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Lithological Variations and Facies Analysis of the Lower Part of the Bekhme Formation in Specific Outcrops from Dohuk Area, Northern Iraq

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ABSTRACT

The present study concerns the sedimentology of the lower part of the Bekhme Formation at the Bekhair anticline, Dohuk area, northern Iraq. This part shows a high spectrum of lithological and petrographical variations of allochthonous and autochthonous carbonate sediments. Accordingly, the formation is divided into three facies

1.Random clasts Carbonate Megabreccia.
2.Planktonic Foraminiferal Wackestone.
3.Rounded Clasts Intraformational Carbonate Conglomerate.

The facies analysis and their deposition mechanism suggest that the area's deposit environment represents a carbonate slope, which was affected by local tectonism of syndepositional normal faulting. The architectural analysis of the sedimentary environment shows that this fault had affected the facies directly, giving considerable variation in the sedimentary environment (depth, oxygen percent, and bioactivity). These variations are reflected in the carbonate rock types, sedimentary structures, and early diagenetic processes. The constructed sedimentological model for the basin in this particular environment proposed that this syndepositional normal fault was directly responsible for the type of carbonate rocks at the lower part of the formation (the older three facies), and this is reflected by increases in the angle of carbonate slope and also increasing of carbonate sediments mobility towards the half-graben made by the fault. The Bekhme Formation represents part of the main mega sequence (AP9). Within the Late Campanian – Maastrichtian age, this period is characterized by local subsidence caused by secondary normal faults, which are responsible for the formation of the secondary basin. The proposed fault in this study is one of these faults.

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التغايرات الرسوبية والتحليل السحني للجزء السفلي من تكوين بخمة في مكشف محدد من منطقة دهوك، شمالي العراق

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الملخص

تمثل الدراسة الحالية رسوبية تكوين بخمة في لب طية بيخير في منطقة دهوك. أن للمكشف الصخري لهذا التكوين في منطقة الدراسة طيفاً واسعاً من التغايرات الصخرية والبتروغرافية لصخور كاربوناتية منقولة وغير منقولة والتي أمكن في ضوئها تقسيم المكشف الصخري قيد الدراسة إلى عدة سحنات هي:

أ- سحنة البريشيا الكاربوناتية الكبيرة الحجم العشوائية الفتات.

ب- سحنة الحجر الجيري الواكي الحاوي على الفورامنيفرا الطافية.

جـ- سحنة المدملكات الجيرية داخلية التكوين المستديرة الفتات.

يوضح التحليل السحني أن بيئة الترسيب للمكشف قيد الدراسة هي بيئة المنحدرات الكاربوناتية المتأثرة بالعوامل التكتونية والمتمثلة بفالق اعتيادي مصاحب للترسيب. ويبين التحليل الدقيق لهيكلية بيئة الترسيب أن هذا الفالق قد أثر بشكل مباشر في السحنات المترسبة، ليعطي طيفاً واسعاً من المتغيرات البيئية (العمق ونسبة الأوكسجين والكثافة الإحيائية)، ولينعكس ذلك على نوعية الصخور الكاربوناتية المترسبة والتراكيب الرسوبية، ولاحقا على طبيعة العمليات التحويرية المبكرة. يوضح الموديل الرسوبي المقترح لحوض الترسيب ان الفالق الاعتيادي المتزامن مع عملية الترسيب كان المسؤول المباشر عن نوعية الصخور الكاربوناتية المترسبة في الجزء الأسفل من التكوين (السحنات الثلاثة الأولى) وينعكس ذلك من خلال زيادة ميل المنحدر الكاربوناتي وسرعة حركة الرواسب الكاربوناتية باتجاه نصف الخسفة التي صنعها الفالق. يقع تكوين بخمة ضمن التتابع الطباقي الرئيسي (AP9)، ضمن فترة الكمبانيان المتأخر والمسترختيان المبكر . حيث تتميز هذه الفترة بالتجلسات المحلية، الحاصلة نتيجة الفوالق الاعتيادية الثانوية المسؤولة عن تكون الأحواض الرسوبية الثانوية. والفالق المقترح في هذه الدراسة يمثل أحد هذه الفوالق.

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Introduction

Wetzel, 1950 in Bellen *et al.*, 1959 is the first who described the type section sequences of the Bekhme Formation in the far north of the Bekhme Gorge on the eastern bank of the Greater Zab River in northeastern Iraq. He divided the type section sequences for the formation, which is (315) meters thick, into three units depending on its rocky nature and the diversity of its fossils. These units are: The lower unit (10 m thick) is represented by a dark grey basal conglomerate layer sometimes turning brown. This layer is characterized by the presence of polygenetic breccia - conglomerate, and the marl rich in *Globigerina* and iron oxides. The intermediate unit (94 m) is characterized by the dark to light grey detrital reef limestone with rudist debris and other foraminiferal fauna. It is formally known as the "*Cosinella* zone". While the upper unit (211m) is characterized by thick and hard bituminous secondary dolomite layers. It is characterized by its abundance of dispersed glauconite and detrital limestones. Buday (1980) named the combined (Aqra-Bekhme Formation) on the sequences of both formations. While on the contrary, according to Karim's (2013) analysis, there are significant differences between the two formations in terms of lithology, environment, tectonics, and paleontology, necessitating their separation. He has suggested a new name (Perat Formation) for the Bekhme Formation to avoid previous confusion associated with its name, age, boundaries, environment, lithology, fossils, and tectonics. All previous studies (Al-Qayim, 1989; Omar, 2006) mentioned that the bottom contact surface of the formation is erosionally unconformable. Bellen, *et al*. (1959) mentioned the occurrence of polygenetic and basal conglomerate and breccias (about 10 m thick) between the two formations (Bekhme and Qamchuqa) Formation. The conglomerate represents a gap that extends from Late Albian to Early Campanian. A limestone bed terminates at the top of the formation with two hard ground surfaces containing prominent traces of borings. The Hardground surface represents the boundary between Bekhme Formation and the overlaying Shiranish Formation (Bellen, *et al*., 1959). The objective of the current study is to conduct a detailed field lithological description and petrographic analysis of the lower portions of the Bekhme Formation in a specific outcrop that occupies a 3-square-kilometer region in the northern Iraqi city of Dohuk. Then, facies analysis and a proposed sedimentary model have been postulated to reflect the most accurate picture of the formation's depositional environment in the Dohuk area. This picture links all of this to the geological and tectonic history of Iraq and the Middle East.

