Iraqi National Journal of Earth Science
www.earth.mosuljournals.com

Depositional Model of the Sarki Formation (Early Jurassic) in Sule Area, Hendren Anticline, Northeastern Iraq

Wisam M. k. Aljubouri [1*], Mohammed A. Al-Haj [2]

[1,2] Department of Geology, College of Science, University of Mosul, Mosul, Iraq.

Article information

Received: 28- Apr -2024

Revised: 19- -June -2024

Accepted: 28- Jul -2024

Available online: 01- Jan – 2025

Keywords:
Early Jurassic
Sarki Formation
Depositional Model

Correspondence:
Name: Wisam M. k. Aljubouri

Email:
wissam.23scp98@student.uomosul.edu.iq

ABSTRACT

The succession of the Sarki Formation (Early Jurassic) is studied in an outcrop section near the Sule village in northeastern Iraq within the High Folded Zone. The formation consists of dolomitic limestone, massive dolomite including stylolite, layers of limestone containing bedded stromatolites, interbedded black to gray and yellow shale in the lower and middle units. Petrographically, the formation consists of skeletal grains as represented by bivalves and gastropods, ostracod shells, stromatolites, some sponge spines, and calcispheres, as well as non-skeletal grains represented by ooids, intra and extra clasts and peloids. Field work has revealed that four rock lithofacies could be identified: the gray shale rock lithofacies, the yellow shale lithofacies, the brecciated dolomitic limestone lithofacies, and the laminated stromatolite lithofacies. Based on the petrographic components, five main microfacies are distinguished: the mudstone limestone microfacies, the wackstone microfacies, packstone microfacies, grainstone microfacies, and boundstone microfacies, which in turn are divided into eleven submicrofacies. All of these facies reflect the deposition in a shallow marine environment that extends into three secondary environments: the pertidal environment, lagoon environment, and oolitic sand shoal barrier environment. The paleogeography setting reveals that the formation sequences were deposited in shallow environments within the restricted basins that were formed as a result of affecting to tectonic movements that led to fluctuations in sea level which helped in creating sedimentary basins during the Early Jurassic period. Finally, a sedimentalogical model for the formation is drawn.

DOI: 10.33899/earth.2024.150306.1289, ©Authors, 2025, College of Science, University of Mosul.

الموديل الرسوبي لتكوين ساركي (الجوراسي المبكر) في منطقة سيلي، طية هندرين المحدبة، شمال شرقي العراق

وسام محمد خلف الجبوري[1*] ، محمد احمد الحاج [2]

[2،1] قسم علوم الارض، كلية العلوم، جامعة الموصل، الموصل، العراق.

معلومات الارشفة

تاريخ الاستلام: 28– ابريل –2024

تاريخ المراجعة: 19– يونيو –2024

تاريخ القبـول: 28– يوليو –2024

تاريخ النشر الالكتروني: 01– يوليو –2025

الكلمات المفتاحية:

الجوراسي المبكر

تكوين ساركي

الموديل الرسوبي

المراسلة:

الاسم: وسام محمد خلف الجبوري

Email: wissam.23scp98@student.uomosul.edu.iq

الملخص

دُرست تتابعات تكوين ساركي (الجوراسي المبكر) في مكشف صخري قرب قرية سيلي في شمال شرقي العراق ضمن نطاق الطيات العالية. يبلغ سمك التكوين في المقطع (210m) ويتألف من الحجر الجيري المتدلمت والدولومايت الكتلي الحاوي على الاستايلولايت وطبقات من الحجر الجيري حاوية على الستروماتولايت المتطبق، والطفل الأسود الى رمادي اللون، فضلاً عن طبقات رقيقة من الطفل الأصفر. يحد التكوين من الأسفل تكوين بلوطي بسطح تدريجي متوافق ومن الأعلى تكوين سيهكانيان بسطح متوافق ايضاً ولكن حاد. بتروغرافياً، تتكون صخور التكوين من الحبيبات الهيكلية المتمثلة بذوات المصراعين وبطنيات القدم، واصداف الاوستراكودا، والستروماتولايت، وبعض اشواك الاسفنجيات، والكرات الكلسية، فضلاً عن الحبيبات غير الهيكلية المتمثلة بالسرئيات والفتات الصخري بنوعيه الداخلي والخارجي والدمالق. حقلياً، تم تشخيص أربع سحنات صخرية وهي السحنة الصخرية للطفل الرمادي، والسحنة الصخرية للطفل الأصفر، وسحنة الحجر الجيري المتدلمت المتكسر، وسحنة الستروماتولايت المترقق الصخرية. اعتماداً على المكونات البتروغرافية، تم تمييز خمس سحنات دقيقة رئيسة هي سحنة الحجر الجيري الطيني، وسحنة الحجر الجيري الواكي، وسحنة الحجر الجيري المرصوص وسحنة الحجر الجيري الحبيبي وسحنة الحجر الجيري المترابط، والتي قسمت بدورها الى احدى عشرة سحنة ثانوية. عكست هذه السحنات جميعاً ترسب تتابعات التكوين في بيئة بحرية ضحلة تمتد في ثلاث بيئات ثانوية هي البيئة المدية، وبيئة اللاكون، وبيئة حاجز السرئيات الضحل، اذ بينت وضعية الجغرافيا القديمة ترسب تتابعات التكوين في بيئات ضحلة ضمن الاحواض المحصورة التي تشكلت نتيجة تعرض المنطقة الى حركات تكتونية ادت الى تذبذبات في مستوى سطح البحر ساعدت على نشوء احواض رسوبية خلال العصر الجوراسي المبكر، واخيراً، تم رسم موديل رسوبي للتكوين.

DOI: 10.33899/earth.2024.150306.1289 ,

Introduction

The Sarki Formation (Early Jurassic) is one of the carbonate formations widely exposed in northeastern Iraq in the High Folded Zone and the Imbricated Zone. The formation was deposited as a part of the Arabian plate (AP6). This part includes various groups of Early Jurassic formations, such as the clastic and carbonate sequences of the inner shelf (Ubaid and Husseiniyat formations), while the carbonate and evaporite deposits include the Adaya Evaporite Formation and the Allan Evaporite Formation, whereas, the closed shallow basin deposits are represented by the Sarki Formation (Jassim and Buday, 2006).

The formation was first described by Wetzel (1952; in Bellen et al., 1959) in the type locality at Chia Gara region, south of Amadiya, northern Iraq. The thickness of the formation is 303m, and its lower part consists of 122m dark grey dolomitic limestone and thick layers of dolomite and recrystallized breccia, while the upper part consists of 181m dolomitic limestone and dark brown dolomite with thin layers of gray shale.

The study aims to identify the petrographic components and diagenetic processes affecting the formation in order to distinguishing lithofacies and microfacies, and then to determine the depositional environment in addition to draw a depositional model of the formation in the study area.

Geological setting

The study area is located in northeastern Iraq, where a surface Sule section is chosen due to the appearance of the whole formation sequences, in addition to the fact that the section had not been studied previously (Fig. 1A). The section is located in the Sule Village, 3km south of the Warte City, approximately 39 km east and southeast of Rawanduz, within the borders of Erbil Governorate, at latitude (36° 28' 24" N) and longitude (44° 45' 14" E). Tectonically, it is located in the High Folded Zone within the Hendren fold (Jassim and Goff, 2006) (Fig. 1b).

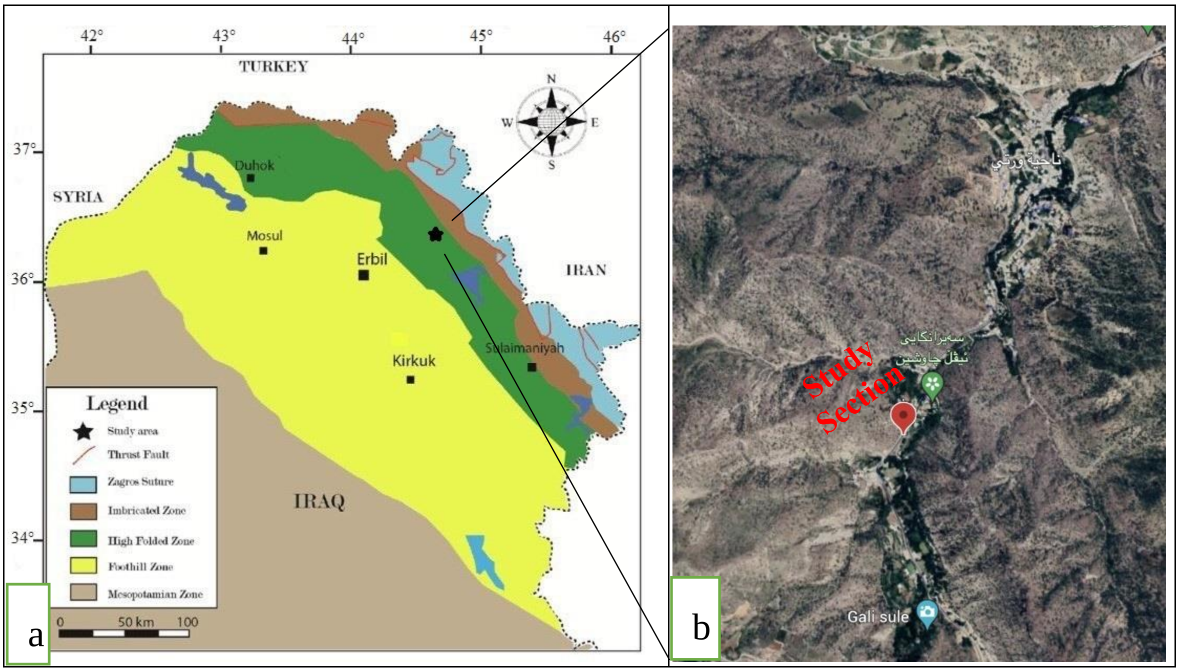

Fig. 1. (a). Geological map of northern Iraq showing the tectonic divisions and location of the studied section (modified after Jassim and Buday, 2006). b) Aerial photo of the study section.

