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Petrography and Diagenetic History of The Sarki Formation (Lower Jurassic) in Selected Sections from Kurdistan Region, Northeastern Iraq

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ABSTRACT

The petrography and diagenetic processes of the lower Jurassic Sarki Formation as one of the main Jurassic formations in Iraq, are studied in two selected sections in Warte and Zarwan, in the Imbricated Zone, Kurdistan Region, northeastern Iraq. The lithology of the Sarki Formation comprises dolomitic limestone and dolomite, thick-bedded brecciated dolomitic limestone, brecciated dolomite and very thin bedded marl. Mineralogical study using X-ray diffraction analysis has revealed that the main minerals include dolomite, calcite, quartz and illite. The petrographic investigation reveals the presence of few allochems mostly affected by different diagenetic processes especially dolomitization. The skeletal grains include ostracods, bivalves and echinoderms. Ooids, peloids and intraclasts are the main non-skeletal grains. The Sarki Formation has been subjected to different types of diagenesis processes, which are dolomitization, micritization, compaction (physical and chemical), cementation, dissolution, pyritization and fracturing. The diagenetic processes of the Sarki Formation relate to four diagenetic environments including marine, meteoric, burial and uplifting.

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البتروغرافية وتاريخ العمليات التحويرية في تكوين ساركي (الجوراسي الاسفل) في مقاطع مختاره من اقليم كوردستان، شمال شرقي العراق

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الملخص

تمت دراسة البتروغرافية والعمليات التحويرية في تكوين ساركي (الجوراسي الاسفل) احد أهم تكاوين الجوراسي في العراق في مقطعي وارتي وزاروان في منطقة التراكب، اقليم كوردستان، شمال شرقي العراق. تتألف صخارية التكوين من الحجر الجيري الدولومايتي والدولومايت مع طبقات سميكة من الجير الجيري الدولومايتي البريشي، الدولومايت البريشي وطبقات نحيفة من المارل. تبين من الدراسة المعدنية باستخدام تحليل الاشعة السينية الحائدة أن أهم المعادن هي الدولومايت والكالسايت والكوارتز والالايت. أظهرت الدراسة البتروغرافية وجود قليل من الحبيبات والمتأثره بالعديد من العمليات التحويرية وخاصة الدلمتة. الحبيبات الهيكلية تشمل الاوستراكودا، ثنائية المصراع وشوكيات الجلد. تشكل السرئيات والدمالق والفتات الداخلي اهم المكونات غير الهيكلية. لقد تأثرت صخور تكوين ساركي بالعديد من العمليات التحويرية وهي الدلمتة، المكرتة، الانضغاط (الفيزيائي والكيميائي)، السمنتة، الاذابة، تكون البايرات والكسور. وتعود هذه العمليات التحويرية الى اربع بيئات تحويرية هي البحرية والميتيورية والدفن والنهوض.

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Introduction

The Jurassic rocks are the major petroleum source rocks in the oilfields of Iraq. The Lower Jurassic Sarki Formation is one of the most widespread, thick and well-known rock formations among twenty formations recorded in the Jurassic column of Iraq. The Sarki Formation was first defined by (Dunnington 1952; in Bellen *et al.*, 1959) at its type locality in the Chia Gara Mountain, Duhok Governorate, northern Iraq. The formation has a various thickness; at the type locality, the thickness is approximately 303 m and divided into two units, upper unit with a thickness of 181 m comprises soft, grey dolomites, highly cavernous and weathered into massive bedded intercalated with soft cherty dolomites, yellowish shale and blocky marls with melikaria (box work structure). The lower unit, which has a thickness of 122 m, consists of thin-bedded cherty dolomitic limestones and weathering whitish, pale grey, fine-grained cherty shale intercalated with sugary dolomite. Due to lack of fossils, the age of the formation is assigned according to its stratigraphic position as Liassic (Early Jurassic). The formation underlain by the upper Triassic Baluti Formation and overlain by the Lower Jurassic (Middle-Late Liassic) Sehkaniyan Formation. The Sarki Formation is exposed in the Sirwan Gorge, Chia Gara, Ser-Amdia, Ora, Shaver Valley, and in the cores of some other anticlines in the Kurdistan region of Iraq (Bellen *et al.*, 1959).

In the current study, the Sarki Formation is studied in two outcrop sections in the Imbricated Zone of northern Iraq (Kurdistan Region). The sections are well exposed and have a thickness and lithological content similar to the lithology of the type locality. They include Warte and Zarwan Village sections, which belong to Rowanduz town, Erbil Governorate, Iraqi Kurdistan region (Fig. 1). The Warte section is located within Handren anticline exactly 3 km to the south of Warte district, close to the main road between Rowanduz and Raniya towns and bounded by latitude 36° 28' 24" N and longitude 44° 45' 14" E. The Zarwan section is located within Spi Balis anticline exactly 500 m to the north of the Zarwan Village, bounded by latitude 36° 38' 44" N and longitude 44° 39' 53" E.

This study is the first attempt to gain new stratigraphic and diagenetic description and interpretation on the Sarki Formation. Petrographically, the study focuses on carbonates rocks of the formation that has been affected by extensive diagenetic processes making the rock constituents difficult to determine.

