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

Depositional Environment of Khurmala / Sinjar Formation from Two Selected Sections, Northern Iraq

Eman Nathim Al-Assaf [1], Zaid A. Malak [2*]

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

Article information

Received: 03- Dec -2023

Revised: 20- Jan -2024

Accepted: 02- Mar -2024

Available online: 01- Apr – 2025

Keywords:
Depositional environment
Khurmala Formation
Sundor
Shiraswar
Iraq

Correspondence:
Name: Zaid A. Malak
Email:
zaidmalak@uomosul.edu.iq

ABSTRACT

In Northern Iraq, the Khurmala Formation sections at Sundor in Duhok City and the Shiraswar section in Erbil City have been studied from a sedimentary point of view. The formation's thickness is 53 meters in the Sundor section and roughly 13.5 meters in the Shiraswar section. Petrographic analysis of 48 thin sections of the Khurmala Formation shows that the majority of skeletal grains are of shallow marine environment and consist of fossils as benthonic foraminifera, pelecypod, bryozoan, red algae, coral, and non-skeletal granules including peloids, oolite and lithoclasts (intraclasts and extraclast). Three main microfacies and five lithofacies are identified based on field observations and petrographic analysis of the formation. These include lime mudstone, lime wackestone, lime packstone microfacies, and red algae bindstone lithofacies, coral framestone lithofacies, algal lime bindstone lithofacies, cross bedding bearing carbonate sand lithofacies and intraformational conglomerate lithofacies. The results of the current study indicate that the carbonate succession have been deposited in a spectrum of sedimentary environments, as most of the facies are located between the tidal flats environment to the upper parts of the slope environment, and it should be noted that the facies diagnosed in the carbonate succession exposed in the Shiraswar section differ in most of them from those diagnosed in the Sundor section, and they reflect the deposition of the reef environment, which calls for changing the name of these carbonate succession exposed in the Shiraswar section from the Khurmala Formation to the Sinjar Formation.

DOI: 10.33899/earth.2024.145090.1185, ©Authors, 2025, College of Science, University of Mosul.

البيئة الترسيبية لتكوين خورمالة / سنجار من مقطعين مختارين، شمالي العراق

ايمان ناظم العساف[1] ، زيد عبد الوهاب ملك [2*]

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

معلومات الارشفة

تاريخ الاستلام: 03– ديسمبر –2023

تاريخ المراجعة: 20– يناير –2024

تاريخ القبـول: 02– مارس –2024

تاريخ النشر الالكتروني: 01– ابريل –2025

الكلمات المفتاحية:

البيئة الترسيبية

تكوين خورمالة

صندور

شيراسوار

العراق

المراسلة:

الاسم: زيد عبدالوهاب ملك

Email: zaidmalak@uomosul.edu.iq

الملخص

في شمالي العراق، تمت دراسة مقطع صندور في مدينة دهوك ومقطع شيراسوار في مدينة أربيل لمعرفة المزيد عن البيئة الترسيبية لتكوين خورمالا. في المقاطع قيد الدراسة، كان سمك التكوين 53 متراً في صندور وحوالي 13.5 مترا في شيراسوار . أظهرت نتائج التحليل البتروغرافي لـ 48 شريحة رقيقة من تكوين خورمالة أن غالبية الحبيبات الهيكلية تدل على بيئة بحرية ضحلة تتكون بشكل عام من المتحجرات والحبيبات غير هيكلية والاخرى تشمل السرئيات والفتاتات الخارجية والدمالق والفتاتات الداخلية. تم تحديد ثلاث سحنات مجهرية دقيقة وخمسة سحنات صخارية بناء على الملاحظات الميدانية والتحليل السحني للتكوين، وتشمل هذه سحنة الحجر الطيني الجيري، وسحنة الحجر الجيري الواكي، وسحنة الحجرالجيري المرصوص، السحنة الصخارية للحجر الجيري المترابط الحاوي على الطحالب الحمراء، والسحنة الصخارية للحجر الجيري الحاوي على المرجان، والسحنة الصخارية للحجر الجيري المترابط الحاوي على الطحالب والسحنة الصخارية للحجر الجيري الرملي الحاوي على التطبق المتقاطع والسحنة الصخارية للمدملكات الداخلية. اظهرت نتائج الدراسة الحالية ان التتابعات الصخارية الكاربوناتية عموما قد ترسبت في طيف من البيئات الترسيبية حيث ان معظم السحنات تقع ضمن الانطقة السحنية الواقعة مابين النطاق السحني التاسع ممثلاً ببيئة المسطحات المدية الى النطاق السحني الرابع ممثلاً باجزاء من بيئة المنحدر، وتجدر الإشارة الى ان السحنات المشخصة في التتابعات الكاربوناتية المنكشفة في مقطع شيراسوار تختلف في غالبيتها عن تلك المشخصة في مقطع صندور وانها تعكس ترسيبها في بيئة الحواجز الحيدية، مما يدعو الى تغيير تسمية تلك التتابعات الكاربوناتية المنكشفة في مقطع شيراسوار من تكوين خورمالة الى تكوين سنجار .

DOI: 10.33899/earth.2024.145090.1185,

Introduction

The megasequences of the Middle Paleocene - Eocene are deposited in the period of subduction regeneration and increased volcanic arc activities associated with the eventual closure of the Neo-Tethys (Jassim and Goff, 2006). This tectonic activity was accompanied by a lifting of the northeastern edge of the Arabian plate with the formation of basins and barriers whose axis is northwest-southeast if these basins and barriers are located in the northern and central parts of Iraq, but if they are located in southern Iraq, the direction of their axis is east-west. The lifting of the northeastern edge of the Arabian plate during the early Paleocene caused the loss of Danian sediments in most of the high fold zone and the foothills zone. It should be noted here that recent studies have identified the presence of an almost complete stratigraphic column of the boundary between Cretaceous and Paleocene formations in some sections of northern Iraq (Sharbazheri, 2008). Another study that dealt with this topic is the study of Malak (2011), who refers in his study to the Paleocene – Eocene sequences (Kolosh Formation) in the Bekhme gorge indicating a slight loss of some of the biozone of the planktonic foraminifera that represents the beginning of the deposition of Arabian plates Megasequence (AP10). A regional unconformity was diagnosed at the base of the middle

Eocene, according to which the Megasequence (AP10) was divided into two parts, the sediments deposited during the Paleocene-early Eocene and the sediments deposited during the late – middle Eocene. The Khurmala Formation falls within the middle part of the AP 10 (Sharland et al., 2001). What interests us in this study is the period in which the Khurmala Formation (Paleocene-early Eocene) was deposited. During this period, within the unstable shelf, two basins were developed, namely the Kolosh basin and the red beds basin found in the northeastern region of Iraq, separated from each other by a barrier, which extends along the Balambo-Tanjero zone that started from Amadiya City in the northwest and passed Rowanduz and Rania towards Halabja in the southeast of Iraq (Dunnington, 1953; in Jassim and Goff, 2006). In the southwest of this barrier, a relatively narrow deep marine basin was developed, which is filled with clastic sediments of Kolosh Formation and the limestone of Sinjar and Khurmala formations in the shallow basin. Moving further southwest of this barrier, especially the northeastern edges of the Mesopotamian basin, the Kolosh Formation is eroded and replaced by Aaliji Formation (Jassim and Goff, 2006) (Fig. 1).

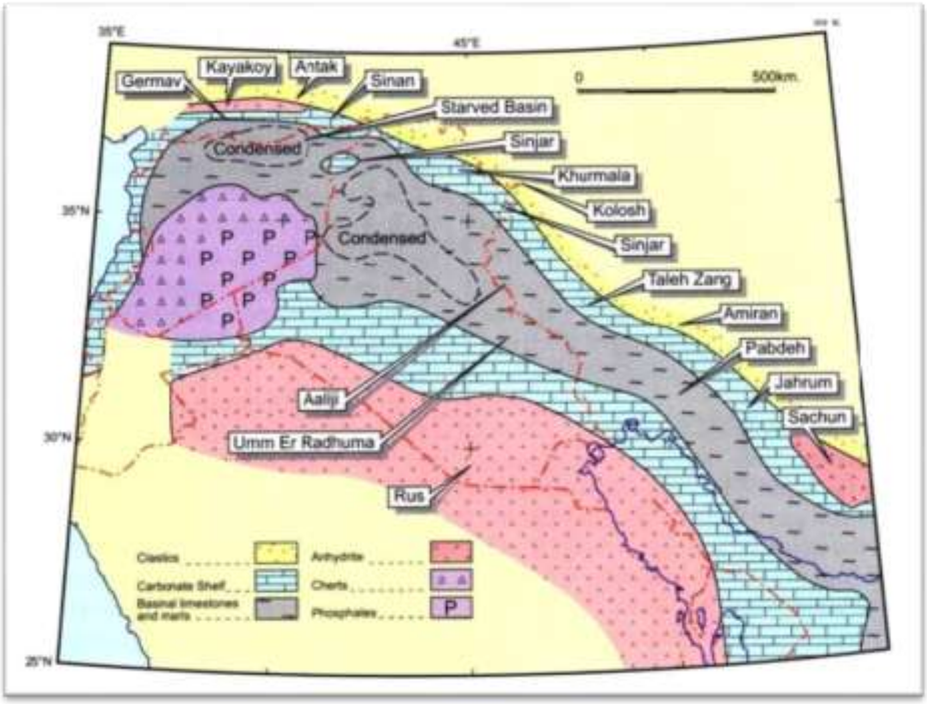

Fig. 1. Ancient geographical map of Iraq for the early Paleocene age (Aqrawi et al. 2010).

