DOLOMITIZATION AND POROSITY EVALUATION OF KHURMALA FORMATION, GARA ANTICLINE, DOHUK AREA, KURDISTAN REGION, IRAQ

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ABSTRACT

The Khurmala Formation (Late Paleocene – Early Eocene) is well exposed at the southern limb of Gara mountain, Dohuk area, Kurdistan Region of north Iraq. The thickness of the Formation is 91 m and generally consists of buff to grey, medium to thick-bedded stromatolitic dolostone alternating with thin beds of buff to dark gray shale or marlstone. Shale interlayers increased in thickness upwards. The studied section has been divided into three units based on shale ratio. The focus of this study is to investigate the type and origin of the dolomite and its impact on the porosity using field observation, petrologic and petrographic investigations with SEM microscopy. The common dolomite types include (1) Unimodal, cryptocrystalline to fine crystalline dolomite of nonplanar mosaic. This type is associated with the relics of the stromatolites and commonly recognized in the upper part. (2) Unimodal fine to medium crystalline, planar-e to Planar-s dolomite mosaic, which is associated with dolomite horizons showing ghosts or relics of benthic foraminifera, algae, ostracods and other bioclasts. The other types are less common and include (3) Porphorotopic dolomite and (4) Bimodal medium to fine, planer-e to planar-s dolomite mosaic. The latter is associated with dolostone horizons display important moldic and vug porosity. Molds, vugs and intercrystalline porosity are noticed in all types but with variable percentages. Fenestral porosity is common in the stromatolitic dolomite of type one. The vertical distribution of the different type of dolomite and its porosities indicate cyclic alternation of the studied Khurmala section which implies effective eustatic control on deposition and dolomite diagenesis. The dolomitization resulted from a possible combined effect of seawater refluxion and sabkha evaporation mechanisms.

Keywords: Khurmala; Dolomitization; Porosity; Iraq; Dohuk
INTRODUCTION

Khurmala Formation is a carbonate unit dominant by dolostone. It is developed over the shoaling Zagros foreland basin during the Late Paleocene to Early Eocene time Al-Qayim et al. (2012). The formation is developed as a lagoonal-tidal complex behind a belt of discontinuous reefal-shoal limestone of the Sinjar Formation (Bellen et al., 1959, and Al-Qayim, 1995). The latter is intergrades laterally into the basinal marly limestone of the Aaliji Formation. According to the description of Bellen et al. (1959) from a subsurface section (well K-114) at Kirkuk oilfields, the thickness of the formation reaches 185m and composed of porous dolomite with shale interlayers at the upper part. The dolostone contains ghosts of miliolids, valvulinids, small gastropods and algal fragments. Its lower part consists of dolomite and dolomitic marly limestone intercalated with the upper part of the Kolosh clastic formation. Thus, the contact is conformable. On the other hand, the formation is covered by the nummulitic limestone of the Avanah Formation unconformably. Examination of outcrop sections of the Khurmala Formation came later and includes Al-Omari and Sadik (1973) from the core of Jabel Maqlub. The formation here is composed of 50 m of lagoonal marly limestone. At Harir area the formation gets thinner (around 10 m) with similar lithology Al-Shaikh et al. (1975). The lagoonal carbonate sequence of the upper part of Kolosh Formation at Haibat Sultan Ridge is considered as Khurmala Formation by Al-Qayim and Nisan (1989). Al-Qayim (1995) had studied the lithostratigraphic relations of the formation at four, basin-wide localities (Aqra, Bekhme, Shaqlawa and Haibat Sultan Ridge). He suggested that Khurmala Formation is deposited in a lagoonal facies belt associated with onshore tidal flat. Al-Banna et al. (2006) examine the Khurmala Formation at Bade section of Bekhair anticline, north of Dohuk city. The formation here is dominated by shallow marine limestone of four microfacies associations: shoal bank, lagoon, intertidal and supratidal environments. At Avanah dome of Kirkuk field the formation thickness is over 152 m thick represented by back-reef lagoonal limestones, frequently dolomitized, with low permeability (Al-Naqib et al. 1971, in Aqrawi et al. 2010). Al-Ehmeedy et al. (2012) studied the formation at Dukan area and find out that the formation is characterized by carbonate association of semi-restricted and quiet lagoon in association with reef mound and tidal flat. Omer et al. (2014) Examined the diagenetic aspects of the Khurmala rocks from five outcrops in northern Iraq using cathodoluminescence spectroscopy. He recognized three types of dolomite and three groups of carbonate cement. In the Sulaimani area Karim et al. (2018) concluded that the environment of Khurmala Formation is back reef or lagoon. A recent work on the Khurmala Formation by Asaad and Balaky (2018) at Aqra area indicates that Khurmala Formation was deposited in a shallow marine environment of a partly quiet and semi-restricted shelf lagoon.
According to Jassim and Goff (2006) fossils of Khurmala Formation are mostly dwarf and obliterated by crystallization and has a restricted distribution in a belt between Jabal Maqlub in the NW and the Chemchemal-Qizil Dagh area in the SE. It was most probably deposited in a relict basin corresponding to the SE part of the Kolosh trough. This basin is separated from the offshore Aaliji basin by a partly disconnected submarine ridge on which shoals of the Sinjar Formation were deposited.

