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Dolomitization Model of the Lower Jurassic Sarki Formation Depending on Petrography and Carbon/Oxygen Isotopes, Northeastern Iraq-Kurdistan region

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Abstract

The shallow marine carbonate strata of the Lower Jurassic Sarki Formation are exposed at the northeastern limb of the Handreen and Spibalies anticlines in Rawanduz area, Kurdistan region, northeastern Iraq. The Sarki Formation is made up of light grey dolomitic limestone, dark grey dolomite, brecciated dolomite, grey brecciated dolomitic limestone, and thin-bedded dark grey marlstone. Based on the crystal size and geometry, five dolomite textures are identified, Dolomite-1: fine crystalline, planar-s (subhedral); Dolomite-2: fine to medium crystalline planar-e (euhedral); Dolomite-3: medium to coarse, planar-e (euhedral) to planar-s (subhedral) dolomites; Dolomite-4: coarse crystalline, planar-s (subhedral) to nonplanar-a (anhedral) dolomites; Dolomite-5: planar (subhedral) pore-filling dolomite cement. The Sarki dolomites have depleted values of $\delta\ ^{18}O$ from Dolomite-1 to Dolomite-5. The notable decrease in $\delta\ ^{18}O$ is due to an increase in the temperature of the dolomitization fluid relative to the increase of burial depth. Fine to medium crystalline dolomite is associated with the early stages of dolomitization, whereas coarse crystalline dolomite is associated with the late diagenetic stage. The petrographic study, that is, stable carbon and oxygen isotope analysis, suggests a sabkha and mixing zone models of the Sarki dolomites.

Keywords: *Dolomitization, Stable Isotope, Lithostratigraphy, Sarki Formation, Iraqi Kurdistan*

1. Introduction

The shallow marine Sarki Formation is a carbonate succession outcropping in the north and northeastern Iraq. It was deposited in an intertidal-supratidal setting (Delizy and Shingaly, 2021). It was first defined by Dunnington (1952) in (Bellen et al., 1959) from Chia Gara mountain, south of Amadyia, northern Iraq, which constitutes a part of the Arabian Plate (AP 6) tectonostratigraphic megasequence that ranges from middle Permian to middle Jurassic (Sharland et al., 2001). The lateral equivalent of the Sarki Formation in central Iraq is the Butma Formation. The thickness of the formation varies from one place to another. At the type locality, the thickness is estimated to be 300m: the upper part is 180m, and the lower part is 120m (Buday, 1980). The thickness of the studied sections is 176m in the Warte section, and 115m in the Zarwan section. Lithologically, the Sarki Formation is composed of dolomites and brecciated dolomites in the upper part with some ghosts of bivalves and ostracods. The lower part of the formation consists of brecciated dolomitic limestones, interbedded with marly thin beds in the middle part. The lower contact of the Sarki Formation is gradational with the Baluti Formation, and the upper contact is conformable with Sehkaniyan Formation (Jassim and Goff, 2006). The lower boundary of the Sarki Formation in the Zarwan section is not exposed.

The Sarki Formation outcrops of Northern Iraq were investigated by Bellen et al., (1959), Buday (1980), Surdashy (1999), Jassim and Goff (2006), AL- Badry (2012), AL-Jboury and Mccann (2013), Delizy and Shingaly (2022), and Omar (2022). The main aim of the current study is to describe the dolomite textures, the dolomitization model, and the origin of the dolomites based on the isotopic analysis and petrographic study.

2. Geologic Setting

The Sarki Formation is well exposed in the core and limbs of several anticlines in the imbricated and Northern thrust zone of Iraq. During the Middle Permian to Triassic and Jurassic periods, breaking off north and northeast microplates of the Arabian portion of Gondwana land occurred due to the active extinction and rifting (Alsharhan and Nairn, 2003). The opening of the Neo-Tethys ocean involved two stages. The first one started during the Permian and Triassic periods when the Iranian Plate (microplate) began to move towards the Eurasian Plate away from the Arabian Plate. The next stage occurred as the Neo-Tethys reached its greatest width of 4000 km during the Late Triassic to Middle Jurassic periods (Sadooni and Alsharhan, 2004).

The platform part of the Iraqi territory is separated into two main units: a stable and an unstable shelf (Buday, 1980). The stable shelf is characterized by a relatively thin sedimentary cover and a lack of significant folding (Al-Ghreri et al., 2018). The unstable shelf has a thick and folded sedimentary cover, and the intensity of the folding increases toward the northeast (Al-Juboury et al., 2023). During the

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present work, two outcrops were measured in the imbrication zone in northern Iraq. The Warte section is located 3 km to the south of Warte town, close to the Karukh Mountain, and approximately 39 km to the east and southeast of Rawnduz district within the Erbil Governorate (Lat. 36° 28’ 24” N and Long. 44° 45’ 14” E), whereas the Zarwan section was chosen in Zarwan village, which is located 500m to the north of the Zarwan village, about 15 km in northeastern Rawanduz district in Erbil Governorate (Lat. 36° 38’ 44” N and Long. 44° 39’ 53” E) (Fig. 1).

Structurally, the Sarki Formation in Warte section is located in the core of Handreen anticline in the imbrication zone (Fig. 2). The Handreen anticline is asymmetrical: the fold axis is trending NW-SE and plunging in the NW, and its length is around 30 km. The NE limb dips steeply, and the SW limb dips gently at 40^{o} approximately. The Zarwan section is exposed at the northeastern limb of asymmetrical Spibalies anticline, with fold axis trending NW-SE (Balaki, 2004). The anticline is doubly plunging around 26 km length, the NE limb steep dips angle, and the SW limb dips 50^{o} approximately (Delizy and Shingaly, 2022).