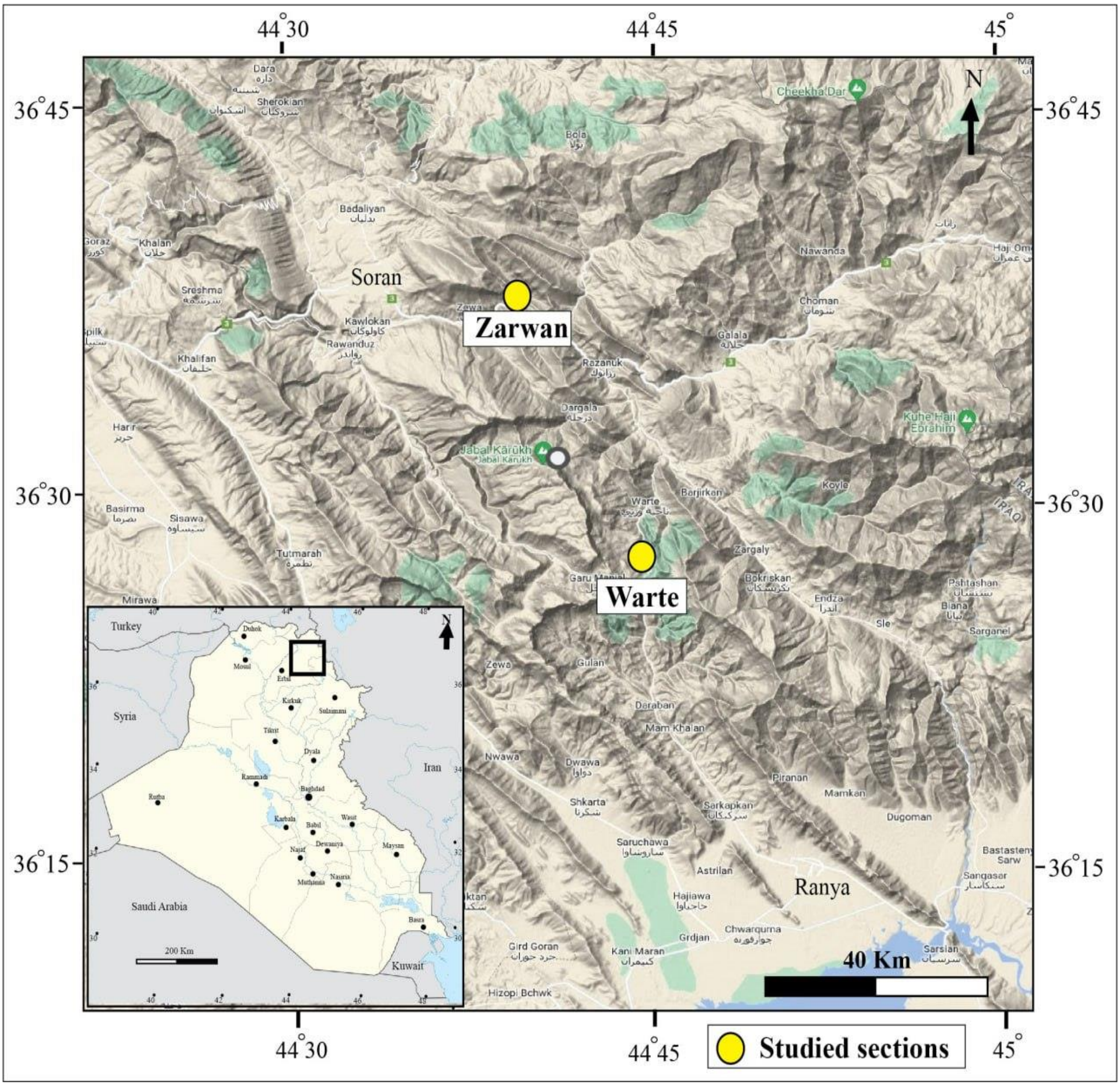

Fig. 1. Location map of the studied sections.

Geologic Setting

The tectonic stability of the Arabian Plate during Jurassic has enabled the shallow shelf to develop at the western passive margin of the Neo-Tethys Ocean allowinhg deposition of carbonates along the shelf and inner platforms (Al-Saad, 2008; Al-Shammary *et al.*, 2023). According to Sharland *et al.* (2001) and Jassim and Goff (2006), the Arabian Plate Megasequence (AP6) spans the middle Permian to middle Jurassic, where the Sarki Formation is located. In the northern and eastern parts of Iraq, in the High Folded Zone and Imbricated Zone, the Liassic sequence is visible in anticlines (Jassim and Buday, 2006). Three facies assemblages were identified (1) at west, the clastic-carbonate of inner shelf setting includes the Ubaid, Hussainiyat and Amij formations; (2) the inner shelf carbonate-evaporate deposition in central Iraq includes Butmah, Adaiyah, Mus, and Alan formations; and (3) to the north and northeast of Iraq, the deposition of the restricted lagoonal environment is represented by the Sarki and Sehkaniyan formations (Jassim and Goff, 2006).

The area was covered by shallow water during the early Jurassic leading to deposition of the lagoonal Sarki and Sehkaniyan formations. The structural trend of all anticlines in the studied area is NW-SE with very complex deformations as folding and faulting.

The lithology of the Sarki Formation in both studied sections is somewhat homogenous and consists of dark-grey, hard, massive dolomitic limestone, brecciated dolomitic limestone, hard, greyish, well-bedded dolostone and thin beds of dark-grey marl (Delizy and Shingaly, 2022) (Fig. 2). The Sarki Formation is well differentiated from the underlying Baluti Formation by gradational change from dark-green shales and marls of the Baluti Formation to thick, hard, grey dolostones and dolomitic limestones of the Sarki Formation. The overlying boundary represents the sharp change from well-bedded, whitish-grey dolomitic limestones of the Sarki Formation to the massive-bedded, dark-brown, hard, foetid dolostones of the Sehkaniyan Formation (Fig. 3). No sufficient previous study on the Sarki Formation had been conducted due to the complexity of the areas where the Sarki Formation exposed in the Thrust Zone, Imbricated Zone and parts of the High Folded Zone.

The studied sections of Sarki Formation are located in the Imbricated Zone, northeastern Iraq. The Warte section is located at the core of Handren anticline in the Imbricate Zone, while the Zarwan section is located at the northeastern limb of the Spi Balies anticline (Fig. 4).

Materials and Methods

Fieldwork is carried out in the area around both the Warte and Zarwan areas in the Imbricated Zone of northeastern Iraq. It includes the study of the general geology and stratigraphy of the Jurassic successions in order to choosing the suitable sections for the purpose of the current study. The main lithology of the studied formation is grey dolomitic limestone, dolostone and brecciated dolomitic limestone with some thin beds of marl. Eighty-five carbonate samples were collected from both studied sections. In addition, to confirm the location of the underlying and overlying contacts, some supplementary representative samples were also collected.

Typically, the samples were taken at random sampling intervals whenever there is a change in lithology or color. Detailed description of samples (macroscopic study) using hand lens and dilute HCl acid is performed in the field. The sum of 80 thin sections was prepared in the workshop of the Scientific Research Center of Soran University. These thin sections are then stained with the Alizarin Red Solution (ARS) following the procedure of Friedman (1959) to distinguish between calcite and dolomite. Four samples of dolomitic limestone and dolostone from Warte section are selected for SEM analysis in order to identify dolomite textures in the laboratories of the Petroleum Geoscience Department of Soran University. Mineralogical investigation with X-ray diffraction (XRD) for selected samples from the Warte section are analyzed after powder preparation for bulk sediment using X-ray diffraction (XRD) using a D8

Advance from the company Bruker AXS GmbH) at the Institut für Geowissenschaften-Geologie of Bonn University, Germany.