The Khurmala Formation was first recorded by Bellen (1953) in the well of Kirkuk 114 (Bellen et al., 1959). The Khurmala Formation consists in its type section of recrystallized limestone and dolomitic limestone containing in some parts pseudo oolite. Many studies indicate the deposition of the Khurmala Formation within a range of environments represented by the environment of lagoons and tidal environments. Kassab (1978) studied the Khurmala Formation in the Kirkuk well (117), and stated that it consists of dolostone and recrystallized limestone, and gave the formation an uncertain age of lower Eocene.

Al-Banna et al. (2006) indicated in their study of the Khurmala Formation, which is exposed at the northern limb of Bekher anticline, northeast of Duhok, that this formation was deposited in environments extending from shallow shoal, lagoon environments, and the inter tidal to supratidal environments. Karim (2009) also pointed out in her study to the Khurmala Formation in Shaqlawa area and to the presence of this formation in the form of a tongue at the top of the Kolosh formation, and she concluded that the depositional environments of the formation is the beach basins containing patch reef. Omer et al. (2014) studied the Khurmala Formation, which is exposed in many parts of northern Iraq and they mentioned that the formation was subjected to different diagenetic processes such as micritization, compaction, dissolution, neomorphism, pyritization and cementation that occurred during marine to shallow burial stages and culminated during intermediate to deep burial later stages. Malak (2011) studied the Khurmala Formation in selected exposed sections within the Perat anticline in Aqra City, and he pointed out that the depositional environment of the formation is a shallow marine environment distributed between shallow lagoon and tidal flats. Asaad and Balaky (2018) studied the microfacies and the sedimentary environment of the Khurmala Formation in Zanta area near the village of the Zanta and concluded that the formation was deposited in a shallow, calm and semi-confined environment. Asaad et al. (2022) studied the Khurmala Formation in Nerwa area near the Akre City, where the formation was divided into three units, and based on the microfacies analysis of the Khurmala Formation, five microfacies were diagnosed that reflect the deposition of the formation in the back reef and the lagoon containing patch reef. The aims of the study is to determine the ancient depositional environment of Khurmala Formation based on field evidence and microfacies analysis, then determining the depositional model, and trying to prove that the carbonate succession exposed in both sections belongs to the same formation, which is the Khurmala Formation.

Geological Setting

The Khurmala Formation was studied in two exposed sections in northeastern Iraq within the Governorates of Erbil and Dohuk, which are located tectonically within the unstable zone and exclusively within the high fold zone (Fouad, 2015). The formation is revealed in Sundor section within the Governorate of Dohuk at the coordinates 36° 54' 23" N and 43° 05' 14" E, 15 km northeast of Duhok City. While the formation is revealed in Shiraswar section within Shaqlawa City northeast of Erbil Governorate at the coordinates 36° 24' 28" N and 44° 15' 26" E (Fig. 2).

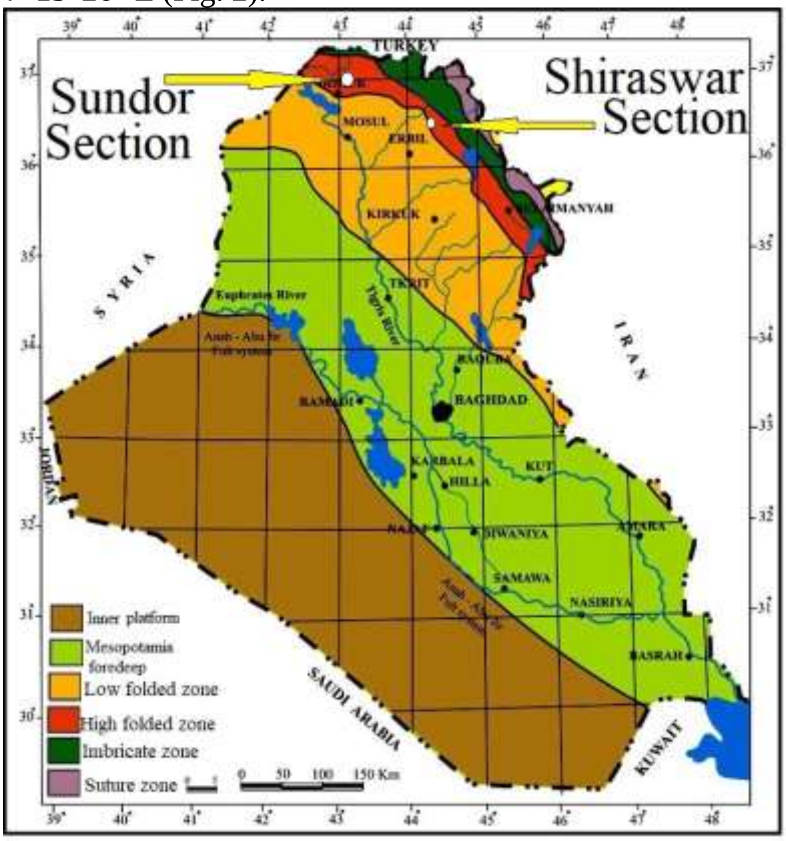

Fig. 2. Tectonic map of Iraq showing the two sections of the study (after Fouad, 2015).

Methods and Materials

The field study included many field trips for the study sections (Sundor and Shiraswar), during which the best exposed paths were selected in terms of clarity of the succession of the studied formation and the exposure of the upper and lower contacts, as well as measuring the thickness of the beds and color of the rocks and describing the trace fossils, as well as many field photographs were taken. 33 samples were collected from Sundor region and 15 samples from Shiraswar region. 48 thin sections were made for all samples to be examined microscopically to identify the rocks' granules and mineral components in each rock sample, to diagnose their internal fossils, to identify the diagenetic processes by which they have been affected., and then to nomenclate their microfacies and lithofacies following Dunham classification (1962) modified by Embry and Klovan (1971) in order to elucidate the depositional environment of the formation and drawing finally its sedimentary model.

Field Work

The Khurmala Formation is revealed in the Sundor section, where it appears as a tongue shape overlapping the upper part of the Kolosh Formation (Fig. 3a). The thickness of the formation is approximately (53) m. The formation generally consists of limestone, which is well bedded in some parts and massive in others (Fig. 4). The appearance of the formation begins with a (2) m thick bed of limestone and dolomitic limestone whose texture is rough, followed upwards by (2.5) m thick hard dolomitic limestone bed containing some vugs in its lower part. It is topped with a bed of high-hardness dolomitic limestone (3.7 m thick). This part is followed by (3.5) m thick hard dolomitic limestone consisting of beds with thicknesses range between 15 and 30 cm, as the lower part of this sequence is characterized by the presence of limestone with spherical concretion structure, while the upper part of this sequence is characterized by its high rigidity and containing gaps. This part is followed by another sequence of ten m thick beds of limestone (2 m thick), coarse in touch (sandy) containing spherical limestone concretion structure in its lower part, followed by a (0.7) m bed of limestone containing fossils (Mollusca shells), followed by a (2) m thick bed of thin laminated limestone with phacoid structure, topped by a (1) m thick bed of hard dolomitic limestone containing vugs. The remaining ten meters part contains (4.30) m hard limestone. This is followed by a yellow dolomitic limestone bed (3 m thick) characterized by increasing hardness at the end of this bed. It is followed by a bed (1.5 m thick) of laminated limestone.

This is followed by a sequence of (20) m sandstone and shale with an olive color representing the Kolosh Formation. The Khurmala Formation reappears again consisting of a (5) m bed of very hard dolomitic limestone with vugs in its upper part. The formation includes a bed of limestone (sandy in touch) about (1) m thick containing herringbone cross bedding structure (Fig. 3b) followed by the reappearance of the Kolosh Formation (4 m thick), which is directly above by the Gercus Formation.

In the Shiraswar section, the formation about (13.5) m thick) (Fig. 3c) consists of a (2) m thick bed of yellow, friable marl at the bottom, which changes upwards to the gray-colored marly limestone. It is then followed by a bed of limestone containing red algae with a thickness of 40 cm, followed by a hard yellow limestone (1.5) m thick with fossils (Mollusca shells) at the bottom. It is followed by a (0.5) m thick intraformational conglomerate containing bioturbation (skolithos). It is followed by a (2) m thick bed of brittle marl with a gray color, topped by a (2) m thick hard limestone that contains fossils and pieces of coral (Fig. 3d) at the bottom, followed by a (1.5) m thick of marl and marly limestone with a gray to yellow color, followed by (3) m thick hard dolomitic limestone beds with a thickness range between 40-60 cm and some of the beds contain vugs and bituminous material (Fig. 5).