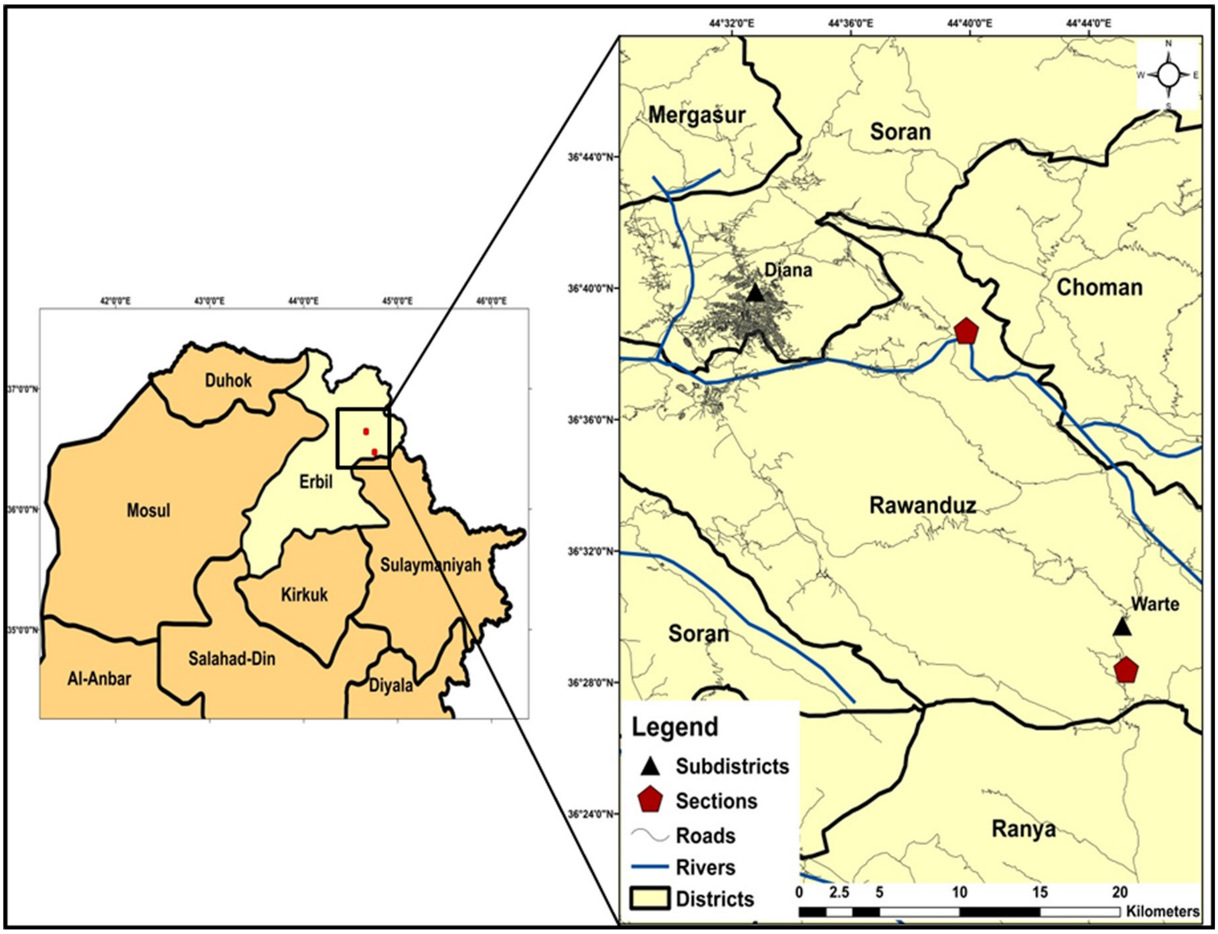

Figure 1. Location map of the studied sections.

3. Materials and Methods

The selected outcrops around the imbrication zone were described and measured in detail in terms of lithology, sedimentary structures, and mineralogy. A total of ninety samples were collected from the two studied sections. 80 samples belonged to the Sarki Formation, and other several samples crossed the contacts of the underlying Baluti Formation and the overlying Sehkaniyan Formation. Samples were taken perpendicularly to the beds’ strikes. The interval between samples is generally determined by changes in the lithology and color. All of the beds have been measured and lithologically described. A total of 80 thin sections were prepared in the workshop of Scientific Research Center, Soran University. For each sample, at least one thin section was prepared. The thin sections were marked, using Alizarin Red Solution (ARS) to differentiate calcite from dolomite minerals according to the procedure suggested by Friedman (1959). To identify the relationships between dolomite fabrics and type of dolomite, scanning electron microscopy was used in the scanning lab of Scientific Research Center of Soran University. For the classification of dolomite textures, the work of Sibley and Gregg (1987) is used to describe different dolomite fabrics based on the microscopic and scanning electron microscope. Twenty samples of the carbonates of Sarki Formation from the two studied sections are chosen for stable carbon and oxygen isotope in order to determine the origin of dolomite. The C and O isotope analyses, employing the conventional digestion method, were performed at the Cornell Isotope Laboratory (COLL), Cornell University, New York, USA.