Materials and Methods

The fieldwork includes an accurate lithological description of all layers in this part of the Bekhme Formation (in the outcrop section) in the Dohuk area, with a follow-up of the vertical and lateral lithologic changes as well as the study of the sedimentary structures and trace fossils. The laboratory work includes preparing thin sections for examination under a polarizing microscope. All thin sections were stained using Alizarin Red S to differentiate between calcite and dolomite minerals as in the procedures suggested by (Friedman,1959).

Location and Geology of the Study Area

The study area is located in the Bekhair anticline, in the high folds zone. This fold is about 6 km northeast of the city of Dohuk (Jassim and Goff, 2006; Numan, 1997). The Bekhair anticline is an asymmetrical double plunging anticline trending NW – SE; the southern limb is steeper than the northern limb, especially in the Dohuk area. Thus, this area is a south-vergency fold, although a north-vergency fold distinguishes it from other areas. It is also sometimes characterized by the presence of an overturning in the layers, specifically in the west of the Zakho area. In this fold, the exposed rocks of the sedimentary sequences range in age from Upper Cretaceous to Neogene. These formations are older to younger (Bekhme, Shiranish, Kolosh, Khurmala, Gercus, Avanah, Pila Spi, Fatha, and Injana). These formations form two topographically elevated areas. The structural specifications of these two highs make them two separate folds, each of which has a plunge, the first being the Spi Rais Fold and the second the Geri Baran Fold. There is also an anticline fold separating these two structures. The reason for its existence has been explained by the basement faults' effect (Al-Alawi, 1980). The Karmawah Valley is the boundary between these two structures and serves as the folded saddle (Al-Hubaiti, 2008). The study area (Outcrop 3 Km) lies geographically in the north and northeast of the city of Dohuk, northern Iraq. This outcrop extends from the south of the village of Ikmalah and along the valley of Kay Sandalki, which meets the valley of Karmawah. It is located between latitudes 36˚34' 29"- 36˚32' 16” N and longitudes 43˚03' 19" – 43˚oo' 47" E (Fig. 1).

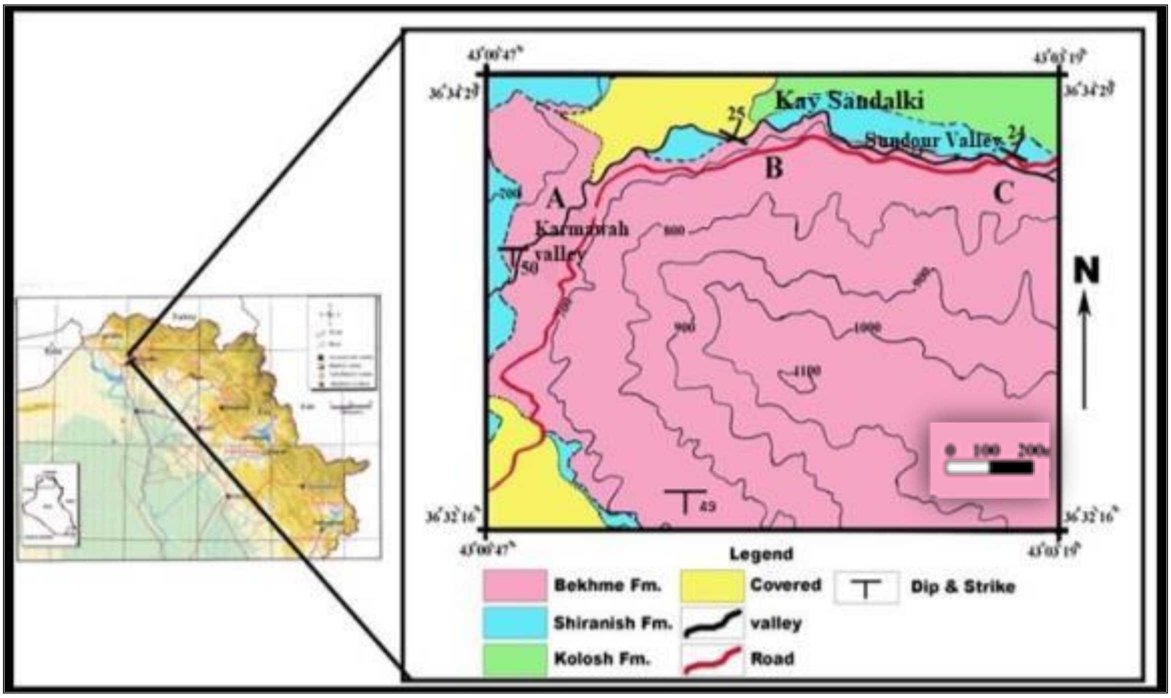

Fig. 1. Location map of the study area showing a geologic map of the exposed rocks under study an location of the studied outcrops: (A) Karmawah valley, (B) Kay Sandalki, and (C) Sundour Valley.