Although the Formation had been studied in different sections in the Kurdistan Region, still its stratigraphic relations is debatable and need further studies especially in Duhok area. Therefore, this study aimed at revealing the stratigraphic status of the formation at Duhok area and to show its facies associations. Another goal is to examine the dolomite type and its texture to evaluate the associated porosity evolution. Recent interest in the Khurmala Formation as a potential reservoir is growing up especially around Dohuk after the renewed exploration campaign. The formation at Gara anticline has not been covered by previous work.

GEOLOGIC SETTING

The Khurmala Formation in Dohuk area crops out in Bekhair, Shikhan, Gulley Kerr, Aqra in addition to Gara anticline. However, typical lithologies and complete sections were recognized at both Aqra and Gara anticlines. A well-exposed section of the formation is measured at the southern limb of Gara anticline, 45 km northeast of Dohuk city exactly at 36°57'42.93"N, 43°20'2.94"E coordinates (Fig.1). The Gara anticline is a huge doubly plunging, extending 80 km with width reaches 12 km (Nazar, 2011). The structure oriented almost East-West parallel to the swinging trend of the Zagros structures here. It is part of the Zagros high folded zone according to the tectonic subdivision of Iraq. The oldest rocks exposed in the core of the anticline is the late Triassic (Baluti Formation). The flanks are covered by Jurassic, Cretaceous, and Paleogene rock units. The youngest Neogene units, cover the low areas of the synclines in between. The selected section is located at Spindar valley, at the southern limb of Gara anticline. It is about 50 km to the NE of Dohuk city with a complete exposure including contacts with the associated units. The thickness of the Formation is 91 m.

MATERIALS AND METHODS

A total of 285 samples were taken from this section, 254 samples belong to Khurmala Formation, the rest from adjacent stratigraphic units. All the beds are measured and described lithologically. Field examination concentrated on lithologic characters, sedimentological features, fossils contents, and stratigraphic associations. Laboratory work includes a description of slabbed samples for macro sedimentary features.
Fig. 1: Location map of the study area. Geological map was drawn after Sissakian (2000). Tectonic map of north Iraq (inset) is from Al-Qayim (2012).

The micropaleontological analysis is attempted to investigate the origin and depositional environment of marlstone and shale interlayers. Petrographic analysis and interpretation had been made for 163 thin sections from 158 samples. Some samples thin-section twice for detailed petrographic examination. All the thin section were stained with Alizarin red-S and potassium ferricyanide for differentiated between calcite and dolomite following Dickson (1966). Thin section examination was conducted using a polarized optical microscope with an attached camera for photography. The petrographic examination focused on dominating mineral contents and identification of ghost allochems to restore original components of the sedimentary environment. Microfacies analysis followed the depositional texture nomenclature of Dunham (1962) with slight modification. Scanning Electron Microscopy is used to recognize...
dolomite fabric interrelationship. For dolomite classification, the work of Sibley and Gregg (1987) is followed, which combined microscopic and Scanning Electron Microscope features to describe different dolomite fabrics. Porosity evaluation is made from thin section examination, and the terminology used for porosity classification is from the work of Choquette and Pray (1970). The crystal size terminology used followed the general classes of Lucia (1999) with slight modification due to small crystal