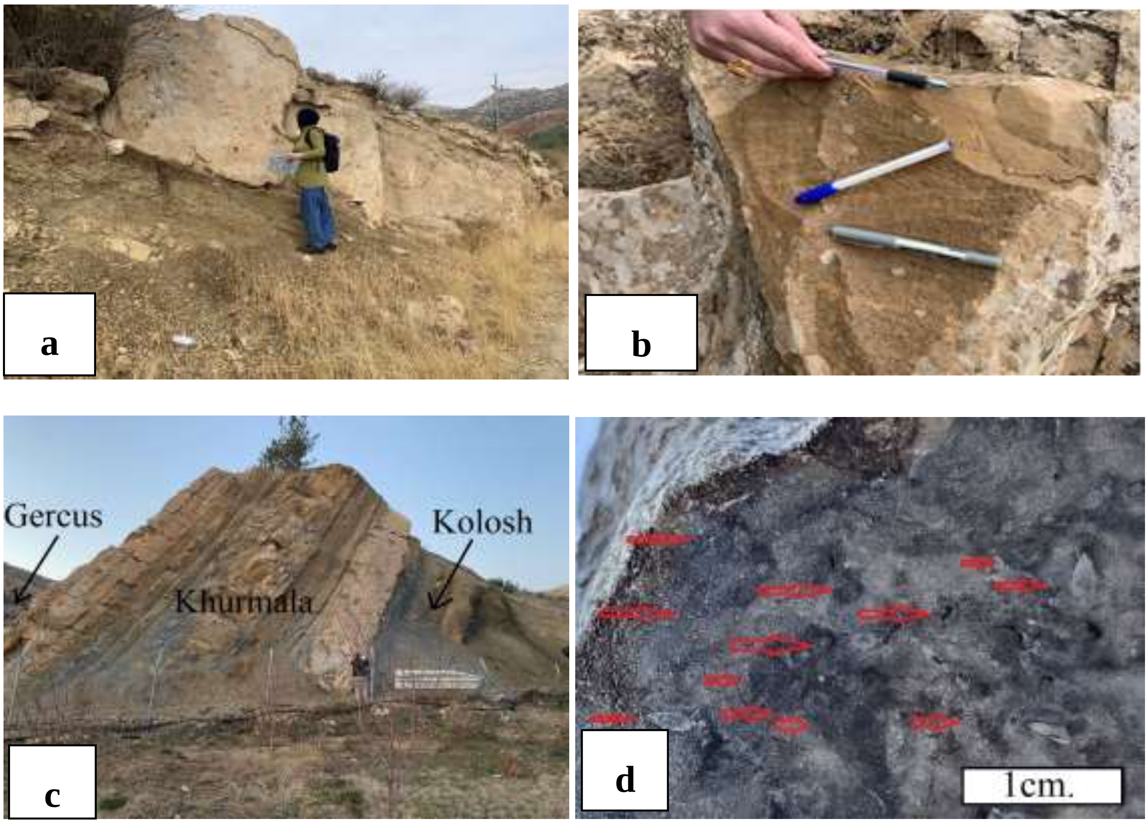

Fig. 3. (a) Field photograph showing the upper part of Khurmala Formation, Sundor section. (b) Herringbone cross bedding, Sundor section. (c) Khurmala Formation in Shiraswar section. (d), Field sample of coral (red arrows), sample no. 7, Shiraswar section.

Results

According to Dunham classification (1962) modified by Embry and Klovan (1971), three main microfacies and five lithofacies are identified based on the field observations and petrographic analysis of the studied Khurmala Formation. These include lime mudstone, lime wackestone, lime packstone microfacies, and red algae bindstone lithofacies, coral framestone lithofacies, algal lime bindstone lithofacies, cross bedding bearing carbonate sand lithofacies and intraformational conglomerate lithofacies (Figs. 4 and 5). The first three microfacies are divided into nine submicrofacies and the following is a presentation of the main and submicrofacies.

1. Lime Mudstone Microfacies (M)

This microfacies is one of the widespread facies within the sequences of the formation and it consists mainly of micrite with a small percentage of granules that do not exceed the barrier (10 %). These granules consist of skeletal granules and bioclasts belonging to the benthonic foraminifera and pelecypods. This microfacies is affected by severe diagenesis processes, especially dolomitization. This microfacies is divided into two submicrofacies according to the type of the its granules containment as follows:

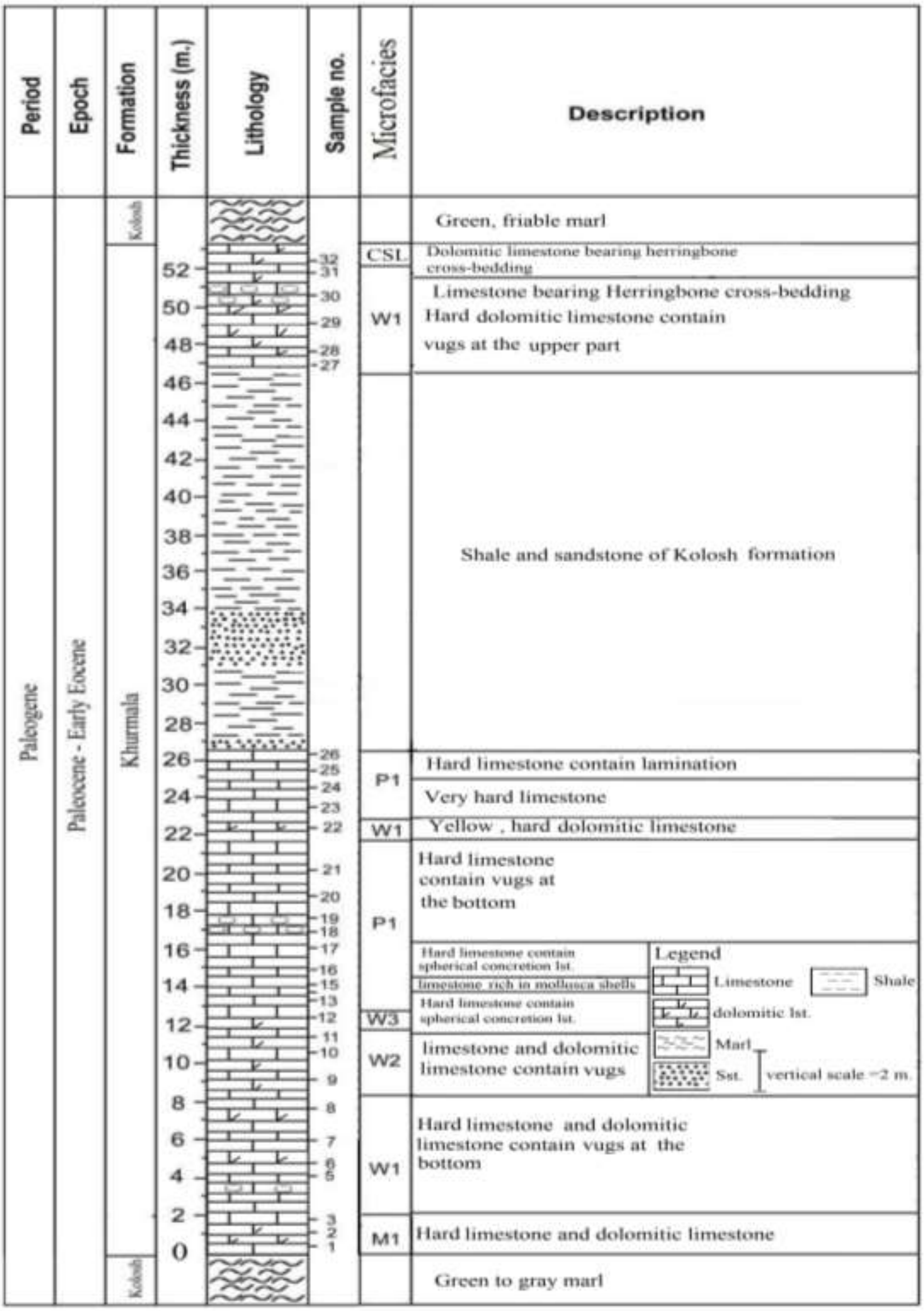

Fig. 4. lithological column of Khurmala Formation, Sundor section, Duhok.

