

## Sedimentological and diagenetic study of the Early Middle Miocene Jeribe Limestone Formation in selected wells from Iraq northern oilfields (Ajil; Hamrin; Jadid; Khashab)

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### Abstract:

Five subsurface sections covering the entire length of the Jeribe Limestone Formation (Early Middle Miocene) were studied from four oilfields in northern Iraq. It is hoped to unravel this formation microfacies ; depositional environment; diagenetic attributes and their parental processes; and the relationship between these processes and the observed porosity patterns. The microfacies were found to include mudstone, wackestone, packstone, and grainstone, which have been deposited respectively in open platform, restricted platform, and edge platform which represent the lagoonal environment, while the deposits of the lower parts of the Jeribe formation especially in well Hamrin- 2 reflect a deeper fore slope environment. By using the lithofacies association concepts, the depositional model of the Jeribe Formation was built. From a reservoir point of view, the formation suffered from two groups of diagenetic processes. The first one includes the porosity destructive ones such as cementation; compaction; mechanical degradation; anhydritization; and silicification. The second group include porosity enhancers ones which to include dissolution; and dolomitization.

**Key words:** Jeribe Limestone Formation, porosity, facies analysis, depositional environment

### Introduction:

Iraq's proven reserve amounts to 113 billion barrels of oil, and 100 trillion cubic feet of gas [1]. On global scale, these numbers places Iraq's proven hydrocarbon reserve second only to Saudi Arabia. The studied formation here belongs to a group of carbonate reservoirs which houses much of Iraq's proven reserve. The Jeribe Formation is an important reservoir in many of Iraq's important oilfields, including those which are the subject study of this paper [2, 3]. Besides it is enormous economic importance, the Jeribe Formation was a faithful witness for the events preceded the vanishing of the Tethys Ocean [4, 5]. These events had great influence on climatic

and paleoceanographic conditions; and faunal population. Therefore, studying the Jeribe Formation offer the opportunity to shed light on these events. The aim of this paper is to better document the microfacies; depositional environment, diagenetic attributes and their parental processes for a number of subsurface sections representing the Jeribe Formation in selected oil fields dispersed throughout northern Iraq. The lesson to be learned are to put forward reliable framework to better understand the processes responsible for making the Jeribe Formation of such excellent reservoir qualities.

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### Geologic setting

Figure 1 depicts the Jeribe Formation stratigraphic relationships. This formation had a gradational contact with the overlain Fatha Formation (Lower Fars Evaporites), but it unconformably overlies the Serikagni Formation due to the absence of the Dhiban Formation [6, 7]. In all places, the Jeribe Formation is characterized by the conspicuous occurrence of the index fossil *Borelis melo curdica* [8]. In addition, the species *Orbulina* occur

in lower part of the formation [9, 10]. It is on the basis of these fossils that an early Late Miocene age was assigned to the Jeribe Formation. Additional fossil list which supports this age assignment was provided elsewhere [11]. The other important constituent is the none-bioclastic grains to include intraclasts and pellets. They both suffered from recrystallization as manifested in the form microspar and pseudospar [12,13].

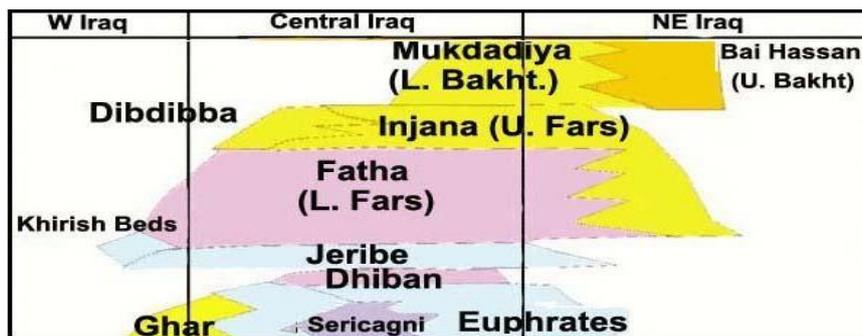


Figure 1, A simplified stratigraphic correlation of the Middle and Late Miocene sequences of northern Iraq [6].

