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Determination of the Origin of Mukdadiya Formation's Gravels in Al-Teeb Region, East of Maysan Governorate, Southern Iraq, Based on Sedimentological and Paleontological Evidence

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Abstract
Mukdadiya Formation represents one of the formations that cover a huge area of Iraq. It contains several clastic deposits, such as sandstone, siltstone, and a noticeable amount of gravels. The gravels are considered as the hallmark to differentiate between Injana and Mukdadiya formations. Therefore, the current study focused on these facies to determine the petrography, paleontology , and origin of Mukdadiya deposits. The results of SEM-EDX and XRD analyses showed two types of gravels, namely the siliceous and lime gravels. The highest percentage of gravels belonged to the sedimentary origin (limestone). The elements of Si, Ca, and Fe represented the common elements that formed the studied gravels. The paleontological study displayed numerous fossils that are composed of these gravels, belonging to several groups, including foraminifera, radiolaria, dinoflagellata, echinoida, gastropoda, and calcisphera. Also, four microfacies were identified in the studied gravels. After comparison of all collected data with selected formations, the results confirmed that the origin of the derived gravels is from the Qulqula Formation, because of their content of radiolaria and the other characterizing fossils.

Keywords: Mukdadiya Formation, Lime Gravels, Qulqula Formation, Al-Teeb geology, Iraq.

أصل الحصى التابع الى تكوين المقدادية اعتمادا على الأدلة الرسوبية والمستحاثية في منطقة الطيب، شرق محافظة ميسان، جنوب العراق

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قسم علم الأرض، كلية العلوم، جامعة البصرة، البصرة، العراق

الخلاصة
يمثل تكوين المقدادية أحد التكاوين التي غطت مناطق شاسعة من العراق، فهو يحتوي على العديد من الرواسب الفتاتية مثل الحجر الرملي، والحجر الغريني، وكميات مميزة من الحصى، وتعتبر الحصى السمة المميزة لتفريق بين تكويني الإنجانة والمقدادية. لذلك ركزت الدراسة الحالية على هذه الرواسب الحصوية لتحديد الصخارية المستحاثية لها، لغرض معرفة أصل رواسب تكوين المقدادية. أظهرت نتائج SEM-EDX و XRD نوعين من الحصى، حصى السيليكاتي والحصى الجيري، حيث النسبة الكبيرة من الحصى تعود الى الحجر الجيري.
تمثل العناصر Si، Ca، Fe اهم العناصر المشتركة التي شكلت الحصى المدروسة. بينما أظهرت دراسة المستحاثات العديد من المتحجرات المشكلة للحصى، وهي تعود إلى عدة مجاميع مثل المنخربات، والراديولاريا،

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والدينوفلاجيلات، والبطنقدميات والكلسيسفيرات. كما تم تحديد أربعة سحنات دقيقة للحصى. بعد مقارنة جميع البيانات التي تم جمعها مع التكاوين عدة، أكدت النتائج أن منشأ الحصى المشتقة هو من تكوين كلكلة، بسبب احتواء هذه الحصى على الراديولاريا والمتحجرات الأخرى.

Introduction

The study area is located in the northeastern part of Maysan Governorate, specifically within Al-Zubaydat area, east and southeast of Al-Teeb city, on the eastern borderline between Iraq and Iran, with coordinates of $47^{0}23'00''$ and $32^{0}23'40''$. Tectonically, the study area falls within the range of the low folds zone [1] and within the Hamrin Subzone- Foothill Zone of the Unstable shelf area [2] (Figure-1). This region is considered as one of the most seismically active places in Iraq, with a seismic intensity value reaching 5.7 magnitude [3, 4].

Mukdadiya Formation is one of the widespread formations in Iraq, which shows many of its outcrops with thicknesses of more than 30 m at Al-Teep region. The formation was studied from the sedimentary aspect in the north, northeast and western regions of Iraq. Those studies were concentrated on the sandy part in particular. A few other studies focused on the clay part due to its geological and application importance, sedimentary environment conditions, and ancient climate indices, on one hand, and as a basic material for most ceramics industries, on the other hand [5].

Pilgrim (1908 in [6]) described the formation of Bakhtiari (Mukdadiya) for the first time in a descriptive study based on hand specimens and field observations inside Iran. The study found that it consisted of conglomerate rocks of limestone and flint, which were in layers intertwined with sandstones (Figure-2).

Slinger and Crichton [7] found that it was thick sediment composed mainly of coarse sandstones and rambles intertwined with thin bands of marl. Al-Naqib [8] divided the formation into two parts: Lower Bakhtiari (Mukdadiya) and Upper Bakhtiari (Bai Hassan), both of which are from the Pliocene age. The deposition environment for this formation is that of rivers (Fluvial and estuarine sediments).

Lees [9] studied formation sediments and concluded that these sediments are the result of the erosion of the Zagros Mountains in northeastern Iraq, which were subsequently deposited in submerged basins located between the Arabian Shield and the Zagros Mountains, which suffer from continuous sitting in their bottoms. Salih (1975 in [10]) diagnosed the presence of a large percentage of limestone in Al-Jazirah desert area in northwestern Iraq. Sadik [11] also compared between the gravel of the Mukdadiya and Dibdibba formations, and distinguished them based on the rock composition of gravel.

He confirmed the presence of the gravel of flint and quartz types in Mukdadiya Formation, while the gravel of igneous rocks is predominant in Dibdibba Formation.