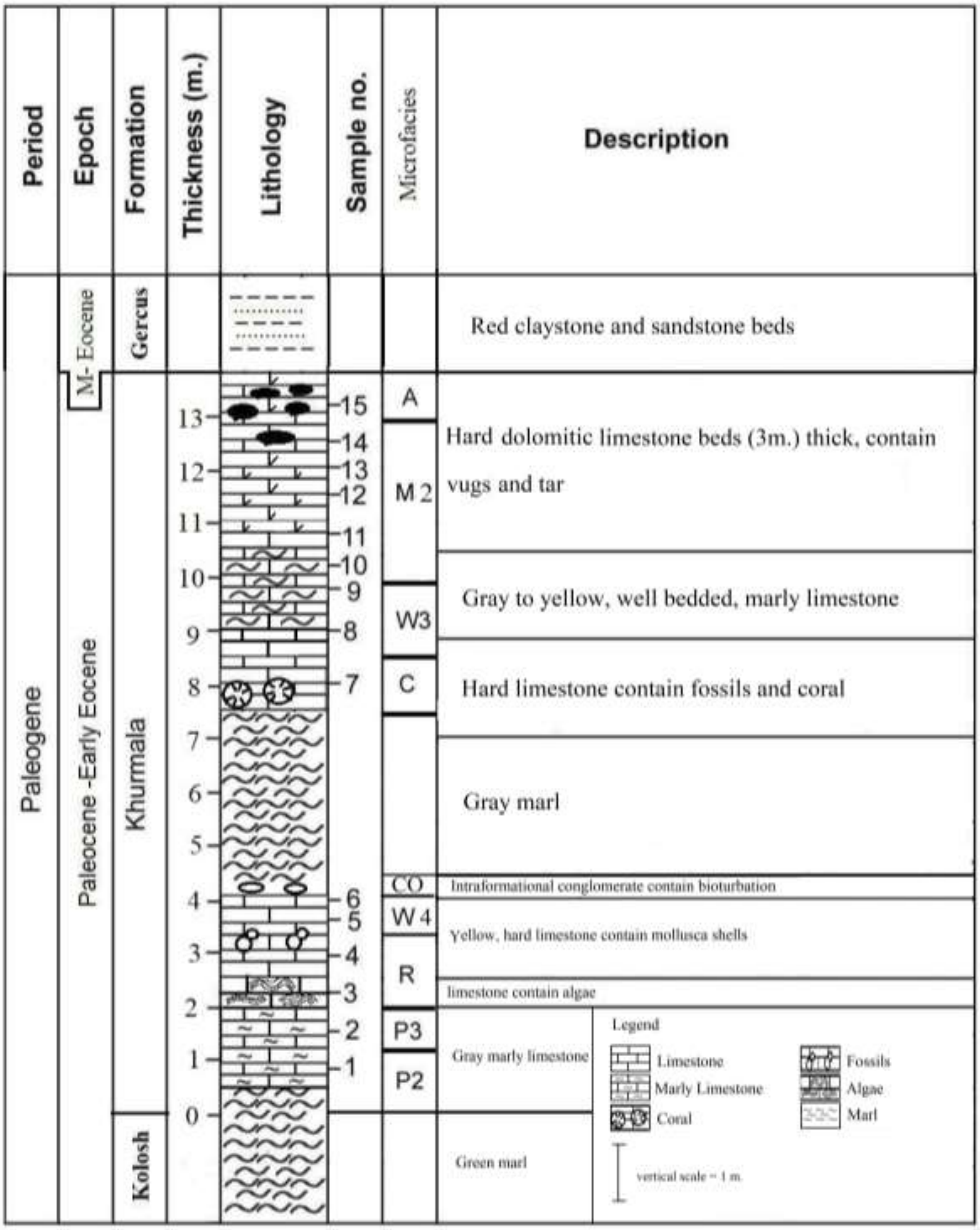

Fig. 5. lithological column of Khurmala Formation, Shiraswar section, Erbil.

Peloidal- Fossiliferous Lime Mudstone Submicrofacies (M1)

This microfacies appears to consist of gray, hard limestone, near the lower contact surface with the Kolosh Formation in Sundor section only. The thickness of this microfacies is approximately (2) m characterized by the prevalence of pelecypod (2 %), benthonic foraminifera (2 %) and pelloid (3 %) (Fig. 6a). The matrix consists of micrite, which turns in some parts into microspar. The dissolution process is an important process where many types of porosity have been diagnosed such as vuggy and moldic porosity. As well as recrystallization and dolomitization where the sieve, spotted and mosaic texture are distinguished.

The general characteristics of this microfacies are similar to the general characteristics of the standard microfacies (SMF-16) and the facies zone (FZ-8) (Flugel, 2010), as this microfacies is deposited in the lagoon environments confined behind the barrier.

Dolomitized Lime Mudstone Submicrofacies (M2)

This microfacies is spread in the upper parts of the formation in the Shiraswar section, where it is found in the form of hard limestone bed up to (3) m thick, and some beds contain empty vugs. This microfacies is characterized by a scarce granules content (except two to three pieces of fossils of unknown origin) and a low percentage (1%) of the detrital quartz and chert spread in the micritic matrix (Fig. 6 b). The dolomitization is one of the most prominent modifying processes diagnosed in this microfacies represented by suture mosaic cement and vuggy porosity, some of the vugs are filled with gypsum.

This microfacies is similar to the standard microfacies (SMF-23) and the facies zone (FZ-8-9) (Flugel, 2010), as this microfacies is deposited in the environment of tidal flats.

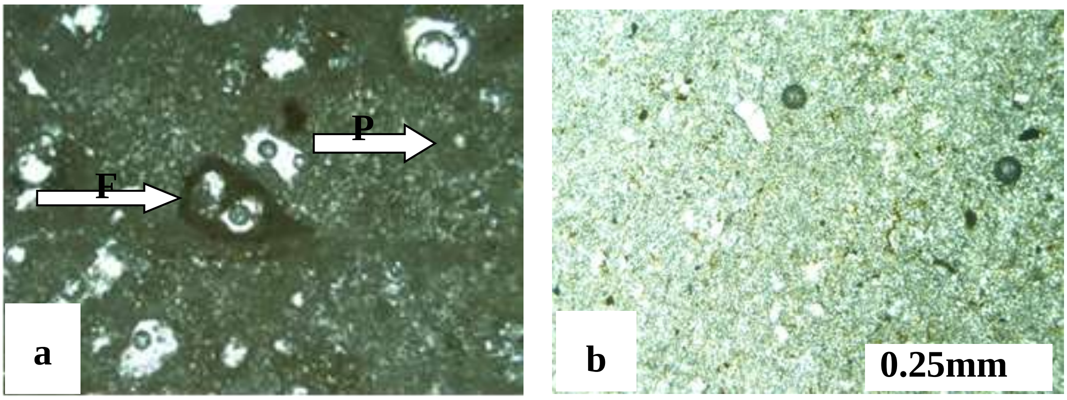

Fig. 6. (a) Peloidal (p) – fossiliferous (F) lime mudstone submicrofacies, sample no. 2, Sundor section. (b) Dolomitized lime mudstone submicrofacies, sample no. 13, Shiraswar section.

2. Lime Wackestone Microfacies (W)

This microfacies is generally composed of (50-10) % carbonate granules within a micritic matrix. The granules of this microfacies consist of benthonic foraminifera, ostracod, bryozoa, algae and coral remain, as well as intraclasts. Depending on the types of its granular content, this microfacies is divided into four submicrofacies:

Fossiliferous Lime Wackestone Submicrofacies (W1)

This microfacies is spread in the upper parts of the Khurmala Formation in Sundor section only. This microfacies is represented by hard limestone beds with thickness ranges between (5-6) m, and contains vugs in different parts of the facies. This microfacies consists of benthonic foraminifera (10-35%) and pelecypod (5%), as well as low percentages of echinoderms, lithoclasts and peloid in a small percentage (Fig. 7a). The matrix consists mainly of micrite. The most important diagenesis processes affected this microfacies are dissolution (vugs, mold and intergranular porosity) and dolomitization, sieve, spotted and suture mosaic fabric are distinguished as well. Recrystallization and cementation (granular cement) are distinguished too.

When comparing this microfacies with the standard microfacies of Wilson (1975, Flugel, 2010), we notice that this microfacies is similar to the standard microfacies (SMF-18) and deposited within the facies range (FZ8), which represents the interior marine platform environment (restricted lagoon).

Bioclastic Lime Wackestone Submicrofacies(W2)

This microfacies is approximately (4) m thick and is spread in the lower parts of the formation in Sundor section, where it consists of limestone beds of medium hardness with a rough texture and contains few vugs. This microfacies consists mainly of bioclasts, which are generally characterized by different shapes and sizes ranging between (20-45%), represented by benthonic foraminifera, pelecypod, echinoderms and ostracods bioclasts, all of which are buried in a micritic matrix (Fig. 7 b). The vuggy, mold and intergranular porosity are present, as well as dolomitization, where sieve, spotted and suture mosaic texture are distinguished too. Recrystallization and cementation (granular cement) are present too.

This microfacies is similar to the standard microfacies (SMF-10) and deposited within the (FZ-7), which represents the interior platform environment (open marine).

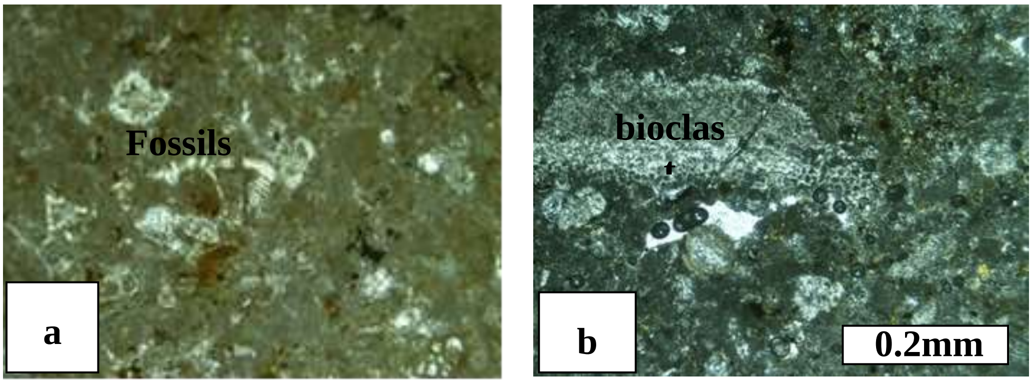

Fig. 7. (a) Fossiliferous lime wackestone submicrofacies, sample no. 6, Sundor section. (b) Bioclastic lime wackestone submicrofacies, sample no. 10, Sundor section.