Materials and Methods

After determining the study section and reviewing previous studies of the formation, the section is described in the field in terms of lithology, bed thickness, color and hardness, and the nature of the bedding, in addition to describing the lower and upper contact boundaries. Fifty-four samples were collected from the section according to the variations in lithology, and then forty- five thin sections were made in the geological workshop of the Department of Geology, University of Mosul. These slides have been examined in the laboratory under a polarizing microscope for diagnosing the petrographic and facies components of the Sarki Formation. For distinguishing between calcite and dolomite, a staining with alizarin red S is carried out according to Friedman (1959), where (0.2 gm) of the alizarin red S was dissolved in (100 ml) of distilled water, and then the slide was placed in the alizarin solution for a minute, as the mineral calcite is colored red, while dolomite is not. In addition to the analysis of (5) samples with an X-ray diffraction (XRD) in College of Science laboratories, Baghdad University to distinguish the main mineralogical couponed as well as the clay minerals.

Results

Stratigraphy

The Sule section is one of the most important rock exposures of the Sarki Formation because all the sequences appear almost completely, in addition to being close to the main road. The thickness of the Sarki Formation in this section is about (210m). The lower contact of the formation is conformable with Baluti Formation in gradual contact surface (Fig. 2a), while it is overlaid by Sehkanian Formation with also a conformable but sharp contact (Fig. 2b).

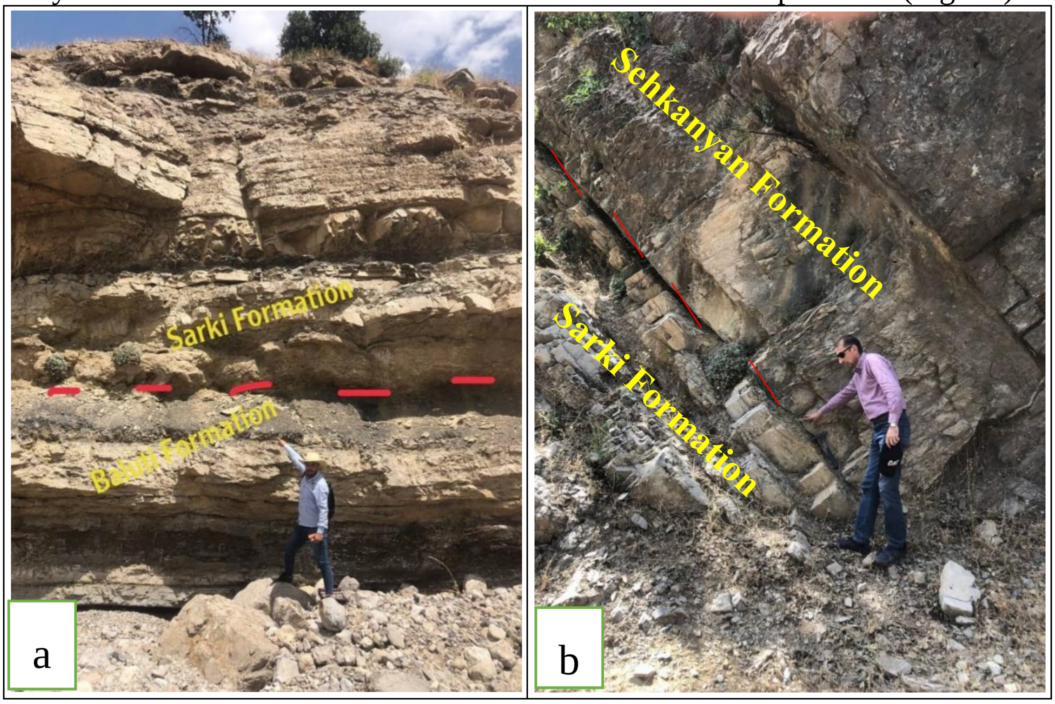

Fig. 2. (a). Lower contact with Balui Formation, (b) Sharp upper contact with Sehkaniyan Formation.

Based on the field characteristics, the formation sequences are divided into three rock units, (Fig. 3) as shown below:

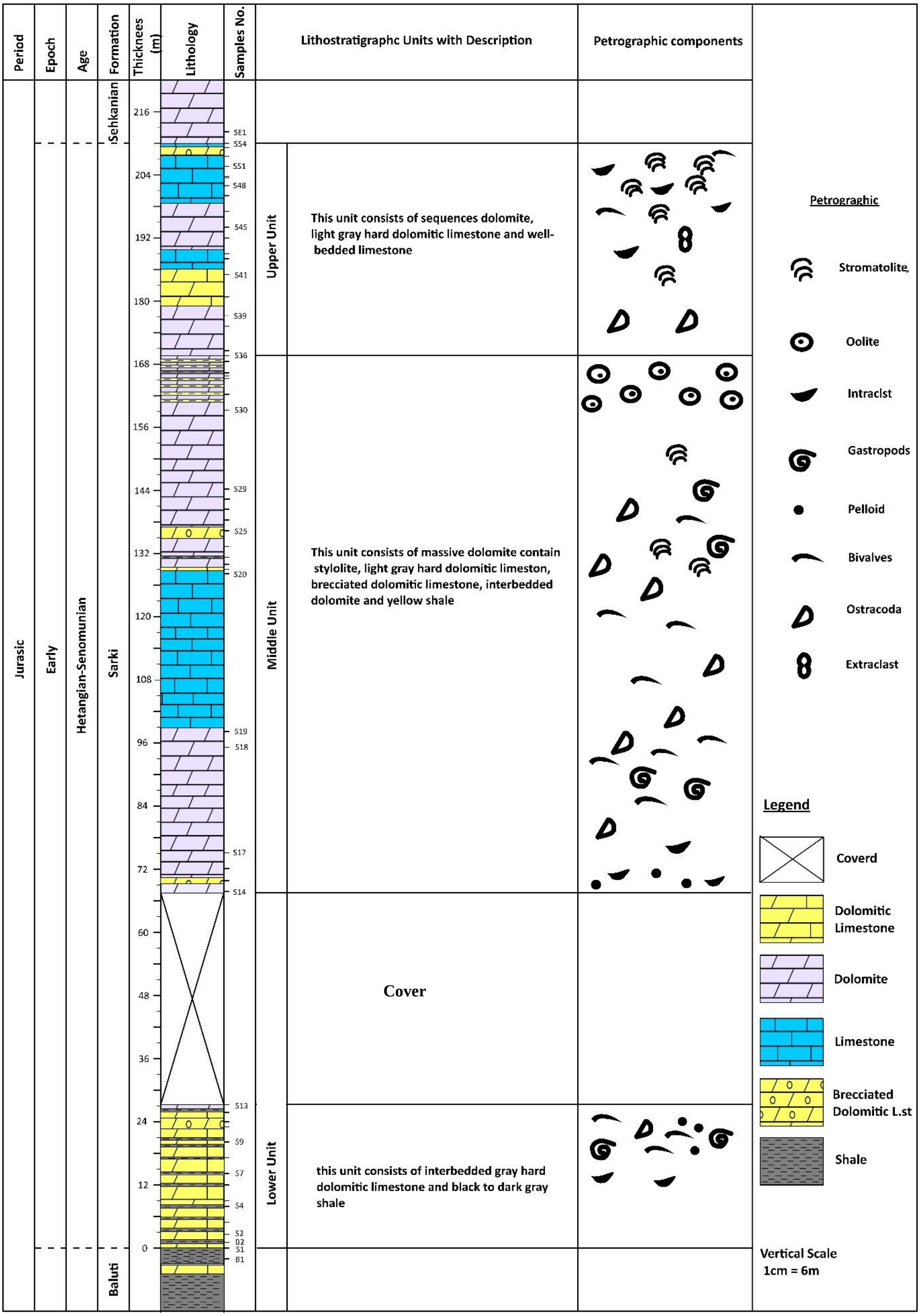

Fig. 3. Lithology of Sarki Formation along with the petrographic components.