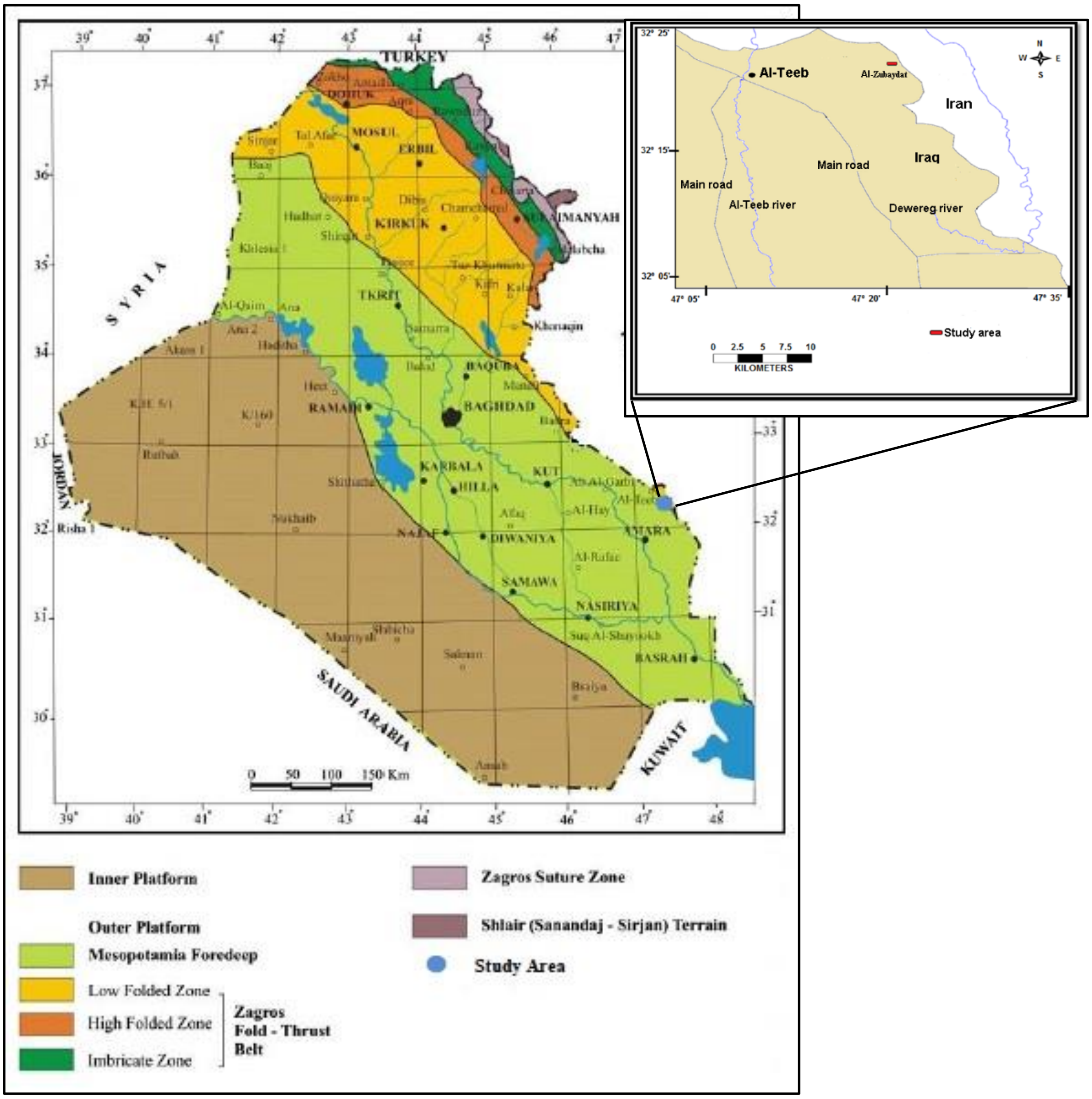


Figure 1- Location of the study area in Al-Teeb area- Zubaydat region, Maysan Governorate [12]

Abdulnaby *et al* [13] in their study of Mukdadiya Formation in southeast regions of Iraq, stated that the typical environment of the Mukdadiya Formation is fluvial that rapidly subsides in the foredeep basin. It consists of continental clastics in which the size of grains ranges from the size of silt to the size of coarse gravel and conglomerates. The size of the gravel increases towards the top, while the presence of conglomerates gravel in the upper part of the formation gave the reason to consider this formation as an independent stratigraphic unit. Eanad [14] studied the stratigraphy and sedimentation of the Mukdadiya Formation in Badra region, where he showed by the petrographic study that the lime gravel is predominant in the formation sediments, followed by the flint and quartz gravel, then the igneous rocks gravel and finally the metamorphic rocks gravel. The ancient currents indicate that the source rocks of the sediments of the Mukdadiya Formation are located at the regions in the north and northeast of Iraq, represented by Zagros mountain range.

Jassim [15] also studied the rocks and sediments of the Mukdadiya Formation in Badra region, eastern Iraq. Carbonate arenite type is the common sandstone that was recorded at the region, because it contains a high percentage of carbonate rock pieces with fewer rates of quartz and feldspar. The formation shows an immature mineral textures composition that appears to the proximity of the source area of the Zagros mountain range, along with a river deposition environment in an arid to semi-arid climate. The age of the formation of Mukdadiya was estimated to be at the Pliocene period based on its location in the stratum column, due to the scarcity of the index fossils, except *Hipparion* sp. (Thomas *et al.*, 1978 in [6]). Al-Samaani [16] concluded that the sedimentation environment for the formation of Mukdadiya was riverine. The sandy rocks in it are characterized by immaturity, and its presence indicates a rapid erosion of the source rocks, a short transport distance of clastics, and a high velocity of sedimentation. The prevalence of calcareous gravel pieces in the Mukdadiya Formation presented the possibility that these pieces are used to determine the source rocks for these sediments, especially since the existence of a large proportion of these gravel supports the near source of these sediments.

This research aims to study the gravel of the distinctive limestone type found within the gravel components, which forming Mukdadiya Formation in terms of sedimentary, mineralogical, and paleontological aspects. We also try to diagnose the types of fossils that were found for the first time in these gravels. These data were collected to identify the source rocks of this formation and the sedimentary environment, which accompanied its rocks before being exposed to the processes of weathering, fracturing, and moving to the new sedimentary basins that accumulated in areas southern Iraq.

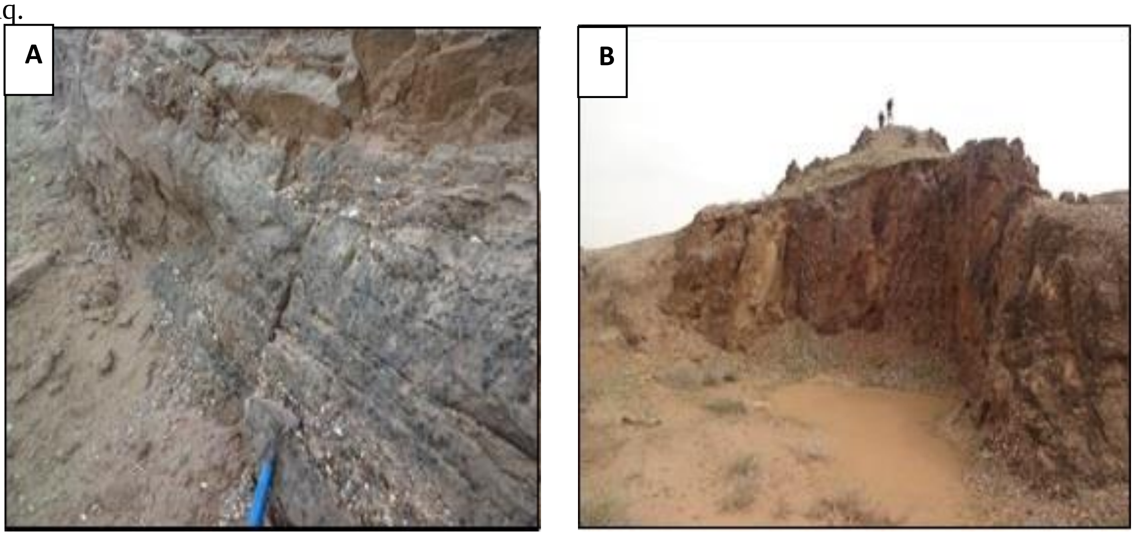


Figure 2- Various views showing sand and gravel components **(A)** in the ridge outcrops **(B)** of the Mukdadiya Formation in the Al-Zubaydat region, Maysan Governorate.