Rotalid Lime Wackestone Submicrofacies(W3)

This microfacies is spread in the middle part of the formation in the Shiraswar section and the lower part of the formation in the Sundor section. It consists of gray to yellow limestone and marly limestone beds of about (15–120) cm. thick in Shiraswar and Sandor sections. This microfacies is characterized by a large prevalence of Rotalid tests with a percentage of (15-25%), as well as the presence of miliolid, ostracoda, echinoderm and pelecypod (Fig. 8 a). The matrix consists mainly of micrite. The dissolution (vuggy, mold), recrystallization and cementation (granular and blocky cement) have been distinguished.

This microfacies is similar to the standard microfacies (SMF18) and deposited within the (FZ7-8), which represents the environment of open water circulation lagoon and restricted platform.

Miliolid Lime Wackestone Submicrofacies (W4)

This microfacies is spread at the bottom of the formation in the Shiraswar section (about 0.5 m thick) and composed of hard limestone. This microfacies consists of benthonic foraminifera tests (Miliolid) (15-40%). *Peneroplis*, pelecypod, echinoderm and red algae (3%) (Fig.8 b). The miliolid is characterized by its large size (1 mm) and its good preservation as well as the presence of large pieces of pelecypod. Dissolution (vugs, moldic, channels and intergranular porosity), recrystallization, cementation (granular, syntaxial rim cement), physical compaction and oxides are diagnosed.

When comparing this microfacies with the standard microfacies of Wilson (1975 and Flugel, 2010), it appears that this microfacies is similar to the standard microfacies (SMF-18) deposited within (FZ-8), which represents the lagoon and the restricted platform environment.

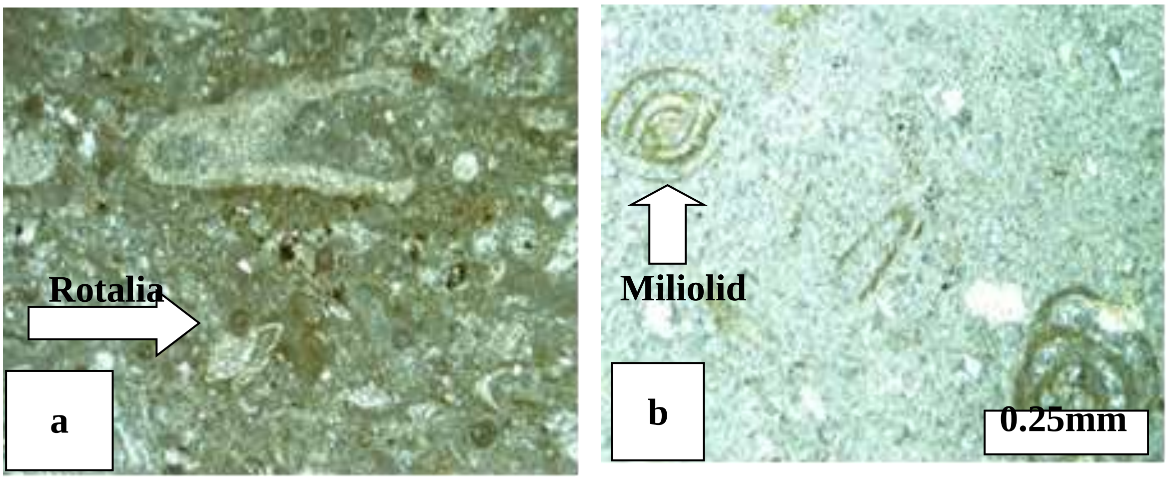

Fig. 8. (a) Rotalid lime wackestone submicrofacies, sample no. 9, Shiraswar section. (b) Miliolid lime wackestone submicrofacies, sample no. 5, Shiraswar section.

3. Lime Packstone Microfacies (P)

This microfacies is characterized by a high abundance of granules pressed with each other with low micritic matrix. The microfacies diagnosed in the Khurmala formation is characterized by their low prevalence, despite the diversity of their granule components, most of which consist of benthonic foraminifera, pelecypod, ostracoda, pieces of green and red algae, echinoderms, as well as bioclasts. This microfacies is divided into three submicrofacies depending on different granular components:

Bioclastic Lime Packstone Submicrofacies (P1)

This microfacies is spread in the middle part of the formation in Sundor section only, with a thickness ranging between (3.5-9) m as white and hard limestone beds characterized by containing vugs in some levels of a white color. The microfacies is composed of benthonic foraminifera, pelecypod, ostracoda, red algae, echinoderms and bryozoan bioclasts (Fig. 9a). The microfacies is affected by dissolution (vuggy, moldic, intergranular and channels porosity), recrystallization, cementation (granular, interparticle cement) and physical compaction are distinguished.

This microfacies is similar to the standard microfacies (SMF-10) and deposited within (FZ-7), which represents the interior platform environment (open marine).

Lithoclastic Lime Packstone Submicrofacies (P2)

This microfacies is spread at the bottom of the formation in Shiraswar section, with a thickness of (1) m as gray marly limestone. This microfacies consists of lithoclasts and bioclasts up to (70%) of benthonic foraminifera, pelecypod, ostracoda and echinoderms (Fig.9 b). This microfacies shows a kind of thin laminae. Dissolution, recrystallization, cementation (granular cement), and physical compression are distinguished. It appears that this microfacies is similar to the standard microfacies (SMF-4) deposited within (FZ-3-4), which represents fore reef environment.

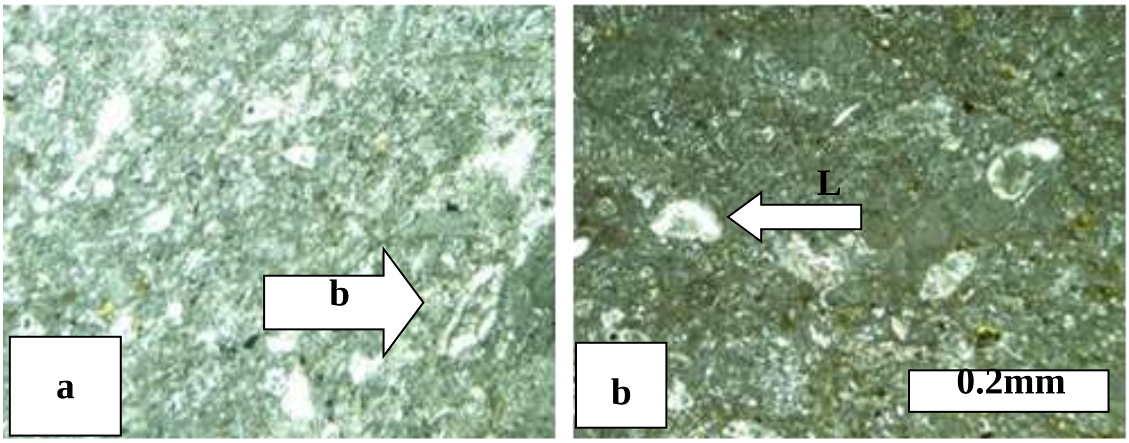

Fig. 9. (a) Bioclastic (arrow b) lime packstone submicrofacies, sample no. 25, Sundor section. (b) Lithoclastic (arrow L) lime packstone submicrofacies, sample no. 1, Shiraswar section.

Red Algal -Bioclastic Lime Packstone Submicrofacies (P3)

This microfacies is spread at the bottom of the formation in Shiraswar section with a thickness of (1) m and appears as hard marly limestone bed. It consists of red algae (10%), echinoderms and benthonic foraminifera (8%) and bioclasts (30%) (Fig. 10a). Dissolution (channels and vuggy porosity), recrystallization and cementation and physical compaction are diagnosed.

When comparing this microfacies with the standard microfacies of Wilson (1975, and Flugel, 2010), it appears that this microfacies is similar to the standard microfacies (SMF-5) and deposited within (FZ-4), which represents the slope environment (Slope).

4. Red Algal Bindstone Lithofacies (R)

This microfacies is spread at the bottom of the formation in the Shiraswar section only, with a thickness of (1.5) m. This microfacies is represented in the field as hard limestone beds containing red algae. The microfacies consists of red algae (*Lithophyllum* sp.) and echinoderms, benthonic foraminifera, pelecypods in low proportions (Fig. 10 b). The most important diagenesis processes recorded are dissolution (channels porosity), recrystallization and cementation (granular and syntaxial rim cement). This microfacies is similar to the standard microfacies (SMF-7) deposited within (FZ5), which represents the platform margin reef environment.