Lower Unit: It has a thickness of approximately (67.5 m), which consists of alternating successions of gray to yellowish dolomitic limestone with layers of black to dark gray shale (Fig. 4a) and layers of brecciated dolomite (Fig. 4b), This unit ends with a covered area (approximately 40 m thick).

Middle Unit: It has a thickness of (102m), which consists of thick successions of dolomite and hard gray limestone (Fig. 4c) and interbedded dolomite with thin yellow shale layers (Fig. 4d).

Upper Unit: This unit is characterized by well bedded, especially in the upper parts close to the contact limit with Sehkaniyan Formation. The thickness of its sequences is about (40.5 m), and it begins with successions of dolomite, in which stylolite, bed of dolomitic limestone, and a gray color limestone characterized by having less resistance to erosion. Thin beds of limestone appear also with stratified stromatolite with dark and light layers (Fig. 4 e, f). The succession ends with thin layers of dolomitic limestone, which represents the upper boundary with the Sehkaniyan Formation.

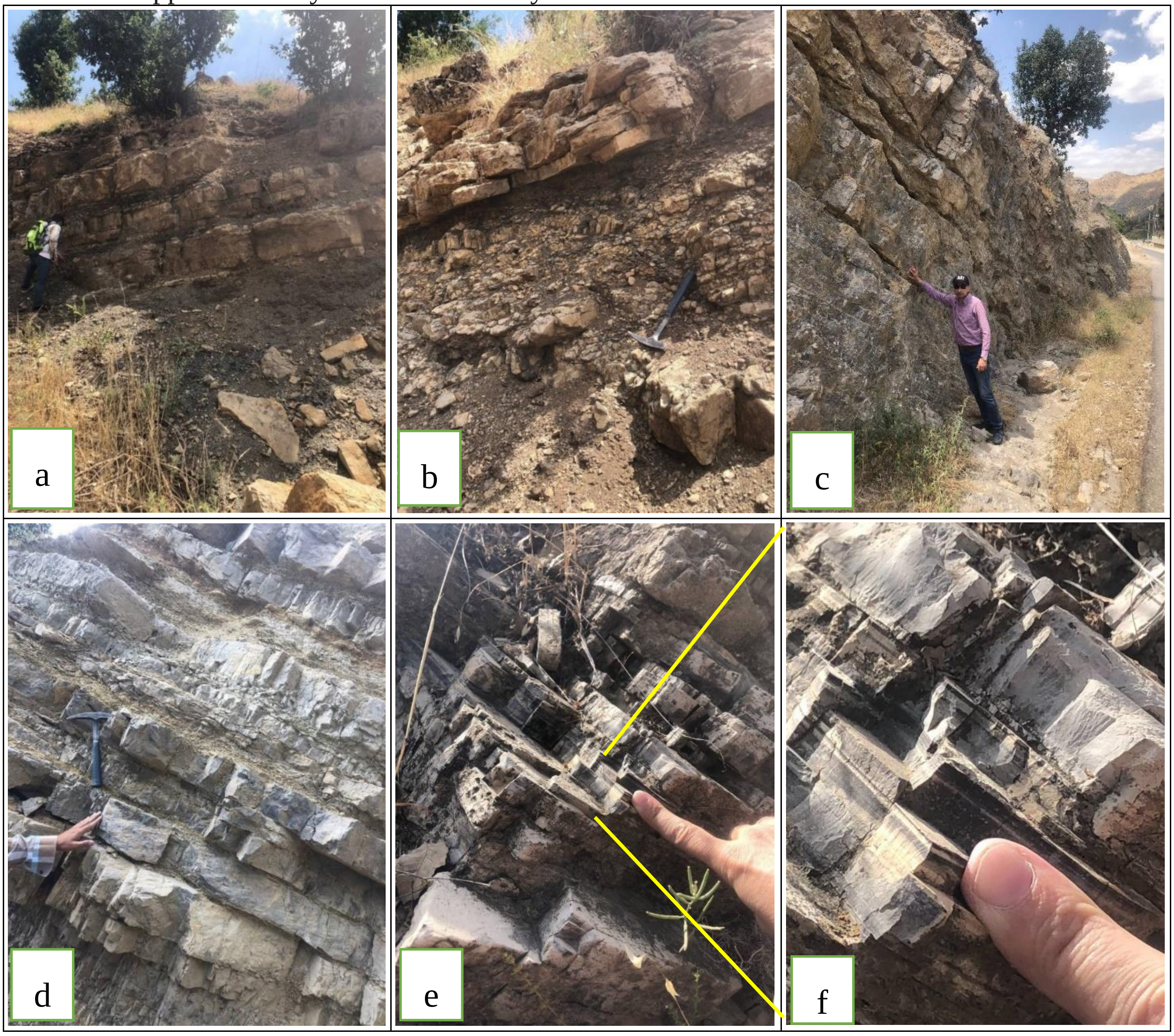

Fig. 4. a). Alternating beds of dolomitic limestone with layers of shale. b) A bed of brecciated dolomite within a matrix of shale. c) Successions of dolomite and hard limestone. d) Beds of dolomite alternate with layers of yellow shale. e) Well bedded limestone exhibiting stromatolite structures near the contact with Sehkaniyan Formation. f) Stratified stromatolite at the end of the upper unit.

Mineralogy and petrography

The petrographic study shows that the main grains components of the Sarki Formation are gastropods, bivalves, ostracoda, sponge and stromatolite, as well as ooids, peloids, and lithoclasts. The most important diagenetic processes affecting its rocks are the dolomitization, cementation, neomorphism, dissolution, dedolomitization and compaction. Mineralogically, the X-ray diffraction (XRD) analysis has revealed that the studied rocks are composed mainly of dolomite and calcite with small content of quartz, in addition to some clay minerals such as illite and montmorillonite (Fig. 5).

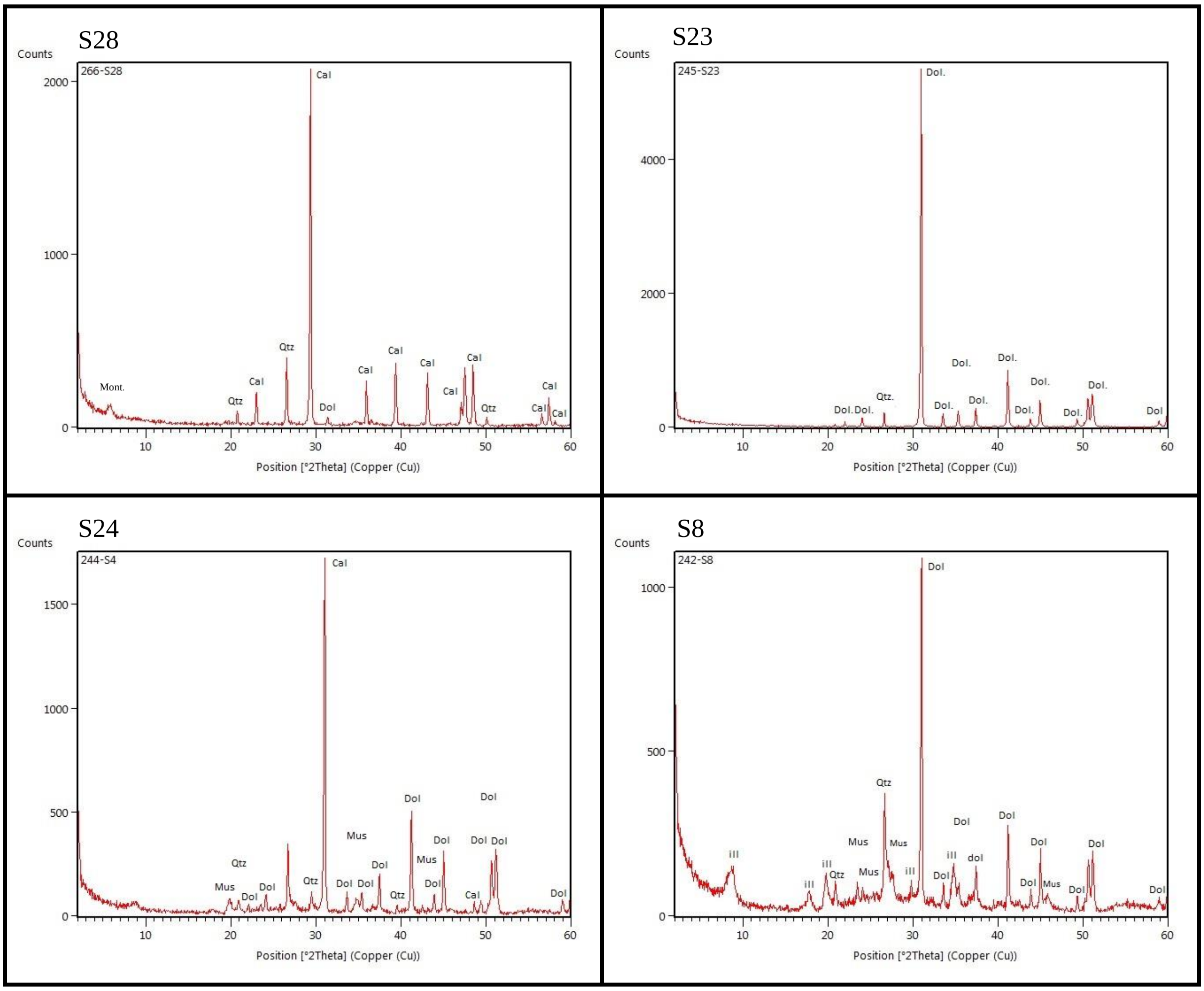

Fig. 5. X-ray diffractogram for selected bulk samples of the studied section.