RESULTS

Lithostratigraphy

The total thickness of the Formation is 90.7 m and generally consists of buff to grey, thin to thick, bedded stromatolitic dolostone alternating with thin beds of buff light grey to yellowish marlstone and grey bluish to green shale (Fig. 2). Shale interlayers increased in thickness upward which assisted for dividing the Formation into three basics units: Lower Unit (A), Middle Unit (B), Upper Units (C) and transitional unit (D).

A- Lower Unit: (Thick-Bedded to Massive Dolostone)

This unit forms the base of the Khurmala Formation. The thickness of this unit is 27 m and consists of thick (30 - 100 cm) to massive, grey, partly bituminous dolostone beds. Strata are cyclic and show thinning upward trend. Calcite crystal nodules are common in medium beds. Porosity is high in this part, and fossil ghost of foraminifera, ostracod and undefined algae are forming moldic porosity due to intensive dolomitization. This unit overly Aqra Formation unconformably through massive brecciated dolostone zone which extends for a few meters in thickness (Fig.3).

B- Middle Unit: (Medium to thick-bedded stromatolitic dolostone and thin marlstone)

This is the thickest unit 31.5 m thick which is composed of medium to thick-bedded, grey thinning upward dolostone sequence, commonly associated with thin stromatolites beds. Dolostone bed is interlayered with yellowish to brownish marl or shale horizons which increased in thickness upwards (Fig.4). The stromatolitic dolostone beds have a thickness of (5-30 cm), and the marl horizon ranges between (2-40 cm) in thickness (Fig. 4).

C- Upper Unit: (Medium to thick-bedded dolostone alternating thin stromatolitic dolostone and thick shale Unit)

The total thickness of the unit is about 20 m and it can be subdivided into two parts Lower and Upper. The lower 12.5 m consist of thick (40 – 80 cm) to some thicker bed occasionally light grey bedded dolostone interbedded with thin (2 – 20 cm) of bluish-grey marl and shale, overlain by 7.5 m of intermediate (10 - 30 cm) to (30- 50 cm) light grey stromatolitic dolostone interbedded with thin to medium to thick (5 – 50cm) beds of bluish-grey marl and bluish and brown color shale (Fig. 5 A).
Fig. 2: Lithostratigraphic column of Khurmala Formation in Spindar section

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness</th>
<th>Sample No</th>
<th>Lithology</th>
<th>Divisions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M Eoc</td>
<td>Gercus</td>
<td>90</td>
<td></td>
<td></td>
<td>Transitional U</td>
<td>Alternation of very thin beds of dolostone light grey with thick green shale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85</td>
<td></td>
<td></td>
<td>Upper Unit</td>
<td>Alternation of thick miliolid lagoonal dolostone horizon with thin stromatolitic dolostone bed and thick shale brown and bluish grey</td>
</tr>
<tr>
<td>Early Eocene</td>
<td>Khurmala Fn.</td>
<td>75</td>
<td></td>
<td></td>
<td>Middle Unit</td>
<td>Medium to thick stromatolitic dolostone alternating with thin shale and marl yellow and brown in color</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td>Lower Unit</td>
<td>Thick to massive stromatolitic dolostone and thick valvulinid lagoonal dolostone horizon</td>
</tr>
</tbody>
</table>

- **Mudstone**: Red
- **Marl**: Green
- **Dolomite**: Grey
- **Shale**: Yellow
- **Stromatolitic Dolomite**: Black
Fig. 3: Lower contact of Khurmala Formation with Aqra Formation in Spindar section

Fig. 4: Middle part of Khurmala Formation in Spindar section showing stromatolitic dolostone

