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Sedimentological analysis of the Dokan Formation (Cenomanian) in Goizha Section, Azmar Anticline, Northeastern Iraq

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ABSTRACT

The Dokan Formation (Cenomanian) has been studied within the Azmar anticline in Sulaymaniyah Governorate (about 4 km northeast of the city center). The field description shows that the Dokan Formation is composed mainly of light-gray limestone rocks and lead-gray marly limestone with thin beds of dark-gray shale. The thickness of the Formation in the studied section is 18 m; The lower and upper contacts of the Dokan Formation are conformable with the Balambo Formation and the Gulneri Formation, respectively. The petrographic study of (55) thin sections reveal the following components: planktonic and benthonic foraminifera, calcospheres, some echinoderm bioclasts, and lesser proportions of ostracods. Many diagenetic processes (dissolution, cementation, chemical and physical compaction, etc.) affected the rocks of the Formation. Two main microfacies are distinguished: the first one is lime mudstone microfacies, and the second is lime wackestone microfacies; these, in turn, are divided into six sub-microfacies. Comparing all microfacies with the standard microfacies indicates that the Dokan Formation was deposited in the zone that extended from the outer shelf to the upper slope environments.

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التحليل الرسوبي لتكوين دوكان (السنوماني) في مقطع كويزة، طية ازمر، شمال شرقي العراق

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الملخص

تمت دراسة تكوين دوكان (السنومينيان) ضمن طية ازمر، شمال شرقي العراق في محافظة السليمانية، وتحديدا ضمن طية ازمر والتي تبعد حوالي 4 كم عن شمال شرقي مركز المدينة. لوحظ من خلال الوصف الصخري حقلياً، أن تكوين دوكان يتألف من تتابعات من الصخور الجيرية ذات اللون الرصاصي الفاتح وبنسبة اقل صخور المارل الرصاصية اللون وصخور الطفل المترقق داكنة اللون. يبلغ سمك التكوين في المقطع المختار 18 متراً. ويكون حدا التماس السفلي والعلوي متوافقين مع كل من تكويني بالامبو وكولنزي على التوالي. ومن خلال الدراسة البتروغرافية وبالاعتماد على الشرائح الصخرية تم تمييز الفورامنيفرا الطافية والقاعية والكالسوسفيرات بشكل رئيس وبعض الفتاتات الحياتية وشوكيات الجلد والاوستراكود بنسب اقل، متأثرة بالعديد من العمليات التحويرية (الاذابة السمنتة الانضغاط الكيمائي والفيزيائي وغيرها). سحنيا، تم تمييز سحنتين رئيستين هما سحنة الحجر الجيري الطيني وسحنة الحجر الجيري الواكي الرئيسة والتي بدورها قُسمت الى ست سحنات ثانوية دقيقة. بعد مقارنتها بالسحنات القياسية الدقيقة، وجد ان تكوين دوكان قد ترسب ضمن بيئة الرصيف المفتوح القريب من المنحدر.

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Introduction

Dokan Formation Late Cretaceous (Cenomanian) was first described by Lancaaster Jones (1957; in Bellen *et al*., 1959), typically at the Dokan area in Sulaymaniyah City within the high folded zone, northeastern Iraq. It consists of light-gray to white oligosteginal limestone. In Subsurface, the Dokan Formation includes dark grey and often argillaceous limestone. The thickness of the formation reaches about 150 m to the southwest in the Chamchamal wells, and reaches 5-30 m in Kirkuk, Bai Hassan, Demir Dagh, and Qara Ash-Shuq areas. The current study is conducted on the Dokan Formation due to the lack of sedimentary studies on the formation, so it includes a detailed study of the petrography and facies reaching the sedimentary environment. The lower and upper contacts of the formation are unconformable in the type section area. The upper contact is with the Gulneri Formation and in some areas with Kometan Formation, while the lower contact is with Qamchuqa Formation or Jawan Formation. The Dokan Formation is one of the important formations in the Late Tithonian-Early Turonian cycle, which is a part of the mega sequence (AP8) (Sharland *et al*., 2001). This cycle includes these formations (Dokan, Gulneri, Jawan, Qamchuqa, Garagu, Balambo, Sarmord, Chia Gara). Previous studies have shown that the environment of the Dokan Formation was within an open marine environment (Ditmar and the Iraqi-Soviet Team, 1971; in Jassim and Goff, 2006). It was later studied by Al-Juboury *et al*. (2002), who deduced the open shelf environment near the lower slope and the slope front environment in wells within Kirkuk Governorate. However, in this study, the aim is to clarify the depositional environment in the studied section; so, it is necessary to address the sedimentary and biological evidence and their link together to reach the identification and well-accepted conclusion of the depositional environment.

According to Abawi and Hammoudi (2010), the age of the Dokan Formation is Cenomanian, and the age of the formation at the Jebel Azmar area is Middle-Late Cenomanian assigned by *Rotalipora cushmani* Zone Abawi and Hammoudi (2010). This refers to a major hiatus between the Dokan Formation and the older Balambo Formation (Middle-Late Albian) in this area.