Facies analysis

Two types of facies are identified in the succession of the current study, the lithofacies, which include four types distinguished in the field, and five main microfacies subdivided into eleven submicrofacies as shown below:

Lithofacies

Gray Shale Lithofacies (Sgl)

This facies consists of gray shale, which exists in beds with thickness ranges between (15-50) cm, alternating with beds of limestone and dolomitic limestone (Fig. 4a). This facies occurs in the upper part of the lower unit and in the middle unit of the formation. The deposition of thin shale layers alternating with limestone beds indicates a low-energy lagoon environment (Anyiam et al., 2017).

Yellow Shale Lithofacies (Syl)

This facies is distinguished by its yellow color and appears in the form of thin layers of shale, whose thickness ranges between (15-30) cm interbedded with dolomite beds. This facies is identified in middle unit of the formation with effect of erosion processes that make it of low hardness in comparison to the dolomite beds (Fig. 4d). The deposition of light-colored shale layers indicates a low-energy environment.

Brecciated Dolomitic Limestone Lithofacies (Sbl)

This lithofacies appears in the form of broken limestone layers in the form of breccia within matrix of gray shale. The thickness of these layers ranges between (50-90) cm. This facies occurs in the middle and upper units of the formation (Fig. 4b).

Stromatolites Lithofacies (Ssl)

This facies consists of laminated and different colors stromatolites, which appear as light and dark laminae. This type of stromatolite is found in intertidal and supratidal environments (Logan et al., 1964). This facies has been identified in the upper unit of the formation near the boundary with the Sehkaniyan Formation (Fig. 4 e, f).

Microfacies

Based on the classification of Dunham (1962), four main microfacies are identified and subdivided into eleven submicrofacies, which are, in turn, compared with the standard microfacies (SMF) according to Wilson (1975) and modified from Flügel (1982, 2010). Below, the defining of the facies zones (FZ) and the standard environments for each facies within the formation are illustrated:

Lime Mudstone Microfacies (Sm)

This facies is characterized by a low content of grains (not exceed 10%) of the total components of the rock, while the rest (90%) is represented by micrite, which forms the groundmass or matrix. It is composed of beds of limestone and dolomitic limestone. Based on the grains content of this facies, it has been divided into two submicrofacies:

Non- Fossiliferous Lime Mudstone Submicrofacies (*Sm1*)

This facies is characterized by absence of skeletal grains as it generally consists of a micrite matrix. This facies exists in the lower unit of the studied section (Fig. 6 a), and it has been affected by a number of diagenetic processes such as chemical compaction (stylolite), dolomitization, and cementation, in addition to the presence of calcite veins. Majidifard (2003) diagnosed this facies during the study of Jurassic facies in northeastern Iran and attributed it to the inter tidal environment. The characteristics of this facies are similar to the standard facies (SMF-23) deposited within the facies zone (FZ-8) according to models of Wilson (1975) and Flügel (1982, 2004), which represent the environment of tidal flats and the lagoon.

Fossiliferous Lime Mudstone Submicrofacies (*Sm2*)

The grains of this microfacies consist of ostracod shells and bioclasts, which do not exceed 7% of the total components of the microfacies in the micritic matrix (Fig. 6 b). This microfacies is identified in the lower and middle units of the formation. The diagenetic processes that affected this facies are dolomitization, cementation, and chemical compaction (stylolite). The general characteristics of this facies are identical to the standard facies (SMF-23) deposited within the facies zone (FZ-8) according to the models of Wilson (1975) and Flügel (1982, 2004), which represent the environment of the tidal flats and the lagoon environments.

Lime Wackstone Microfacies (Sw)

This microfacies is considered one of the most widespread microfacies compared to other microfacies within the formation, as it is identified in all the rock units. It consists of a micrite matrix with a grain that constitute a percentage ranging between (10-45%) of the total components of the sample. This microfacies is affected by some diagenetic processes such as dolomitization, chemical compression, and cementation, in addition to the presence of authigenic minerals. Depending on the dominance of the grains, this main mirofacies is divided into three submicrofacies as follows:

Intraclast Lime Wackestone Submicrofacies (*Sw1*).

This microfacies consists mainly of non-skeletal grains represented by intraclasts, which constitute a percentage of (30-37%) out of the total microfacies components, which are accompanied by some skeletal grains including ostracoda and bivalves (Fig. 6 c). This facies occurs in the middle and upper units of the studied section. It has been affected by some diagenetic processes such as cementation, dolomitization, dissolution and chemical compaction (Stylolite). The characteristics of this facies match the specifications of the standard microfacies (SMF 24) deposited within the facies zone (FZ-8) according to the models of (Wilson, 1975; Flügel, 1982; 2004), which represents the environment of tidal flats.

Osracoda Lime Wackestone Submicrofacies (*Sw2*)

This facies is found within the upper unit of the formation and consists mainly of ostracod shells of various sizes, which constitute approximately (35%) of the total grains of the facies, with the presence of bivalve shells and some bioclast. This microfacies was affected by diagenetic processes such as dolomitization, dissolution and cementation (Figure 6d). After matching the general characteristics of this facies with the standard facies, it was found that it resembles the facies (SMF-12) that was deposited in the facies zone (FZ-7) according to the models Wilson (1975) and Flügel (1982, 2004), which represents the lagoonal environment.

Bioclast Lime Wackestone Submicrofacies (*Sw3*)

This microfacies is considered one of the most widespread facies within the study section as it is widely identified in the middle and upper units of the formation. The majority of its grains consists of bioclast, which constitutes approximately (40%) of the total components content of the microfacies, which are debris shells of ostracods and molluscs represented by bivalves and gastropods, in addition to the presence spicules of sponges and echinoderms (Fig. 6 e). The main diagenetic processes that affected in the microfacies are dolomitization, cementation, and dissolution. The general characteristics of this microfacies are with the standard facies (SMF-9), which deposited within the facies zone (FZ-7) according to the Wilson (1975) and Flügel (1982, 2004) models, which is known as the lagoon environment.

Lime Packestone Microfacies (Sp)

This facies is characterized by the presence of abundance of packed grains in a micritic matrix. The facies is grain-supported, where grains constitute a percentage of (50-80%) out of the total components of the microfacies. This microfacies is widely spread in the Sarki Formation within the study section as it is identified in all the rock units of the formation represented by skeletal grains, which include bioclast and bivalves as well as non-skeletal grains as peloids and intraclasts. This microfacies appears to be affected by a number of digenetic processes such as dolomitization, micritizaton, cementation, and dissolution. This microfacies has been divided into four submicrofacies depending on the type of grains as follows:

Peloidal Lime Packestone Submicrofacies (*Sp1*)

The non-skeletal grains are represented by peloids, which constitute the basic grains component of this mirofacies reaching to 70% of the total microfacies components, in addition to small percentage of intraclasts and some skeletal grains such as ostracoda and bivalves (Fig. 6 f). This facies is identified in the lower unit of the formation. Digenetic processes of cementation and chemical compression (stylolite) and presence of calcite veins have affected it. This microfacies could be correlated with the microfacies (SMF-16) deposited within the facies range (FZ-7) according to Wilson (1975) and Flügel (1982, 2004) models, which represent the lagoon environment.