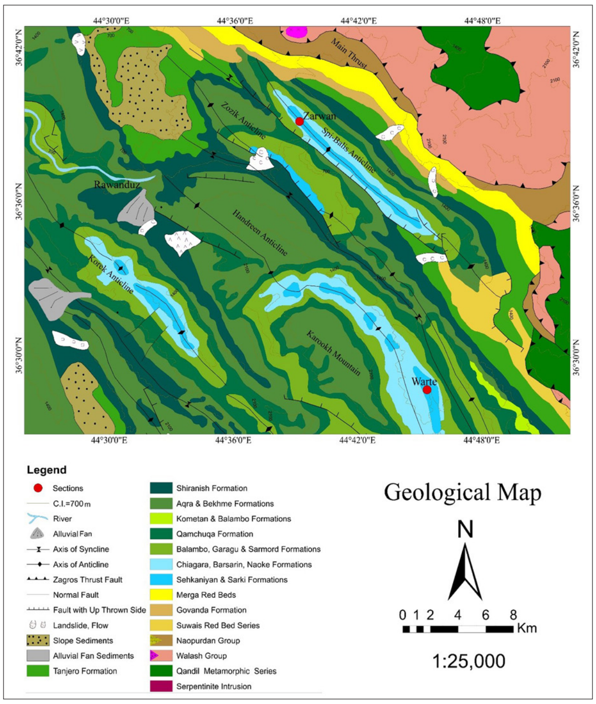

Figure 2. Geological map of the studied area (modified from Abdula et al., 2021).

4. Results and Discussion

4.1. Lithostratigraphy

The total thickness of Sarki Formation in the Warte section is 176 meters thick, and it is 115 meters thick in the Zarwan section. The formation consists of dolomitic limestone, dark grey dolomite, thick-bedded brecciated dolomitic limestone and brecciated dolomite with thin-bedded marlstones. Based on the field observations and petrographic analysis, the Sarki Formation can be subdivided into three lithostratigraphic units: Lower unit (A), Middle unit (B), and Upper unit (C) (Figs. 3 and 4).

A- Lower unit (Thick-bedded brecciated dolomitic limestone)

This unit is overlying the Baluti Formation and is underlying the medium to thick bedded dolomitic limestone and marl (unit B) in Warte section. while in Zarwan section, the lower part of this unit is covered by slope deposits. In Warte section, this unit consists of brecciated dolomitic limestone and dolomitic limestone, but in Zarwan section, it is mostly composed of brecciated dolomitic limestone (Fig. 5a). The thickness of this unit is approximately 40m in Warte section and 30m in Zarwan section. It consists of 40-100cm massive, grey to light grey brecciated dolomitic limestone (Fig. 5b). This unit represents the lower part of the Sarki Formation.

B- Middle unit (Medium-to-thick bedded dolomitic limestone and thin marl)

This unit overlies the thick bedded brecciated dolomitic limestone and is overlain by the medium to thick bedded dolomite. The unit is the thickest among the other units of the studied formation. It is about 80m thick in Warte section and 50m in Zarwan section. It is composed of medium to thick bedded, yellowish grey dolomitic limestone which is interbedded with thin grey marly beds, most precisely to the lower part of the unit (Fig. 6a). The marl in this unit is commonly compacted between hard beds of dolomitic limestone particularly in the Zarwan section (Fig. 6b). The dolomitic limestone beds have a thickness of (5-60cm), and the beds of marl range from 2-15cm in thickness.

C- Upper unit (Thick bedded dolomite and medium-to-thick bedded brecciated dolomite)

The upper unit (Unit C) forms the upper part of the Sarki Formation in the two studied sections. The unit has a thickness of 55m in Warte section and 35m in Zarwan section. It can be separated into lower and upper parts. The lower part of this unit in Warte section is about 25m, and it consist of thick 20-80cm grey brecciated dolomite (Fig. 6c). The lower part in this unit is overlain by thick bedded of dolomite and underlain by medium to thick beds of dolomitic limestone. The upper part of this unit is 30m and consists of thick beds 40-100cm of grey to dark grey dolomite and is overlain by massive and thick beds of dolomitic limestones of Sehkanyian Formation from the two studied sections (Fig. 6d).

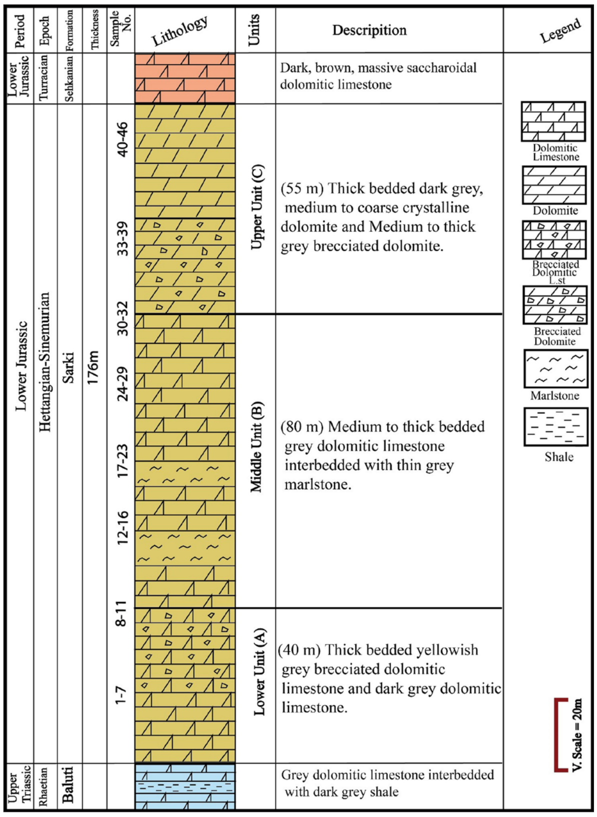

Figure 3. Stratigraphic column of the Sarki Formation, Warte section. Northern Iraq.