Results

Lithological and Facies Analysis

The outcrop under study shows a significant variation in the types of the rock components, as it consists of two main types of carbonate deposits, which are often present in conjunction, namely Type1: allochthonous carbonate deposits: Type2: fine grain carbonate deposits (autochthonous).

To obtain the best possible definition of the lower part of the Bekhme Formation rocks in this outcrop, the current study worked on dividing the apparent sequences into the following types (Fig 2):

1- Carbonate conglomerates: are divided into (a) Basal conglomerates, (b) Carbonate megabreccia, and (c) Intraformational carbonate conglomerates. Most of these lithofacies are well exposed in the Karmawah valley.

2- Marl and marly limestone.

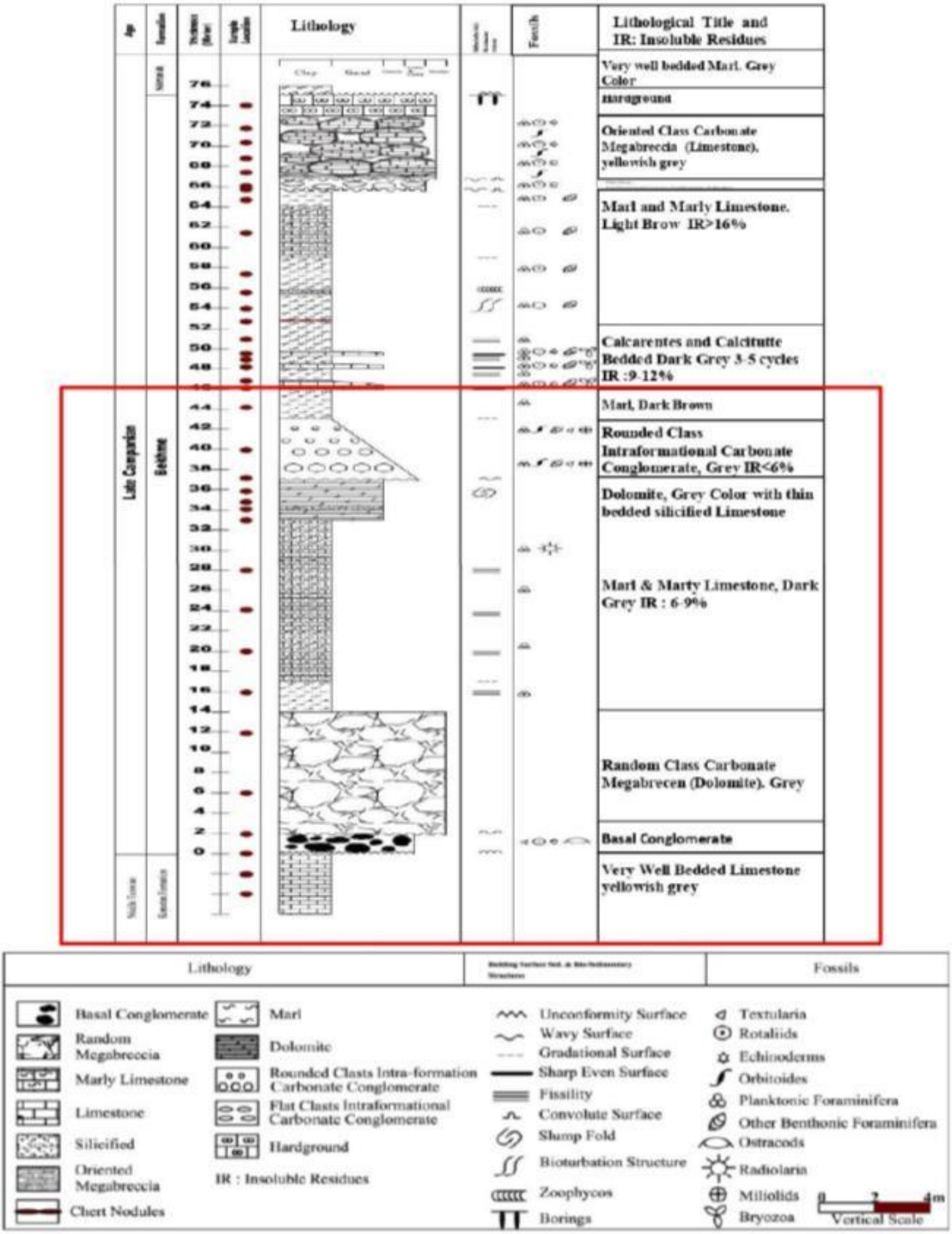

Fig. 2. Composite Section Showing the lithologic succession of the studied part of the Bekhme Formation in the study area.