Fig. 5: (A) Lower part of the Upper Unit of Khurmala Formation at Spindar section. (B) The upper contact of Khurmala Formation with Gercus Formation at Spindar section

**D- Transitional Unit: (Thin to very thin bed of dolomite light grey color and thick green shale considered to be Khurmala/Kolosh formation)**

The last 12 meter which is the mixed zone comprising of a thin 5-10 centimeter of dolostone interbedded with green shale up to 2 m in thickness. The dolostone of this unit is
highly fractured and porous, whitish-grey color, stromatolitic and impregnated by iron oxide. This unit unconformably underlay the red beds of the Cercus Formation. (Fig.5 B).

**Microfacies Analysis**

The aim of this analysis is determination petrographic components and to identify microfacies type in addition to the recognition of possible environmentally index fossils. All these were attempted to recognize the environments of deposition and to investigate the diagenetic processes that had affected the formation. The studied section is strongly affected by variable diagenetic effects especially dolomitization which altered the original fabrics and replaced it by dolomite mosaic. Most of the examined samples are found to be of dolomite type due to the intensive dolomitization, which affected the limestone and destroyed, partly to completely, the original fabric of the rocks. Five microfacies had been recognized as below:

1. **Dolomitized Mudstone**

This microfacies is characterized by cryptocrystalline laminated dolomite. It lacks skeletal and non-skeletal grains (Fig.6.A&B). It contains gypsum crystals at the upper part of the Formation. These facies are present in all units, especially in the middle and upper units. The lacking of fossils, abundance of cryptocrystalline dolomite, and presence of lamination support the interpretation of deposition in the intertidal zone (Tucker and Wright, 1990; Hughes, 2009).

2. **Dolomitized Fenestra Mudstone**

It is generally laminated at a millimeter scale lamella and associated with fine crystalline dolomite mosaic. The main characterized of these facies is fenestral porosity and irregular lamination (Fig.6.C&D). It is widely distributed and had been recognized in the whole section. Lamination is compatible with microbial films and mats which form commonly in tidal environmental condition Flugel (1982).

3. **Dolomitized Small Benthic Foramiferal Wackestones**

These facies are well observed in the lower part and less frequent in the middle part. Generally, the diagnostic features of this microfacies is the benthic foraminifera of valvulina and clavulina (Fig.6.E&F) with appearance of ostracod. It exists with fine and medium crystalline dolomite fabric. Sometimes the foraminifera skeletal had been leached out completely due to dolomitization which leads to form moldic and intraskeletal porosity.

4. **Dolomitized Miliolid Packstone**

This microfacies is characterized by the occurrence of miliolids, green algae and few micro-gastropods in dolomitized micrite. Miliolids are dolomitized and only their ghosts and relics are remained (Fig.6.G). This facies appears mostly at the upper unit. This facies belongs to lagoonal environment. Unrestricted, low-energy, normal salinity subtidal lagoon as
evidenced by richness of foraminiferal species with green algae Hughes (2009). Yet occurrences of gastropods and ostracods indicate occasional increases in salinity and restriction.

5. **Lower Dolomitized Dasycladacean Packstone**

This microfacies is noticed at the upper unit. The skeletal component of this facies is the calcareous green algae mainly of *dasycladacean* (Fig.6.H). The groundmass is dolomitized with fine crystalline dolomite. The green algae dasycladacean which are growing in warm and shallow water Valet (1979) represents lagoon environment Flugel (1982).

![Fig. 6: (A, B) dolomitized mudstone, kh177, PPL. (C) fenestral dolomitized mudstone, kh151, PPL. (E, F) valvulinid and clavulinid kh40, kh40b, XPL. (G) quinqueloculina, kh223, PPL. (H) dasycladacean, kh224, PPL. (I) unpolished sample contain micro-gastropod, kh117](image)

**Dolomite Mosaic Types**

Dolomite of the studied samples is pervasive and occurs in different types and fabrics. It had been grouped into four dolomite types according to the crystal sizes and fabric.