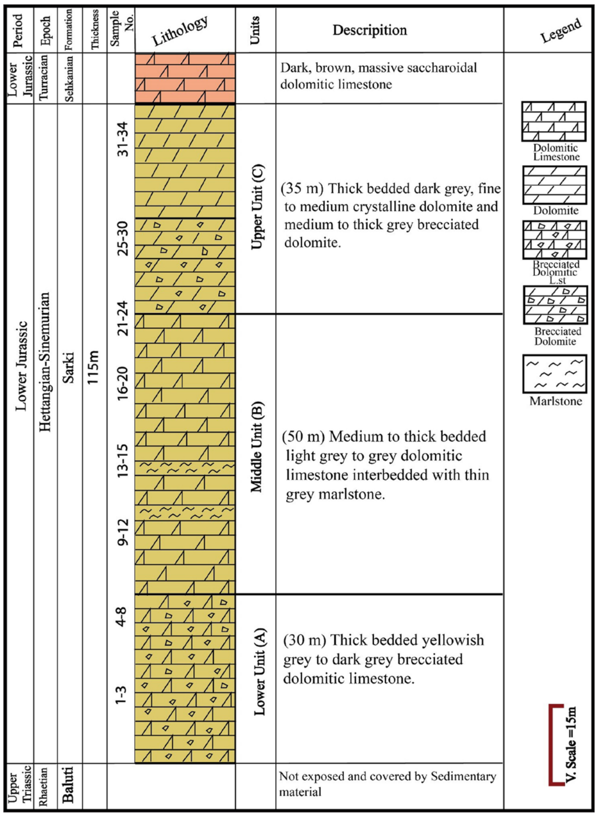

Figure 4. Stratigraphic column of the Sarki Formation, Zarwan section, Northern Iraq.

Figure 5. Field photographs showing: **(a)** The lower contact separating the Sarki Formation and the underlying Baluti Formation in Warte section marking the brecciated dolomitic limestone of the Lower unit (A). **(b)** The lower unit of the Sarki Formation in the Zarwan section showing the brecciated dolomitic limestone.