All sedimentological and stratigraphical studies of the Dokan Formation indicate that it has been deposited in the deep marine environment (e.g., Al-Juboury *et al*., 2002). Karim *et al*. (2013) studied the stratigraphic analysis of the Goizha anticline by nannofossils.

Al-Sheikhly *et al*. (2015) mentioned that the Dokan Formation had been deposited in an open-marine deep shelf environment; it could have been deposited at a deeper shelf to slope and basinal.

This study aims to identify the main petrographic components and diagenesis affecting the Dokan Formation, then determine the microfacies to reconstruct the depositional environment of the formation in the studied area.

Geological Setting

The study area is located in the northeastern part of Iraq within Sulaymaniyah Governorate at the Azmar anticline at latitude 35° 40' 00" N and longitude 45° 25' 00" E. The Azmar anticline denotes the area of the Imbricated Zone within the Foreland belt of the Zagros collision zone (Numan, 1997; Jassim and Goff, 2006) (Fig. 1A). The main Azmar anticline includes a group of secondary folds, namely Bekhola, Harut, Azmar, and Goizha, which were affected by several faults. The length of the Azmar anticline is 91 km, and its width is 1-4.5 km (Karim *et al*., 2013). The Azmar and Goizha are two connected mountains that are located to the north and northeast of Sulaimaniyah City, respectively (Karim *et al*., 2013).

Tectonically, according to Fouad (2015), the selected section is located within the Arabian shelf at the Azmar anticline of the Zagros Orogenic Belt, located within the Imbricated Zone. The selected section is situated at the Arabian Shelf within the Azmar anticline of the Zagros Orogenic Belt, which lies in the Imbricated Zone (Fig. 1B) that arose between the northeast of the edge of the Arabian plate and the Eurasian plate in the form of a Druze belt. While the Arabian and Anatolian plates are connected by the Bitlis range section. The geographical location map is exhibited in Fig. 1C. Aljumaily and Adeeb (2011) also confirmed in their correlation diagram of the Azmar-Goizha anticlines the occurrence of the Dokan Formation in the Goizha anticline. Al-Hakari (2011) also studied the geological setting through his correlation diagram, declaring the connection between the Azmar-Goizha anticlines and the Dokan Formation in the Goizha anticline. Within the Azmar anticline, many exposed formations from oldest to youngest are: Balambo (Valanginian-Albian), Dokan (Cenomanian), Gulneri (Turonian), Kometan (Campinian), Shiranish (Campinian-Maastrichtian), and Tanjero (Maastrichtian).

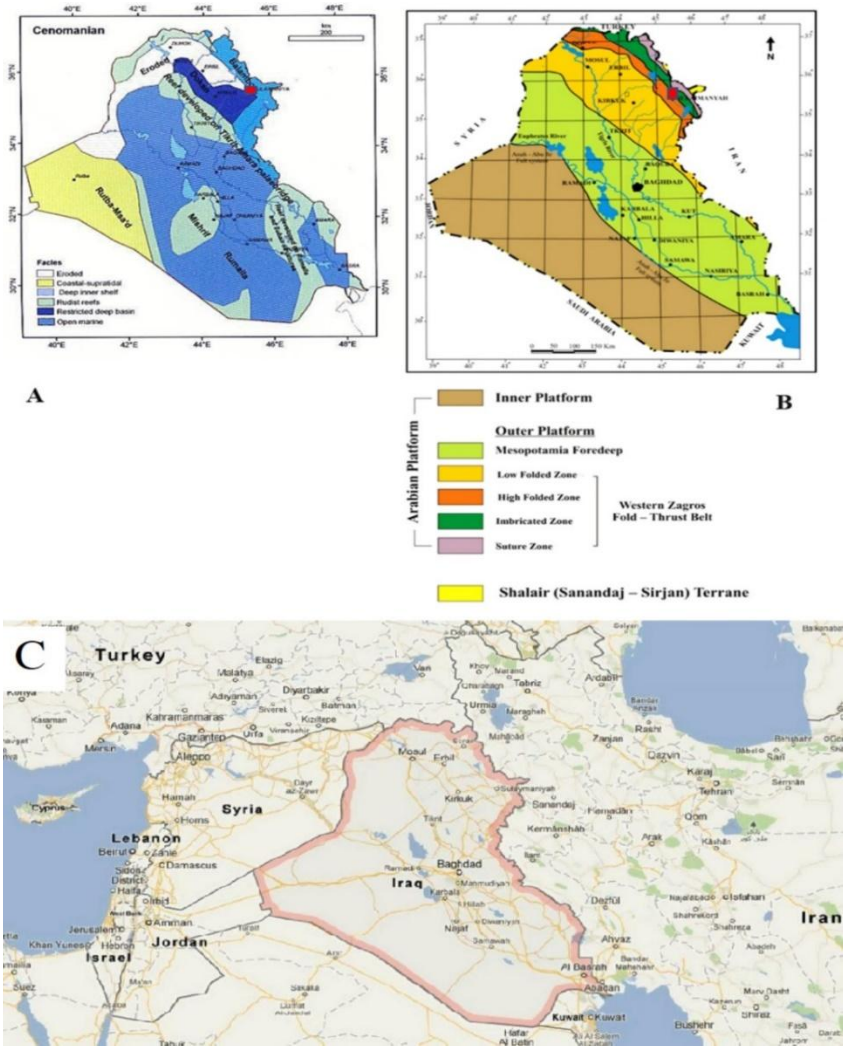

Fig. 1. A. Paleogeography of the Dokan Formation deposits (Jassim and Buday, 2006); B. Modern tectonic division of Iraq from Fouad (2015) showing the current study section; C. Geographical location map.