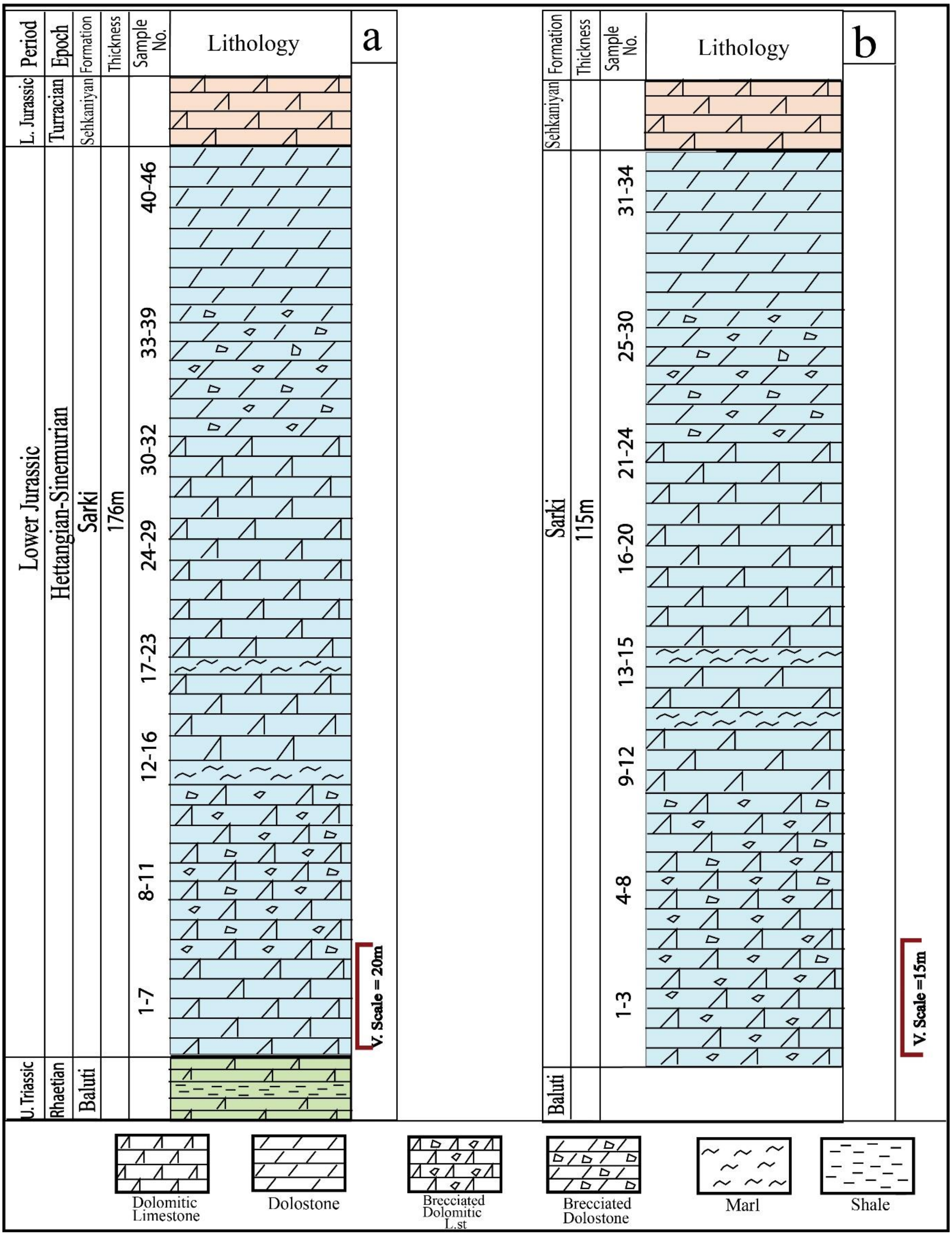

Fig. 2. Stratigraphic column of the Sarki Formation (Lower Jurassic), a) Warte section, b) Zarwan section.

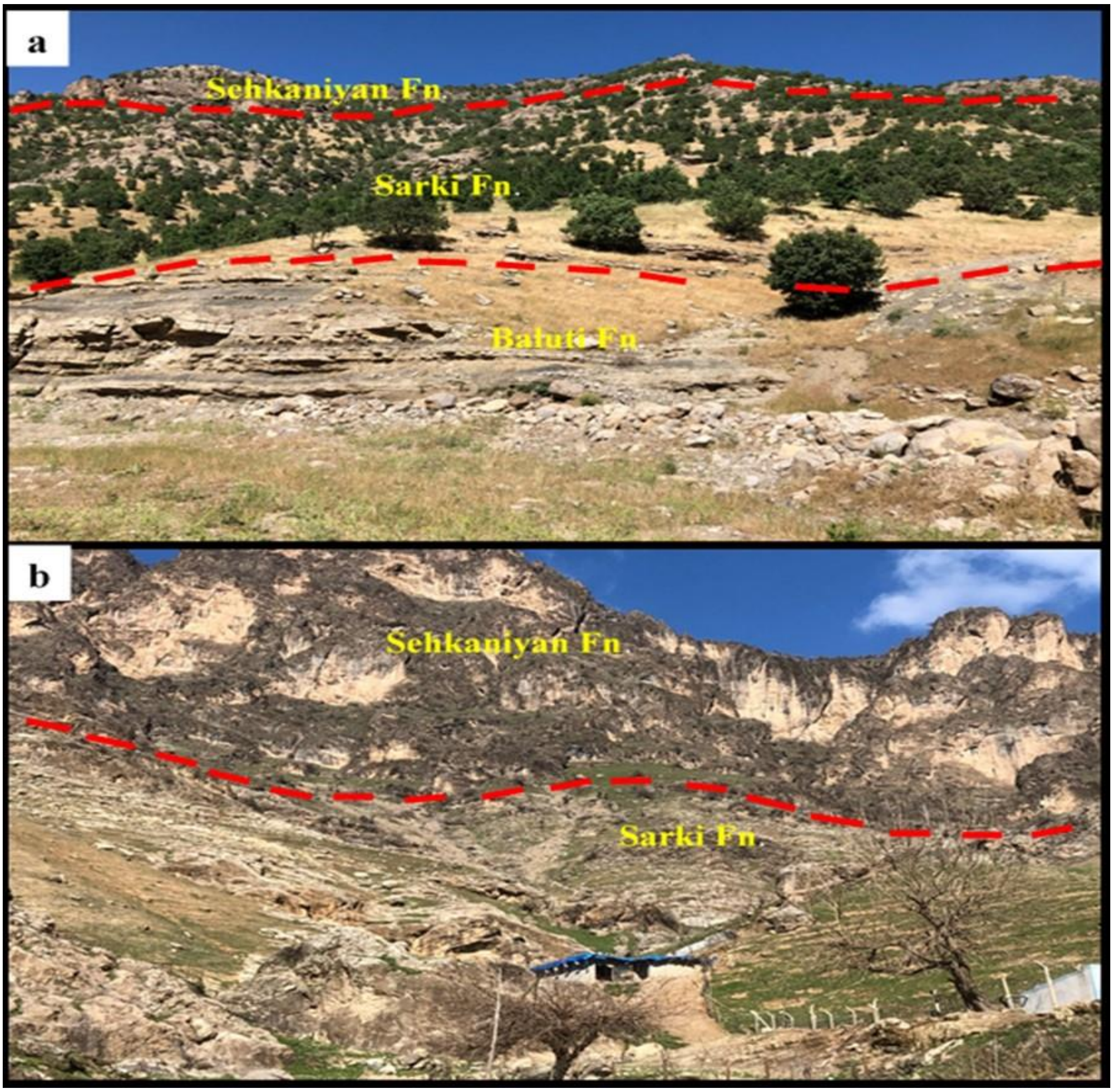

Fig. 3. Field photographs showing: a) Lower contact of the Sarki Formation with Baluti Formation and upper contact with Sehkaniyan Formation in Warte section. b) Sarki Formation with overlying Sehkaniyan Formation in Zarwan section.