Sponges Lime Packestone Submicrofacies (*Sp2*)

Sponges spicules constitute the largest percentage of the grains of this microfacies with about 65% of the total facies components, in addition to presence of bivalve shells and a small percentage of calcispheres (Fig. 7 a). This facies is affected by a number of diagenetic processes, such as cementation, dolomitization, recrystallization, and veins of calcite. This facies is distinguished in the middle unit of the formation. Lukowiak et al. (2013) has mentioned that sponges are found in lagoonal shallow marine environments. This microfacies is equivalent to the standard microfacies (SMF-12), which deposited within the facies zone (FZ-7) according to the Wilson (1975) and Flügel (1982, 2004) models, which represent the lagoon environment.

Gastropods Lime Packestone Submicrofacies (*Sp3*)

This microfacies consists mainly of gastropod fossils, which constitute up to 42% of the total grains in the microfacies, accompanied by bivalve shells and some bioclasts, in addition to the presence of ooids and peloid. This microfacies has been affected by diagenetic processes including dolomitization, micritization, and cementation (Fig. 7 b). This microfacies is identified in the lower and middle units of the formation. The general characteristics of this microfacies could be compared with the standard microfacies SMF (12), which deposited in the facies zone (FZ-7) according to Wilson (1975) and Flügel (1982, 2004) models, which represent the lagoon environment.

Bioclastic Lime Packestone Submicrofacies (*Sp4*)

The grains in this facies consist mainly of bioclast, which constitute about (70%) of the total facies components. These grains consist mainly of debris from the shells of bivalves, gastropods, and ostracods, as well as spicules of sponges and echinoderms. The main diagenetic processes that have affected this microfacies are dolomitization, cementation, and micritization (Fig. 7 c). This microfacies is widely distributed in various parts of the formation. This microfacies is equivalent to the standard microfacies (SMF-10), which deposited within the facies zone (FZ-7) according to the Wilson (1975) and Flügel (1982, 2004) models, which represent the shallow lagoonal environment.

Lime Grainstone microfacies (Sg)

This microfacies is a grain-supported and characterized by a very high percentage of grains, while the matrix is composed of sparite. The effect of some diagenetic processes on this facies is noticed, such as the chemical compaction, dolomitization, micritization and cementation. This microfacies is represented by two submicrofacies as shown below:

Ooids Lime Grainstone Submicrofacies (*Sg1*)

This microfacies is identified within end of the middle unit of the formation, where ooids constitute about 90% of the total grain microfacies components, with few presences of intraclasts. Some diagenetic processes have affected this microfacies such as chemical compaction, dolomitization, micritization and presence of veins cemented with calcite (Fig. 7 d). The general characteristics of this microfacies are similar to the standard microfacies (SMF-15), which deposited in the facies zone (FZ-6) according to the Wilson (1975) and Flügel (1982, 2004) models that represent oolitic shoal.

Intraclast grainstone Submicrofacies (*Sg2*)

The intraclasts are the main component of this facies reaching more than (90%) of the grains within a sparite matrix. These intraclasts are of different sizes and shapes, some of them are small and others are large in size; and in general, they are of medium roundness, which indicates that they were affected by transport conditions and deposited within the same depositional basin. The microfacies was affected by a several of diagenetic processes such as cementation, dissolution, and dolomitization (Fig. 7 e). This microfacies occurs in the middle unit, and equivalent to the standard microfacies (SMF 24) deposited within the facies zone (FZ-7) according to Wilson (1975) and Flügel (1982, 2004) models, which represent the open lagoon environments in the form of lag deposits for the tidal channel or in the tidal flats (Flügel, 2004).

Bindstone Lime Microfacies (Sb)

This name was given by Embry and Klovan (1971), and it is one of the microfacies of limestone rocks deposited in situ, such as reef rocks and stromatolite. This microfacies consists mainly of algal mats represented by stromatolite in addition to some gastropods and intraclasts (Fig. 7 f). The microfacies appears in the upper unit of the study section, and diagenetic processes, such as, dolomitization, micritization, and cementation, affected it. Logan et al. (1964); Illing et al. (1965); and Kinsman and Park (1976) indicated that stromatolite is usually found in intertidal environments. The general characteristics of this facies match the standard facies (SMF-20) deposited in the facies zone (FZ8) according to the Wilson (1975) and Flügel (1982, 2004) models, which represent tidal flat environment.

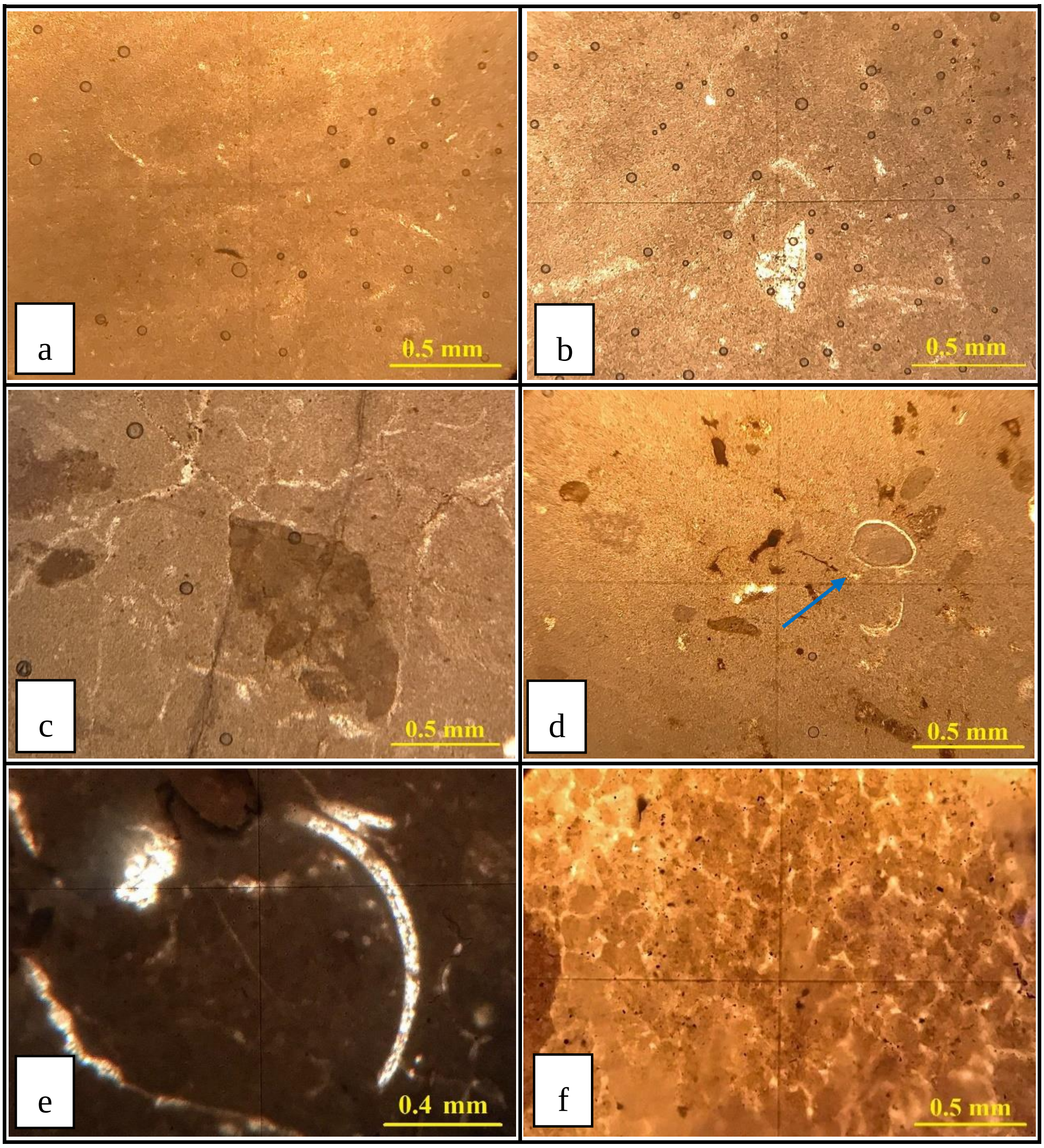

Fig. 6. (a). Non- Fossiliferous Lime Mudstone Submicrofacies (Sm1) in the lower unit. (b) Fossiliferous Lime Mudstone Submicrofacies (Sm2) in the lower unit. (c) Intraclastic Lime Wackestone Submicrofacies (Sw1) in the upper unit. (d) Osracoda Lime Wackestone Submicrofacies (Sw2) in the upper unit. (e) Bioclast Lime Wackestone Submicrofacies (Sw3) in the middle unit. (f) Peloidal Lime Packestone Submicrofacies (Sp1) in the middle unit.