Lower Boundary and Underlying Formation

The Bekhme formation consists of a (2 m) thick basal conglomerate layer in the lower (Figs. 2 and 3). This basal conglomerate consists of clastic rocks of different sizes (2 mm-15 cm), dark brown, poorly sorted, and surrounded by a reddish-grey marl groundmass as an indication of sediment exposure and erosion in an oxygen-rich environment (Fig 3). In the clastic and groundmass, various types of (skeletons and crashed) fossils such as planktonic and benthonic foraminifera, Rotaliids, Ostracods, and Echinoderm observe. The planktonic foraminifera species found in the detrital debris of the Bekhme Formation's basal conglomerate layer are similar to those found in the sediments beneath it, but they did not persist in the sediments above it, particularly the species (*Helvetoglobotruncana helvetica*), index to the Middle Turonian age. (Caron, *et al.,* 1985). In addition to the presence of chert rock fragments, evidence of materials resistant to erosion and transport processes funded from outside the sedimentary basin. The basal conglomerate layer is affected by some diagenesis processes, such as cementation and dissolution. Based on the above, the current study concludes that the basal conglomerate layer is evidence that previous sediments were exposed and eroded before the current formation sequence deposits. These sediments were then re-deposited at the beginning of the sedimentary basin's formation to develop Bkhmeh. Accordingly, this layer (the basal conglomerate) has become an indication of an unconformable surface separating the sediments of the Bekhme Formation, whose age was determined by Al-Mutwali, *et al*. (2008) in the Late Campanian and the sediments below it; the deposit below the Bekhme Formation consists of two layers (2 m) (Fig.3) of yellowish-grey limestone, good bedded, very hard, (Globigerinal - Oligosteginal limestone deposits), (Middle Turonian) age depending on the presence of (*Helvetoglobotruncana helvetica*) index of that age.

Many previous studies, such as (Bellen *et al*., 1959, and Al-Qayim and Shaibani, 1995) confirmed the presence of polygenetic breccias basal conglomerate at the base of the Bekhme Formation. They noted that this contact in the type section is unconformable with the Qamchuqa Formation beneath it. This study on the Bakhme Formation in northern Iraq shows the existence of an unconformable surface indicated by the basal conglomerate layer that separates the Bakhme Formation from the strata beneath it. The current study suggests that these deposits below the Bekhme Formation originally belong to the Kometan Formation because it is one of the most common secondary sedimentary cycle formations (Turonian - early Campanian) in northern Iraq (Jassim and Goff, 2006). And because of the remarkable similarity of lithology facies with the Kometan Formation (Globigerinal - Oligosteginal limestone deposits) according to many studies such as (Bellen, *et al*., 1959; Hamoudi, 1995; Abawi and Mahmood, 2005; Al-Khafaf, 2005, and Al-Jubory and Al-Mutwali, 2019). It seems that the reason for not mentioning most of the geological studies related to the Dohuk area is the presence of sediments from the Kometan Formation in the area due to its small thickness compared to the large thicknesses of the prevailing formations in the region

Fig. 3. The basal conglomerate layer and the yellowish-grey limestone layer extending under the basal conglomerate layer

Facies Analysis and Sedimentary Environment

The diversity of rock components in the current study sequences shows a broad spectrum of rocks represented by allochthonous and fine-grained carbonate deposits (autochthonous). In dividing and naming facies, it is taken into account to show the transport and sedimentation mechanisms of the components of the transported facies (allochthonous); as for the fine-grained facies (autochthonous), the system of Dunham (1962) is adopted to classify and then nomenclate them

1. Random Clasts Carbonate Megabreccia

Fig. 4. Random clasts carbonate megabreccia.

These facies have a thickness of 12 m. It is located above the basal conglomerate layers and is separated from them by an uneven to the wavy contact surface, while the upper contact surface is at the first appearance of dark color marl and marly limestone (Fig. 2). The megabreccia facies is characterized by unclear bedded, poorly sorted random clasts. These clasts have semi-circular and angular to semi-angular edges and range in size from a few centimeters to about 4 meters (Fig. 4). The groundmass surrounding the large-sized clasts in these facies is characterized by poorly sorted clasts ranging in size from small pebbles to sand.

Microscopic analysis reveals dolomite as almost the single fundamental component of the clasts and groundmass. Several different forms of dolomite may be distinguished, including planar-s, microcrystalline, and nonplanar. The microscopic analysis also shows fractures that penetrate the rock's body but stop at the rock's edges and do not continue to expand into the groundmass. These fractures range in size from 1 mm to 1 cm (Fig. 5). Numerous generations of limpid dolomite crystals with rhombic shapes or crystals with blades whose long axes are perpendicular to the fracture fill these fractures. This type of cement did not exhibit corrosion indicating that dedolomitization would not occur. Another indication that dolomite does not form in various chemical conditions, such as regions with varying salinities, is the absence of central opaque crystals or those distinguished by the zonation phenomena. Based on what was indicated by Flugel (2004) that understanding the enormity of the modulatory processes and the tectonic timing of the breccia is done by knowing the type of cement and its spatial distribution. This study concludes that the fractures and this process of dolomite occurred in these rocks before the formation and development of the large breccia (before brecciation) and may go back to the oldest formation.