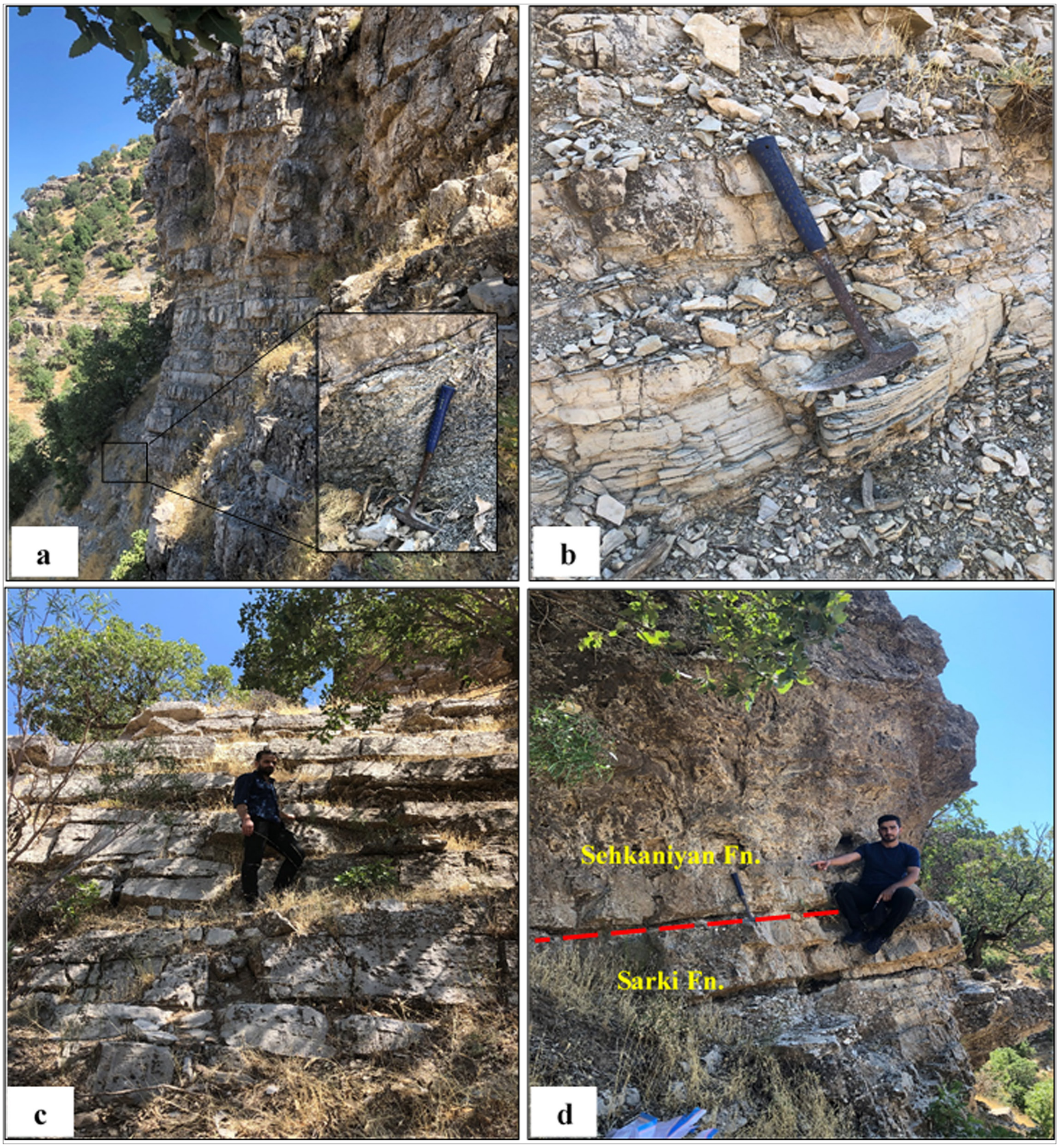

Figure 6. Field photographs showing: **(a)** Light grey dolomitic limestone interbedded with grey marl from the middle unit, (B) of Sarki Formation, **(b)** Thin marly beds between hard dolomitic limestones at the middle unit (B), (c) Thick bedded of grey to dark grey brecciated dolomite from upper unit **(C)** of the Sarki Formation, **(d)** The upper contact of the Sarki Formation underneath the Sehkaniyan Formation in Warte section, and showing the thick dolomite beds of Sarki Formation which is overlain by the massive saccharoidal dolomitic limestone of Sehkaniyan Formation.

4.2. Dolomite types

By using the petrographic microscope, SEM, stable isotope analysis, crystal size distribution, boundary shapes (planer and non-planer), and according to the classification scheme of Sibley and Gregg (1987), five dolomite textures have been recognized and classified in the Sarki Formation from the two studied sections. The time of dolomitization is determined based on crystal size (fabric) and $\delta^{18}O$ isotopic composition of different types of dolomite. The carbon and oxygen isotopes for different types of dolomite are plotted in Fig. 7, Table 1.

1- Fine crystalline, planar-s (subhedral) dolomite (Dolomite type 1)

Fine crystalline dolomicrite to dolomicrosparite ranges in size from 10 to 35um (with an average of 20um) and is typically characterized by planar-s (subhedral) mosaic with regular intercrystalline boundaries in micritic groundmass (Fig.8 a, b). Dolomite type 1 is developed under near-surface low temperatures during an early diagenetic stage, indicating a supratidal to upper intertidal environments (Machel, 2004). Dolomite type 1 is characterized by a dense and fine texture of dolomitized mudstone, lacking allochems and porosity. The crystal size is usually used to determine boundaries between early and late diagenetic dolomite phases (Gregg and Sibley, 1984; Wright, 2001). This type of dolomite is the most commonly studied succession and is widely distributed in the lower and middle parts of the Warte section. Dolomite 1 is a microcrystalline dolomite (dolomicrite), having δ [18] O and $δ^{13}C$, and ranges from (-1.88‰ to -2.33‰) and (-0.89‰ to 2.75‰) respectively. The high micrite content indicates an early stage of dolomitization. The δ [18] O values in this type of dolomite are less negative and not heavier than those of other dolomite types which indicate a low temperature and shallow burial depths during the earliest stages (Schidlowski, 2000).

2- Fine to meinfilldium crystalline planar-e (euhedral) to planar-s (subhedral) dolomite (Dolomite type 2)

This type of texture is characterized by a mixed distribution of fine and medium dolomite crystal sizes with a dense crystalline mosaic. The fine crystals component is subhedral to euhedral planar-s crystal shape, and the medium dolomite crystals component is commonly euhedral and ranges in size from 20-80 um (average: 60 um) (Figs. 8c, d). Commonly, this type shows a cloudy texture and represents the end of early to intermediate diagenetic replacement dolomites. Dolomite type 2 is observed in the lower and middle parts of the Sarki Formation in the Warte section, and the middle part of the Zarwan section. The $δ^{18}O$ of this type of dolomite ranges from (-2.40‰ to -2.61‰), and the $δ^{13}C$ ranges from (-1.12‰ to 2.80‰). The $δ^{18}O$ of dolomite 2 is more depleted than dolomite 1, indicating that dolomite 2 has generated at early to intermediate stages with increasing temperatures. Dolomite 2 represents fine to medium crystalline dolomite texture. The increase in crystal size from fine to medium indicates the early and shallow burial diagenesis.

3- Medium to coarse, planar-e (euhedral) to planar-s (subhedral) dolomite (Dolomite 3)

This type of dolomite is common in the middle part of the Zarwan section and consists mainly of medium to coarse, planar-e (euhedral) to planar-s (subhedral) crystals. It ranges from 80- 300 um (Fig. 8, e). The voids and spaces between crystals are mostly infilled by bitumen, and fractures are infilled by cement. This texture type is dominantly formed in an intermediate diagenetic stage during a high rate of burial temperatures. It resulted in the recrystallization of finer dolomites during burial or near the surface meteoric zone and in the mixed marine-meteoric zone too. The results of stable carbon and oxygen isotope analysis show that the $δ^{18}O$ for dolomite 3 ranges from -2.55‰ to -7.39‰, whereas $δ^{13}C$ ranges from -2.03‰ to 1.48‰. This type is related to the presence of chemical solution (stylolites). The $δ^{18}O$ in dolomite type 3 is lighter than it is in types 1 and 2 dolomites, but it is heavier than dolomite types 4 and 5. The oxygen isotope of the dolomite 3 is more negative and indicates an increasing degree of temperature and depth of burial.