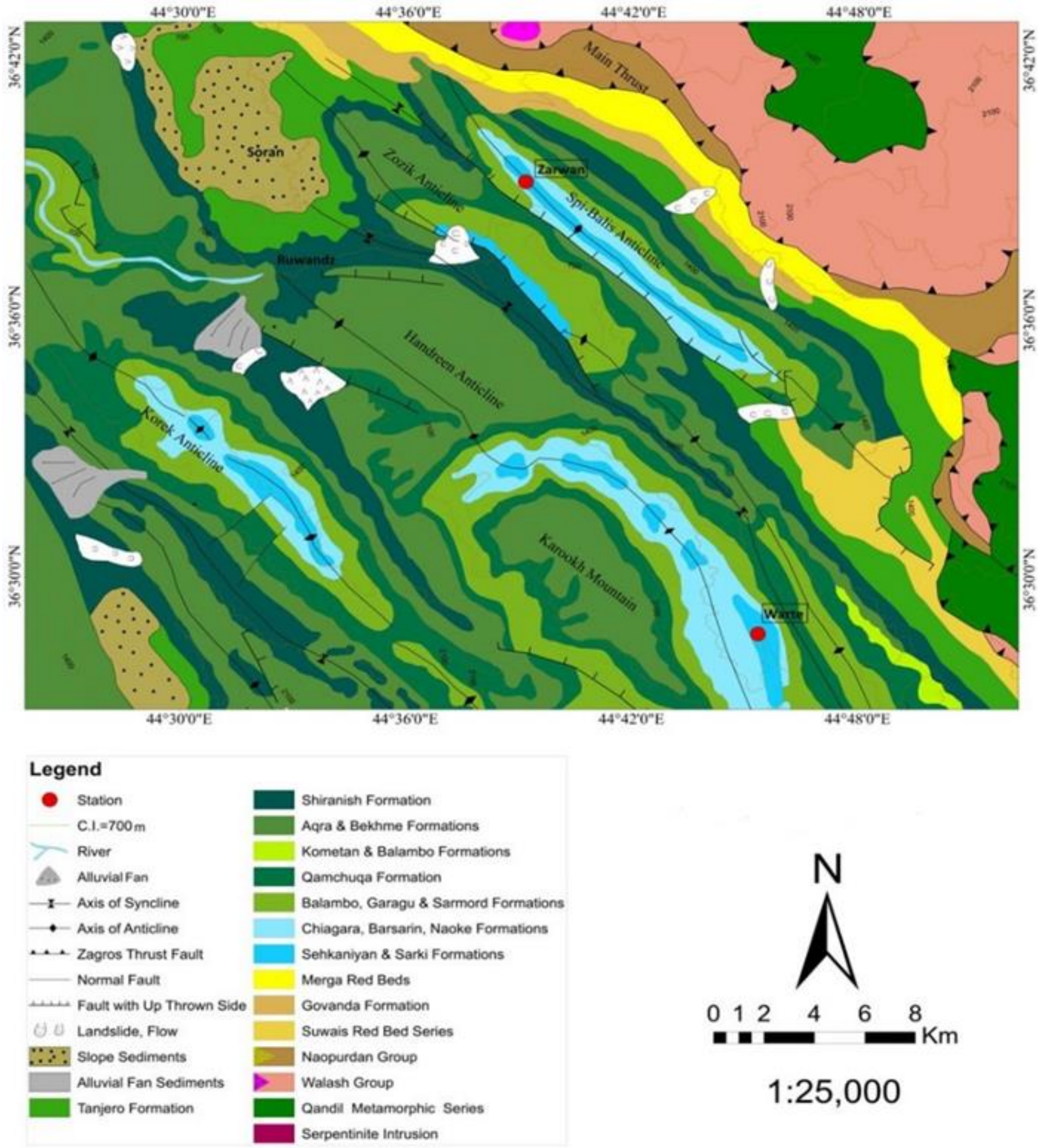

Fig. 4. Geological map of the study areas (modified from Delizy and Shingaly, 2022).

Results and Discussion

Petrography and Mineralogy

Few allochems form the main petrographic constituents of the Sarki Formation, are affected mostly by severe dolomitization. Dolomite is the common mineral indicated from the mineralogical XRD study (Fig. 5), while other minerals are calcite quartz and illite.

The petrographic investigation of the Sarki Formation is carried out on 80 thin sections from both studied sections. The skeletal grains recognized in the carbonate of Sarki Formation include: ostracods (Fig. 6a), bivalves (pelecypod) (Fig. 6 b) and echinoderms (Fig. 6 c). Whereas the non-skeletal grains are ooids (Fig. 6 d), peloids (Fig. 6 e) and intraclast (Fig. 6 f).

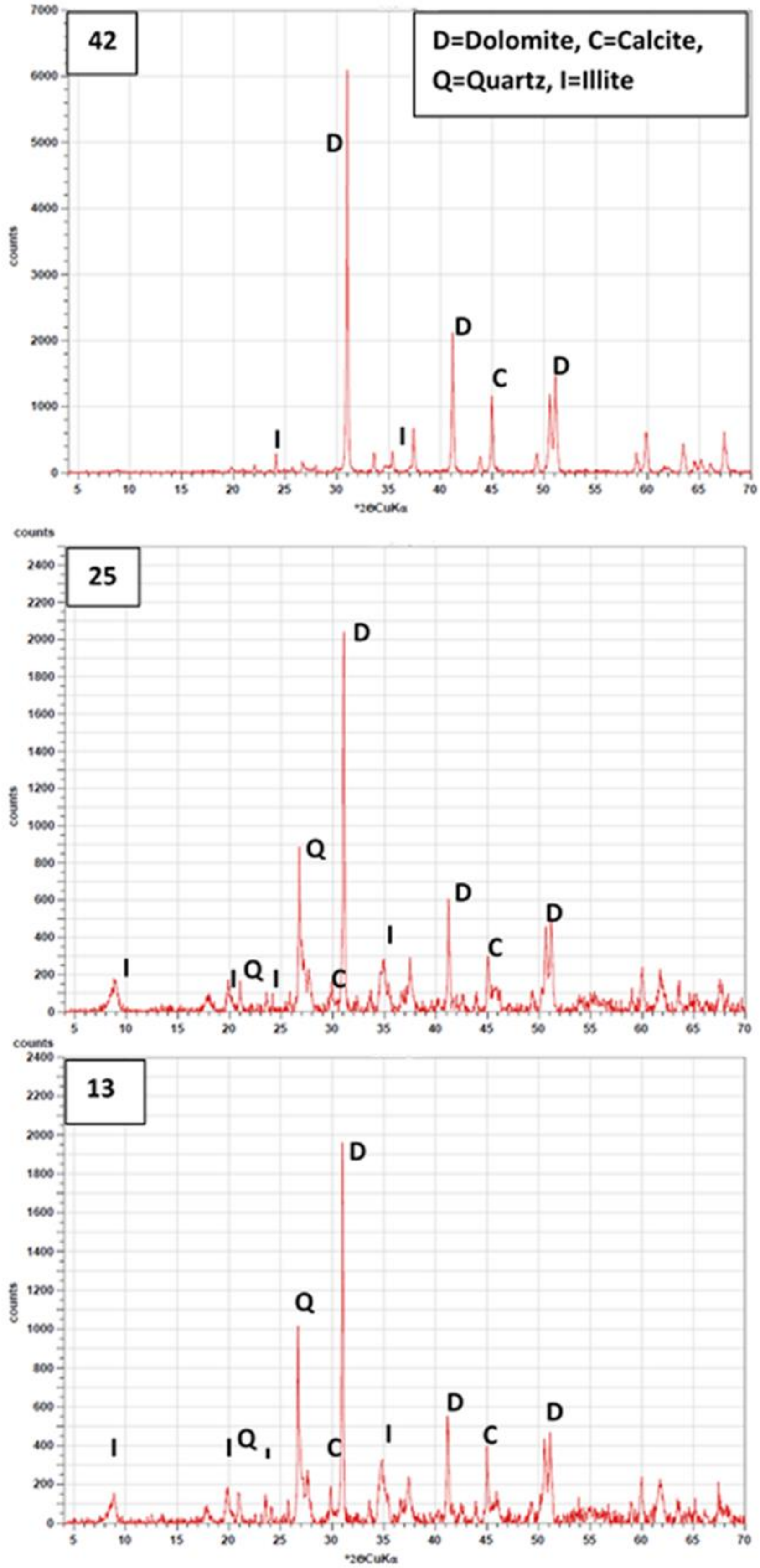

Fig. 5. X-Ray diffractograms of selected samples of the Sarki Formation at Warte section, see Figure (2a) for samples locations.