Materials and Methods

The study methods include the field and laboratory works; in the field work, the description of the exposed rocks of the Dokan Formation is achieved in some selected outcrops in order to obtain a detailed lithological description. The sampling process is based on the facies change and color contrast.

In the laboratory, rock slices (thin sections) of 25 rock samples are prepared and studied under a polarizing microscope (Swift type) in order to determine the petrographic components, diagenesis, and microfacies.

Results

Lithostratigraphy

The lower and upper contacts of the Dokan Formation are conformable with Balambo and the Gulneri, respectively (Fig. 2). The thickness of the Dokan Formation is about 18 meters. The first exposed part of the formation begins with flat-bedded light lead-colored to white limestone rocks with a thickness of 4m (Fig. 3). They are followed by thin successions of yellowish-white flat-bedded marly limestone beds with a thickness of 2m; the succession ended by a bed of gray-colored thin shale with a thickness of 1m. Then, another succession of light grey limestone flat beds with 4m thick starts, followed by a bed of 1m thick grey shale, continued by a succession of grey-white limestone beds with 4m thick, then a bed of grey marly limestone with 60 cm thick occurs, and finally returns to limestone at the contact with Gulneri Formation.

Fig. 2. A. Lower contact of the Dokan Formation with the Balambo Formation; B. Upper contact with the Gulneri Formation.

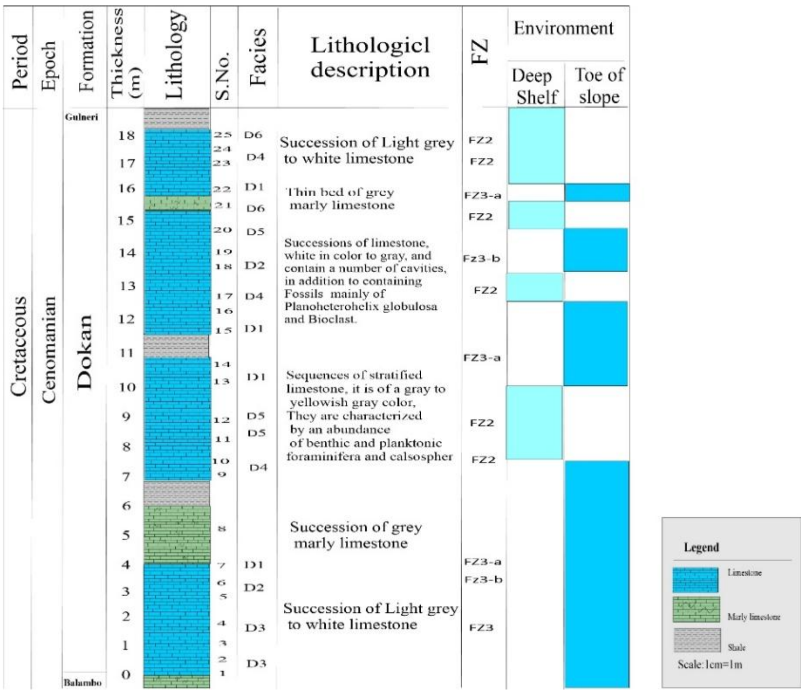

Fig. 3. Lithological column showing the rock sequence of Dokan Formation.

Petrography

The petrographic examination of the Dokan Formation reveals a diversity in grain size; each type of grain reflects specific environmental and sedimentary conditions, and can reveal features of the diagenetic processes that affected it. According to Tucker (1981, 2003), skeletal grains encompass all types of fossils, which are either complete in form (biomorpha) or in the form of bioclasts of varying shapes and sizes. The Dokan Formation is known to be rich in fossil content. The presence of well-preserved fossils allows researchers to identify various species and to determine the environmental conditions. This formation can provide insights into the evolutionary history of the region, as well as the paleoecological dynamics during the period it represents. This formation also offers valuable insights into the region's evolutionary history and the paleoecological dynamics of its period. The main skeletal grains are Foraminifera, including both planktonic and benthonic. The planktonic includes: Globigerinelloides bentonensis (Plate 1-A), Globigerinelloides ultramicus (Plate 1-B,2-F), Rotalipora cushmani (Plate 1-C), Planoheterohelix globulosa (Plate 1-D), Rotalipora ticinensis (Plate 1-E), Whiteinella archeoeretacea, Rotalipora sp. (Plate 1-F), Favusella washitensis.