### Materials and Methods :

To fulfill the aims of this study, five subsurface sections have been selected from wells of four oil fields located in north Iraq. These wells were Aj-6 (Ajil-6); Hr-2 (Hamrin-2); Hamrin-18 (Hr-18); Jd-1 (Jadida -1); Kb-1 (Khashab). Figure 2 is a location map for these wells. For this purpose more than 368 thin sections (mostly taken from core samples) were described and interpreted, together with several

hundred thin-sections previously prepared by the Iraq Oil Exploration Co. (OEC). All these thin sections were studied petrographically by applying classification mentioned in [14] and its modified version as presented in [15]. In addition, X-Ray diffraction technique was used to determine the mineralogical composition of a selected number of samples.

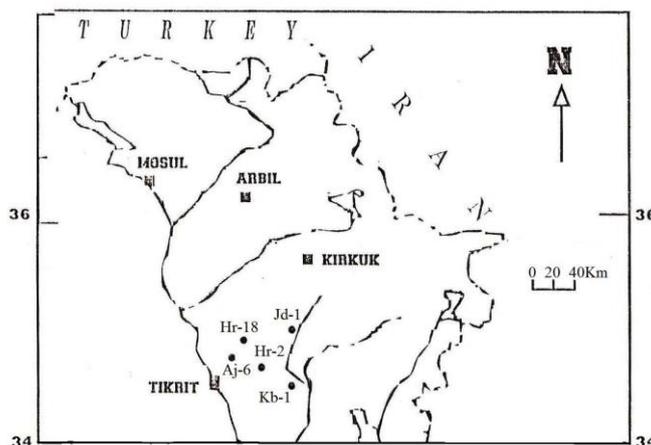


Figure 2, Location map of the studied wells.

### Petrography of the Jeribe Formation

Petrographic analysis revealed that the Jeribe Formation consists mainly of micrite and to less extent various skeletal and none skeletal grains. Below is a detailed description of each of these components:-

#### Skeletal grains

Benthic foraminifera of various sizes are the most common skeletal grains in the Jeribe Formation, particularly increasing from the slope shoreward [16]. These to include *Dendritina rangi*; *Borelis melo melo*, *Borelis melo curdica*; *Peneroplids*; *Rotalids*; *Miliolids*; *Quinqueloculina* sp. Planktonic foraminifera are also seen, but less common than their benthic counterpart. *Orbulina* is the dominant planktonic genus. They are very common in the lower parts of the Jeribe formation of the basinal facies.

#### Non-skeletal grains

In the Jeribe Formation, peloids are the main non-skeletal grains. They range in size from silt to sand sizes. Some peloids are probably micritized ooids. Peloids are characteristic constituents of carbonate sediments laid down in shoal and subtidal environments, respectively [17]. Intraclasts are interpreted to be reworked grains within the subtidal and intertidal environment arising from current agitation.

### Micrite

Micrites are represented by microcrystalline calcite which mostly was agglutinated like peloids. They appear with clotted texture as the most common in most of the studied boreholes.

#### Spray calcite cement

Different types of spray calcite cements have been recognized throughout the Jeribe Formation such as drusy, granular, syntaxial and blocky cements.

#### Depositional microfacies

The Jeribe Formation allochems were classified following [14,15], and as in turn was revised in [17]. The observed allochems were classified into mud- or grain-supported textural types. Each type consists of many subsidiary microfacies, as shown in Table 1. The environmental interpretation of each of these microfacies and its subsidiaries was according to what was mentioned in [15,16,18].

#### 1 - Lime mudstone microfacies

This microfacies occurs at different levels throughout the studied sections, but was most noticeable in the lower parts. Micrite is the main component, but planktonic foraminifera mostly of the genus *Orbulina*, and benthic foraminifera mostly of the species *Dendritina rangi*, *Borelis melo melo*, *Borelis melo curdica* etc are also

present in various proportions but usually less than 50 % .