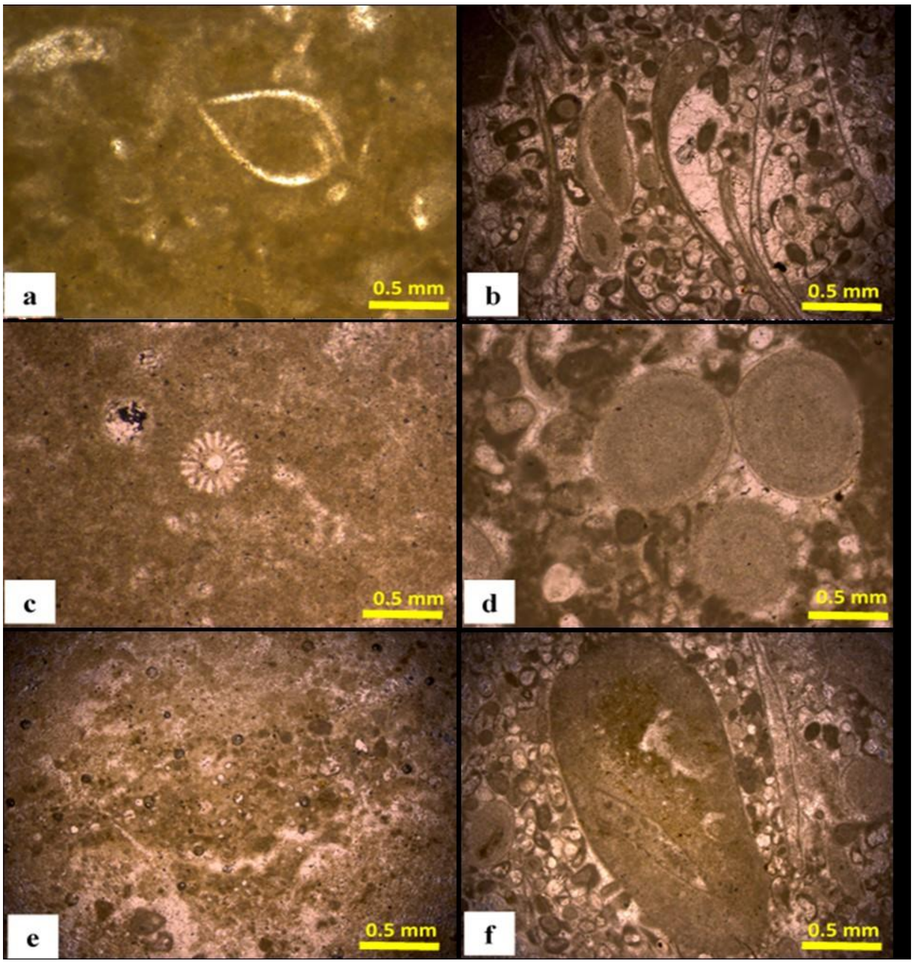

Fig. 6. Photomicrographs showing petrographic components of the Sarki Formation (a) Articulated ostracod in a micritic groundmass, WS. 31, P.P. (b) Valve of pelecypod, curved shape and filled by cement and affected by micritization, WS. 42, P.P. (c) Spines of echinoid single crystal calcite, enveloped in dolomitized micritic matrix, WS. 27, P.P. (d) Non-skeletal grains, spherical (ooids) or affected by micritization, WS. 40, P.P. (e) non-skeletal grains (peloids) within a neomorphosed micrite matrix, WS. 45, P.P. (f) An intraclast including bioclasts, surroundded by peloids grains and fragment of bivalves, WS. 41, P.P. {WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichols}.

Diagenesis

Dolomitization is the common diagenetic process affecting on various-age carbonate successions at northern Iraq (Barzani and Al-Qayim, 2019). In the carbonate rocks of the Sarki Formation, many processes occurred in various environments such as vadose, meteoric water, shallow and deep-marine and deep burial environment. Several diagenetic processes including dolomitization, micritization, cementation, compaction, dissolution, fracturing and pyritization have been distinguished.

Dolomitization

It occurs in both early and late phases, which is the primary diagenetic process that had various degrees of impact on different parts of the formation. Both early and late phases of dolomitization are observed in the studied dolomite rocks of the Sarki Formation. The early dolomitization phase is characterized by fine crystals of dolomite and more common in the Warte section, particularly in the middle part of the formation. Coarse dolomite crystals, which are indicative of late dolomitization phase are dominated in the middle part of the studied sections (Fig. 7).

Using the dolomite rock classification scheme of Sibley and Gregg (1987), four dolomite textures have been identified: (1) Fine crystalline, planer-s (subhedral) dolomites (Fig. 7a, b); (2) Subhedral, planar-s to euhedral, planar-e dolomite, in fine to medium crystals (Fig. 7c, d);

(3) Euhedral, planar-e to subhedral, planar-s dolomites, medium to coarse crystals (Fig. 7e); and (4) Subhedral, planar-s to anhedral, nonplanar-a dolomites with coarse crystals (Fig. 7f).

Micritization

It is the process in which crypto- or microcrystalline carbonate crystals replace the margins of carbonate grains or the total volume of grains (Blatt, 1982). In both studied sections, the micritization process affected both the skeletal and non-skeletal grains, especially the margins of thin shell (valves) (Fig. 8a) and ooids grains (Fig. 8b). This diagenetic process is highly affected the margins of the grains from upper part of the formation in the Warte section

Cementation

It occurs when calcium carbonate from a saturated solution is deposited as cement in between or within grains, or in pores and fissures (Larsen and Chilingar, 1979, Mahdi *et al.*, 2021). Granular, blocky and drusy cements are most common cement types detected in the carbonate of the Sarki Formation. Granular type cement is observed filling shell of fossils and fractures related to compaction (Fig. 8c). Blocky cement type is one of the most common types of cement in the Sarki Formation and recorded in the middle to upper part of formation comprising medium to coarse grained crystals (Fig 8d). Drusy cement is less common in the Sarki Formation and observed in inter-skeletal pores and molds, where the crystal size increases toward the center of voids (Fig. 8e).