Methodology

More than 45 pieces of lime and siliceous gravels of different sizes and shapes were collected from Mukdadiya Formation in the outcrops of Al-Zubaydat area, east of Al-Teeb region. These gravels ranged in sizes between 2 to 5 cm with different colors, varied between white, light brown and dark brown, with some mixed-colored samples. Some of these samples were examined with XRD technique (4 samples) and EDX- scanning electron microscope (3 samples) in the laboratories of the Physics Department of Basrah University to identify their rock and mineral types and distinguish them from other types of igneous and metamorphic gravels. Also, 30 thin section of these gravels were made to study the microfacies, especially carbonate pieces. Then, a paleontological study was conducted to discover whether they contain a large number of fossils of different types and species, with the goal of identifying the sedimentary environment that accompanied the microfacies and determine their source rocks.

Geological and stratigraphical setting

The age of the Mukdadiya Formation (lower Bakhtiari Formation) was determined to be at the Late Miocene –Pliocene, depending on its position between Injana and Bai Hassan Formations, because it is devoid of index fossils and composed of transported deposits [17]. At Al- Teeb region, Mukdadiya Formation is formed of numerous sedimentary cycles. Mostly, the cycles are composed, from the bottom, of conglomerates, sandstone and claystone. There are also different sizes of gravels and sand, but still represents fining upward cycles reflecting fluvial environments. The range size of gravel varied between 0.2 to 5 cm.

The total thickness of the studied formation is not exceeding 60 m (Figure-3). it has many sedimentary structures, such as planer cross- bedding, Hummocky cross stratification, load casts, trough cross-bedding, graded bedding, and channeling, sometime filled with gypsum. The contact with two formations (Injana and Bai Hassan) is conformable, sometimes covered with Quaternary deposits. Most Quaternary sediments of the Mesopotamian plain southern Iraq cover large areas of the unstable shelf [18]

Mineralogy and petrography

In order to make the initial diagnosis and determine the mineral composition of the studied gravel samples, these samples were first manually examined to determine their general characteristics. The stones selected were light brown to dark reddish-brown colored (Figure- 4), separated from the pebbles of igneous or metamorphic origin that were characterized by dark gray, black or dark colors. Most of the samples were characterized by more smooth texture, greasy luster, and smooth edges than the other types of gravel.

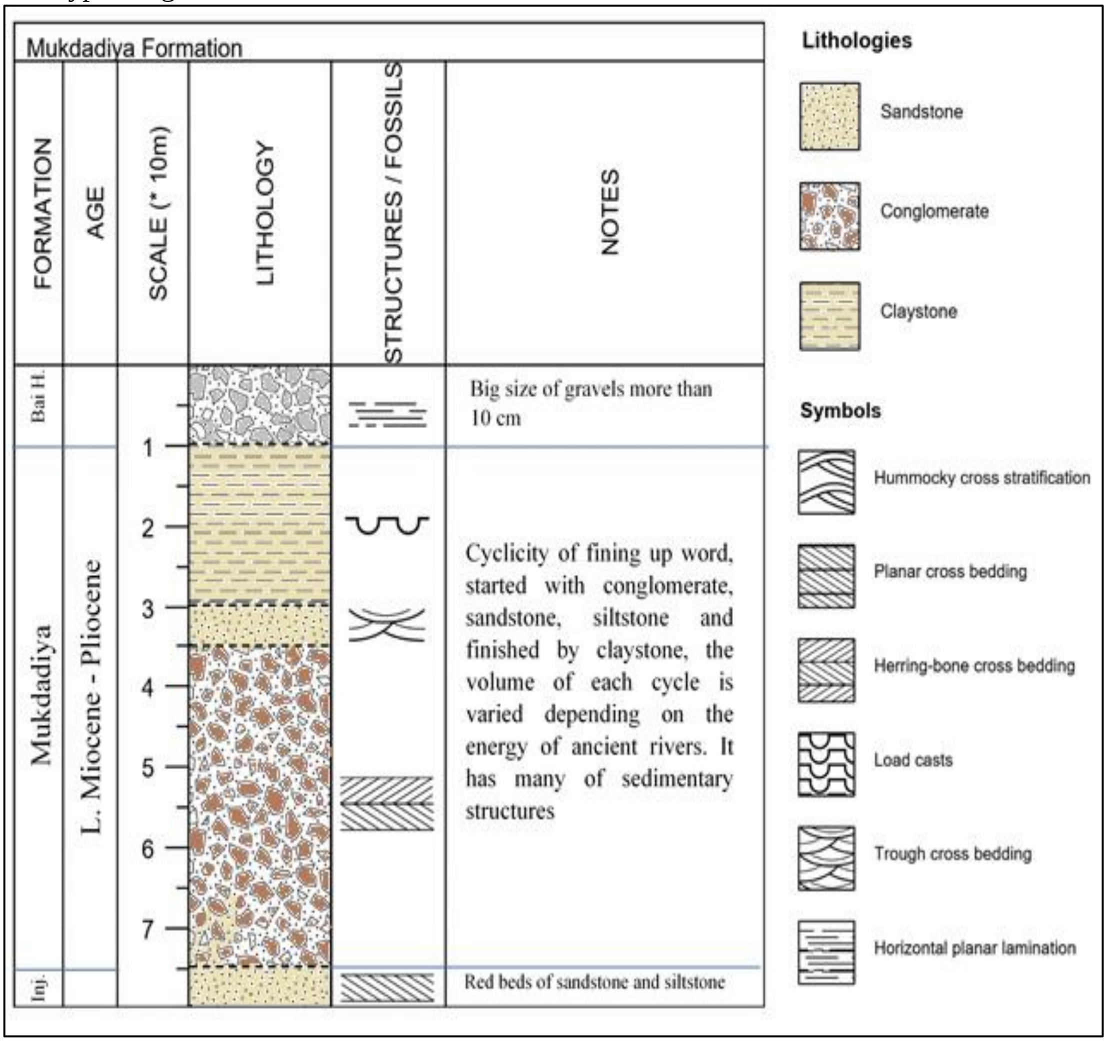


Figure 3- Stratigraphic column of Mukdadiya Formation at Al-Teeb region, Maysan Governorate.