**1. A - Fossiliferous lime mudstone submicrofacies**

It is composed of dark-gray micrite, rich with argillaceous and organic matters. Benthic foraminifera are commonly indicated by Miliolids, Dendritina rangi, Borelis melo curdica, etc. This submicrofacies is a characteristic of shallow water with open circulation environments.

**1.B - Non-fossiliferous lime mudstone submicrofacies**

Micrite is the main components of this submicrofacies which had recrystallized to microspar. This submicrofacies is a characteristic of hyper saline tidal ponds in restricted platform environments at places.

**2 - Lime wackestone microfacies**

It is the most common microfacies in the Jeribe Formation, and may locally be dominated by a specific type of bioclast at various levels within the formation succession. At times, limited occurrence of planktonic foraminifera was also observed. The microfacies are characteristic of shallow, open-marine environments.

**2. A - Bioclastic lime wackestone submicrofacies**

This submicrofacies is dominated by echinodermal plates, mullascan shell fragments, and algal debris of various sizes. Benthonic foraminifera such as Miliolids also occur with some argillaceous materials and detrital sand grains. This submicrofacies is typical of shallow water with open circulation in open platform environments.

Table 1: Summary of the whereabouts of the main microfacies and their subsidiaries of the Jeribe Formation in the studied Boreholes.

Main Microfacies Types	Code	Subsidray-Microfacies	Boreholes
Lime Mudstone	M	Fossiliferous Lime Mudstone Non-Fossiliferous Lime Mudstone	All All except Aj-6
Lime Wackestone	W	Bioclastic Lime Wackestone Miliolids Lime Wackestone Orbulina Lime Wackestone	Hr-2; Hr-18; Aj-6; Kb-1 Hr-2; Hr-18; Kb-1; Jd-1 Hr-2 only
Lime Packstone	P	Bioclastic Lime Packstone Peneroplids Lime Packstone Peloidal Lime Packstone	All except Hr-18 All except Hr-18 ;and Aj-6 Jd-1
Lime Grainstone	G		Aj-6; Hr-2; Jd-1

**2.B - Miliolids lime wackestone submicrofacies**

Diversified assemblage of benthonic foraminifera such as mainly Miliolids species, with rare Peneroplids, Dendritina rangi; Borelis melo curdica; Rotalids; etc, occur in this

submicrofacies, with proportions up to 50%. They are all buried in micritic groundmass. This submicrofacies is typical representative of quiet shallow open marine environments.

**2.C - Orbulina lime wackestone submicrofacies**

This submicrofacies is characterized by high abundance of *Orbulina* planktonic foraminifera with limited occurrence of echinodermal plates, pelecypods shell fragments and algal debris which all engulfed in dark highly argillaceous micrite. Some peloids and detrital sand grains also occur but in smaller proportion. This submicrofacies is typical representative for open marine environments of open circulation conditions.

### **3 - Lime packstone microfacies**

It represents one of the most common microfacies of the Jeribe Formation. This microfacies is principally composed of peloids of various sizes, many of which have uncertain internal structure. In addition, benthic foraminifera shell fragments, ooids and ostracods also occur. This microfacies is common in the upper parts of the Jeribe Formation, and it is interpreted to indicate shoals and subtidal zones with moderate wave agitation.

#### **3. A - Bioclastic lime packstone submicrofacies**

Bioclasts of various sizes are the main components of this submicrofacies with moderate occurrence of peloids, intraclasts, ooids, green algae and benthic foraminifera. Micrite is the main groundmass being observed in this submicrofacies. It is interpreted to indicate a shallow open marine environment.

#### **3. B - Peneroplids lime packstone submicrofacies**

This submicrofacies is a common submicrofacies in the studied successions. It is characterized by the occurrence of the benthonic foraminifera, such as *Peneroplids* and *Miliolids*, *Dendritina rangi*, *Borelis melo melo*, *Borelis melo curdica*, *Elphidium*, *Rotalids*. This submicrofacies is interpreted to be of tidal bars; channels; and lagoons within the open and restricted platform environments.