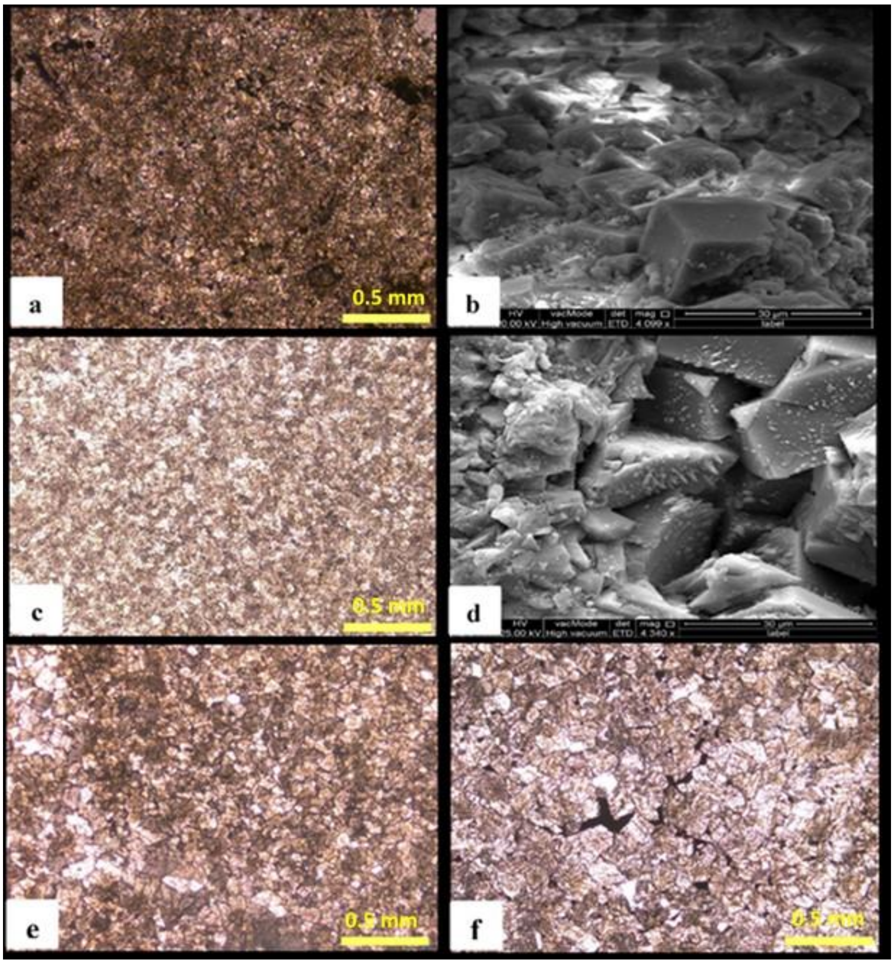

Fig. 7. Diagenetic features of the Sarki Formation: (a) Fine crystalline, planer-s (subhedral) dolomites, WS. 24, P.P. (b) SEM image showing fine crystalline planer-a (subhedral) dolomites. (c) Fine to medium crystalline planar-s (subhedral) to planar-e (euhedral) dolomite, WS. 22, X.N. (d) SEM image showing fine to medium crystalline planar-s (subhedral) to planar-e (euhedral) dolomite. (e) Medium to coarse, planar-e (euhedral) to planar-s (subhedral) dolomites, ZS. 16, P.P. (f) Coarse crystalline, planar-s (subhedral) to nonplanar-a (anhedral) dolomites, WS. 14, X.N. {WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichols}.

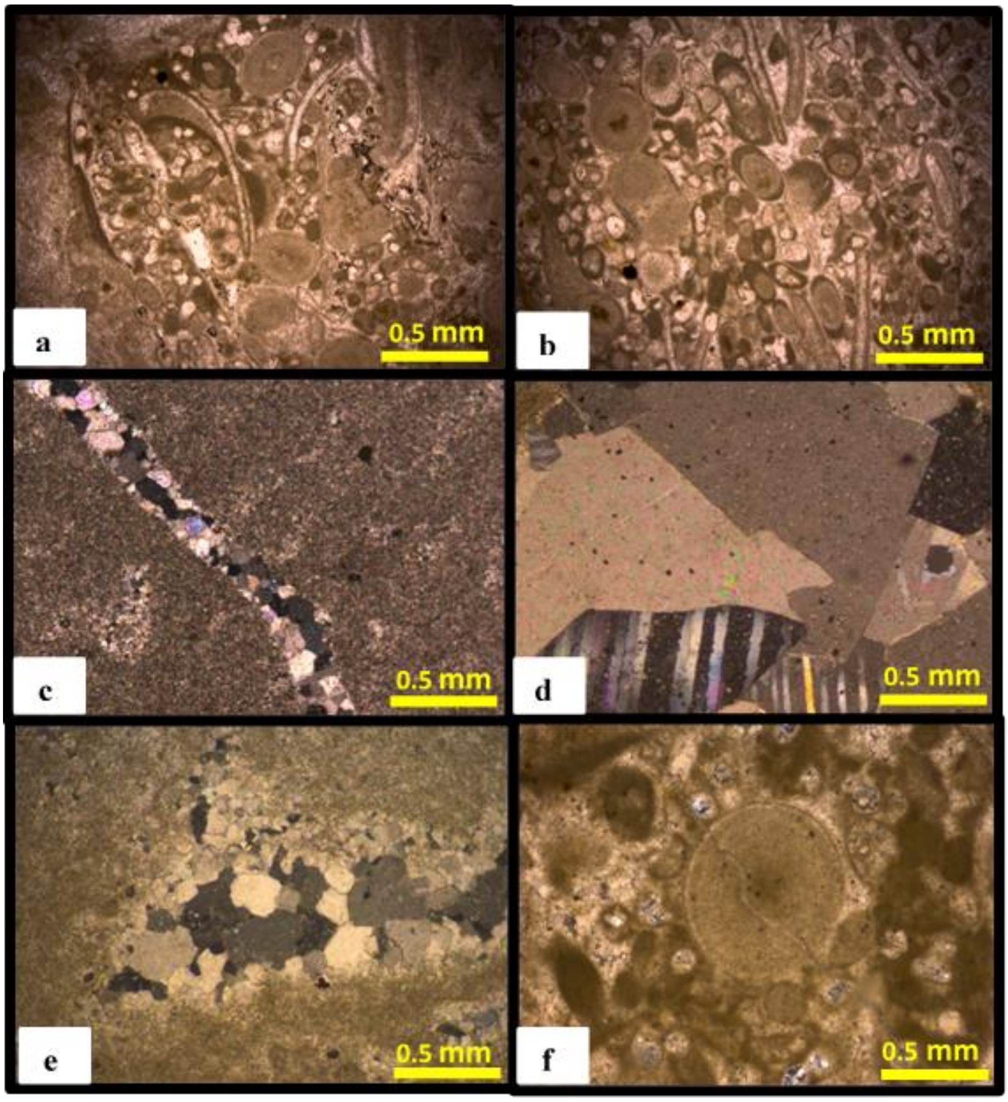

Fig. 8. Diagenetic features of the Sarki Formation: (a) Micrite envelopes (rim) surrounding articulated bivalves shell, WS. 42, P.P. (b) Micrite envelops (rim) surrounding ooids grain affected by micritization process, WS. 42, P.P. (c) Fracture (vein) filled by granular cement in micro-spar groundmass, WS. 33, X.N. (d) Dissolution of bioclast filled by the blocky cement, WS. 38, P.P. (e) Drusy cement filling a bioclast mold surrounded by micrite matrix, WS. 34, X.N. (f) Breakage in an ooid grain due to effect of the compaction processes, WS. 42, X.N. {WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichols}

Compaction

Any process that reduces the bulk volume of rocks and has an effect on carbonate sediments at the deep burial stage is referred to compaction (Flügel, 2010). Both types of physical and chemical compactions have been detected in the Sarki Formation. Breaking (Fig. 8f), flattened grains (Fig. 9a), concave-convex contact (Fig. 9b) and plastic bending (Fig. 9c) are the most common types of physical compaction recorded in the Sarki Formation. Different shapes of stylolite observed in the carbonate rocks of the Sarki Formation, which include sutured seam stylolite with irregular type with peaks of high amplitude (Fig. 9d) and sutured seam stylolite irregular type with peaks of low amplitude (Fig. 9e), are evidences of chemical compaction.