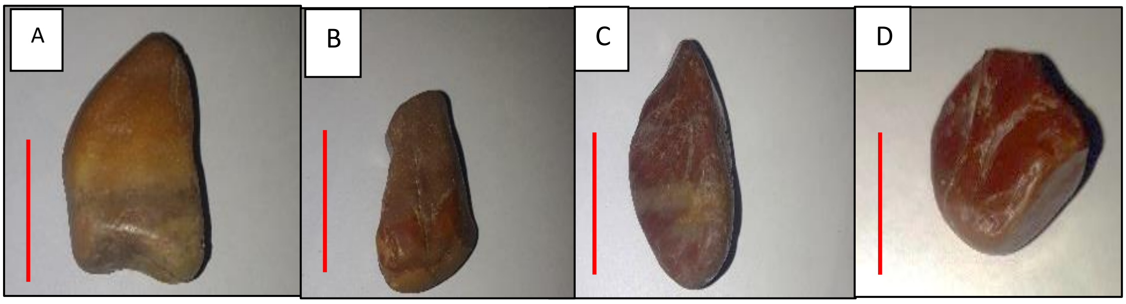


Figure 4- Various samples of lime gravels abundant in Mukdadiya Formation, showing the colors gradient from white to dark brown (length of red line= 2cm).

Selected samples of these gravels were examined using XRD technique in the laboratories of the Department of Physics at the College of Science / University of Basra. These tests showed two types of these sedimentary gravels; the first type was the siliceous gravel that consists of quartz minerals with a small percentage of calcite and dolomite minerals (Figure-5.1). The other type was the lime gravel composed mainly of calcite with a small percentage of dolomite and quartz minerals (siliceous) (Figure-5.2), meaning that these mineral components are present in most of the studied gravel types, but in varying proportions.

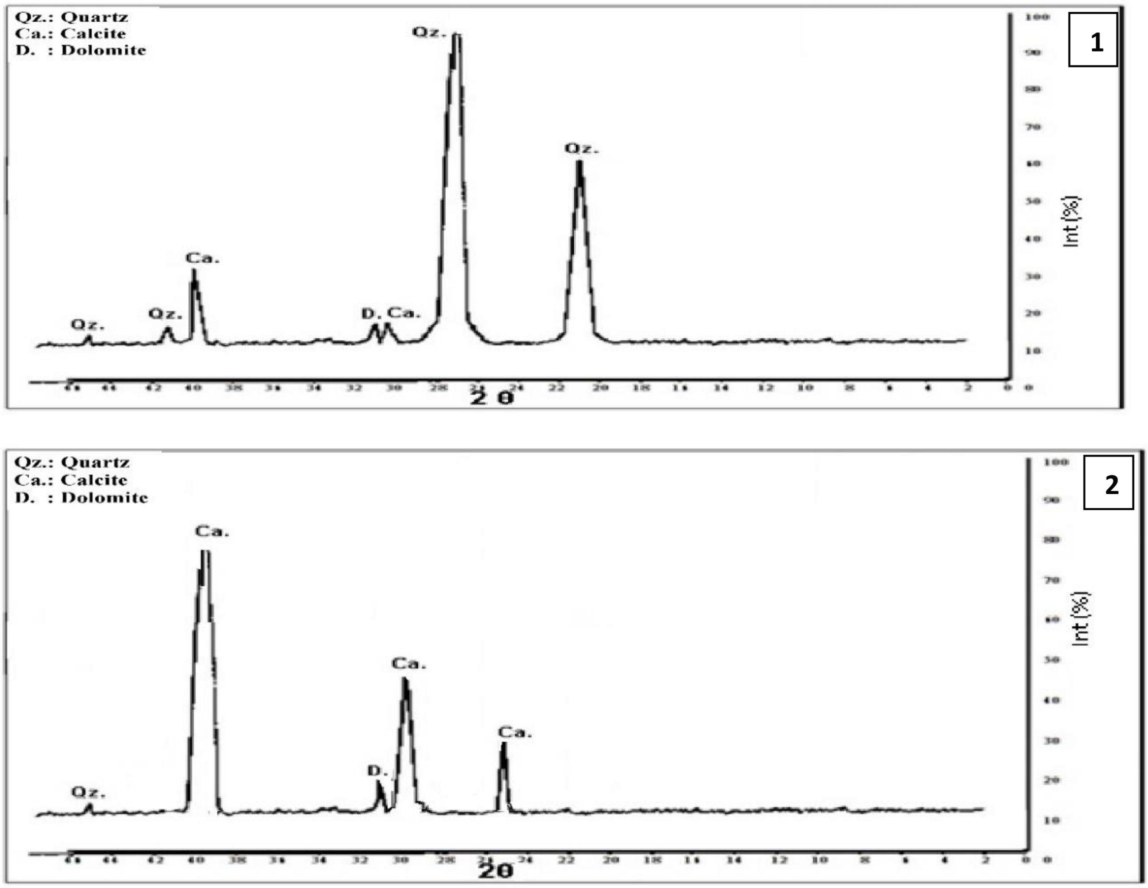
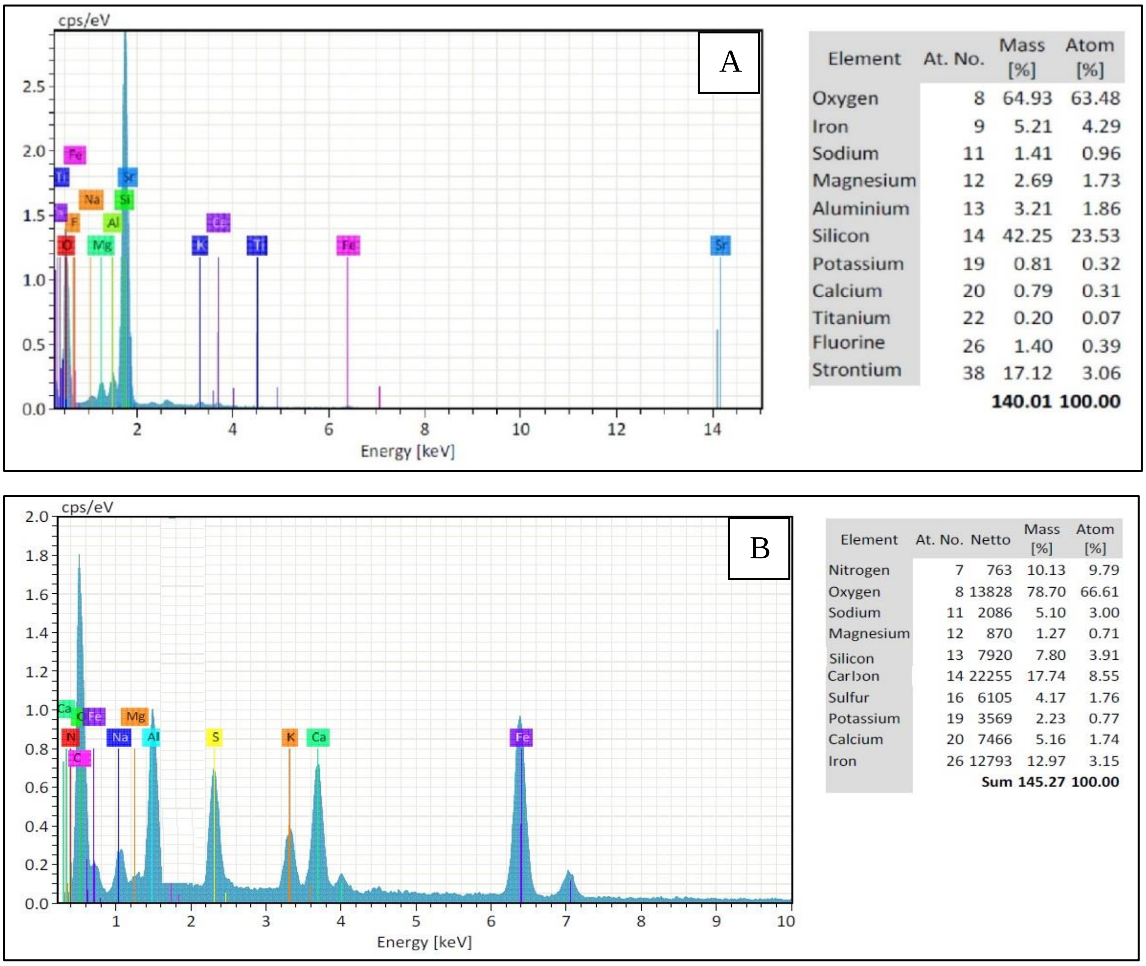