Benthic foraminifera are identified in the study area sequences in very small amounts; this presence is important in the microfacies analysis to infer the sedimentary environment, whether the marine environments are shallow or deep (Flügel, 2004). According to Milliman (1974), the small percentage of benthic foraminifera in the sediments generally indicates deep marine environments (Wilson and Evans, 2002), and they include both Textularia sp. (Plate 2-A) and Nodosaria sp. (Plate 2-B). The association of benthic foraminifera with the planktonic ones indicates an open shelf environment (Bishop, 1972). The other fossil grains are Calcispheres that indicate limestone deposition in the deep-sea environment (Flügel, 2010). The calcispheres are identified generally by small size, spherical to oval in shape, and their diameter ranges between 30-33 microns. They are well preserved and filled with spary calcite, and their percentage is around 70% in the study sediments (Plate 2-C). Bivalve or oval-shaped shells belonging to freshwater, mixed, and marine environments (Abawi et al., 2000) generally characterize ostracods. Ostracods occur in very small proportions and are often affected by modification processes (Plate 2-A). Echinoderms are also identified in the current study in very small amounts (Plate 2-D). In general, it is believed that most of the bioclasts identified in the current study are due to the debris of the shells of foraminifera, in addition to Calcispheres, Echinoderms, and Ostracods (Plate 2-E). They are peloid grains may be present but not identified. They may be within a bioclast.

The examined rocks are predominantly characterized by the presence of micrite groundmass as a matrix between and within the grains and microfractures of the rocks. Micrite is mechanically deposited in the marine environments that are characterized by low energy, where currents and strong waves have minimal impact (Friedman, 1985). Where micrite is found as a pale, opaque, black, or dark color groundmass, depending on the percentage of organic matter or even the type of clay materials (Plate 2-A).

The **most important diagenetic processes** diagnosed in the current study are:

Compaction: The mechanical and chemical compaction affects the formation deposits. The intensity of mechanical compaction varies in contact, as in (Plate 4-A, C), such as the breakage of shells, the presence of their debris, or the elongation of limestone balls (Plates 1-E, 4-D). Some shells exposed to compaction (Plate 1-D) show fullness microfractures or are filled with organic materials. Chemical compaction is indicated by the dissolution lines in the form of the porosity of the matrix (Plate 3-A). fractures (Plate 3-C) due to the presence of affecting digenesis.

Recrystallization: It is a process noticed by the microspar spots in the micrite floor (Plate 2-E), and in some fossil shells were affected by the recrystallization process (Plate 1-B).

Cementation: Carbonate minerals appear within the rocks of the formation either within fossils or filling voids, cracks, fractures, and veins. The main texture types of cementations are granular cement (Plate 3-C), which is one of the types of late-forming cement (Flügel, 1982; Bathurst, 1975). Blocky cement, which consists of large and fully faceted crystals that have no direction in growth, may be formed after the dissolution of granules or carbonate cement or by late diagenesis (Boggs, 2006). Blocky cement is abundant in the deposits of the formation (Plate 3-B), formed by late diagenesis and filling either fossils or vugs and cracks (Plates 1-D,3-D).

Dissolution: is a process that affects the Dokan Formation deposits through partial dissolution of the non-skeletal components and skeletal shells. It results in the formation of many types of pores, including intragranular porosity. These pores are formed inside some skeletal grains as a result of dissolving the soft parts of fossils (Plates 3-A, 4-A). Also, vuggy porosity appears as gaps of different shapes and sizes associated with mold porosity and often cuts the groundmass and grains (Plate 3-A).

Micritization: This process may include the entire grain (Boggs, 2006), where the micrite is not limited to the outer bed of the grain, but rather extends to its internal parts, leading to the obliteration of the internal features of the grain (Plate 4-B).

Authigenesis: It is recorded through pyrite mineral as one of the authigenic minerals scattered in the deposits of the Dokan Formation, and it is characterized by its isotropic appearance and dark brown color (Plates 1-E,3-E). Neither replacement nor alteration is observed.

Facies analysis

Detailed field description and petrographic analysis of the carbonate rocks of the Dokan Formation reveal that these rocks could be organized into two major microfacies and six submicrofacies.

A- Lime Mudstone Microfacies

The mudstone microfacies is one of the common facies that have been diagnosed within the deposits of the Dokan Formation. This facies occurs within the lower beds of the studied section and consists mainly of the micritic matrix and a small number of grains that do not exceed 10% of the components of the facies, including planktonic foraminifera and calcispheres, which can be subdivided into three submicrofacies depending on the petrographic components:

1. **Planktonic Foraminiferal Lime Mudstone Submicrofacies (D1)**

   This microfacies is predominantly made up of micrite and Planktonic Foraminifera (Plate 4-A) represented by: *Globigrinelloides bentonensis* and *Globigerinelloides*; it is affected by diagenetic processes like dissolution and cementation, distributed in all parts along the formation, but increased towards the top. This microfacies is equivalent to the standard Microfacies (SMF3) according to Flügel (2004), which is deposited within the facies zone (FZ3-a), the outermost slope known as the deep-water zone (Open Sea Shelf environment) near the slope.