4- Coarse crystalline, planar-s (subhedral) to nonplanar-a (anhedral) dolomite (Dolomite type 4)

This type of dolomite is composed of dense, clear boundaries and close-packed coarse crystals, ranging in size from (200-500um). Two different crystal shapes of dolomite 4 are observed: planar-s (subhedral) type and nonplanar-a (anhedral) type (Fig. 8f). In the Sarki Formation; this type of dolomite is observed in the middle part of the Zarwan section and indicated development in deep burial during the late diagenetic stage. The $δ^{18}O$ value of dolomite 4 is -3.82‰, and the $δ^{13}C$ value is -1.23‰. Dolomite type 4 has more depleted $δ^{18}O$ values, compared to other types of dolomite. The coarse crystals' size and the more negative oxygen isotope of $δ^{18}O$ are indicators of temperature increase and deep burial.

5- Planar (subhedral) void-filling dolomite cement (Dolomite type 5)

This type of dolomite consists of coarse crystals, pores filling, milky clusters, vugs, and fractures (Fig. 8g, h). Dolomite type 5 occurs in ghost filling of bioclasts and small veins, indicating a late stage of dolomitization. The crystals ranged in size from 100-600um, and their shapes refer to planar-s (subhedral) mosaic dolomite. It occurs in the upper part of the Sarki Formation in the Warte section, particularly, in the molds of bivalves and ostracods. The values of $δ^{18}O$ and $δ^{13}C$ for dolomite 5 are similar and nearly equal to dolomite 4 values which range between -3.86‰ and -0.17‰ respectively. The crystals' sizes and values of $δ^{18}O$ for pore filling dolomite 5 are similar to those of dolomite 4 and may have occurred during the late deeper burial diagenesis stage compared to other types of dolomite.

Table 1. Carbon and oxygen isotopic ratios of dolomites sample of the Sarki Formation in the Warte and Zarwan sections.

Dolomite texture	Sample no.	$δ^{18}O$ VPDB	$δ^{13}C$ VPDB
Dolomite 1	W.S. 12	-2.04	2.75
	W.S. 30	-1.99	1.01
	W.S. 40	-2.08	-0.89
	Z.S. 14	-1.90	0.87
	Z.S. 24	-2.33	1.18
	Z.S. 30	-1.88	2.02
Dolomite 2	Z.S. 8	-2.45	-1.12
	Z.S.15	-2.51	-0.25
	W.S. 10	-2.40	1.03
	W.S. 11	-2.61	2.80
Dolomite 3	W.S. 22	-7.39	-3.32
	W.S. 28	-3.17	1.30
	W.S. 31	-3.31	-0.76
	W.S. 32	-3.62	-1.07
	W.S. 34	-4.07	0.91
	Z.S. 16	-2.64	0.52
	Z.S. 17	-2.93	-2.03
	Z.S. 28	-2.55	1.48
Dolomite 4	W.S. 23	-3.82	-1.23
Dolomite 5	W.S. 46	-3.86	-0.17

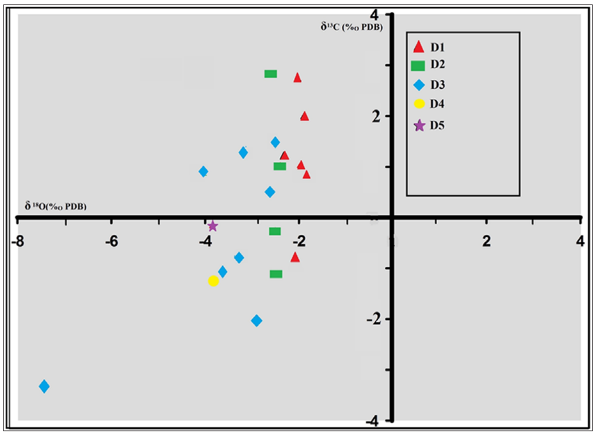

Figure 7. Plot of δ18 O and δ13C values of the different types of dolomite in Sarki Formation.

4.3. Dolomitization stage

Delizy and Shingaly (2022) indicated that the the Sarki Formation was deposited in peritidal shelf lagoon and shoal environments. The presence of micrite and rims of skeletal and non-skeletal grains indicates an early diagenetic stage. The sediments in the studied sections are mostly affected by different types of marine and meteoric cementation before reaching the burial environments. Depending on the petrographic, stable carbon and oxygen isotope analysis of different types of dolomite, the time of diagenesis can be determined (Fig. 9). Fine crystalline dolomite (dolomite type 1) is formed under the near surface (shallow burial) and low-temperature degree in the supratidal environment, whereas the depleted values of $\delta^{18}O$ and sizes of crystals in type 2 dolomite suggest that this type is formed in shallow burial depths. Dolomite type 3 is characterized by planar crystal boundaries and more depleted $\delta^{18}O$ than dolomite types 1 and 2. This result indicates a formation in the early to late stages of burial. Dolomite types 4 and 5 have more depleted $\delta^{18}O$ and coarser crystal sizes, indicating the advanced stage of diagenesis and the formation under high rate of temperature and deep burial.

Both early and late stages of dolomitization are noticed in the Sarki Formation in which the early diagenetic dolomitization is characterized by fine crystalline dolomites while coarse crystalline types indicate a late diagenetic dolomitization.