Figure 5- Results of XRD analyzes of selected samples of Mukdadiya Formation gravels in Al-Teeb area **(1)** siliceous gravels **(2)** lime gravels.

To support the results of the mineral study, an SEM-EDX examination was performed for these samples. The first type of sedimentary gravel, consisting of silica degree, appeared mainly (Figure-6a), while the second type was clearly of lime type (Figure- 6b). Good concentrations of iron oxides appeared in these samples, which explain the brown color of these types of gravel. They had a proportion of 4.29% of the siliceous gravel type (Figure-6a), along with 3.15% of the lime gravel type (Figure- 6b). This is believed to be the cause of the dark red-brown color in the hand specimens of siliceous gravel samples (Fig. 4 C, D) compared with lime gravels (Figure- 4A, B). The siliceous composition of the siliceous gravel as well as the limestone's containment of good proportions of silica may have been produced from silicification processes that the original rocks were exposed to before weathering and moving from the source rocks. This is due to the fact that this process increases the cohesion and hardness of sedimentary rocks and makes them resistant to the weathering processes and moving to great distances from the source rocks.

Thin microscopic sections were made for these gravels. Their optical and mineral properties were studied and their sedimentary and bio- facies were diagnosed in detail, which enhanced the results of the mineral analysis of these stones. It was diagnosed that some samples contain silica minerals (quartz) (Figure-7A), mainly with calcite and dolomite minerals. While the other samples are represented by calcareous rocks composed of calcite mineral in the form of micrite, sparite, or bioclast granules, with high levels of silica, as matrix, and cementing materials (Figure-7B).

A simplified statistical study was conducted for the studied random samples (45 samples) by distinguishing calcareous samples from silicified ones, as well as determining the degree of roundness and sphericity of these samples by comparing them with Power Chart, 1953 (Figure- 8, Table- 1). Through the examination of these stones, it was found that the percentage of the silicate type is higher than that of the calcareous type. In addition, the calcareous gravels were more rounded and spherical than the silicate gravel. This is due to the high hardness that is characterized by the silicate stones over the calcareous ones, as well as the transfer of gravel from the source rocks by transportation makes the gravel highly roundness.



Element	At. No.	Mass [%]	Atom [%]
Oxygen	8	64.93	63.48
Iron	9	5.21	4.29
Sodium	11	1.41	0.96
Magnesium	12	2.69	1.73
Aluminium	13	3.21	1.86
Silicon	14	42.25	23.53
Potassium	19	0.81	0.32
Calcium	20	0.79	0.31
Titanium	22	0.20	0.07
Fluorine	26	1.40	0.39
Strontium	38	17.12	3.06
		140.01	**100.00**

Element	At. No.	Netto	Mass [%]	Atom [%]
Nitrogen	7	763	10.13	9.79
Oxygen	8	13828	78.70	66.61
Sodium	11	2086	5.10	3.00
Magnesium	12	870	1.27	0.71
Silicon	13	7920	7.80	3.91
Carbon	14	22255	17.74	8.55
Sulfur	16	6105	4.17	1.76
Potassium	19	3569	2.23	0.77
Calcium	20	7466	5.16	1.74
Iron	26	12793	12.97	3.15
		Sum	**145.27**	**100.00**

Figure 6- SEM-EDX analyses of selected samples of Mukdadiya Formation gravels in Al-Teeb area; (A) siliceous gravels (B) lime gravels.

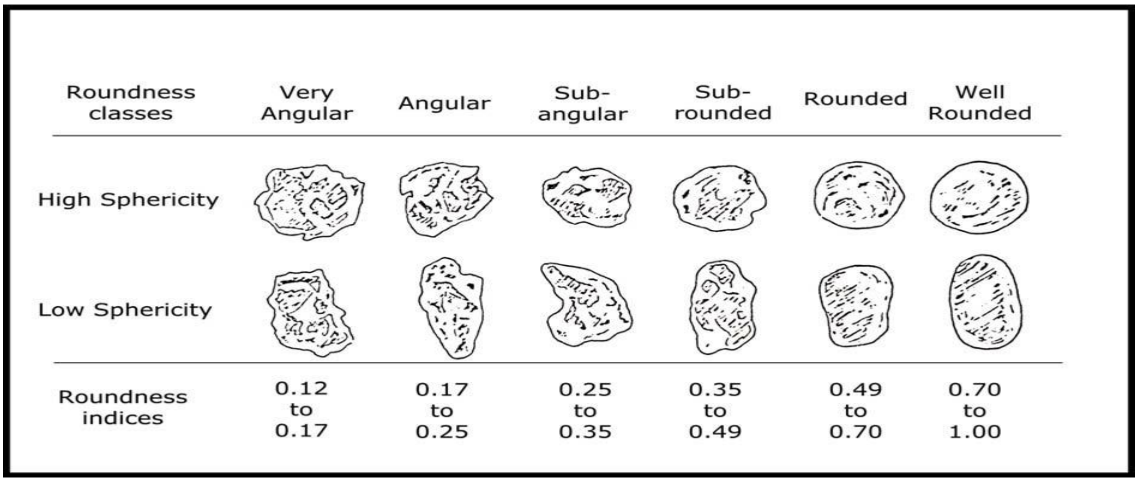


Figure 7- Estimating chart for the roundness and sphericity of sedimentary grains [19]