**D1 - Unimodal, cryptocrystalline, non-planar dolomite mosaic**

This type is characterized by clean and fine texture of dolomitized mudstone with no evidence of any skeletal or non-skeletal grains occurrences (Fig.7.A&B). It has very fine crystalline dolomite type of no more than (5 µm). It is associated commonly with the relics of
the stromatolites and recognized at all parts specially in the middle and upper units. The non-planar dolomite texture is represented by closely packed anhedral crystals, with mostly curved or irregular inter-crystalline boundaries Gregg and Sibley (1984).

**D2 - Unimodal fine to medium crystallin, planar-e to planar-s dolomite mosaic**

It is associated with dolomite horizons showing ghosts or relics of benthic foraminifera such as *valvulinid* and *clavulinid*, algae and ostracod. It is widely distributed in all parts but mostly at lower part and it shows relics of stromatolite (Fig.7.1). Planar-e dolomite has straight and planar boundaries between crystals (Fig.7.C & D). The other type of dolomite of this facies is Planar-s type of subhedral form where most of the dolomite crystals are subhedral shape with straight compromise boundaries at many crystal face junctions (Gregg and Sibley, 1984).

**D3 - Porphorotopic dolomite**

This type is associated with course dolomite crystals floating in fine crystalline mosaic (Fig.7 F). Usually the coarse dolomite crystals are euhedral and up to 200 μm in size, whereas, the fine crystals are often anhedral to subhedral and have mud size (<5um). This type is similar to the floating rhombs fabric of Gregg and Sibley (1984) and Randazzo and Zakhos (1984). Floating rhombs defined as isolated coarse crystal floating in fine crystals. It occurs in the lower part mainly. Dedolomitization through the dissolution of euhedral crystals of dolomite can be seen within this texture (Fig. 7F&E).

**D4 - Bimodal medium to fine, planar-e to planar-s dolomite mosaic**

This type of dolomite is characterized by mixed distribution of crystal size of fine and medium crystalline mosaic (Fig.7.G&H). The finer parts are anhedral to subhedral crystal shape, and the medium size crystals are commonly euhedral. Bimodal term refers to heterogeneous crystal sizes of dolomite (Gregg and Sibley, 1984).

**Porosity Types**

Visual evaluation of porosity types following Choquette and Pray (1970) were attempted, using thin-sections and SEM photos. Moldic, vuggy, intercrystalline, fenestral, and intraskeletal pore type are the most common.

**P1- Intercrystalline porosity**

This porosity is the most common porosity type within dolomite. It indicates the micro-pore spaces in between or around dolomite crystals Lonoy (2006). Where pore spaces and their interconnections are controlled by dolomite crystals size, shape and packing (Fig.8.A&B). The intercrystalline porosity in the examined samples are of uniform crystal size producing uniform.

**P2- Moldic porosity**

It is secondary pore that forms by selective, complete or partial dissolution of carbonate grain, this definition is slightly modified by Lonoy (2006) from Choquette and Pray (1970) by
Fig. 7: (A, B) D1 unimodal, cryptocrystalline to fine crystalline dolomite of nonplanar mosaic, kh67, PPL. (C, D): D2 unimodal fine to medium crystalline, planar-e to Planar-s dolomite mosaic, kh4, PPL. (E, F) D3 Porphorotopic dolomite. Kh14 PPL. (G, H): D4 bimodal medium to fine, planer-e to planar-s dolomite mosaic, kh40, XPL. (I) fine to medium crystalline dolomite showing relics of stromatolite, kh4, XPL

including pores formed by partial dissolution and recrystallization. In the studied samples most of the moldic porosity is related to dissolution of benthic foraminifera, Ostracod, and algae (Fig.8C). In other cases, molds of dissolved coarse crystals of dolomite are noticed especially in the porphorotopic dolomite fabric (Fig. 8D).