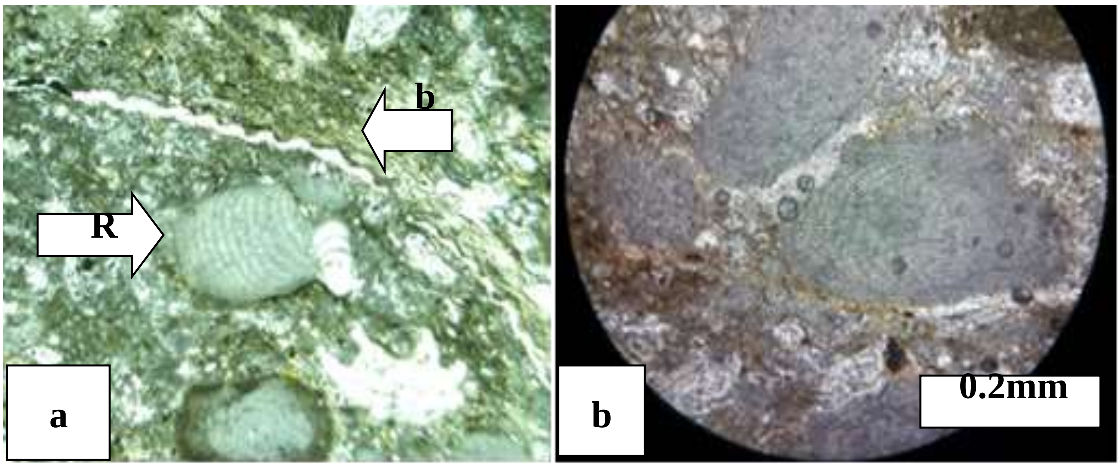

Fig. 10. (a) Red algal (arrow R)-bioclastic (arrow b) lime packstone submicrofacies, sample no. 2, Shiraswar section. (b) Red algal bindstone lithofacies, sample no. 3, Shiraswar section.

5. Coral Framestone Lithofacies (C)

This microfacies appears in the central part of the formation in a Shiraswar section with a thickness of (1) m as hard limestone bed. This microfacies is characterized by the prevalence of coral that prevails in the microfacies with a few benthonic foraminiferal bioclasts and pelecypods that spread between the branches of the coral (Fig. 3 d). The microfacies is affected by recrystallization and cementation where granular cement is distinguished. This microfacies is similar to the standard microfacies (SMF-7) and deposited within (FZ-5), which represents the platform margin reef.

6. Algal lime Bindstone Lithofacies (A)

This microfacies appears at the top of the formation in the Shiraswar section only as a hard dolomitic limestone bed (1 m thick) and some parts of the bed contain vugs and bituminous materials. The microfacies consists of algae (undiagnosed) that are horizontal in arrangement (Fig. 11 a, b), but are subjected to strong and severe dolomitization, so that the distinction of its internal structures is seen except for some pieces. Dolomitization process (suture mosaic) is distinguished, in addition to a few extraclastic and intraclastic granules arranged horizontally with pieces of quartz and gypsum filling in some small vugs. This microfacies is similar to the standard microfacies (SMF-20) and deposited within the facies zone (FZ-9), which represents the environment of the tidal flats.

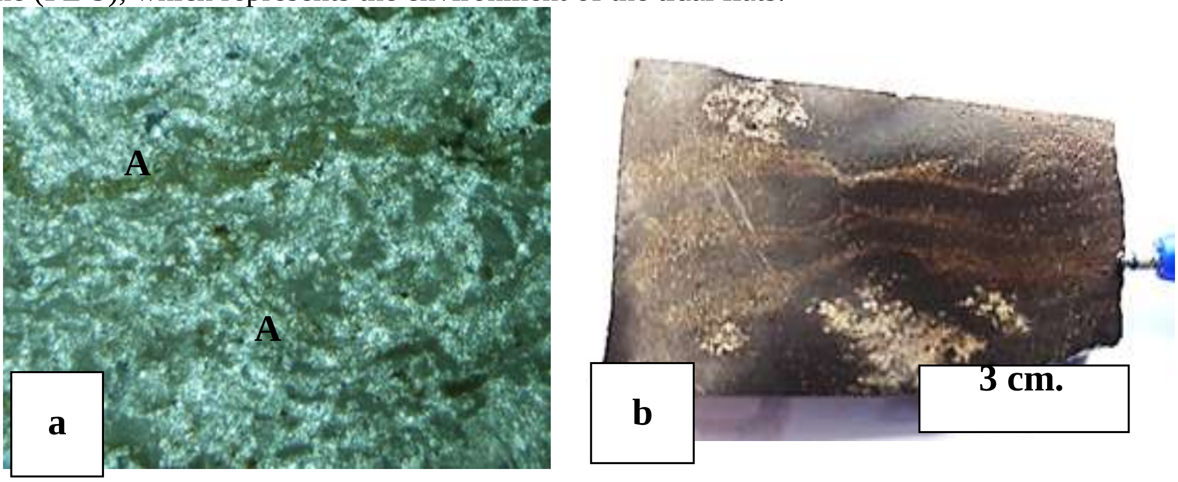

Fig. 11. (a) Algal lime bindstone under thin section (A), sample no. 15, Shiraswar section. (b) Field sample of algal lime bindstone lithofacies, sample No. 15, Shiraswar section.

7. Cross bedding bearing carbonate sand lithofacies (CSL)

These facies are spread at the top of the formation in Sundor section only with a thickness of up to (1) m, where this facies consists of hard limestone that contains the cross-bedding of the herringbone (Fig. 3 b.). This microfacies consists mainly of bioclasts and extraclast (2-40%). Some benthonic foraminifera test of unknown origin and bioclasts are present (Fig. 6 d). The extraclasts are represented by detrital quartz scattered in the micritic matrix, which is characterized by affected by dolomitization (sieve, spotted and suture mosaic cement), dissolution (vuggy and moldic porosity), cementation (granular cement) and recrystallization are present. Several studies have indicated that such a microfacies can be deposited in the tidal channels within subtidal to intertidal environments, which are located below and above low tide (Bogg, 1995), deposited by carrying the bottom during the high velocity phase of tidal cycles (Onuigbo et al., 2012).

8. Intraformational conglomerate lithofacies

This facies appears in Shiraswar section only, in the form of a beds approximately (40) cm thick of intraformational conglomerate, which is characterized by containing bioturbation (Skolithos) in the form of straight vertical pipes with a diameter of (1) cm. This lithofacies is usually found in the upper part of subtidal and intertidal environments (Eren et al., 2002). The presence of bioturbation in these facies usually indicates a high activity of benthic organisms because the sedimentation conditions are suitable for their living and such conditions are usually found in intertidal environments (Boggs, 2006).

Depositional environment and model

Depending on the microfacies diagnosed from the Khurmala Formation for both sections, there is a clear difference in the types of the microfacies diagnosed in each section, and this difference may be attributed to tectonic factors and to the sea level variation accompanied by a significant change in the energy of sea currents, which put its clear fingerprints in the formation facies (Qader, 2020). Based on the microfacies analysis, which shows a similarity in the general characteristics of the formation microfacies with the general characteristics of the standard microfacies installed by Flugel, it is found that the formation is deposited in a range of sedimentary environments, where most of the microfacies are located within the facies zone located between the (Fz– 9) represented by the tidal flat environment to the (FZ-4) represented by the slope environment, which shows a pattern of shallow in the sedimentary basin from the bottom of the formation to the top as shown below:

1. Tidal Flat Environment

The microfacies of this environment are located at the top of the Khurmala Formation in the Shiraswar section, with a thickness of up to (0.5) m represented by the algal lime bindstone lithofacies (A) and the intraformational conglomerate lithofacies at the middle part of the formation. This microfacies consists of algal lamination (undiagnose) that are subjected to severe dolomitization with some vugs (bird's eye) containing gypsum as well as quartz pieces. Severe dolomitization with some bird's eye is clear evidence on the deposition of this microfacies at the top of the intertidal environment to the supratidal environment. The presence of the intraformational conglomerate lithofacies is another evidence to the intertidal environment (Shinn, 1983; Flügel, 2010).

The microfacies of this environment also appears at the top of the formation in Sundor section with a thickness of up to (1) m, where it consists of hard sandy limestone with rough texture that contains the large cross bedding of the herringbone type. This microfacies consists mainly of bioclasts and extraclasts with some benthonic foraminifera tests. Many studies indicate the development and formation of this type of cross bedding in many sediments and is formed in several different ways in many environments including the tidal flat (intertidal) environment (Tentirri, 2011). Constant changes in tidal energy play a key role in producing this sedimentary structure (Mutti et al., 1985).

2. Platform Interior (Restricted lagoon to open marine) Environment

This environment is represented by (FZ-8), which represents the restricted lagoon environment, and (FZ-7) represented by the open marine environment. This environment is a shallow marine environment and is located behind sandy barrier islands or reef, thus making the environment less connected to the open sea and characterized by the predominance of wacke lime microfacies (Hallam, 1981; Read, 1985; Flugel, 2010). The microfacies of this environment are represented in the Khurmala Formations in Sandor section with the following submicrofacies: peloidal-fossiliferous lime mudstone (M1), fossiliferous lime wackestone (W1), bioclastic lime wackestone (W2), rotalid lime wackestone (W3) and bioclastic lime packstone (P1). In Shiraswar section, it is represented by the following secondary standard facies: dolomitized lime mudstone (M2), rotalid lime wackestone (W3) and miliolid lime wackestone (W4). The microfacies of this environment occupy the largest part of the Khurmala Formation in Sandor section, while occupying the upper and middle parts of the formation in Shiraswar section.

Several studies have indicated that microfacies are composed largely of lime mud indicating low energy sedimentary environment conditions, and that their containment of peloids indicating their deposition in shallow marine environments including restricted lagoon environments (El-Azabi , Al-Araby, 2007, Simo, et al., 2023 and Al-Shammary, et al., 2023).