Table 1-Types and properties of gravels that collected randomly from Mukdadiya Formation, Maysan

Sample No.	Gravel type	Roundness (%)		Sphericity (%)	
		Sub-rounded	Rounded	Low	High
45	**Siliceous** (28)	79	21	89	11
	Calcareous (17)	88	12	24	76

2. Sedimentological and Paleontological studies

Many types of sedimentary microfacies were recognized for the Mukdadiya gravels, but we can classify them into four microfacies, these are**:**

1. Radiolarian -rich siliceous facies: siliceous groundmass was recorded at the varied types of gravels**.** The radiolarian assemblages form most of the identified siliceous gravels, whereas spumellaria assemblages disperse with abundant amount, where the ghosts of the rounded radiolarian are still existing (Figure- 8 A).

2. Crystalline limestone: Recrystallization refers to changes in crystal size, crystal shape and crystal lattice orientation without changes in mineralogy [20]. Two types of crystalline limestone of studied gravels were identified; the recrystallized limestone is the type which is completely changed to limestone rock (Figure- 8 B), whereas the partially recrystallized type implies that it suffered from neomorphism with less degree of diagenesis. It is generally thought that micrites can eventually transform to microspar through aggrading [21]. Because of the high diagenesis for groundmass, this microfacies rarely has fossils (Figure- 8 C).

3. Calcispheric Packstone Microfacies: These facies are characterized by an assemblage of Calcispheres. This type of fossils was diverse at the Cretaceous period and then started to extinct during the middle Cenozoic. Its small calcite spheres, up to 500µm in diameter, are believed to be of algal origin. They consist of a micrite wall enclosing an interior, which is hollow or filled with sparry-calcite (sparite) [22] (Figure- 8 D and E). The type of calcisphere is varied in size and shape, sometimes being of micritic or spiritic structures with an obvious ring. The second dominant group that disperses in that microfacies is Radiolaria. Also, there is another fossil with this microfacies, that is echinoids (Figure- 9A). The groundmass has a little micrite, while the percentage of fossils reaches to 90 % with a rare mount of pyrite [20].

4. Radiolarian Wackestone Microfacies: this microfacies is characterized by dispersion of radiolarian species. It is full with spumellaria assemblages that are floated in an organic matrix (Figure- 8 F). Also, many fossils exist at this facies, such as pteropod shells (Figure- 9C). The types of radiolarian are varied in shape and cover most of the microfacies; most of the identified genera are*:* *Dictyomitra multicostata* (Figure-9-B), *Pantanellium* sp. (Figure- 9D*),* spumellaria assemblages (Figure- 9E), *Nassellaria* sp. (Figure- 9F), *Cryptamphorella* sp. (Figure- 9G and H), with specially recorded *Dinoflagellate cyst Parastomiosphaera* sp. (Figure- 9E). Unfortunately, the other of the existence fossils not-identified by thin section, they need several of chemical analysis until extracted and classified. The percentage of micrite is high compared with that of the second facies, reaching to 20%.

Results and discussion

The current study aims to determine the origin of the deposit for Mukdadiya Formation in Al -Teeb region, by using simple information that are available from lime and siliceous gravels. However, sedimentary and paleontology evidence was collected. The most common fossils found are Radiolaria and Calcisphera. The calcispheres is a famous fossil that dispersed during the Cretaceous, with rare existences at the Jurassic period. Therefore, it is present in many formations in Iraq, such as Chiagara, Baluti, Sargelu, Naokelekan, Najmah, Qamchuqa, Sarmord, Qulqula, Rumaila, Kometan, Gulneri, Dokan, Balambo, Khasib, Hartha, Mushorah and Shiranish.

Most of these formations are deposited at deep marine environments. Generally, the huge dispersion for radiolarian genera was recorded in most of the studied gravels. These crowds of fossils resemble the calcisphere, but they are different in wall composition. Therefore, the polarized microscope was used to differentiate between them. Fortunately, the radiolarian groups were discovered at few formations in Iraq, Qulqula Formation represents the most important formation where radiolarian occurred. It also collects all the discovered fossils, such as calcisphere and gastropod shells. Qulqula Formation is divided into two units, namely the bedded and conglomeratic deposits. The suggestion that the origin of Mukdadyia's Formation is the lower part of Qulqula Formation is based on conglomeritic units.