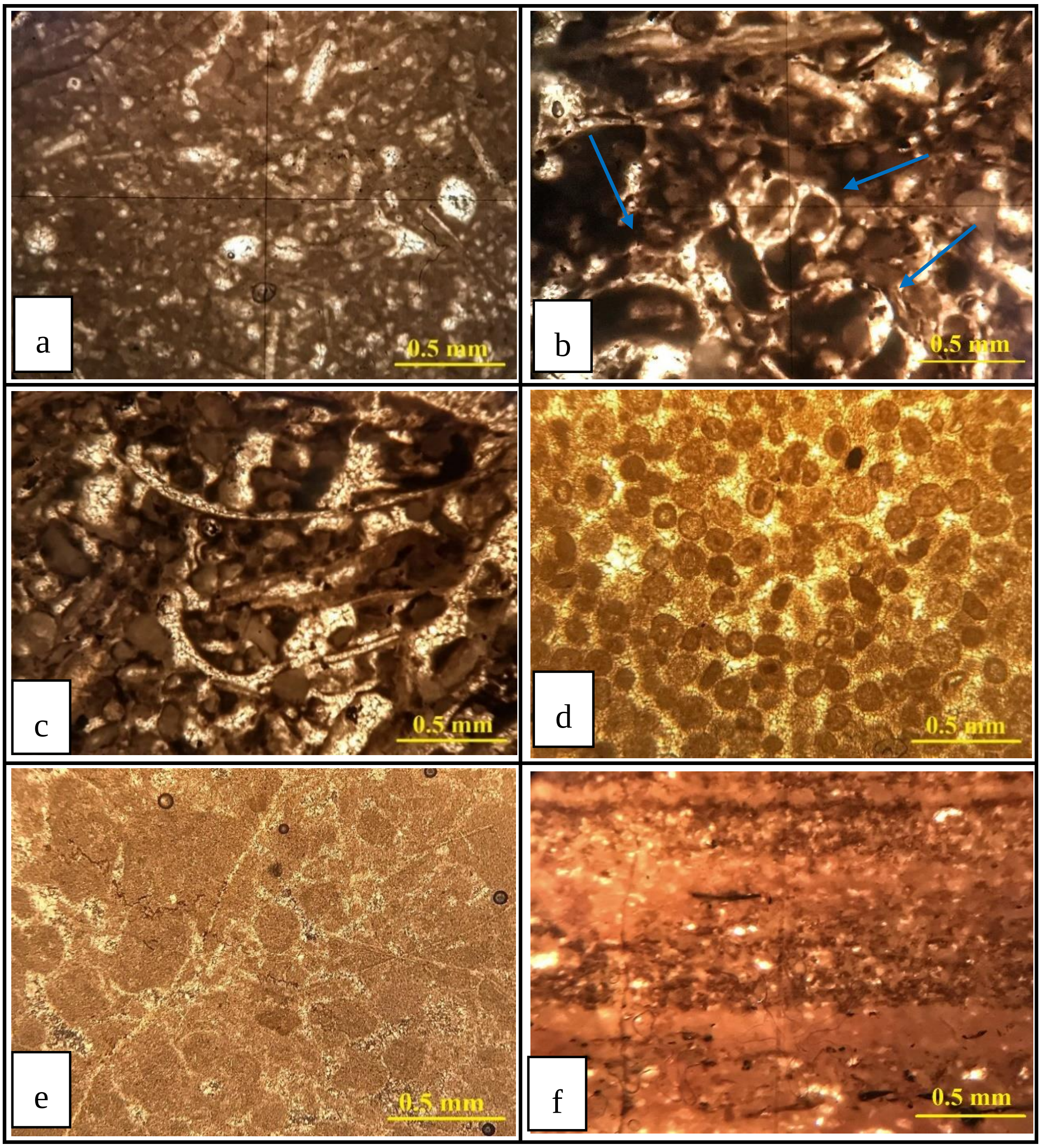

Fig. 7. (a). Spongs Lime Packestone Submicrofacies (Sp2) in the middle unit. (b) Gastropods Lime Packestone Submicrofacies (Sp3) in the upper part of lower unit. (c) Bioclast Lime Packestone Submicrofacies (Sp4) in the middl unit. (d) Ooids Lime Grainstone Submicrofacies (Sg1) in the upper part of middle unit. (e) Intraclast grainstone Submicrofacies (Sg2) in the middle unit. (f) Bindstone Lime Microfacies (Sb) in the upper unit.

Discussion

Depositional Environment

Facies analysis shows that the studied succession of the Sarki Formation was deposited within a shallow marine environment. Where the microfacies are correlated with the standard microfacies (SMF8, SMF9, SMF10, SMF-12, SMF-15, SMF-16, SMF -20, SMF-23, SMF-24) deposited within the facies zones (FZ-6) represented by the oolitic shoal environment; and (FZ-7) represented by the open lagoon environment and (FZ-8) represented by pertidal environment (Table 1). Below is a discussion of these environments:

Table 1: Microfacies and related facies zones determined within the Sarki Formation in the studied section.

Standard Microfacies and Zones (Flugel, 1982, 2004, 2010)			Facies of sarki Formation
Location Zone Microfacies	**Zone Microfacies (FZ)**	**Standard Microfacies (SMF)**	**Microfacies**
Oolitic Sand Shoal	6	15	Lime grinstone microfacies (Sg)
Lagoon	7	23	Fossiliferous Lime Mudstone Submicrofacies (Sm2)
		12	Osracoda Lime Wackestone Submicrofacies (Sw2)
		9	Bioclast Lime Wackestone Submicrofacies (Sw3)
		16	Peloidal Lime Packestone Submicrofacies (Sp1)
		12	Spongs Lime Packestone Microfacies (Sp2)
		12	Gastropods Lime Packestone Submicrofacies (Sp3)
		10	Lime Packestone Submicrofacies Bioclast (Sp4)
		24	Intraclast grainstone Submicrofacies (Sg2)
Pertidal	8	23	Non-fossiliferous Lime Mudstone Submicrofacies (Sm1)
		24	Intraclastic Lime Wackestone Submicrofacies (Sw1)
		20	Bindstone Lime microfacies (Sb)

Pertidal Environment

This environment is represented by the first parts of the tidal flat environment on the landward side (Wright, 1984), which is characterized by lack of fossils and being limited to some bioclast and non-skeletal grains represented by intraclast, in addition to stromatolite. The most lithofacies identified in the succession of the current study and characteristic of this environment is the laminated stromatolite lithofacies (Ssl), while the microfacies are represented by the lime mudstone submicrofacies (non-fossiliferous) (Sm1), intraclast lime wackestone submicrofacies (Sw1) and bindstone lime microfacies (Sb). All these facies indicate their deposition in the facies zone (FZ-8), which represents the tidal flat environment.

Lime mudstone submicrofacies (non-fossiliferous) was deposited in the upper intertidal areas, while the presence of stromatolite is an important indication of deposition in an intertidal environment (Illing et al., 1965; Kinsman and Park, 1976) as pointed out by Smith et al. (2018), who mentioned that stromatolite exists in an intertidal and supratidal environment. Moreover, Al-Badrani and Al-Humaidi (2019) identified a stromatolite facies within an intertidal environment in the Barsaren Formation in the Kurdistan region. And the presence of bivalve debris within the fossiliferous lime mudstone submicrofacies indicates their deposition within the intertidal environment (Lucia, 1972; Brasier, 1980), as well as the occurrence of intraclast within the intraclast lime wackestone submicrofacies (Sw1), which is one of the most important indicators of this environment (Turi et al., 2011; Solak et al., 2016; Gale, 2015). The succession of this environment is widespread in the upper parts of the formation (upper unit).

Lagoon Environment

It is a shallow lake confined between the land and any elevation or barrier within the sea. It often connects the open sea by tidal channels or grooves extending within the sea barrier (Longman, 1981). This environment is characterized by having high energy at the tidal channels connected to the sea near the barrier, and the water energy decreases towards the coast, where there is moderate energy in the center of the lagoon and calm in the shallow part near the land (Kjerfve, 1994; Colombo, 1977). The types of sediments in this environment also differ depending on the nature of the lagoon, as sediments characterize the confined lagoon with high salinity and a clay predominance, while the connected lagoon is characterized by sediments diversity and normal salinity, as well as diversity of life groups (Longman, 1981).

This environment matches the facies zone (FZ-7). The most prominent microfacies identified in the current study that are distinctive for this environment are: lime mudstone submicrofacies (fossiliferous) (Sm2), osracoda lime wackestone submicrofacies (Sw2), bioclast lime wackestone submicrofacies (Sw3), peloidal lime packestone microfacies (Sp1), sponges lime packestone submicrofacies (Sp2), gastropods lime packestone submicrofacies (Sp3), lime packestone microfacies bioclast (Sp4), and intraclast grainstone submicrofacies (Sg2). In addtion to gray and yellow shale lithofacies.