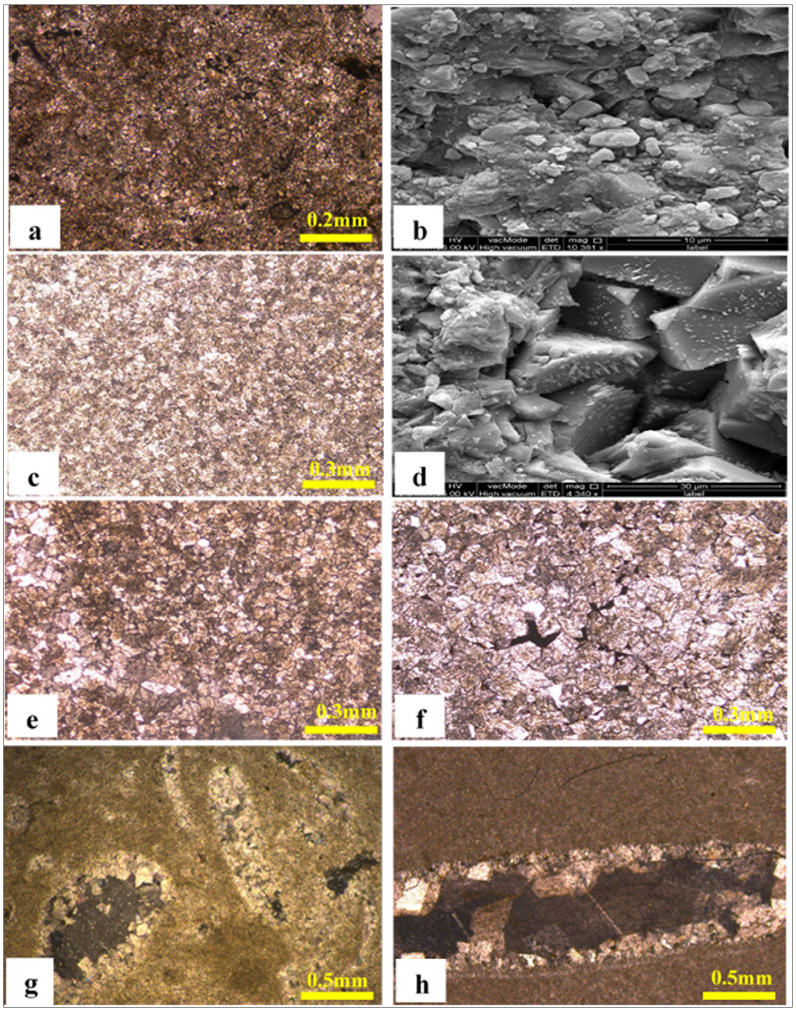

Figure 8. Photomicrographs of Sarki Formation dolomites: **(a)** Fine crystalline planer-s (subhedral) dolomite 1, ZS. 24, P.P. **(b)** SEM image of fine crystalline planer-s (subhedral) dolomite 1, WS. 40 **(c)** Fine to medium crystalline planer-e (euhedral) to planar-s (subhedral) dolomite 2, WS. 10, P.P. **(d)** SEM image of fine to medium crystalline planar-e (euhedral) to planar-s (subhedral) dolomite 2, WS. 11 **(e)** Medium to coarse, planar-e (euhedral) to planar-s (subhedral) dolomite 3, WS. 22, P.P. **(f)** Coarse crystalline, planar-s (subhedral) to nonplanar-a (anhedral) dolomite 4, WS. 23, P.P. **(g)** Planar (euhedral) to planar (subhedral)-filling dolomite cement, dolomite 5, WS. 46, P.P. **(h)** Planar (euhedral) to planar (subhedral) void-filling dolomite cement, ZS. 23, P.P.

WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichol

4.3.1. Early diagenetic dolomitization

The dolomitization in the Sarki Formation is of an early diagenetic type and is characterized by fine crystals. The crystal size ranges from 10 to 100um and has a planar-e to planar-s morphology. It includes the textures of dolomite type 1, dolomite type 2, and medium size of dolomite type 3. It is supposed that these dolomite types were developed under shallow burial and probably during the mixing of a meteoric phreatic wedge with marine water (Machel, 2004). This type of dolomitization is more common in all parts of the Sarki Formation in the Warte section, but it is more common in the lower part of the Zarwan section.

4.3.2. Late diagenetic dolomitization

The late diagenetic dolomitization is characterized by a coarse crystalline dolomite mosaic of planer-e to planar-s fabrics of coarse crystal size dolomite 3 and dolomite 4. Most coarse crystalline dolomite in this stage developed in the fractures and moldic ghosts (dolomite type 5). The pore filling with euhedral, equant, and coarse dolomite crystals that increase in size inwards are more common. The coarse crystalline dolomite fabric, microfracture healing, and moldic pore-filling indicate late diagenetic events in a deep-burial environment (Amthor and Friedman, 1991; Machel, 2004). Late diagenetic dolomites are observed in the Sarki Formation, especially in the middle part of the Zarwan section and the upper part of Warte section.

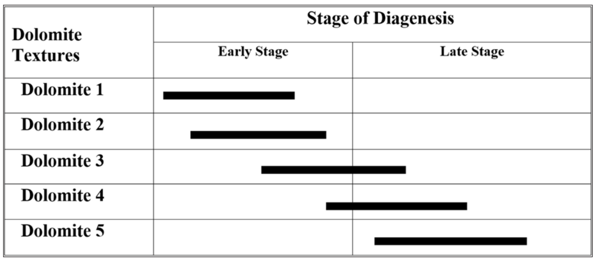

Figure 9. Paragenetic sequence of different dolomite textures in the Sarki Formation.