2. **Calcispheres Lime Mudstone Submicrofacies (D2)**

   Micritic matrix is the most abundant in this microfacies, followed by Calcisphere grains (less than 10%) and some Planktonic Foraminifera (4-B). The main diagenetic processes of this microfacies are cementation and micritization with the presence of pyrite authigenesis. This microfacies occurs at the middle and upper deposits of the formation; it is equivalent to the standard Microfacies (SMF3) according to Flügel (2004) and is deposited within the facies zone (Fz3-b), which is known as the proximal deep-water zone (Open Sea Shelf environment) near the slope.

3. **Bioclastic Lime Mudstone Submicrofacies (D3)**

   The grain components in this microfacies consist of foraminifera shell fragments and Calcispheres, representing about 10% of the microfacies (Plate 1-B), with the presence of pyrites; it is affected by the recrystallization process within the groundmass and shells.

This microfacies is locally present at the lower part of the formation, which is equivalent to the standard Microfacies (SMF3) according to Flügel (2004) and is deposited within the facies zone (FZ3) known as the deep zone near the slope.

B- Lime Wackestone Microfacies

Generally, these facies are composed of skeletal grains that exceed (10%) and do not exceed (50%) of the facies components and micritic matrix. Planktonic foraminifera and calcispheres and their debris (10%) represent the grains. These facies can be divided depending on the petrographic components into:

1. ***Planoheterohelix globulosa* Lime Wackestone Submicrofacies (D4)**

Planktonic organisms, particularly Planoheterohelix globulosa, are the most abundant, followed secondarily by the ultramicud Globigerinelloides. These organisms are present in the limestone beds, specifically within the middle and upper parts of the formation. The identified diagenetic processes here are compaction and cementation (Plate 4-C). This facies is equivalent to the standard microfacies (SMF8) according to Flügel (2004), which is deposited within the facies zone (FZ2) known as the open sea shelf environment near the lower slope.

2. ***Globigerinelloids* Lime Wackestone Submicrofacies(D5)**

Globigerinelloids are the major common constituent of the grains in this microfacies (Plate 4-D). The Ground is composed mainly of micrite. This microfacies has been affected by the diagenetic processes: cementation, dissolution, and compaction. The microfacies is represented within the limestone deposits in the middle of the formation. It corresponds to the standard microfacies (SMF8) (Flügel, 2004), deposited within the facies zone (FZ2) known as the open sea shelf environment near the lower slope.

3. **Bioclastic Lime Wackestone Submicrofacies (D6)**

This microfacies contains bioclasts of foraminifera and echinoderms; the bioclasts constitute 35% of the facies, affected by micrization and compaction (Plate 2-B), and are found at the end of the upper beds of the formation. This microfacies is equivalent to the standard microfacies (SMF2) according to Flügel (2004) and is deposited within the facies zone (FZ2) known as the outer shelf environment near the lower slope.

Discussion

Depositional Environment

The following is a list of the most important sedimentary and biological evidence that are relied upon in formulating the depositional environment:

Facies Sedimentological evidence

All the identified microfacies are composed primarily of micrite with only a small percentage of sparite, suggesting deposition in calm and low-energy environments situated below the wave base level. The alternation of limestone beds with shale and marly limestone, further with flat-bedding, indicates a deep and tranquil sedimentary setting. Additionally, the presence of authigenic minerals such as pyrite points to a deep-water environment with low oxygen levels (Nichols, 1999).

Facies Biological evidence

Three biological evidences refer to the deep marine environment; the first is the abundance of planktonic fossils and the lack of benthic fossils within the rocks (Murray, 2006); the second is the association of planktonic fossils and calcispheres; and the third is the lack of bioclasts identified within the studied rocks. Nevertheless, the association of both Textularia sp. and Nodosaria sp. indicates an open shelf environment (Murray, 2006).

Depending on the biological, sedimentological evidence, and microfacies analysis data compared with the standard microfacies listed in Wilson (1975) and Flügel (1982, 2004), the microfacies of the Dokan Formation in the studied section include (SMF2, SMF3, and SMF8). They are deposited within the two facies zones (FZ2, FZ3) interpreted to be located within the toe of slope and the deep shelf margin (Table 1). In the outer shelf (100-200 m deep), the living organisms are planktonic foraminifera and a few benthic foraminifera, whereas in the toe of slope environment, there is an increase in planktonic foraminifera and calcispheres.

Table 1: Microfacies and facies zone of the Dokan Formation in the studied section.

Microfacies of the Dokan Formation	SMF of Flügel (2010) and FZ of Wilson (1975)		
	SMF	FZ (Wilson, 1975)	Location of SMF (Flügel, 2010)
Planktonic Foraminiferal Lime Mudstone Submicrofacies (D1)	(SMF3)	(FZ-3)	Toe of slope
Calcispheres Lime Mudstone Submicrofacies	(SMF3)	(FZ-3)	Toe of slope
Bioclastic Lime Mudstone Submicrofacies (D3)	(SMF3)	(FZ-3)	Toe of slope
Planoheterohelix globulosa Lime Wackestone Submicrofacies(D4)	(SMF8)	(FZ-2)	Deep Shelf
Globigerinelloids Lime Wackestone Submicrofacies(D5)	(SMF8)	(FZ-2)	Deep Shelf
Bioclastic Lime Wackestone Submicrofacies (D6)	(SMF2)	(FZ-1)- (FZ-2)	Deep shelf