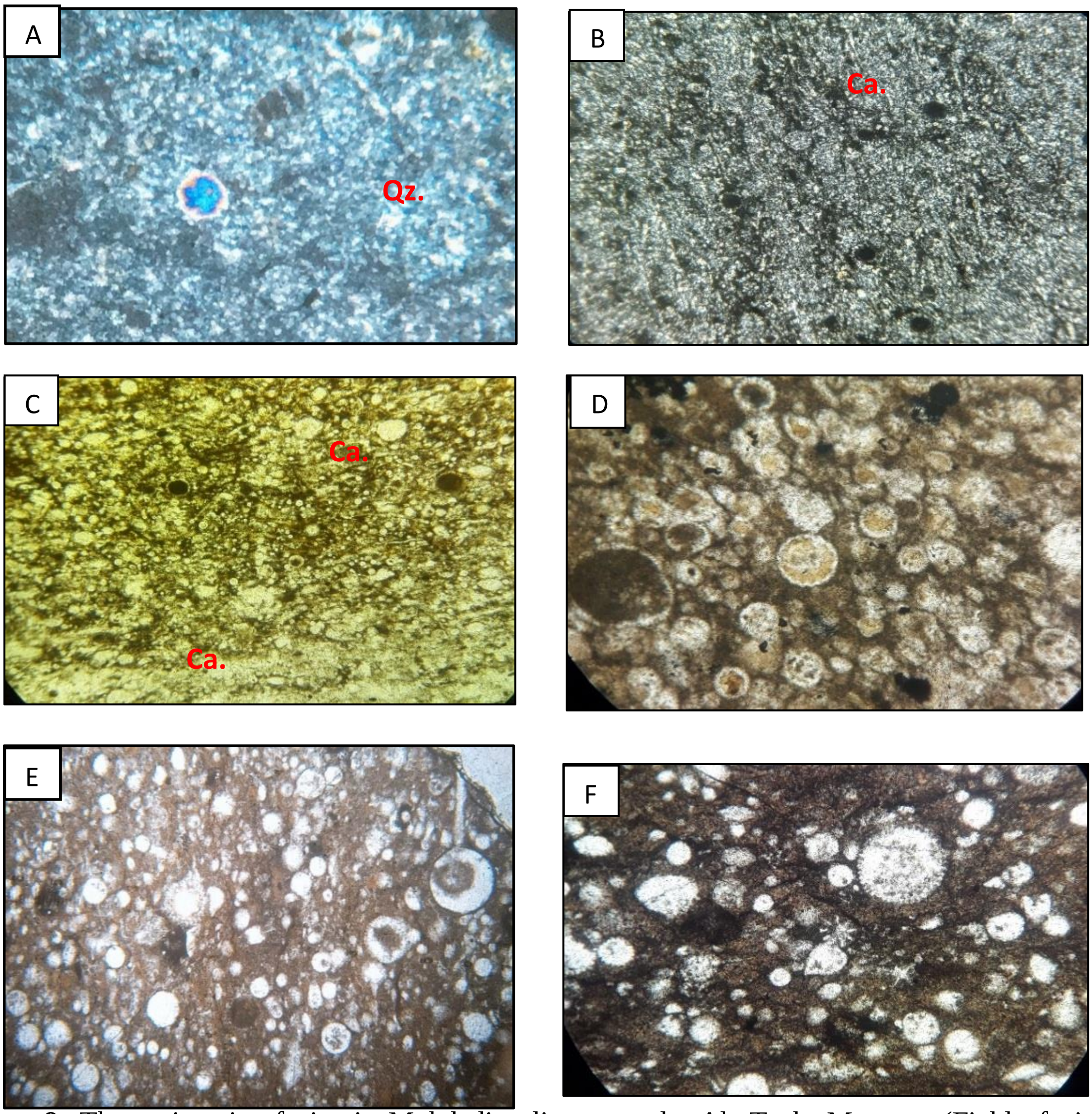


Figure 8- The main microfacies in Mukdadiya lime gravels, Al- Teeb, Maysan (Field of view = 1mm).

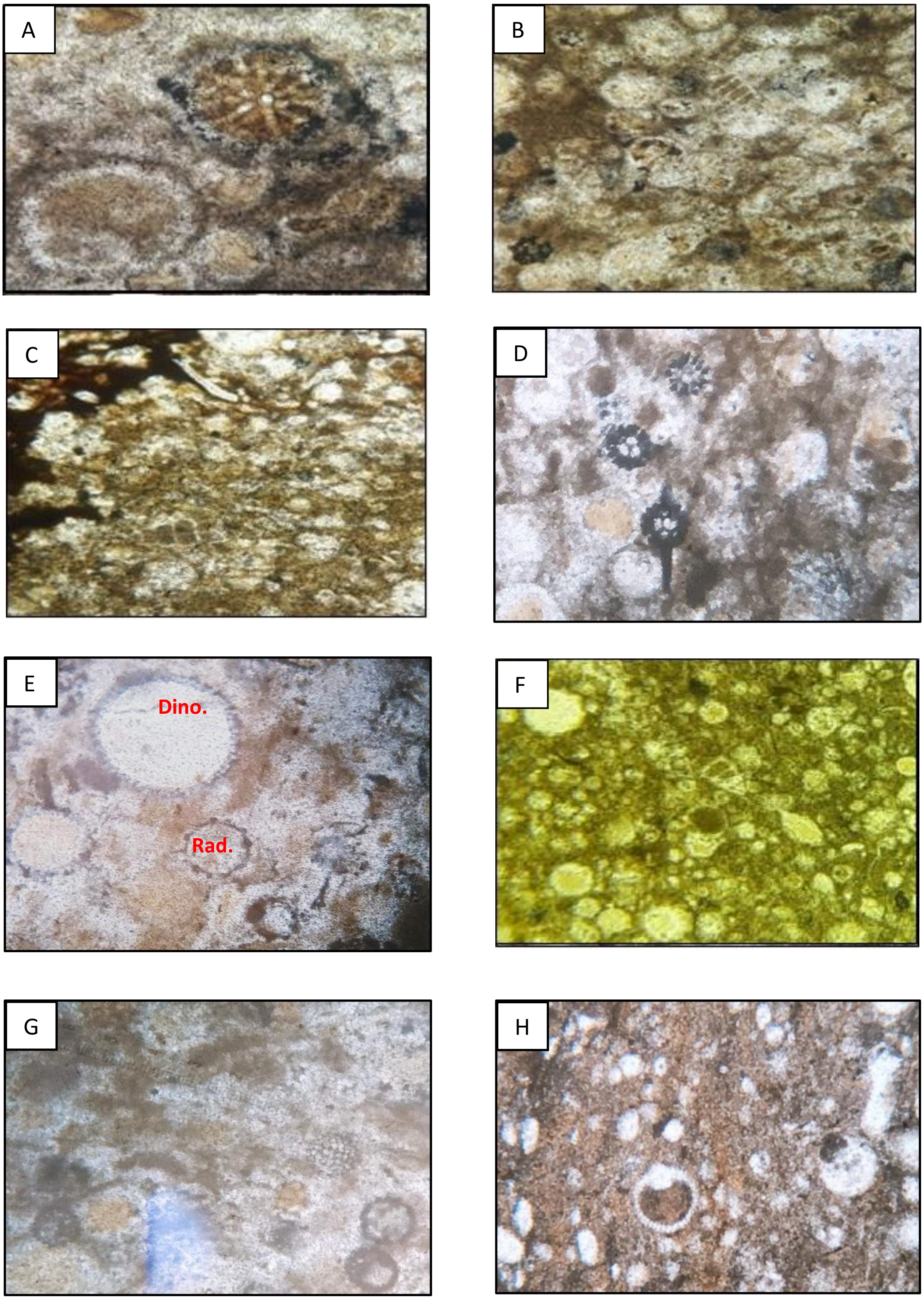


Figure 9- The main types and species of microfossils identified in Mukdadiya Formation lime gravels (Field of view = 0.5 mm) (Dino: Dinoflagellate; Rad: Radiolaria).

The age of this formation is considered to be a mysterious puzzle. The most recent study assigned the formation to an extended age that started at the Bajocian (Middle Jurassic) and ended at the end of the Cenomanian (early Late Cretaceous) (89 My) [23]. Pelagic sediments are characterized in the deep-marine basins in open-marine and deep shelf settings [24]. This is the common microfacies present in the Mukdadiyah's gravels. The existence of Qulqula Formation is restricted at the northeastern part of Iraq within Zagros suture zone [25, 26] (Figure- 10).