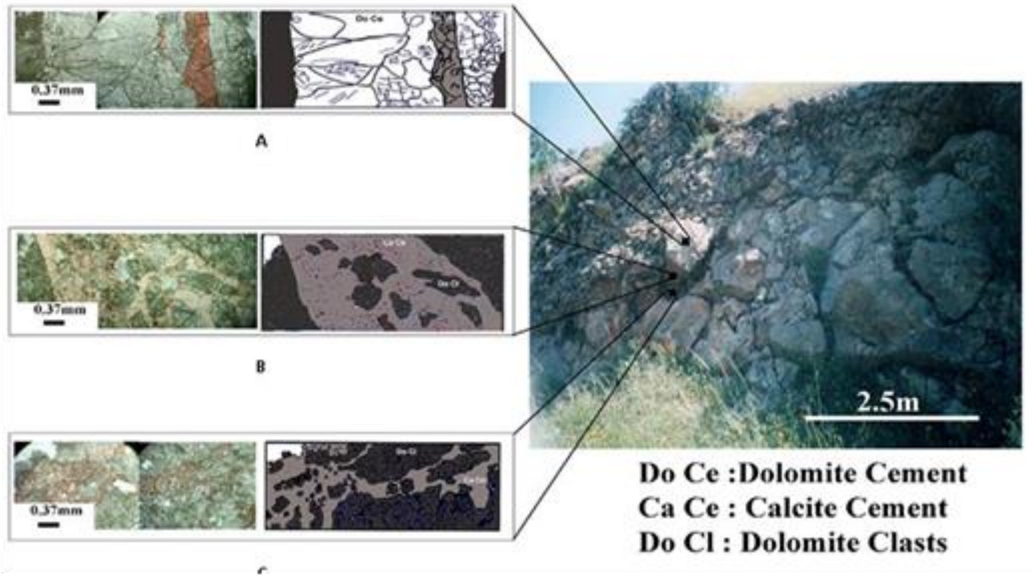

Fig. 5. Penetrating fractures of clast in the layer of megabreccia: (A) center clast, (B) the outer edges of the clast, and (C) groundmass.

It is clear from the characteristics and location of this carbonaceous breccia that they are topped by marl and limestone reflecting deep marine sediments. And by contrasting them with the features of the carbonaceous breccia species mentioned by (Flugel, 2004) that the breccia under study is like the type known as (submarine rockfall breccia) and was created by the rockfall process (Nardin, *et al*., 1979; Lowe, 1979 and Flugel, 1982).

2. Planktonic Foraminiferal Wackestone Facies.

These facies represent the marl and marly limestone layers that are dark in color and fissile. The facies appears twice during the studied section; the thickness of the first appearance is estimated as more than (21m), while the thickness of the second appearance is estimated as (3 m) (Fig. 2). The facies analysis of this facies shows that it contains fine grains of micrite rich in planktonic such as (*Heterohelix* sp., *Hedbergella* sp., *Globigerinelloida* sp.) and a percentage of (*Globotrauncanita* sp. and radiolaria skeletons), which indicates its deposition in a calm environment with low current energy that is unable to remove it, and this environment is usually under the base of the influencing waves and can reach the slopes environment (Sliter, 1972). Most of these grains are immersed in a micrite floor containing between (9% and 6%) of the clays, indicating the energy of calm currents and sedimentation in marine environments far from the coastline and the occurrence of marine progress (Flugel, 1982). The diagenesis processes affecting these facies differ according to their different vertical stratigraphic location. It is strongly dolomitized in its upper parts, specifically within the last four meters, thus forming a layer of uneven mosaic dolomite with interconnected and well-interconnected crystals. The most significant characteristics of this dolomite layer are the following: the dolomite part contains some slumping structures (Fig. 6A and C), the presence of pyrite mineral in its various forms within the dolomite layer (Fig. 6C), the insertion of a layer of chert in-between the dolomite crystals (Fig. 6B), its dark color, the excellent preservation of the fossil structures (Fig. 6D), and finally their freedom from trace fossils

That suspension settling mechanism is likely responsible for the deposition of these facies. The study relied on naming these facies on microscopic facies and not on field facies because these facies represent fine-grained carbonate deposits (autochthonous), which is based on Dunham's classification in diagnosing and naming them.

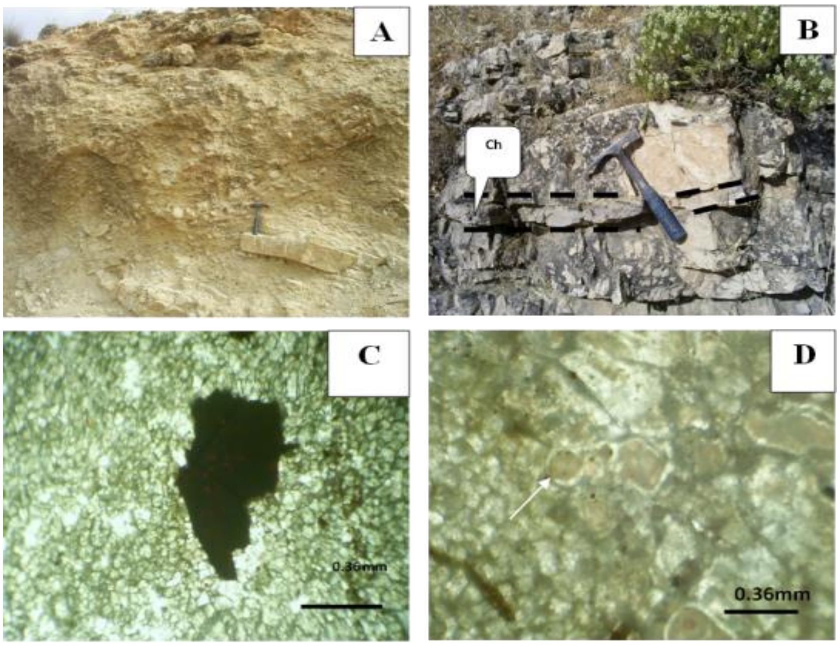

Fig. 6. A. Slump Fold in the dolomitization part, B. Inserting a layer of chert into the marl rocks, C. pyrite in the dolomite layer, and D. the excellent preservation of the fossil structures or (skeleton).