The lime mudstone and lime wackestone contain planktonic foraminifera, calcispheres, and bioclasts, with a lack of sedimentary structures. These characteristics are related to the deep marine environment, ranging from the slope environment to the open sea environment (Brandly and Krause, 1998). The presence of the genus *Globigerinelloides* indicates the open marine environment and may reach the outer shelf environment (Abdel-Kireem, 1983). The disappearance of Rotalipora cushmani is linked to a significant turnover in marine organisms, affecting both planktonic and benthic foraminifera, as well as calcareous nannofossils (Abdel-Kireem, 1983). This event occurred shortly before the onset of Oceanic Anoxic Event 2 (OAE 2), which represents the sedimentary signature of the global late Cenomanian anoxic event (Coccioni et al., 2016). The presence of *Planoheterohelix globulosa* indicates its deposition in the open marine environment under the influence of waves (Rahimpour-Bonab *et al*., 2012; Omidvar *et al*., 2014; Gowhari *et al*., 2020), and may have been broken up in lower environmental sites represented by the open sea shelf.

Depending on the aforementioned, the current study suggests that Dokan Formation rocks were deposited in the open sea deep shelf environment extending to the toe of slope environment. These environmental conditions are calm, below the level of the base of the wave. Regarding the climate, northeastern Iraq during the Cenomanian period was located within a tropical climate zone (Beydoun, 1991). The suggested model for the Dokan Formation is illustrated in Fig. 4.

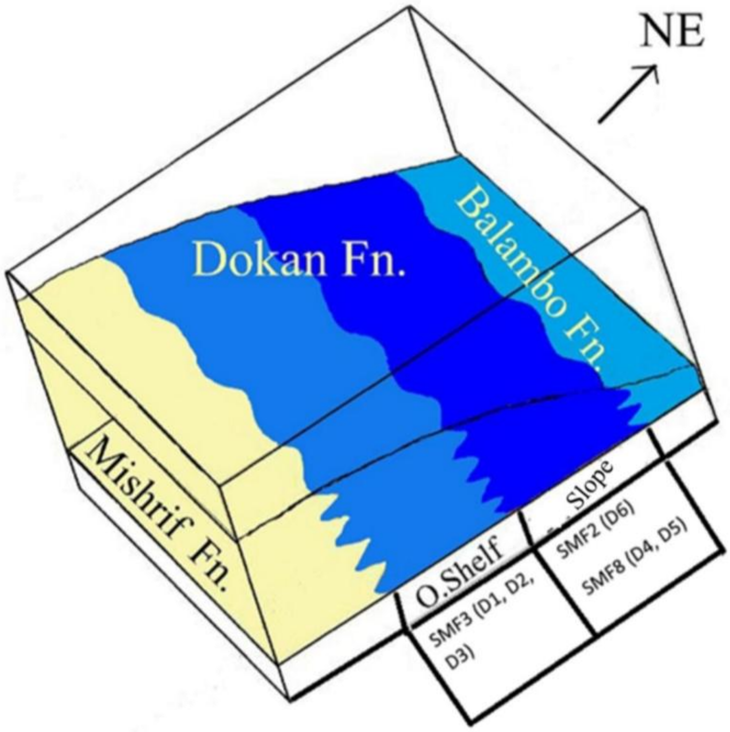

Fig. 4. Sedimentary model of the Dokan Formation in the study area under a tropical climate.

Conclusions

The thickness of the Dokan Formation exposed in the studied section is about 18m. It consists mainly of limestone sequences alternating with marly limestone beds and thin shale beds. The lower and upper contacts of the Dokan Formation are conformable with the Balambo Formation and the Gulneri Formation, respectively. Petrographically, foraminifera, calcisphere, and some bioclastics are distinguished as grains merged in micritic matrix, affected by many diagenetic processes (dissolution, cementation, chemical and physical compression, etc.).

Two mains distinguished microfacies (lime mudstone microfacies and lime wackestone microfacies) are divided into six secondary submicrofacies after comparing them with the standard facies.

The current study indicates that the deep shelf environment is represented by the open shelf environment near the lower slope, which is calm, below the level of the base of waves, and the environment of the slope. This is confirmed by the presence of calcispheres and Foraminifera. Through environmental analysis of the formation deposits, a microfacies and petrographic compatibility is found, represented in the slope environment towards the open sea. Based on these details, a sedimentary model is constructed that explains the formation deposit.

The Dokan Formation had been deposited in an isolated basin between the Balambo basin to the northeast and the Mishrif basin to the southwest. A fluctuation in the sea level variation is observed depending on the environmental variation between the Toe of the slope and the Deep Shelf environment.

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Plate 1

A: *Globigerinelloides bentonensis* found in the central parts section.

B: *Globigerinelloides ultramicus* for planktonic foraminifera, Bioclastic Lime Mudstone Submicrofacies in the upper parts section affected by the recrystallization process indicated by the arrow.