#### **3. C - Peloidal lime packstone submicrofacies**

This submicrofacies is characterized by the abundant occurrence of peloids of unknown origin, which is larger than the pellets. Their shape is highly variable, but mostly exhibits a spherical or ovoid shape. This submicrofacies is interpreted to be a restricted platform.

### **4- Lime grainstone microfacies**

It represents the less common microfacies of the Jeribe Formation. It is composed of more than 90% of peloidal grains embedded mostly in a spary calcite groundmass with minor amounts of micrite. This microfacies is interpreted to be of restricted platform.

#### **Diagenesis**

Many diagenetic processes had operated on the depositional constituents of the Jeribe Formation. In what will come we will first point out to the environments in which these processes had taken place. Subsequently, we will briefly describe each of these processes.

#### **Diagenetic environments**

Diagenetic features in the bioclastic mudstone; wackestones; packstones; and grainstones indicate early nearsurface alteration in the meteoric phreatic and mixing zones. Dolomite rhombs in the wackestone and mudstones indicate mixing-zone diagenesis in intertidal flats as evidenced by the small size of the dolomite crystals [19, 20], which further elude to their precipitation from a brackish-water. On the other hand, syntaxial overgrowths on echinoderm plates and equant calcite cements are interpreted to be products of local meteoric phreatic digenesis [21]. The development of moldic, vuggy and channel porosity, particularly in fossils-bearing intervals; mudstone; wackestone; packstones; and

grainstones; indicate a similar diagenetic environment.

### **Diagenetic processes**

#### **1-Micritization**

Micritization is an early diagenetic process which effect skeletal grains. It is the most common process affecting the skeletal fragments in the packstones and wackestones microfacies of the Jeribe Formation.

#### **2-Cementation**

Many types of cements had been observed. These to include: (a) micrite cement; (b) overgrowth cement; (c) displacement cement; (d) granular cement; and (e) druzi mosaic. These varieties occur in various microfacies filling inter-and intragranular pores and fractures. They are believed to be of late diagenetic origin, although the mosaic cement may have formed during two or more phases including a near surface one.

#### **3-Neomorphism**

It is of two mode occurrence in this formation. It either occurs as inversion of aragonite to calcite or high magnesium calcite recrystallized to low magnesium calcite. Both types involve the complete dissolution of the precursor carbonates and the subsequent precipitation of cement [21]. Regardless of the pathway, this process is called calcitization [17].

#### **4-Dolomitization**

Scattered, fine-grained dolomite rhombs occur within the mud-supported microfacies, and are often concentrated along stylolites surfaces. The fine grain-size nature of the rhombs and their occurrence within the mud-supported facies indicates their early- diagenetic origin. In addition, aggregates of larger dolomite crystals, of a clear-rimmed, cloudy-centered type probably formed during later diagenesis [22] were also observed.

The classification of dolomite textures was according to the scheme put forward in [23]. There were two

types of textures prevalent within the Jeribe microfacies. They are the aphenotopic fabric, which is composed of fine crystals and occur in the lime mudstone microfacies. The other one is selective mosaic fabric, which is composed of very fine crystals aggregates of dolomite rhombs which is reflected in fine to medium mosaic dolomite groundmass occurring in the lime wackestone microfacies.

#### **5-Silicification**

It is another characteristic diagenetic process which had operated in the Jeribe Formation but it is not common in samples of the studied boreholes. It may fill some pores as cementing material, or replacing the original sediment constituents or it selectively produced silicified fossils. The main sources of silica may were due to one or both of the following processes: (a) the supply of detrital sand grains from the shore line; (b) inorganically precipitated silica reaching the ocean by silica rich river water [24].