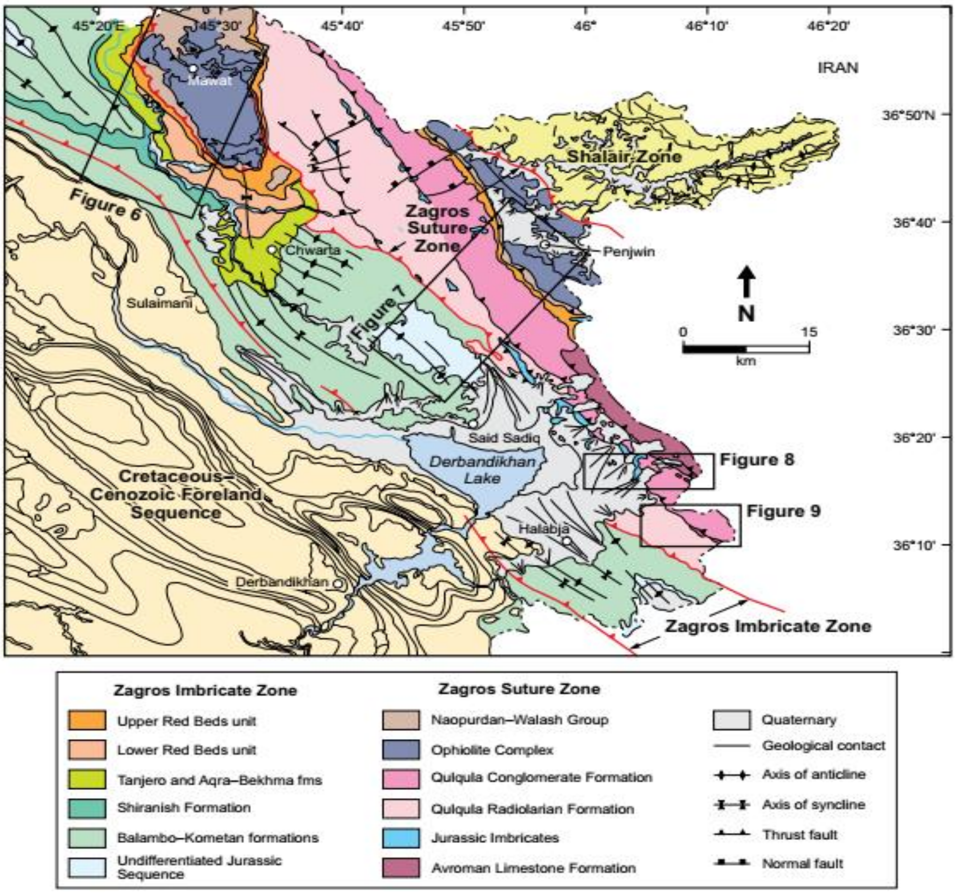


Figure 10- Geological map of the important existence of Qulqula Formation in northern Iraq, illustrating the long distance between the origin of Qulqula Formation and the study site at Al-Teep area [23].

The calcareous gravels of Mukdadiya Formation resist the eroded processing due to their internal structure. The presence of Radiolaria species with huge numbers leads to the cohesion of the structure of gravels, which is believed to work as cemented material to the facies. Al-Jubuory [27] determined the dispersion map of the movement direction of Mukdadiya Formation, which reinforces the hypothesis of the path transform of the sediments from north to south (Figure-11).

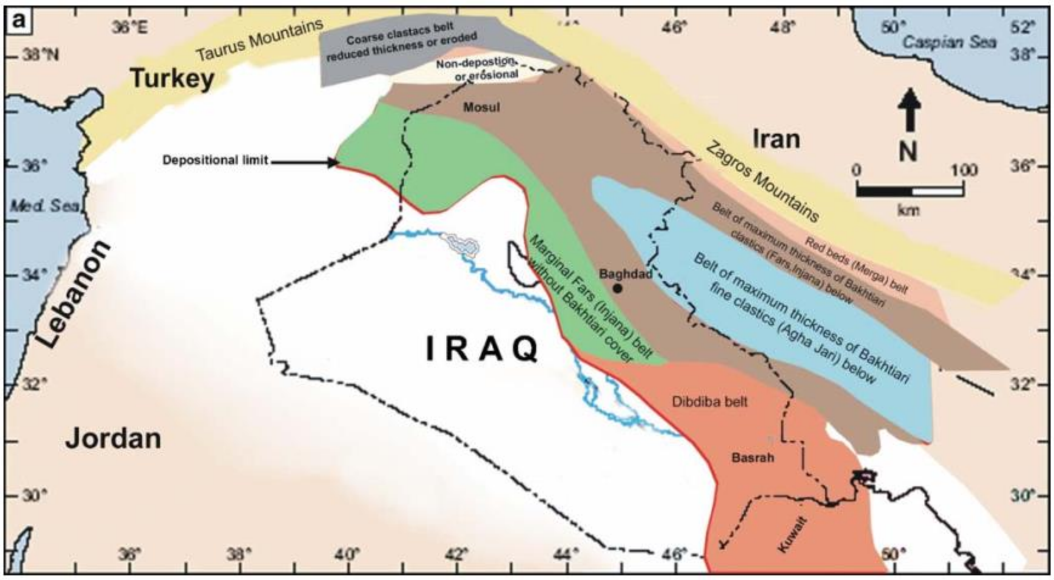


Figure 11- Lithofacies map for Mesopotamian Basin in Iraq during L. Miocene -Pliocene, showing the dispersion of Injana, Mukdadiya, and Bai Hassan Formations in Iraq [25].

Conclusions

The studied gravels of Mukdadiya Formation reveal long distances of transportation. The petrography and paleontology studies concentrate on Qulqula Formation as source rocks for these gravels, exactly at the lower part of Qulqula Formation. The occurrence of a large number of sedimentary gravels in the composition of Mukdadiya Formation in these areas is characterized by the color shades, from brown to dark reddish brown, due to its content of high concentrations of iron. This may indicate that it was deposited under oxidizing environmental conditions. Qulqula Formation comprises pelagic radiolarian chert and siliceous limestone, radiolarian red claystone, siliceous mudstone, reddish-green mudstone, and limestone. The age of these deposited are M. Jurassic to E. Cretaceous. The source of the gravel is transfer from Northeastern part of Iraq, one of the most important reasons for moving the sedimentary gravel to great distances from the source is believed to be the effects of severe silicification on the original rocks, which increased their hardness and thus their resistance to weathering and erosion processes.

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