The presence of bioclasts from the shells of gastropods and bivalves within bioclast lime wackestone submicrofacies reflects brackish open lagon environment (Brandano et al., 2009; Erfani et al., 2016; Al-Taha and Al-Haj, 2024). It also includes common ostracods along with the presence of some fecal pellets among the basic grain's components of the lagoon environment (Pomar, 1991). The presence of coarse peloids resulting from the micritization of skeletal grains reflects a shallow lagoon depositional environment (Carbone and Sirna, 1981). In addition, the presence of intraclast within the intraclast grainstone submicrofacies indicates to a lagoon environment (Asaad et al., 2022), where this microfacies is found near the oolitic shoal (Flügel, 2004). The succession of this environment represents the majority of the sequences of the Sarki Formation as they are spread throughout the formation. Therefore, the lagoon environment is considered the most important sedimentary environment of the formation.

Oolitic Shoal Environment

This environment corresponds to the facies zone (FZ-6), which represents a high-energy shallow marine environment (shoal), which was distinguished based on the presence of a ooids lime grainstone submicrofacies (Sg1). This is an in-sea barrier separating the lagoon and the tidal flats towards the continent separated from the open sea, and this barrier may consist of a aggregation of non-skeletal grains represented by ooids, which are usually formed at the platform margin (Gischler et al., 2020).

This environment is characterized by the absence of micrite and is limited to sparite due to the continuous washing process because of the high energy of the water. The succession of this environment appears in the upper part of the middle unit of the formation through the appearance of a ooids lime grainstone submicrofacies, where ooids with a concentric nucleus were abundantly identified in a sparite matrix. The presence of ooids within the ooids lime grainstone submicrofacies is direct evidence of deposition in a shallow high-energy environment (oolitic shoal) (Wilson, 1975; Hussein et al., 2017). Delizy and Shingaly (2022) have distinguished this facies in the Sarki Formation in northern Iraq attributed to the oolitic shoal environment.

Depositional model of the Sarki Formation

The vertical succession of litho and microfacies shows an alternation in the secondary sedimentary environments of the formation. It begins with the muddy limestone facies representing the intertidal environment. Then it progresses in the central parts to the wacky and packy limestone microfacies containing bioclast debris and peloidal limestone microfacies representing the open lagoon environment. The ended middle unit ooids lime grainstone submicrofacies represents the environment of the oolitic sand shoal environment.

Then the intertidal environment facies return again in the upper parts of the formation represented by the wacky limestone microfacies containing interaclast, bioclast and the boundstone limestone microfacies with stromatolite. We infer from these facies that the lower part of the formation was deposited in the pertidal environment; then there was a deepening of the formation basin within the lagoon towards the sea, where the middle unit was deposited in the open lagoon environment reaching the shallow oolitic barrier environment at the end of the middle unit. Then it returns again to the facies of the pertidal environment in the upper unit.

Based on the data of the facies analysis and its environmental evidence of the succession of the Sarki Formation as well as the paleogeographic situation during the period of deposition of the formation, it is possible to take a look at the sedimentary model of the formation. This model explains the processes contributed to the deposition of the facies of the formation starting from the tectonic processes and topography of the region in ancient times all the way to the sedimentary basin, in which it was formed. It becomes clear that the formation was deposited in a shallow and restricted basin, where tectonic movements at the end of the boundary separate between the Paleozoic and Cenozoic eras. This had led to a major marine recession in the Middle East (Buday, 1980), after which the Arabian plate stabilized tectonically during the Early Jurassic period allowing a shallow shelf to be formed, in which a group of formations were deposited including the Sarki Formation (Jassim and Buday, 2006). According to Jassim et al. (2006) and Aqrawi et al. (2010), the western regions of Iraq were characterized during the Early Jurassic by clastic deposits in shallow environments. Meanwhile, the northern and northeastern parts of Iraq contained carbonate sediments deposited in shallow environments within the restricted basins, at which formation sequences were deposited. The latter region was exposed to fluctuations in sea level that helped to create sedimentary basins during the early Jurassic period. Based on all the aforementioned above, a sedimentary model of the Sarki Formation is drawn for the study area (Fig. 8).

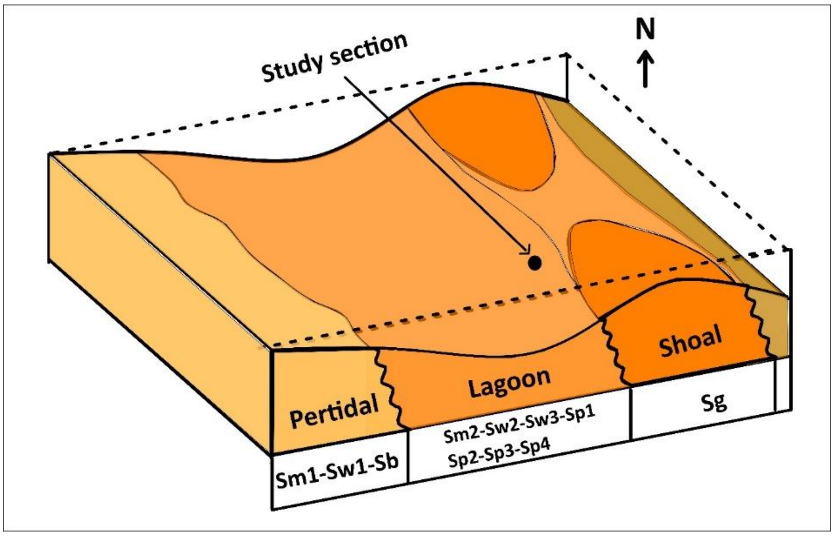

Fig. 8. Depositional model for the Sarki Formation of the study section.

Conclusions

The Sarki Formation appears in the study section with 210 m thickness. It has been divided into three lithostratigraphic units. The lower unit consists of alternating successions of dolomitic limestone and dolomite with thin beds of black to gray shale. The middle unit consists of thick beds of dolomite and hard, gray-colored limestone with thin-bedded gray and yellow shale. The upper unit is composed of massive dolomite containing stylolite and well bedded limestone layers containing laminated stromatolite. The lower contact of the formation is gradual surface conformable with Baluti Formation, while the upper contact with Sehkaniyan Formation is also conformable but sharp. Minerlogically, dolomite constitutes the most common mineral found within the formation succession, followed by calcite with a little quartz. The identified clay minerals were muscovite, illite, and montmorillonite. Petrographically, the formation’s rocks consist of skeletal grains represented by bivalves, gastropods, ostracoda, stromatolites, some sponge spicules, and calcispheres, in addition to non-skeletal grains represented by ooids, peloids, lithoclast of both types, intraclast and extraclast. A group of diagenetic processes affected the formation. The most important are the dolomitization, cementation, disolution, recrystallization, dedolomitization, dissolution, and chemical compression (stylolite), micritization, veins, and fractures in addition to the process of authigenic minerals represented by pyrite.

Four lithofacies are diagnosed according to the field characters: gray shale lithofacies, yellow shale lithofacies, brecciated dolomitic limestone lithofacies, and laminated stromatolite lithofacies. As for the microfacies, five microfacies are distinguished: lime mudstone microfacies, lime wackstone microfacies, lime packestone microfacies, lime grainstone microfacies, bindstone lime microfacies. These microfacies, in turn, are subdivided into eleven submicrofacies distinguished according to the petrographic compounds into:

Non-fossiliferous lime mudstone submicrofacies (Sm1), fossiliferous lime mudstone submicrofacies (Sm2), intraclastic lime wackestone submicrofacies (Sw1), osracoda lime wackestone submicrofacies (Sw2), bioclast lime wackestone submicrofacies (Sw3), peloidal lime packestone submicrofacies (Sp1), sponges lime packestone microfacies (Sp2), gastropods lime packestone submicrofacies (Sp3), bioclast (Sp4), oolit grainstone submicrofacies (Sg1) and intraclast grainstone submicrofacies (Sg2).

The identified facies of the Sarki Formation reflect the deposition of its succession in a shallow marine environment that extended within three secondary environments: pertidal environment, lagoon environment, and oolitic shoal environment. A sedimentary model for the formation is reached, based on the status of the sedimentary basin and the paleogeography of the Early Jurassic period. It turned out that the formation was deposited in a shallow and restricted basin, where tectonic movements at the end of the boundary between the Triassic and Jurassic led to a major marine recession in the Middle East region (Buday, 1980). Then the Arabian Plate stabilized tectonically during the Early Jurassic period, allowing the emergence of a shallow shelf, in which a group of formations were deposited, including the Sarki Formation. The northern and northeastern regions of Iraq were characterized by carbonate sediments deposited in shallow environments within restricted basins.

Acknowledgments

The authors thank the College of Science, University of Mosul for providing facilities to accomplish this work. We would like to thank Prof. Dr. Ali Al-Juboury for reading the manuscript and his fruitful comments.

References

Al-Badrani, M. and Al-Humaidi, R., 2019. Environmental Criteria of Stromatolitic Limestones in The Barsrain Formation from Surface Sections, Northeastren Iraq. Iraqi National Journal of Earth Science, 19(2), pp. 80-99.