On the other hand, the prevalence of benthonic foraminifera, especially the genera Miliolid (*Quinqueloculina, Triloculina),* rotalid and their bioclasts, indicates their presence in the shallow lagoon environment (Brasier, 1980). The prevalence of miliolid and rotalid refers to the shallow lagoon’s environment (Bathurst, 1971) and restricted lagoons behind the reefs (Ghose, 1977), with a water depth of less than (30) m based on the presence of the genera of *Quinqueloculina*. The great diversity of benthonic foraminifera, especially the miliolid in these environments, undoubtedly reflects the conditions of prosperity within a marine environment with a depth of less than (40) m and warm waters and high salinity. These sediments reflect the environment of shallow semi restricted lagoon (Hallock and Clenn, 1986; Brasier, 1980).

3. Reef Environment

The microfacies of this environment appears only in the Shiraswar section within the lower and middle parts of the formation represented by the lithoclastic lime packstone microfacies (P2), red algal-bioclastic lime packstone microfacies (P3), red algal bindstone lithofacies (R) and coral framestone lithofacies (C).

The bioclastic lime packstone and red algae consist of echinoderms bioclasts andred algae. The most important manifestation of these deposits is the presence of thin lamination, which results from the volumetric sorting of bioclasts arranged in the form of parallel laminae and deposited close to the reef body towards the open sea (Dabrio et al., 1981, Assad, et al., 2022). These sediments are often formed by the influence of waves and sea currents, as well as the influence of organisms, as the aforementioned factors lead to the erosion and cracking of the reef that are transported to the fore reef or slope, as they are deposited there (Bathurst, 1971; James and Ginsburg, 1979). This microfacies represents the first stage of growth of the reef called stabilization (Sholle et al., 2003).

Red algae, found in the R microfacies, are the most important marine organisms that have a key role in building the general structure of algal reef (Ghose, 1977) such as the ancient Miocene reefs in Malta, and modern reefs as in the Maerl region in northeastern Atlantic (Maerl - NE Atlantic), and these red algae usually build algal reefs within an area that extends towards the open sea, as they absorb most of the energy of the sea waves and their appearance depends on many main factors as the water depth and their position from the equator (Bosence, 1983), the presence of these species of red algae (*Lithophyllum* sp.) in this microfacies, the reef edge environments, and sometimes the deeper parts of the middle shelf environment (Ghose, 1977; Racz, 1979) within warm subtropics characterized by a low water depth (50) m and high water energy (Misra et al., 2000). This microfacies may represent the second stage of growth of the reef, which is called colonization.

On the other hand, the facies consist of coral builder of the reef as well as the presence of red algae as well with a few benthonic foraminifera and pelecypod bioclasts that spread between the branches of coral. The presence of adherent organisms in these facies that have the ability to build calcareous skeletal (coral and red algae) with the presence of organisms accompanying the facies (benthonic foraminifera, echinoderms and mollusks), all indicate the development of reef patch, perhaps in lagoons, or a complete reef grows if the conditions are suitable for its development and in all four stages. The patches reef are small, separated from each other and reach up to several meters thick (Selley, 1976), and these patches reef usually grow on a base (shallow rubble) consisting of red algae debris, echinoderms and lithoclasts that form a ground on which the coral settles in the form of patch within shallow lagoons (Al-

Qayim, 1995), which are characterized by depths not exceeding (50) m with warm water within the area of the inner shelf or the lagoon environment (Checconi et al., 2007).

From the foregoing, it is clear that the Khurmala Formation in Sundor section has been deposited in a rather shallow marine environment extending from the top to the bottom of the formation, from the tidal flat environment (intertidal to subtidal environments) at the top of the formation through the lagoon environment to the open marine environment within the interior marine platform, indicating the shallowing in the marine sediments towards the top of the formation, without the development of any type of sedimentation representing the reef environment.

As for the microfacies diagnosed in the Khurmala Formation in the Shiraswar section, it reflects the deposition of the formation through a spectrum of environments extending from the base of the formation top, represented by the reef environment, passing through the interior marine platform environment (open marine and lagoon) and ending with the tidal flat environments.

Consequently, as a result of the difference in the lithofacies and microfacies diagnosed in the Shiraswar section, which are completely different from the facies diagnosed in the Sundor section, it is clear that it is not possible to decide at all that both carbonate succession is of the same formation, which is Khurmala. However, the facies diagnosed in the Shiraswar section are similar in content and sedimentary environment to those of the Sinjar Formation. As most of the facies are diagnosed in many previous studies of Sinjar Formation, including studies Al-Haj and Al-Hamdani (2005; Daoud, 2009; Barzani and Al-Qayim, 2021) in the Sinjar area west of Mosul, Hazar Mird and Qazan southwest of Sulaymaniyah City and the Baribahar area in Dohuk, respectively, are similar to what was diagnosed in the Shiraswar section. Therefore, we propose to change the name of the exposed carbonate succession in the Shiraswar section from the Khurmala Formation to the Sinjar Formation. Perhaps the rimmed carbonate platform model is one of the most suitable models that describe the depositional environment of the two formations (Fig. 12).

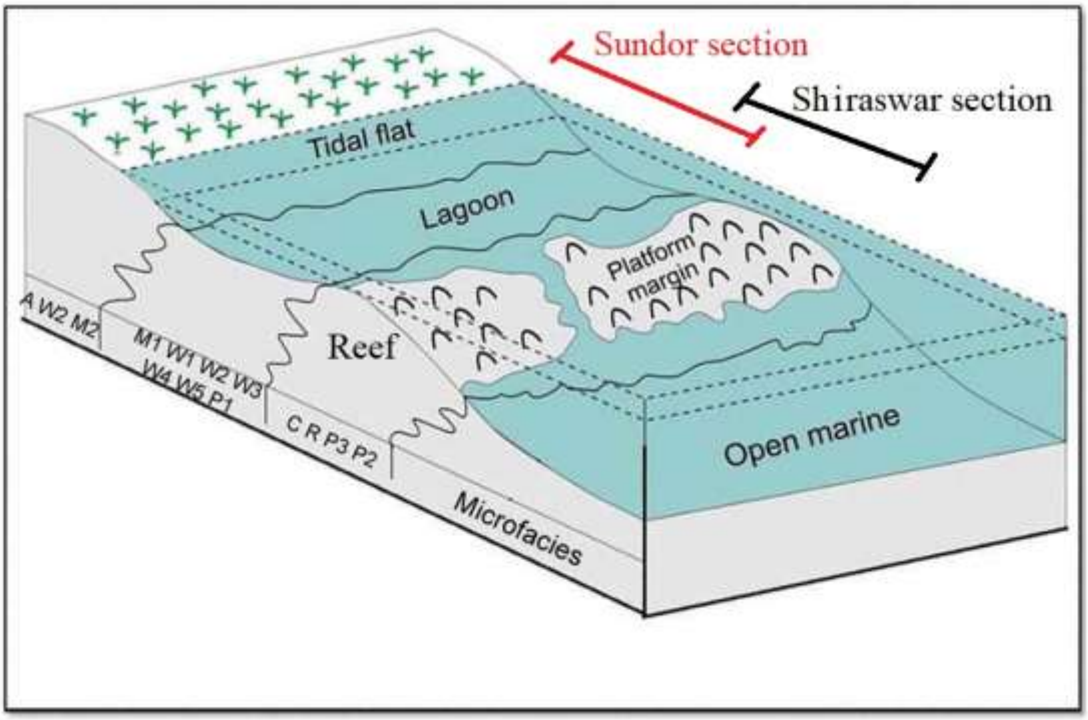

Fig. 12. Rimmed carbonate platform model that describes the depositional environment of the Khurmala /Sinjar Formation.

Conclusion

1. Based on field observations and petrographic examination of the Khurmala Formation, and the microfacies analysis, the formation is deposited in a variety of sedimentary settings from the tidal flat passing through interior platform and reef environments from the top to the base of the formation in the two sections; theses facies zone in the sedimentary basin has a shallow pattern.

2. According to the field observations, lithofacies, and microfacies, we propose to rename the exposed carbonate succession in the Shiraswar section to Sinjar Formation instead of the old name Khurmala Formation, because the nature of its microfacies and lithofacies components is significantly different from that diagnosed in the Khurmala Formation in the Sundor section. As the facies containing red algae and coral are present in the exposed carbonate succession in the Shiraswar section and not diagnosed in the Sundor section, and this comes in line with many previous studies that diagnosed the presence of such facies in the Sinjar Formation, as we mentioned previously.

Acknowledgements

The authors are very grateful to the College of Science, University of Mosul for providing facilities, which helped to improve the quality of this work. The authors are very grateful to the Editor in Chief Prof. Dr. Rayan Ghazi, the editorial board members, and the technical editors for their great efforts and valuable comments.

References

Al-Banna, N.Y., Al-Mutwali, M.M. and Al-Ghrear, J.S., 2006. Facies Analysis and Depositional Environment of Khurmala Formation in Bekhair Anticline – Duhok Area, North Iraq. Iraqi Journal of Earth Science, 6, (2), pp. 13-25. DOI: 10.33899/earth.2006.36375

Al-Qayim, B., 1995. Sedimentary Facies Anatomy of Khurmala Formation Northern Iraq, Iraqi Geological Journal, 28, (1), pp. 36-46.