#### **7- Anhydritization**

Anhydritization is a common in the Jeribe Formation. It produces patches in particular intervals filling some voids of different shapes and sizes (ranging from 2 mm to 7 cm) as a subsequent diagenetic process after dissolution. Many anhydrite textures were recognized in the various Jeribe Formation microfacies. According to the classification mentioned in [25], these textures can be described as the following:

1 - Blocky texture of equidimensional crystals (> 0.06 mm in diameter).

2- Lath-shape texture of random elongated crystals (> 0.5 mm).

3 - Microcrystalline texture of equidimensional crystals (< 0.06 mm in diameter).

#### **8-Compaction**

This process reflects the compaction due to the heavy lithostatic load (> 1000 m thickness), which eliminate

porosity [16, 25]. It was mostly observed in the packstone and grainstone microfacies which gave them the orientation property being observed for some of their internal structures. According to many authors [15, 26], compaction has no direct relationship with early diagenetic cementation.

### **9-Stylolitization**

Pressure solution has resulted in the formation of dissolution surfaces, clay seams and stylolites. Stylolites in both mud- and grain- supported microfacies took the form of horse-tail and irregular anastomosing sets.

### **10-Dissolution**

Dissolution is considered as one of the most important diagenetic process operated within the Jeribe Formation. Dissolution was most obvious in the coarse-grained facies. This process acted to dissolve the internal material of the skeletal grains whereby only the micritic envelope was lifted thereby forming the observed moldic porosity or vuggy porosity upon enlargement the latter ones. When these pores are enlarged in their turn they will develop into cavern or channel porosity. Some times there are open space structures due to the effect of the selective dissolution [27, 28, 29]. The above description of porosity varieties was according to the classification given in [30], and which was given in their Figure 7.

### **Reservoir characters**

Figure 3 is a pictorial depiction of porosities most prevalent in the Jeribe Formation. Here below is a brief description for the stratigraphic behavior of each type of these porosities:

1- Interparticle porosity is less common in all of the Jeribe's microfacies. This microporosity was mainly observed in packstone and grainstone microfacies.

2- Vuggy porosity was observed only in mudstone and wackestone microfacies.

3- Moldic porosity was observed in grain and mud supported microfacies, where the algae disappear in the primary microfacies and leaves only their molds.

4- Selective dissolution was observed in all of the Jeribe Formation microfacies, where some fossils shells dissolved selectively while others had remained intact.

5- Fractured porosity is observed mostly in the mudstone and wackestone microfacies which were composed of soft mud. Some of the fractures were observed to develop into channel porosity.

6- High porosity was observed in the high energy microfacies as intraparticles variety, especially in fossils rich microfacies which their porosity may reach more than 15% to 26%, and their permeability range between 1- 100 mD or more.

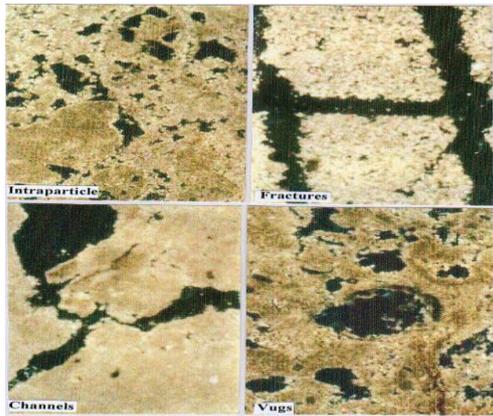


Figure 3, Representative types of porosities observed throughout the Jeribe Formation. Adapted from [8].

**Relevancy to the depositional model**

At the late lower Miocene, there were continuous tectonic movements which resulted in the uplift of the southwestern parts of the basin with a consequence subsidence of the north eastern parts of the depositional basin. These events were reflected in being the sea regressing from the south western shore and transgressing toward the northeastern parts. Due to the shallowing that exist near the northeastern shore (Badra well, Bd-1), and in the middle parts of the basin (Musaiyib well, Mu-1), the Dhiban anhydrite was deposited followed by the deposition of anhydritic limestone beds that was recognize as the Jeribe Limestone Formation (Early Middle Miocene), taking into consideration that the deep parts of the basin still shallow in the vicinity of Ahdab well, (Ad- 1). The fossils of the Jeribe limestone formation such as Borelis melo (Fictel & Moll) var. Curdica Reichtel and Borelis melo melo (Fictel & Moll) indicate a depth ranging between 25-35 m for the depositional environment. Furthermore, the existence of other fossils such as Peneroplids and Miliolids reflect a lagoonal marine environment with high salinity [31]. The existence of Orbulina in micritic groundmass within the lower part of Hamrin well