Al-Taha, S.A.A. and Al-Haj, M.A., 2024. Depositional Setting of the Euphrates Formation (Early Miocene) in Selected Wells, Hamrin Oil Field, Northern Iraq. Iraqi National Journal of Earth Science, 24(1), pp. 136-155. DOI: 10.33899/earth.2023.141083.1095

Anyiam, O.A., Onuorah, L.C. and Okwara, I.C., 2017. Depositional Framework and Stratigraphy of the Konshisha Area, Southern Benue Trough. Global Journal of Geological Sciences, 15, pp. 41-55. DOI: http://dx.doi.org/10.4314/gjgs.v15i1.4

Aqrawi, A.A., Goff, J.C., Horbury, A.D. and Sadooni, F.N., 2010. The Petroleum Geology of Iraq. 442 P.

Asaad, I.S., Al-Haj, M.A. and Malak, Z.A., 2022. Depositional Setting of Khurmala Formation (Paleocene-Early Eocene) in Nerwa section, Berat Anticline, Kurdistan Region, Northern Iraq. The Iraqi Geological Journal, pp. 20-39. DOI: 10.46717/igj.55.1F.2Ms-2022-06-17

Bellen, V.R.C., Dunnington, H.V., Wetzel, R. and Morton, D.M., 1959. Lexique Stratigraphique International. V. III, Asie, Fascicule, 10a, Iraq, Centeral National deal

Brandano, M., Frezza, V., Tomassetti, L., Pedley, M. and Matteucci, R., 2009. Facies Analysis and Palaeoenvironmental Interpretation of the Late Oligocene Attard Member (Lower Coralline Limestone Formation), Malta. Sedimentology, 56(4), pp. 1138-1158.

Brasier, M.D., 1980. Microfossils, George Allen and Unwin Pop. Comp. 193 P.

Buday, T., 1980. The Regional Geology of Iraq, Stratigraphy and Paleogeography. Dar Al-Kutub publishing house, Mosul University. Mosul, Iraq, 445 P.

Carbone, F. and Sirna, G., 1981. Upper Cretaceous Reef Models from Rocca Dicave and Adjacent Areas in Latium, Central Italy: In Toomey, D.f.(ed) European Fossils Reef Models. SEPM, special publication. No.30, Tuisu, pp. 427-445.

Colombo, G., 1977. Lagoons. In: The Coastline, ed., Barnes, R.S.K. New York: John Wileyand Sons, pp. 63-81.

Delizy, B.A. and Shingaly, W.S., 2022. Microfacies Analysis and Depositional Environment of Sarki Formation (Early Jurassic), Rawanduz Area, Kurdistan Region, Northern Iraq. Tikrit Journal of Pure Science, 27(1), pp. 24-35. DOI: http://dx.doi.org/10.25130/tjps.27.2022.004

Dunham, R.J., 1962. Classification of Carbonate Rocks According to Depositional Texture, In: Ham, W.E., (eds.): Classification of Carbonate Rocks, A.A.P.G. Mem. -1, Tulsa, Okla., pp. 108-121.

Embry, A.F. and Klovan, E.I., 1971. A Late Devonian Reef Tract on Northeastern Banks Island. N.W.T.-Bull. Publisher, Memoir 1. Tulasa Oklahoma, pp.108-121.

Erfani, S., Adabi, M.H., Majidifard, M.R. and Ghadimvand, N.K., 2016. Facies Interpretation, Depositional Environment and Sequence Stratigraphy of the Gachal Formation in the Madbeiki Section, Kalmard Block, East Central Iran. Open Journal of Geology, 6(06), 439.

Flügel, E., 1982. Microfacies of Limestone, Christenson, K. Springer- Verlag, Berlin: 633 P.

Flügel, E., 2004. Microfacies of Carbonate Rock, Analysis, Interpretation and Application. Springer-Verlag, Berlin, 976 P.

Flügel, E., 2010. Microfacies of Carbonate Rocks, Springer, Verlag, Berlin, Heidelberg, 976 P.

Friedman, G.M., 1959. Identification of Carbonate Minerals by Staining Methods, Journal of Sedimentary and Petrography, 29 (2): pp. 87-97

Gale, L., 2015. Microfacies Characteristics of the Lower Jurassic Lithotid Limestone from Northern Adriatic Carbonate Platform (Central Slovenia). Geologia, Vol. 58, No. 2, pp. 121-138.

Gischler, E., Birgel, D., Brunner, B. and Peckmann, J., 2020. Microbialite Occurrence and Patterns in Holocene Reefs of Bora Bora, Society Islands. Palaios, 35(6), pp. 262-276.

Hussein, D., Collier, R., Lawrence, J.A., Rashid, F., Glover, P.W.J., Lorinczi, P. and Baban, D.H., 2017. Stratigraphic Correlation and Paleoenvironmental Analysis of the Hydrocarbon-Bearing Early Miocene Euphrates and Jeribe Formations in the Zagros Folded-Thrust Belt. Arabian Journal of Geosciences, 10, pp. 1-15.

Illing, L.V., Wells, A.S. and Taylor, J.C.M., 1965. Penecontemporary Dolomite in the Persian (Arabian) Gulf. In: Pray, L.C. and Murray, R.C. (eds.). Dolomitization and Limestone Diagenesis: A Symposium- SEPM Special Pub. No.13, pp. 89-111.

Jassim, S.Z. and Buday, T., 2006. Unite of the Unstable Shelf and the Zagros Suture, In: Jassim, S.Z. and Goff, J.C. Geology of Iraq, Published by Dolin Prague and Moravian Museum, Brno, pp. 71-83.

Jassim, S.Z., Buday, T., Cicha, I. and Prouza, V., 2006. Late Permian-Liassic Megasequence AP6. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, Czech Republic, pp. 104-116.

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, Czech Republic, 341 P.

Kinsman, D.J.J. and Park, R.K., 1976. Algal Belt and Coastal Sabkha Evolution, Trucial Coast, Persian (Arabian) Gulf. In: Walter, M.R. (Ed.). Stromatolites. Developments in Sedimentology Vol. 20, Elsevier, Amsterdam, pp. 421-433.

Kjerfve, B., 1994. Coastal Lagoons. In Elsevier Oceanography Series, Vol. 60, pp. 1-8.

Logan, B.W., Rezak, R. and Ginsburg, R.N., 1964. Classification and Environmental Significance of Algal Stromatolite. Jour. Geol. Vol. 72, pp. 68-83.

Longman, M.W., 1981. A Process Approach to Recognizing Facies of Reef Complexes: In Toomey, D.F., (Eds.) European Fossils Reef Models. SEPM, special publication, No. 30, pp. 9-40.

Lucia, F.J., 1972. Recognition of evaporate-carbonate Shorline sedimentation; in: Rigby, J.K. and Hamblin, W.K., (eds): recognition of ancient sedimentary environment, Special Publication, No. 16, Soci. Econ. Paleon. Minera, pp.160-191.

Łukowiak, M., Pisera, A. and O'dea, A.A.R.O.N., 2013. Do Spicules in Sediments Reflect the Living Sponge Community: A Test in a Caribbean Shallow-Water Lagoon. Palaios, 28(6), pp. 373-385.

Majidifard, M.R., 2003. Biostratigraphy, Lithostratigraphy, Ammonite Taxonomy and Microfacies Analysis of the Middle and Upper Jurassic of Northeastern Iran, Unpublished Ph.D. thesis, Wurzbürg Univ., 201 P.

Pomar, L., 1991. Reef Geometries, Erosion Surfaces and High-Frequency Sea-Level Changes, Upper Miocene Reef Complex. Maloraca, Spain. Sedimentology, Vol. 38, pp. 243-269.

Smith, A., Cooper A., Misra, S., Bharuth, V., Guastell, L. and Botes, R., 2018. The Extant Shore Platform Stromatolites (SPS) Facies Association: A Glimpse into the Archean. Biogeosciences, Vol. 15, pp. 2189-2203.

Solak, C., Tash, K. and Koc, H., 2016. Early Createaceous Shallow-Water Platform Carbonates of the Bolker Mountains, Central Taurides-South Turkey: Facies Analysis and Depositional Environments. Earth and Environmental Science, Vol. 44, pp. 1-5.

Turi, V., Sasaran, E. and Bucur, I., 2011. New Data on the Upper Jurassic – Lower Cretaceous Limestone from Bihor Mountains: Case study of Garda Seaca- Hodobana Region, Romania. Studia UBB Geologia, Vol. 56, No. 1, pp. 11-27.

Wilson, J.L., 1975. Carbonate Facies in Geologic History. Springer-Verlag, Berlin. 471 P.

Wright, V.P., 1984. Peritidal Carbonate Facies Models: A Review. – Geological Journal, 19, pp. 309-325