3. Rounded Clasts Intraformational Carbonate Conglomerate Facies

These facies, with a thickness of (6 m), is revealed after the first appearance of the planktonic foraminiferal wackestone facies and separated by a sharp, erosional, uneven contact surface. In contrast, the upper contact surface is a gradient with the same facies (Figs. 2 and 7). These facies are distinguished by the presence of semi-round to round clasts that can range to 10 cm in diameter, finning gradient towards the top. The clasts show the clast-supported fabric in the lower parts of the facies, while the matrix-support fabric appears in their upper parts. These facies exhibit a smooth gradient towards the top.

Fig. 7. Rounded clasts intraformational carbonate conglomerate layer, note the bottom contact surface (uneven sharp stripper or erosional).

Microscopic analysis reveals that the clasts in these facies contain the large and benthic foraminifera life assemblies (*Pseudochrysalidina* sp, *Textularia* sp, *Omphalocyclus* sp, Miliolids, Rotaliids). While shown in the groundmass that there are planktonic foraminifera and a small amount of clay (less than 6%). These facies were affected by several diagenesis processes, most notably the recrystallization process, which has a substantial impact on the clast. Some iron oxides were also observed in the form of a thin crust, sometimes extending to the cracks around the edges of that clast indicating a transfer process. The current study suggests that the mechanism responsible for forming these facies is gravity flow or debris flow according to the classifications of Nardin *et al*. (1979); Lowe (1979); and Flugel (1982).

Discussion

The Structure of Sedimentation Environment

The facies division in this study shows that the depositional environment of these sediments is the carbonate slope environment. The distinct facies in this study can be compared to several other similar facies in this environment. All studies concur that the succession of these facies reflects the slope's characteristics, whether the slope's inclination angle or the type of sediment (clast or carbonate) it contains. The outcrop under the current study shows that it consists entirely of carbonate rocks. Accordingly, its environmental analysis will confine to the environment of the carbonate slope deposits. According to Drzewiecki (2002), this environment is distinguished from the environment of clastic slopes by the following characteristics:

1. Higher depositional slope angles
2. Potentially higher sedimentation rates
3. Early cementation
4. Linear sediment sources
5. Local sediment production
6. Carbonate slopes are affected by external factors that control their development, including changes in sea level, tectonics, paleoceanography events, climate, and siliciclastic influx (Stow, 1986).

To understand the nature and structure of the sedimentation environment of the studied rocks, the facies sequence and their inter-relationships to each other will be discussed.

The outcrop under study is characterized by the random clasts carbonate megabreccia facies, which is suggested by the current study to belong to pre-formed rocks caused by the rockfall process. These facies exhibit a clast-supported fabric, an essential characteristic of submarine rockfall breccia that occurs on high-angle slopes of more than 30 degrees (Drzewiecki, 2002). Those slopes are caused by tectonic activity (the effect of a fault), which results in the formation of a sub-surface groove in one of the directions of the fault surface and subsequently causes the collapse of rocks towards that groove (Friedman and Sander, 1978; Drzewiecki, 2002; Fadhel *et al*., 2019). The stratigraphic age and rock types of the collapsed rocks vary according to the rock sequences exposed to erosion. Therefore, the origin of the collapsed rock fragments can be suggested as the deposits of the most ancient formation. Megabreccia is entirely composed of dolomite rocks, so it is reasonable to believe that the clasts are a part of the Qamchuqa formation. This assumes that the Kometan Formation's thickness is minimal when it is compared to the Qamchuqa Formation, as its thickness does not exceed thirty meters in most of the discovered localities in northern Iraq. Accordingly, the pieces of rock that collapsed from it are few compared to the thickness of the megabreccia.

Planktonic foraminiferal wackestone facies is distinguished by the fine grains of micrite rich in planktonic organisms (*Heterohelix* sp., *Hedbergella* sp., *Globigerinelloida* sp.), and a percentage of (*Globotrauncanita* sp. and radiolaria skeletons). This indicates that they were deposited in a calm marine environment with low current energy that cannot remove them. And this environment is usually under the base of the influencing waves and can reach the slopes environment (Sliter, 1972). This facies' clay content ranges between (9% and 6%), showing the energy of calm currents and deposition in marine environments distant from the coastline, as well as the presence of marine progress (Flugel, 1982). Based on what was presented above, planktonic foraminiferal wackestone facies is equivalent to the (SMF-3) facies deposits in the third facies zone (FZ-3) (Pelagic facies), according to Wilson (1975) and Flugel (1982). These facies represent pelagic facies deposited during the period of relative calm following the severe tectonic event in the carbonate slopes (Mcllreath & James, 1984).

The dolomite part of this facies is characterized by several interpretations, the most important of which are the following:

1. The distinguishing placement of the dolomite rocks in the upper portion of the dark-colored marl and marly limestone (rich in foraminiferous plankton) indicates the deep marine environment with low oxygen.
2. Some slumping structures within that dolomite part (Fig. 6A and C) indicate the severity and speed of burial and isolation. These structures occur when semi-solidified sediments are available on unstable slopes, leading to their slump and fold and thus subject to the documentation process under the influence of the deformation conditions (Selley, 2000).
3. The presence of layers of rounded clasts intraformational carbonate conglomerate (Fig. 2) directly over that dolomite part and with a steep, erosion, uneven surface (Fig.7) is evidence of steep slope, burial, and isolation.
4. The presence of pyrite mineral in its various forms within the dolomite layer (Fig. 6C) can indicate the sulfate reduction process resulting from the decomposition of organic materials and in oxygen-poor reducing conditions (Berner and Westrich, 1985; Lith *et al*., 2000).
5. Finally, the insertion of a layer of chert between the dolomite crystals (Fig. 6B), its dark color, the excellent preservation of the fossil structures (Fig. 6D), and their freedom from trace fossils indicate low levels of oxygen, the speed of burial, isolation, and high content with organic materials.