C: *Rotalipora cushmani* in the central parts with scattered pyrite.

D: *Planoheterohelix globulosa* in the upper parts section, presence of granular cement inside the fossils, compaction.

E: *Rotalipora ticinensis* in the central parts section, presence of pyrite and compaction.

F: Rotalipora sp. in the central parts section.

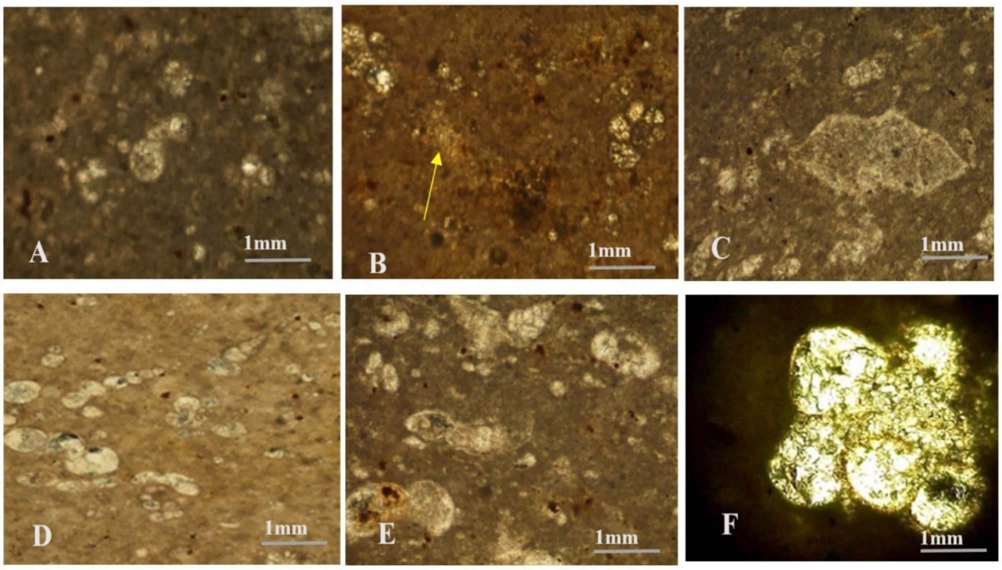

Plate 2

A: Textularia sp. of benthic foraminifera with calcospheres and ostracoda within a micrite in the middle parts section.

B: Nodosaria sp. of benthic foraminifera, Bioclastic Lime Wackestone Submicrofacies in the upper parts section.

C: Calcospherite in upper parts section.

D: Echinoderms in upper parts section.

E: Bioclast with recrystallization in the upper parts section.

F: *Globigerinelloides* ultramicus with micrit (m) and sparite (s) in the upper parts section.