Al-Haj, M.A. and Al-Hamdani, A.M., 2005. New Outlook for the Stratigraphy of Sinjar Formation (Paleocene- Early Eocene) in Sinjar Anticline Northwestern Iraq. Rafidain Journal of Science, 16 (3), pp. 51-64. DOI: 10.33899/rjs.2005.41346

Al-Shamary, M.A., Malak, Z.A. and Al-Badrani, O.A., 2023. The Use of Calcareous Nannofossils in Determining the Age of the Sargelu Formation in the Hanjera Section, Sulimani Governorate, Kurdistan Region, Northern Iraq. Iraqi National Journal of Earth Science, 23, (1), pp.1-12. https://doi.org/10.33899/earth.2022.133948.1016

Aqrawi, A.A.M., Goff, J.C., Horbury, A.D., and Sadooni, F.N., 2010. The Petrolum Geology of Iraq. Statoil Scientific Press, 424 P.

Asaad, I.S., Balaky, S.M., 2018. Microfacies Analysis and Depositional Environment of Khurmala Formation (Paleocene-Lower Eocene), in the Zenta Village, Aqra District, Kurdistan Region, Iraq. Iraqi Bulletin of Geology and Mining, 14, (2), pp.1-15.

Asaad, I.Sh., 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 Iraqi Geological Journal, 55, (1F), pp. 20-39. DOI: https://doi.org/10.46717/igj.55.1F.2Ms-2022-06-17

Barzani, A. and Al-Qayim, B., 2021. Facies and Stratigraphic Associations of Sinjar and Khurmala Formation, Dohuk Area, Kurdistan Region, Iraq. Arabian Journal of Geosciences, 14, (3), pp. 162-180. DOI: 10.1007/s12517-020-06432-1

Bathurst, R.G.C., 1971. Carbonate Sediments and Their Diagenesis, Developments in Sedimentology 12: Amsterdam, Elsevier, 620 P.

Bellen, V.R.C., Dunnington, H.V., Wetzel, R., and Morton, D.M., 1959. Lexique Stratigraphique International. V. III, Asie, Fascicule, 10a, Iraq, Central National deal Recherche’s Scientifique, Paris, 333 P.

Boggs, S., 1995. Principles of sedimentology and stratigraphy, Prentice Hall, Englewood Cliffs, New Jersey, pp. 79-93.

Bosence, D.W.J., 1983. Coralline Algal Reef Frameworks. Journal of Geological Society, London, 140, pp. 365-376.

Brasier, M.D., 1980. Microfossils. George Allen and Unwin Ltd., London, 193 P.

Checconi, A., Bassi, D., Passeri, L. and Rettori, R., 2007. Coralline Red Algal Assemblage from the Middle Pliocene Shallow – Water Temperate Carbonates of the Monte Cetona (Northern Apennines, Italy), Facies, 53, pp. 57-66.

Dabrio, C.J., Esteban, M., and Martin, J.M., 1981. The Coral Reef of Nijar, Messinian (Uppermost Miocene), Almeria Province, SE Spain. Journal of Sedimentary Petrology, 51, (2), pp. 521-539.

Daoud, H., 2009. Microfossils and Carbonate Microfacies of Sinjar Formation, West of Sulaimaniya City, Kurdistan Region, NE Iraq. Iraqi Bulletin of Geology and Mining, 5, (2), pp. 13−28.

El-Azabi, M.H. and El-Araby, A., 2007. Depositional Framework and Sequence Stratigraphic Aspects of the Coniacian Santonian Mixed Siliciclastic/Carbonate Matulla Sediments in Nezzazat and Ekma Blocks, Gulf of Suez, Egypt. Journal of African Earth Sciences, 47, pp.179-202.

Flügel, E., 2010. Microfacies of Carbonate Rocks, Analysis, Interpretation and Application. Berlin, Springer-Verlag, 924 P.

Fouad, S.F., 2015. Tectonic Map of Iraq, Scale 1: 1000 000. 3rd Edition, 2012. Iraqi Bulletin of Geology and Mining, 11, (1), pp. 1-7.

Ghose, B.K., 1977. Palaeoecology of the Cenozoic Reefal Foraminifera and Algae - A Brief Review, Palaeogeography, Palaeoclimatology, Palaeoecology, 22, pp. 231-256.

Hallam, A., 1981. Facies Interpretation and the Stratigraphic Record, Freeman and Company, Oxford, 291 P.

Hallock, P. and Clenn, E. C., 1986. Large Foraminifera a Tool for Paleoenvironmental Analysis of Cenozoic Carbonate Depositional Facies, Palaios,1, pp. 55-64.

James, N.P. and Ginsburg, R.N., 1979. The Seaward Margin of Belize Barrier and a Toll Reefs. Morphology, Sedimentology, Organism Distribution and Quaternary History, International Association of Sedimentologists, Special Publish,3, 200 P.

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

Karim, Ch.A., 2009. Stratigraphical and Paleontological Study of Khurmala Formation (Paleocene – Lower Eocene) in Shaqlawa Area -Northern Iraq. Unpublished MSc. Thesis, Mosul University, Iraq, 103P.

Kassab, I.I. M., 1978. Planktonic Foramininferida of Subsurface Lower Tertiay of N. Iraq. Journal of Geology Society Iraq, 1, pp.119-159.

Malak, Z.A., 2011. Sedimentological and Stratigraphical Study of the Paleocene – Eocene Successions from Selected Areas – North Iraq. unpublished PhD. Thesis, Mosul University, 212 P. DOI: 10.1007/s12517-014-1547-z

Misra, P.K., Jauhar, A.K., Kishore, S. and Chowdhury, A., 2000. Calcareous Algae (Dasycladaceans and Gymnocodiacean) from the Palaeocene Deposits of the Tiruchirapalli (=Trichinopolly) Area. Tamil Nanda, India. Journal of Palaeontological Society of India, 45, pp. 151-164.

Mutti E., Rosell J., Allen G.P, Fonnesu F. and Sgavetti M., 1985. The Eocene Baronia Tide Dominated Delta-Shelf System in the Ager Basin. In: Mila M. and Rosell, J. (eds.) 6th IAS European Regional Meeting, Field Trip Guide Book, pp. 579-600.

Omer, M.F., Ali, D.O. and Zebari, B.Gh., 2014. High Resolution Cathodoluminescence Spectroscopy of Carbonate Cementation in Khurmala Formation (Paleocene-L. Eocene) from Iraqi Kurdistan Region, Northern Iraq. Journal of African Earth Sciences. 100, pp. 243-258. DOI: 10.1016/j.jafrearsci.2014.06.016

Onuigbo, E.N., Okoro, A.U., Obiadi, I.I., Akpunonu, E.O., Okeke, H.C. and Maduewesi, V., 2012. Tide-Generated Sedimentary Structures, Lithofacies and Particle Size Distribution: Proxies to the Depositional Setting of the Ajali Sandstone in the Anambra Basin, Southeastern Nigeria. Journal of Natural Sciences Research, 2, (6), pp. 100-112.

Qader P.O., 2020, Stratigraphy Microfacies and Depositional Environment of Oligocene Early Miocene successions at Sagrma and Aj-Dagh Structures, Kurdistan Region, Northeastern Iraq. In: Dissertation, Sulaimani University, Iraq, 135 P.

Racz, L., 1979. Palaeocene Carbonate Developments of Ras Alhamara, Oman. Bull. Cet. Rech. Explo. Prod. Elf-Aquitance 3: pp. 767-779.

Read, J.R., 1985, Carbonate platform facies Models, AAPG., 69, (1), pp. 1-21.

Sharland, P.R., Archer, R., Casey, D.M. and *et al.*, 2001. Arabian Plate Sequence Stratigraphy, Geo Arabia, Special Publication 2, Gulf PetrolLink, Manama, Bahrain. 371 P.

Selley, R.C., 1976. An Introduction to Sedimentology. Academic Presses, 2nd Ed., London, 408 P.

Sharbazheri, Kh.M.I., 2008. Biostratigraphy and Paleoecology of Cretaceous/ Tertiary Boundary in the Sulaimani Region, Kurdistan, NE-Iraq. Unpublished PhD. Thesis, Sulaimani University, 159 P.

Shinn, E.A., 1983. Tidal Flat, In: Scholle, P.A.; Bebout, D.G. and Moore, C.H., (Eds.), Carbonate Depositional Environments, American Association of Petroleum Geologists, Memoir, 33, pp.172-210.

Scholle, P.A., Scholle, D.S., 2003. Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis. American Association of Petroleum Geologist, 77, 474 P.

Simo, R.T., Malak, Z.A., Hussain, Q.M. and Mahmood, S.M., 2023. Microfacies Analysis and Depositional Environment of Baba Formation in Selected Wells from Kirkuk Oil Field, Northeastern Iraq. Iraqi National Journal of Earth Science, 23 (2), pp.105-123.

Tinterri R., 2011. Combined Flow Sedimentary Structures and the Genetic Link Between Sigmoidal and Hummocky-Cross Stratification. GeoActa, Bologna, 10, pp. 43-85.

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