Because of the characteristics of the rocks, the current study suggested the Al-dolomite model (organogenic/methanogenic dolomitization), with a depth of a few hundred meters (maybe 700m) (Warren, 2000).

As for the rounded clast intraformational carbonate conglomerate facies, gravity flow or debris flow is the reason. Many researchers emphasized the importance of this process in transporting sediments on steep carbonate slopes. Many features characterized by this facade refer to the following explanations:

1. These facies exhibit a smooth gradient towards the top with an uneven contact surface, it is an essential characteristic of debris flows that occur on steep carbonate slopes.
2. the clasts in these facies reflect the nature of the wacky limestone that contains the benthic foraminiferous skeletal and crushers indicating the neritic environment (Grafe, 2005), immersed in the groundmass that contains planktonic foraminifera and a small amount of clay (less than 6%) indicating deep marine environments. All this explains the process of transferring these clasts to deeper sites.
3. Some iron oxides are observed in the edges of that clast indicating a transfer process.
4. It is also possible to explain each of the following phenomena (low clay content of 6%), erosion contact surface, frequent planktonic foraminiferal wackestone facies at the top of these facies; the source of carbonate clasts feeding these facies was far from the coastal areas. And these facies representing the deposits of debris flows was sudden and local, and their appearance is limited to the site (A) in the rock outcrop under study (Fig.1).

Accordingly, the current study suggests that the source of the clasts is the edges footwall. And once it rises to the creation of shallow neritic carbonate sediments, those sediments move to the deep regions of the groove produced by the fault after erosion by the waves. That is, confirming the continuation of the fault movement when deposited. A relative calm follows this after movement, and the planktonic foraminiferal wackestone facies return to precipitation for a second time

Sedimentary Model

The Cretaceous period in Iraq witnessed tectonic compression conditions due to the opening of the Neo-Tethys ocean, which led to the form of listric normal faults, rift basins, and suspended basins (Numan, 2000). The Late Campanian period in northern Iraq is characterized by local subsidence (Sharland *et al*., 2001). This study of the Bekhme Formation in the Dohuk area proposed a model of the environments of the carbonate slopes resulting from a submarine fault synchronous with sedimentation. This fault is a reflection of the tectonic factors affecting the sedimentary environment. To give the final picture of the sedimentary model, the idea of carbonate ramps emerged as a result of the development of pelagic carbonate platforms (PCPs) proposed by Santantonio (1994). The followings are the basic types of these models (Fig.8):

1-Pelagic carbonate platforms with semi-flat sedimentation surfaces.

2-Pelagic carbonate platforms with inclined surfaces of more than (3º).

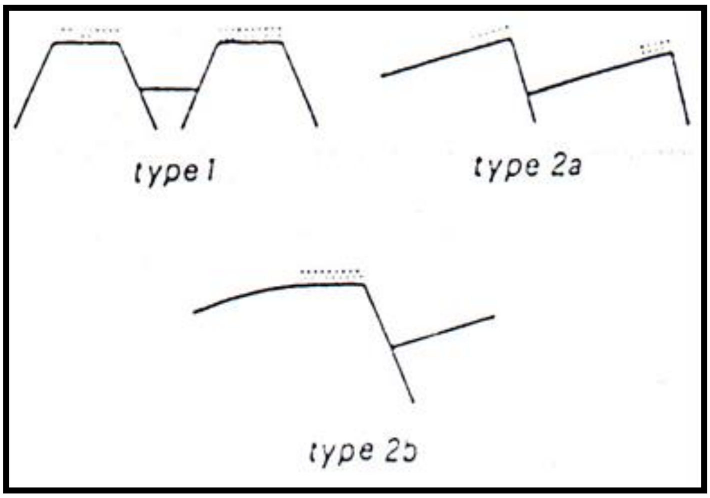

Fig. 8. The main types of models of pelagic carbonate platforms (Santantonio, 1994).

Based on the identified facies data, the current study suggests pelagic carbonate platform systems with inclined surfaces greater than (3º). As the inclined mass formed by a fault synchronized with sedimentation and by a greater inclination to one of the sides along the surface of the fault creates what is called a half-graben structure. This structure surrounds on both sides by two slopes, a somewhat high slope representing the fault surface and a less inclined slope representing the carbonate slope on the opposite side (Fig.9). Accordingly, there are two types of transported sediments:

The first type: are the sediments coming from the direction of the fault plane. They are controlled by the nature of the fault's slope and the continuity of its movement and direction. This type applies to the deposits of the current study.

The second type: are the sediments coming from the carbonate slope. This type represents the deposits of the upper part of the Bakhme Formation in the current study, outside the scope of the current research.

Megabreccia facies records the rock falls caused by the occurrence of the fault. These facies work to fill the half-graben formed by the fault and the continuity of its movement. When the fault movement slows, the precipitation processes of planktonic foraminiferal wackestone facies begin. The continuation of the gradual increase in depth towards the half-graben is caused by either continuity of fault movement downward, or/and the continuity of marine progress. The sedimentary basin registers its maximum depth. It then begins to form the appropriate environment for the dolomitic process (700m) within the half-graben represented by the subsidence block of the fault. Interestingly, the maximum flood surface type (K175) determined at depths close to that layer of dolomite (Al-Mutwali *et al*., 2008) is a result of a sudden marine overflow.