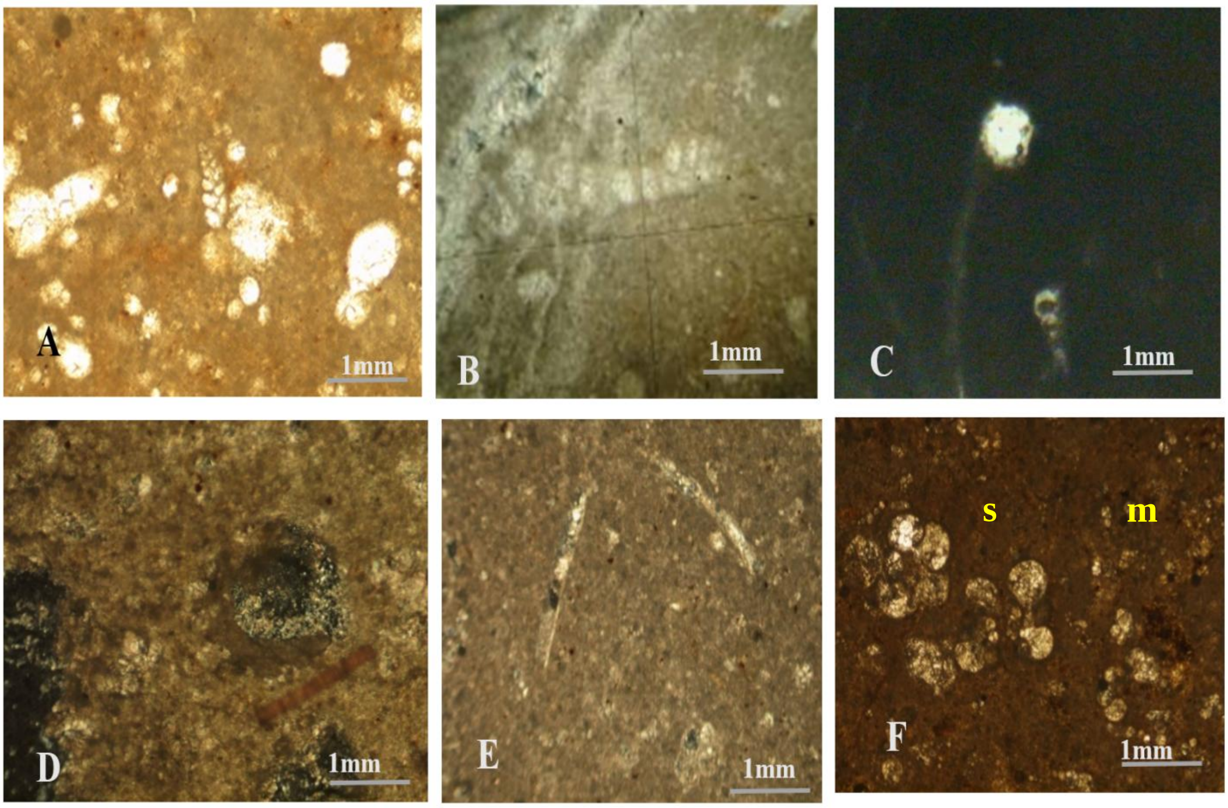

Plate 3

A: Mold porosity, dissolution.

B: Cement in the form of blocky cement is one of the most common types of cement under study.

C: Fractures: due to the presence of chemical solutions, cement.

D: A vein of calcite-filling voids.

E: Presence of localized minerals as well represented by scattered pyrites.

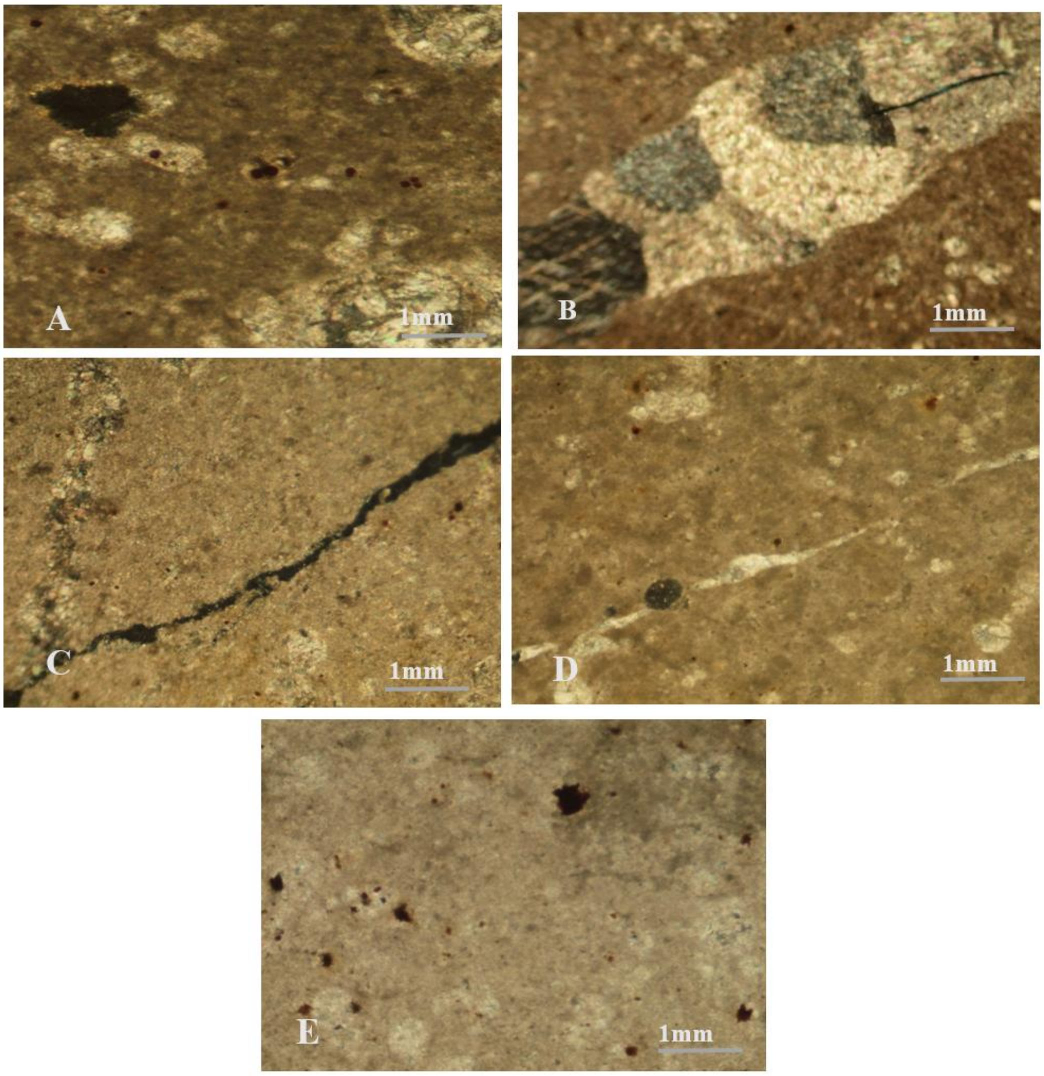

Plate 4

A: Planktonic Foraminiferal Lime Mudstone Submicrofacies.

B: Calcispheres Lime Mudstone Submicrofacies.

C: *Planoheterohelix globulosa* Lime Wackestone Submicrofacies.

D: *Globigerinelloids* Lime Wackestone Submicrofacies.