**P3- Intraskleatal porosity**

It also called intraparticle porosity. It is caused by partial solution of fossils material leaving behind a pore spaces simulate to chambers and organic structural framework (Fig.8.E &F). This pore space is either of primary origin or formed through the decay of organic material in carbonate skeletons. A skeletal wall will therefore enclose, at least partly, most of intraparticle porosity. The definition of intraparticle porosity i modified by Lonoy (2006) to discards porosity related to dissolution. This type of porosity is limited in distribution and associated with dolomite microfacies shows relics of fossils such as benthic foraminifera.
**P4 - Fenestral porosity**

This type is commonly associated with stromatolitic dolomite facies where the pores are layered in subparallel lines (Fig.8.G & H). The pores are normally much larger than the grain size (Major et al., 1990). Formerly these pores are known as birdseye porosity (Folk, 1959). It is a primary porosity bound to synsedimentary open-space structures, and commonly associated with supratidal and intertidal, algal- and microbial-related, mud-dominated sediments (Choquette and Pray, 1970; Lucia, 2007). In some cases, these pores might be reduced in size due to early calcite cementations (Fig.8. I).

**P5 - Vuggy porosity**

It is secondary solution pores that are not fabric selective i.e., the pores cut across grains and/or cement boundaries (Choquette and Pray, 1970). Vuggy porosity, as defined by (Lucia, 1983), is pore space that occurs within grains or crystals or that is significantly larger than grains or crystals. Vugs are commonly started as moldic, intercrystalline or intraskeletal pores and enlarged by further solution a diagenetic modification into larger and irregular cavities (Lucia, 2007). Vugs and molds exhibit a secondary porosity due to the dissolution of skeletal components (Fig.8.C). They are typical of most dolomite reservoirs (Choquette & Pray, 1970).

Figure 8: (A, B) P1 intercrystallite porosity, kh15, PPL. (C, D) P2 and P5 moldic and vug porosity, kh 50, XPL. (E, F) P3 intraskeletal porosity and intercrystalline porosity, Kh6, Kh14 (XPL). (G, H, I): P4 fenestral porosity. Kh114, Kh22, PPL, XPL
DISCUSSION

The inferred microfacies interpreted from relict components of the original sedimentary facies of the formation suggest that the formation is deposited within a lagoonal environment adjacent to an extensive tidal flat (Flugel, 2010). The lagoonal components such as miliolids, and green algae suggest a semi-closed lagoon which open intermittently to open see conditions. The occurrences of the small Textularids (i.e. benthic foraminifera of valvulina and clavulina, (Fig.6.E&F) suggest that such assemblages of deeper subtidal conditions could be brought in contact with (OMZ) Oxygen Minimum Zone of shallower depth during lowstands (Wilson, 2007). The tidal flat influence is inferred from the frequent occurrences of stromatolitic horizons within the different parts of the Khurmala section, with their diagnostic wavy laminations and the fenestral porosity. Supratidal environment is inferred from the relatively well-preserved stromatolites. Other tidal features are conceivably destroyed by the intensive dolomitization. Similar results regarding the Khurmala Formation depositional environment was reached by Al-Qayim (1995), Al-Banna, et al. (2006), Al-Ehmeedy et al. (2012), and Asaad and Balaky (2018). The type and distribution of the dolomite of the Khurmala Formation at this locality is more likely to have been developed within similar situation.

Based on the mode of formation, dolomites can be divided into two groups: primary dolomite and secondary dolomite Pichler (2001). Dolomites that originate via replacement of CaCO3 are called replacement dolomites or secondary dolomites Machel (2004). The studied dolomite of Khurmala Formation has two basic dolomite fabric and types which indicate an early diagenetic mode of formation. Both types reoccur repeatedly following the cyclic stratigraphic nature of the sequence. Both are closely associated with lagoonal-tidal facies belt and thus related to two classes of dolomitization models which are reflux and sabkha evaporation model (Tucker & Wright, 1990).

Reflux Model

This model involves the generation of dolomitizing fluids through evaporation of lagoon water or tidal flat pore waters and then the descent of these fluids into underlying carbonate sediments (Tucker & Wright, 1990). The model was originally proposed from seawater evaporated beyond gypsum saturation in lagoonal and shallow marine settings (Adams & Rhodes 1960). In these locations reflux mechanism was responsible for dolomitization of lagoonal carbonate sediments (Fig. 9). These dolomites are fine to medium crystalline and matrix-selective, commonly with good-excellent fabric preservation.