On the other hand, the rising mass that reaches shallow depths is quite suitable for producing neritic carbonate deposits above it at the fault level. After then, the sediments begin to collapse as semi-consolidated clastics towards the half-graben to record the precipitation of rounded clasts intraformational carbonate conglomerate facies over planktonic foraminiferal wackestone facies. The planktonic foraminiferal wackestone facies returns to precipitation for a second time indicating either the filling of the half-graben or the stopping of fault motion while the sea advance proceeds. Thus, the production of shallow carbonate deposits in the rising mass of the fault stops with increasing depth (immersion). Thus, the collapsed clasts that consist of rounded clasts and intraformational carbonate conglomerate facies gradually stop. All of the deposits representing the above facies had low clay content, indicating that the source of carbonate clasts feeding these facies was mainly towards the open sea.

The proposed normal fault in the sedimentary model presented by the current study represents what was theoretically postulated by other researchers. This type of fault was called a normal secondary fault. The main faults are the normal listerian faults, which arose on the Arabian plate's northeastern edge as a result of the opening of the Neotethys ocean, which peaked in the early and middle Jurassic periods. The general direction of the racket of these listerian faults is northwest-southeast (Numan, 2000). As for the normal secondary faults, which the current study suggests, have affected the rocks of the Bekhmeh Formation, they are located between the main faults parallel to them, and are often in the same faulting system. However, it occurs later, with a small displacement and a shorter geographical extension. Secondary faults correspond to the so-called longitudinal faults (Ameen, 1992). These secondary faults are responsible for the formation and alteration of many sedimentary basins to form the pelagic carbonate platforms PCPs (Santantonio, 1994) or suspended basins (Numan, 2000). Sharland *et al*. (2001) indicated that the late Campanian period in northern Iraq is characterized by local subsidence due to those normal secondary faults synchronous with sedimentation. Sharland et al. (2001) showed that the flood surface of the type (K175) is one of the difficult-to-distinguish surfaces that arise in response to local subsidence due to tectonic faults. This surface came in the current study to characterize the maximum extent of the fault movement or/and the continuity of marine progress to record the full depth of the sedimentary basin.

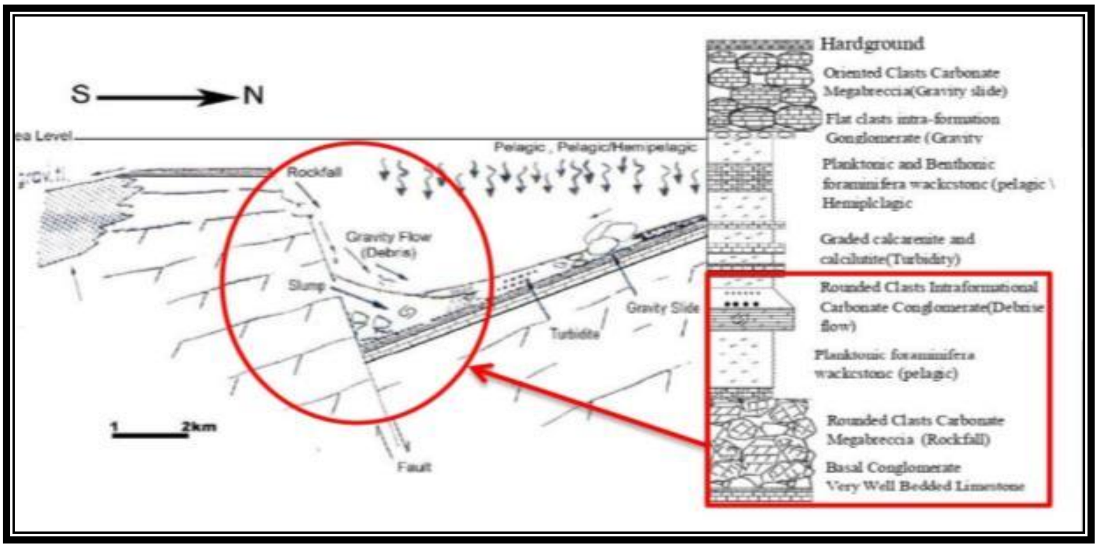

Fig. 9. Sedimentary Model. Note: (Inclination angles, vertical scale) are indicative only.

Conclusion

The followings are concluded in the current study:

• The field study of the outcrop of this upper part of the Bekhme Formation shows that the carbonate rocks understudy can be divided into two main categories: allochthonous carbonate and fine-grained carbonate (autochthonous).

• Based on the rock variations in physical field characteristics and laboratory petrography, the rocks of the current study are divided into three facies. By comparing the diagnosed facies with their published counterparts, it is possible to identify the sedimentary processes responsible for their formation as follows:

1. Random clasts carbonate megabreccia facies (submarine rockfall).
2. Planktonic foraminiferal wackestone facies (suspension settling).
3. Rounded clasts intraformational carbonate conglomerate facies (debris flow).

• The facies analysis and their deposition mechanism suggest that the area's environment of deposition was a carbonate slope, which was in turn affected by tectonism, represented by a syndepositional normal fault.

• Due to the period in which the formation sequences understudy of the Late Campanian were identified from local subsidence caused by the faults, the fault in the current study represents one of the normal secondary faults located between the main faults arising on the northeastern edge of the Arabian plate. These secondary faults are also characterized by being parallel to the main faults and having the same cleavage system. However, it occurs later, with a small displacement and a shorter geographical extension. Secondary faults correspond to the so-called longitudinal faults. These faults create and alter many sedimentary basins, thus contributing to the creation of pelagic carbonate platforms (PCPs), or the so-called suspended basins.

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