4.4. Dolomitization Model

Dolomitization is a heterogeneous process, developed under various conditions and can be divided into two groups including primary and secondary dolomites (Pichler and Humphrey, 2001). Primary dolomites are precipitated directly while secondary dolomites are produced by the replacement process and are also called replacement dolomites (Machel, 2004).

Based on the detailed petrographic study of stable carbon and oxygen isotope analysis, the dolomites of the Sarki Formation are formed in two diagenetic environments: the Sabkha and the mixing zone (Fig. 10).

4.4.1. Sabkha model

The Sarki Formation is a shallow water carbonate succession, deposited in peritidal environments which include intertidal-supratidal subenvironments (Delizy and Shingaly, 2022). The δ ^{18}O values of dolomicrite (dolomites 1), close to positive and fine crystal size of crystals (euhedral to subhedral rhombs), indicate a hypersaline environment. Based on petrographic data such as the fine crystalline texture, syndepositional dolomites and very early diagenetic dolomites are indicators of the Sabkha model for dolomite 1. In terms of mechanism and hydrogeological circumstances, the Sabkha dolomitization is very similar to reflux dolomitization (Machel, 2004). This type of dolomite is characterized by a fine crystalline texture that is formed in shallow burial, low temperature, and saline environment. Moreover, the existence of fine-crystal dolomites in Sabkha fine-grained micritic sediments indicates appropriate locations for nucleation of coarser dolomite crystals (Sibley and Gregg, 1987). In shallow burial subsurface, dolomitizing fluids have been recharged through seawater flowing by tidal currents and a high rate of evaporation in supratidal and intertidal areas (Yoo and Lee, 1998).

4.4.2. Mixing zone model

In mixing zone model, the dolomitizing fluids are generated by mixing seawater and subsurface meteoric water. When CO_2-saturated subsurface meteoric water is combined with seawater, the new solution is undersaturated in $CaCO_3$ and supersaturated in dolomites (Machel, 2004). Based on the stable isotopic analysis of different types of dolomite, it shows that the depleted δ ^{18}O values and relatively light δ^{13}C values indicate dolomitization by mixing fresh and marine waters. Isotopic analysis of dolomite in the Sarki Formation shows more negative δ ^{18}O and depleted values in δ^{13}C v (Table 1), hence the mixing between fresh and marine water is indicative of the mixing zone model for dolomitization of the Sarki Formation.

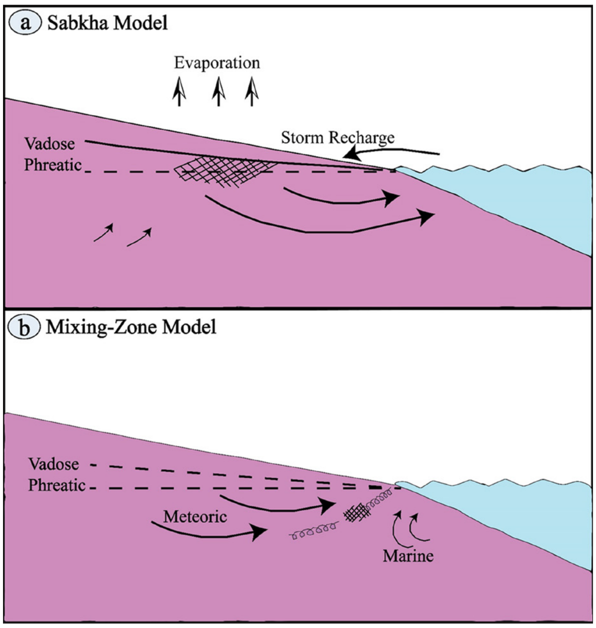

Figure 10. Figure 10. Dolomitization models of the Sarki Formation (after Warren, 2000).

5. Conclusions

It concluded that the Sarki Formation is composed of light grey dolomitic limestone, dark grey dolomite, brecciated dolomite, grey brecciated dolomitic limestone, and thin-bedded dark grey marlstone. The total thickness of the formation is 176 m in the Warte section and 115 m in the Zarwan section. Three different lithostratigraphic units were recognized through the petrographic study and field observation: thick-bedded brecciated dolomitic limestone, medium to thick-bedded dolomitic limestone and thin marl, and thick-bedded dolomite and medium to thick-bedded brecciated dolomite.

In the Sarki Formation, there are five different dolomite rock textures: Dolomite 1 fine crystalline, planar-s (subhedral) dolomite, Dolomite 2 fine to medium crystalline planar-e (euhedral) dolomites, Dolomite 3 medium to coarse, planar-e (euhedral) to planar-s (subhedral) dolomites, Dolomite 4 coarse crystalline, planar-s (subhedral) to nonplanar-a (anhedral) dolomites, and Dolomite 5 planar (subhedral) pore-filling dolomite cement. Based on the stable oxygen isotope values of dolomite samples, the Sarki dolomites show depleted values of $\delta\ ^{18}O$ from dolomite 1 to dolomite 5. This reduced value in $\delta\ ^{18}O$ indicated a temperature increase of the dolomitization fluid that is related to increasing depth of burial from early diagenetic to late diagenetic stage. The Sarki Formation was associated to the Sabkha and mixing zone models, according to a detailed petrographic study and analysis of stable carbon and oxygen isotopes. Fine to medium crystalline dolomite (dolomite 1, dolomite 2 and medium crystalline dolomite 3) indicated an association with an early stage dolomitization while coarse crystalline dolomite (coarse crystalline dolomite 3, dolomite 4 and dolomite 5) indicated a late diagenetic stage.

6. Conflicts of interest

The authors declare no conflict of interest

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