the host carbonate rocks. Medium -crystalline planar-e (euhedral) replacement dolomite may be formed from replacement of the fine calcite and/or dolomite. The replacement originated from shallow-medium burial late diagenetic processes. Unimodal, medium to coarse-crystalline non-planar-s-a (subhedral- anhedral) mosaic dolomite is occurred as replacement of a precursor limestone or dolostone. Polymodal, planar-s-e (subhedral-euhedral) mosaic dolomite; Polymodal, planar-s dolomite formed probably by non-mimetically replacement and dissolution of undolomitized matrix and allochems.

Coarse to very coarse-crystalline non-planar-c (cement) saddle dolomite may be formed at relatively elevated temperatures. Polymodal, non-planar-p (porphyrotopic) dolomite represented variations in the local growth rate a replacive origin and this dolomite texture may be formed at higher temperatures. Dolomitization is closely associated with the development of secondary porosity; dolomitization pre-and post-dates dissolution and corrosion. The most common porosity types are non-fabric selective moldic and channel porosity and intercrystalline porosity. These porous zones are characterized by late-diagenetic coarse-crystalline dolomite (Middle Member), medium-crystalline dolomite (Upper Member) whereas the non-porous intervals are composed of dense mosaics of early-diagenetic dolomites (Lower Member). The distribution of dolomite rock textures indicates that porous zones were preserved as limestone until late in the diagenetic history and were then subjected to late-stage dolomitization in a medium burial environment, resulting in coarse-crystalline porous dolomites (Middle Member). Um Bogma dolomites have been formed as early diagenetic at the tidal-subtidal environment and as the late diagenetic at the shallow-deep burial depths.

Mineralogically, Three main groups of dolomites are identified; at the base beds of Um Bogma Formation they are finely crystalline nearly stoichiometric (46.6-48 mole % $CaCO_3$) dolomites associated with Fe-Mn ores (at Lower Member). The second group at Middle Member; coarsely crystalline near-stoichiometric (47.6-49.6 mole % $CaCO_3$) dolomites and third group is medium crystalline Ca-rich (49.3- 51 mole % $CaCO_3$) dolomites, not associated with evaporates (Upper Member). Groups 2 and 3 dolomites are generally of late diagenetic burial origin, whereas the first group is usually near-surface early diagenetic [51]. The dolomites display relatively low concentrations in Sr, Na, Fe and Mn minor elements, in agreement with the nearly stoichiometric composition and high ordered. Generally, the dolomite types of the Lower Member, Sr^{2+} (69-89 ppm) and Na (365-420 ppm) Concentrations are relatively higher and Mn^{2+} (32-40 ppm) concentrations are lower, compared with those dolomite types of Middle and Upper members. The studied dolomites reveals the presence of two distinct diagenetic dolomite stages: Early Diagenetic; Selective Dolomite (Type I) and Pervasive Dolomite (Type II) Dolomite. The second stage is Late Diagenetic Dolomite; Pervasive Dolomite (Type III) and Dolomite Cement (Type IV). Dolomite (Type I) is confined to the Lower Member of the succession. Dolomite of (Type II) of Middle Member; dolostone and argillaceous dolostone beds and dolomite (Type III and IV) is recorded at the Upper Member of the succession. Finally, these features of Um Bogma Formation dolomites suggest that the formation were in the early diagenesis in shallow-marine carbonate environment (tidal-subtidal) within meteoric-marine mixed water area at low temperature and shallow to deep burial condition at high temperatures.

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