Dissolution

It impacts all types of rocks as a common diagenetic process particularly on the Jurassic and Cretaceous rocks of Iraq (Al-Haj *et al.*, 2019; Omar et al., 2023; Al-Taee et al., 2024; Al-Lhaebi et al., 2024). Typical low-Mg-calcite, high-Mg-calcite and aragonite respond faster to solutions (Friedman, 1964). The effect of solution is noticed extensively in both studied sections of Sarki Formation. The pore spaces are created during dissolution and later filled by different types of cement. According to Choquette and Pray (1970) classification, different types of porosity are identified in the Sarki Formation as moldic (Fig. 9f), interparticle (Fig. 10a), intraparticle (Fig. 8b), intercrystalline (Fig. 10b) and fracture porosity (Fig. 10c).

Fracturing

It is a common process in the Sarki Formation and most of the fractures are mainly filled with different types of cement. It is more common in the Zarwan section compared to the Warte section where the section has a high effect on tectonic activity than the second section (Fig. 10c).

Pyritization

Under reducing alkaline circumstances, pyrite is formed inside the carbonate rock beds (Berner, 1984). Most of the patches are formed by pyrite in beds of limestone and filling the voids with different shapes and sizes. According to petrographic study of the Sarki Formation, most common pyrite forms observed are small cubic pyrite especially in the middle part of Warte section (Fig. 10d).

Diagenetic sequence

The diagenetic history of the Sarki Formation based on the petrographic study from both studied sections can be divided into four phases: marine, meteoric, burial and uplift (Fig. 11).

Marine diagenesis

Marine phreatic diagenesis required early micritization of allochems and subsequent precipitation of isopachous fibrous cement. Common diagenetic processes occurring in marine realm include dissolution, cementation and micritization (Bathurst, 1975). Depending on the petrographic study of the Sarki Formation, micrite envelopes around most of thin shells (valves) and ooids. During marine diagenesis stage, an early compaction progressively reduces the primary porosity, and fine crystalline structure of dolomite are also formed.

Meteoric Diagenesis

It began with meteoritic vadose diagenesis, secondary fabric- and non-fabric selective porosity was created by dissolving metastable skeletal and non-skeletal grains (Longman, 1980; Al-Haj *et al.,* 2019; Rasool *et al.,* 2023, 2024). When meteoric waters filled the pore spaces during phreatic diagenesis, cements with various fabrics (drusy, blocky and granular) are produced. The types of cement fabrics are good indicators of active saturated freshwater phreatic zone. Primary and secondary pores were gradually closed by these second-generation cements.

Burial Diagenesis

In the Sarki Formation, increased overburden stress and pressure solution defined this stage of diagenesis. Many of the processes such as breakage, deformation, silicification, plastic bending and over closing packing of grains, concave-convex contact between grains are occurred. Compaction in the absence of cementation decreased primary and secondary porosities, late dolomitization process, which includes coarse crystalline dolomite, and authigenic mineral formation such as pyrite.

Uplift

This forms the last stage of the Sarki Formation diagenetic history due to the effect of the Alpine orogeny that caused folding and fracturing of the formation. Uplift caused increased dissolution and vuggy porosity in the Sarki Formation as a result of exposure to fresh water particularly in Zarwan section.

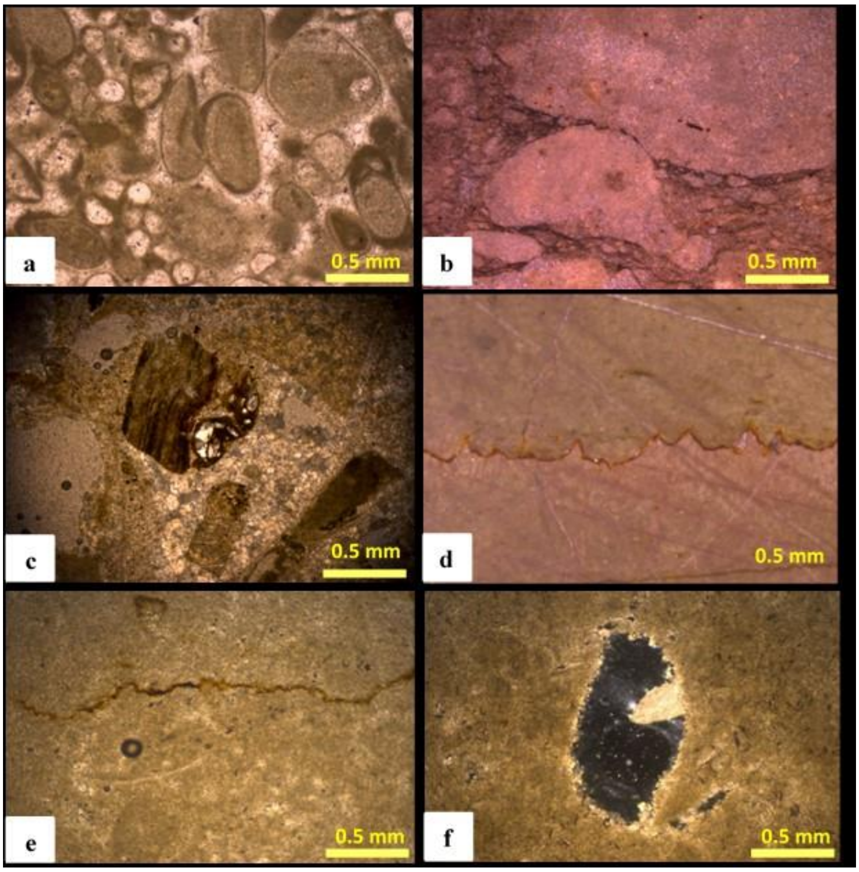

Fig. 9. Diagenetic features of the Sarki Formation: (a) Flattened and contacted ooid grain due to over close packing under effect of compaction, WS. 42, P.P. (b) Suture contact forms due to close packing on non-skeletal grain, ZS. 2. P.P. (c) Deformation of the non-skeletal grain of viewing the wave appearance, ZS.6, P.P. (d) Sutured seam irregular stylolite with peaks of high amplitude (columnar stylolite), ZS. 7, P.P. (e) Sutured seam irregular stylolite with peaks of low amplitude, filled by bituminous materials, SW. 27, X.N. (f) Moldic porosity as a result of dissolution, SW. 27, X.N. {WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichols}.