(Hr-2), and the recognition of basal conglomerate in the lower part of this formation within Jadida well (Jd-1), constitute a good indication for the transgression which is responsible for the deposition of both the basal conglomerate and basinal sediments rich in planktonic foraminifera. An approximate sketch representing the depositional model of the Jeribe Formation was depicted in Figure 4, which was redrawn from [32].

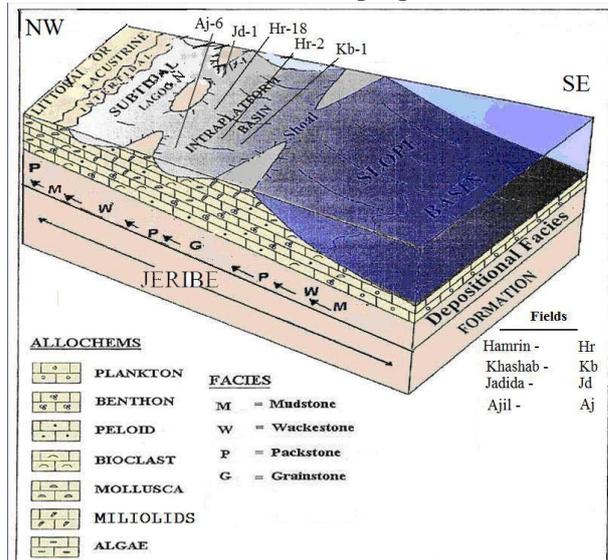


Figure 4, Schematic block diagram representing the proposed depositional model for the various microfacies of the Jeribe Formation, (Note the boreholes locations are not according to scale). Model graphing was adapted from [32].

**Conclusions**

1-Many microfacies have been identified within the Jeribe Formation. These were lime mudstone; lime wackestone; lime packstone; lime grainstone. These carbonates have been affected by a variety of diagenetic processes.

2-The depositional environment of Jeribe Formation in the studied wells were found to represent deposition in the whole range from shallow marine restricted to open deep marine settings.

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### دراسة رسوبية وتحويرية لتكوين الجريبي الكلسي (المايوسين الاوسط المبكر) في أبار مختاره من حقول شمال العراق (عجيل، حميرين، جديدة، خشاب)

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#### الخلاصة:

أجريت الدراسة على خمس مقاطع تحتسطحية تغطي الطول الكلي لتكوين الجريبي المترسب في المايوسين الاوسط المبكر من أبار مختاره من حقول نبط شمال العراق، لغرض توثيق كل من الاتي: السحن الدقيقه، البيئه الرسوبيه، العمليات التحويريه وعلاقتها بالخصائص المكمنيه الملاحظه. وقد تم التوصل الى ان السحن الدقيقه تشتمل على كل من الاتي: المدستون، الواكستون، الباكستون، والكرينستون، والتي تمثل الترسيب في كل من البيئات الاتيه: رصيف مغلق، رصيف مفتوح، حافة الرصيف، بيئه عميقه مفتوحه، وبأستخدام فكرة الترابط السحني فقد جرى بناء النموذج الرسوبي للتكوين المدروس. ومن وجهة نظر مكمنيه وجد بأن تكوين الجريبي قد عملت عليه العديد من العمليات التحويريه، ومن هذه العمليات ما حسن المساميه كالاذابة والدلمته، ومنها ما عمل على العكس، أي الاقلال من المساميه، والتي منها التسميت، والتضاغط المسبب للتحلل الميكانيكي، وترسب الانهيدرايت والسليكا.