The seepage-reflux model relies on Mg2+-rich fluids being produced by evaporation and gypsum precipitation descending into the subsurface through density differences with pore waters in underlying sediments. The evaporated seawater flows downward into and seaward
through the platform sediments because of its increased density (i.e. active reflux), thereby dolomitizing the penetrated sediments (Machel, 2004).

Fig. 9: Dolomitization models of Khurmala Formation (slightly modified by Flugel, 2010 after Tucker, 1985)

Sabkha Model

Sabkhas are intertidal-supratidal deflation surfaces that are episodically flooded by hypersaline intertidal-supratidal flat (Butler 1970; McKenzie et al. 1980; Patterson & Kinsman 1982; Baltzer et al. 1994). Sabkhas undergo hydrological and hydrochemical cycles as a result of their episodic flooding (Fig. 9). The resulting dolomite crystals are small, euhedral to subhedral rhombs which range in size from 1-5 μm (Budd 1997). These dolomites are accompanied by sequences showing the characteristics of Sabkha model such as supratidal facies, fenestral lamination and evaporate crystals Warren (2000 and 2006). Additionally, the presence of fine-crystal dolomites is an indicator of appropriate sites for nucleation of larger dolomite crystals in Sabkha fine-grained micritic, sediments (Sibley and Gregg, 1987). The dolomitic supratidal crusts are usually ascribed to precipitation from evaporated seawater, with the early dolomitization of the surficial sediment layer (Shinn, 1983).

The petrographic and SEM data of the studied dolomite fabric indicate that dolomitization is formed by replacement of carbonate sediments during the early stage of diagenesis (Tucker and Wright, 1990). The dolomite type D1 (cryptocrystalline to fine crystalline) dolomites with few evaporite crystals and fenestral fabric can be related in origin to the Sabkha model. The fine-grained dolomites are interpreted to have occurred in response to seawater flow through
the shallow subsurface driven by tidal pumping, and by high evaporation rates on the supra and intertidal areas (McKenzie et al. 1980). Dolomitization of intertidal to supratidal facies occurred during times of relative sea-level falls or highstand situation (Loucks and Anderson, 1980).

The reflux model is suggested also especially for dolomite fabric of lagoonal facies origin i.e. for dolomite includes relics of lagoonal benthic foraminifera and other related fossils and widely used to explain dolomite of cyclic lagoonal sequences (Tucker & Wright, 1990; Machel, 2004). Therefore, the dolomite of the Khurmala Formation in the studied section is possibly resulted from the effect of the two mechanisms. Both models have combined works at different but adjacent environment to produce the recognized type of dolomite.

CONCLUSIONS

1. Khurmala Formation at Gara mountain of Dohuk area is composed mainly of 91m of intensively dolomitized carbonate which alternate with thin, gray shale or marlstone interlayers.
2. The recognized microfacies are intensively dolomitized: mudstone, stromatolitic mudstone, small benthic foraminifera wackestones, miliolid packstone, and dasycladacean packstone.
3. The restored microfacies, the lithologic characters, and the nature of the dolomite suggest deposition in a combined complex of lagoon-tidal flat association.
4. Dolomite type recognized in four different fabrics. The most common types are the cryptocrystalline to fine crystalline nonplannar unimodal mosaic and fine to medium crystalline planar-e to plannar-s mosaic.
5. The presence of high porosity especially in fine to medium crystalline bimodal dolomite in the lower and middle part is related to fenestral, moldic and vug porosity greatly enhanced by intensive dolomitization process.
6. The intensive dolomitization, the abundance of dolomitized mud fabric, and the inferred relics of the sedimentary facies and ghost fossils, suggest an early stage of diagenesis resulted from a possible combined effect of lagoonal reflux flow, and sabkha evaporation mechanisms.

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