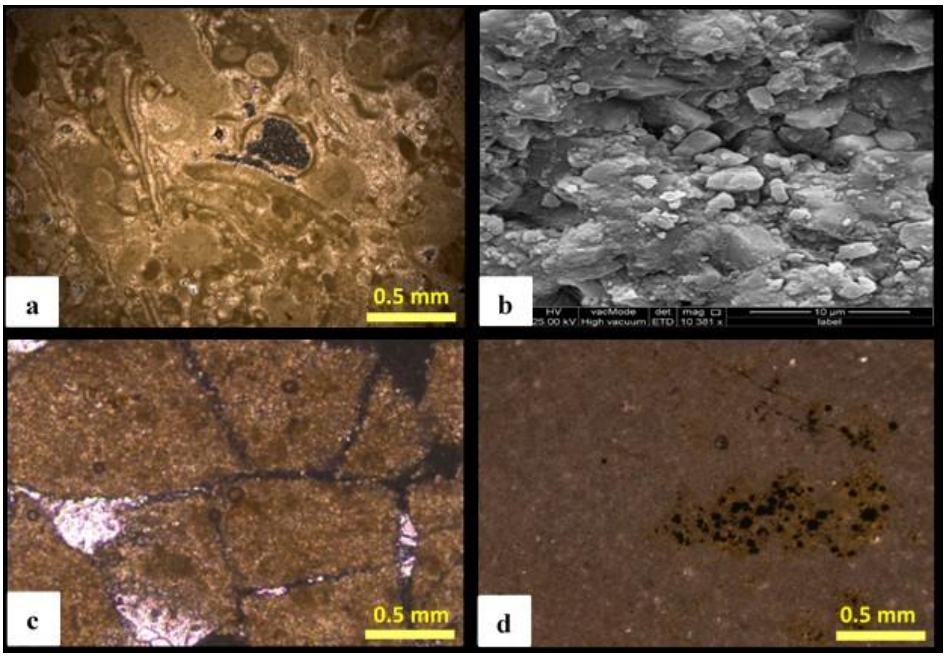

Fig. 10. Diagenetic features of the Sarki Formation: (a) Intraparticle porosity within ooid grain reduced by cementation, WS. 42, X.N. (b) SEM image showing intercrystalline porosity formed between dolomite crystals, WS. 19. (c) Fracture porosity reduced by cementation processes, ZS. 4, X.N. (d) Pyrite authigenic mineral developed in aggregated cubic and circular shapes, WS. 39, X.N. {WS: Warte –Sarki, ZS: Zarwan-Sarki, P.P: Plane Polarized light. X.N: Crossed Nichols}.

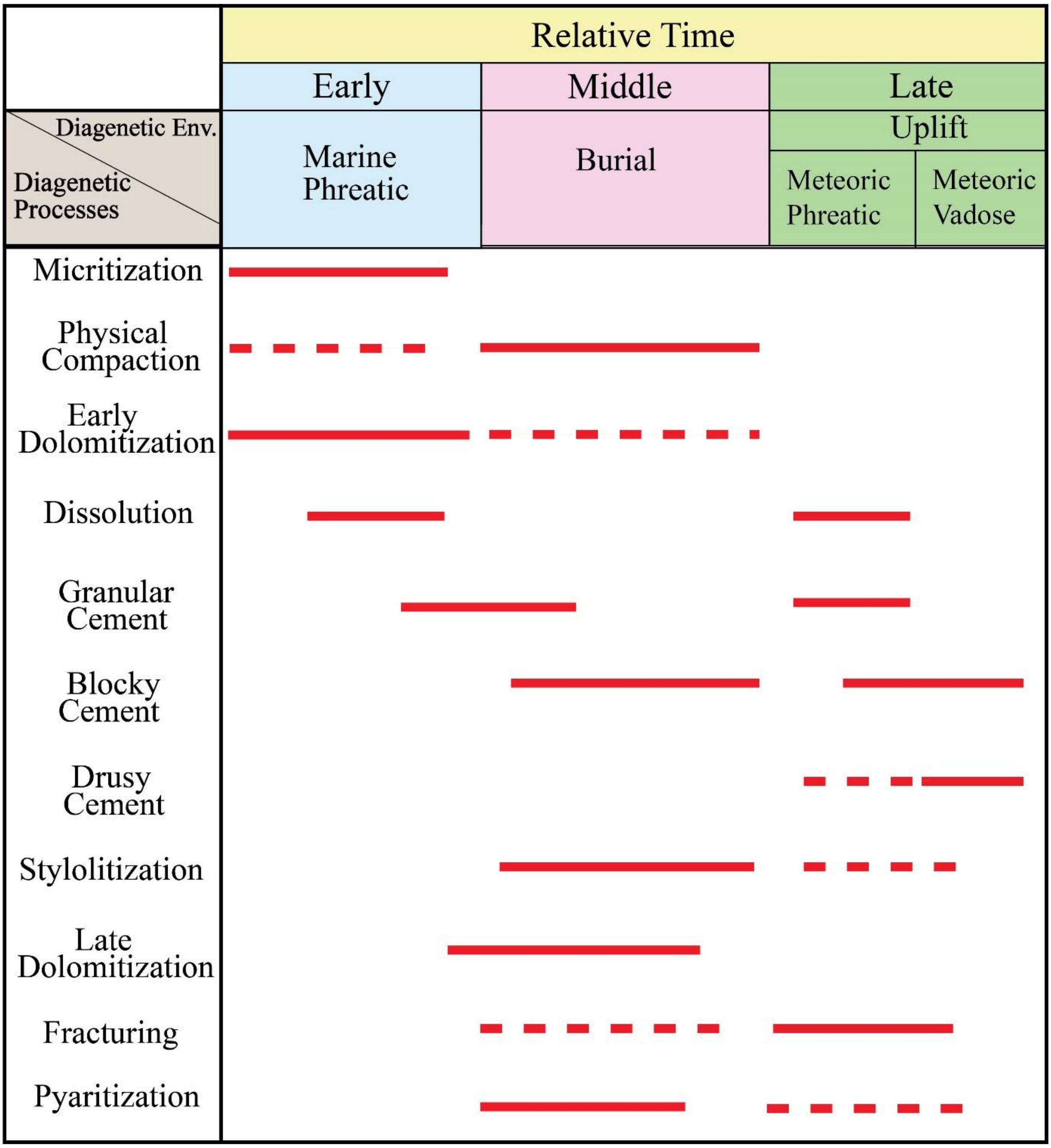

Fig. 11. Paragenetic Sequence of the Sarki Formation (Lower Jurassic) in Imbricated Zone, Northern Iraq

Conclusion

The Sarki Formation consists of dark-grey, hard, massive dolomitic limestone; brecciated dolomitic limestone; hard, greyish, well-bedded dolostone and thin beds of dark-grey marl. Ostracods, bivalves and echinoderms form the main skeletal components while ooids, peloids and intraclasts represent the main non-skeletal fragments in the studied formation. These components are highly affected by diagenesis. The Sarki Formation has been exposed to different types of diagenetic processes including dolomitization, micritization, compaction (physical and chemical), cementation, dissolution. pyritization and fracturing. These diagenetic processes have been occurred in marine, meteoric, burial and uplifting diagenetic environments.

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