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## Diagenesis Processes Impact on Reservoir Quality in Carbonate Yamama Formation /Faihaa Oil Field

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### Abstract

The Yamama Formation is a significant reservoir in the southern part of Iraq. This formation consists of limestone deposited throughout the Lower Cretaceous period within main retrogressive depositional series. This study aims to identify the impact of the diagenesis processes on the reservoir's characteristics (porosity and permeability). Diagenesis processes' analysis and the identification of Yamama Formation depended on the examination of more than 250 thin sections of the core samples from two wells that were used to determine different diagenetic environments and processes. The three identified diagenetic environments that affected Yamama reservoir were the marine, meteoric and burial environments. Eight diagenetic processes were recognized in Yamama Formation and showed positive and destructive effects on the reservoir quality; Dissolution and fracture had highly positive effects through creating and improving porosity and permeability that led to improving reservoir quality. Cementation and compaction had destructive effects, through reducing porosity and permeability, that led to reducing reservoir quality. Other processes such micritization, dolomitization, bioturbation and neomorphism did not have strong effects on reservoir quality. Based on genetic classification of porosity, most of porosity within Yamama Formation in this field was formed by diagenesis processes, implying that Yamama reservoir is a type of diagenetic reservoir.

**Keywords:** Diagenesis Processes, Yamama Formation, Southern Iraq.

### تأثير العمليات التحويرية على جودة المكنم الجيري تكوين اليمامة/ حقل الفيحاء النفطي

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### الخلاصة

تكوين اليمامة، هو من المكامن الكبيرة في جنوب العراق. هذا التكوين يتألف من الحجر الجيري. ترسب خلال حقبة اسفل الطباشيري، ضمن الدورة الراجعية الترسيبية الرئيسية، هدفت الدراسة الى تحديد تأثير العمليات التحويرية على الخواص المكنمية (المسامية والنفاذية). تحليل وتحديد العمليات التحويرية في تكوين اليمامة كانت بالاعتماد على فحص اكثر من 250 شريحة صخرية من عينات اللباب لبئرين استخدمت لتحديد البيئات والعمليات التحويرية المختلفة. ثلاثة بيئات تحويرية حددت تؤثر على جودة المكنم، البيئات التحويرية كانت بحرية، نيزكية وبيئات الدفن. ثمان عمليات تحويرية حددت في تكوين اليمامة: الاذابة والتكسر لها

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تأثيرات ايجابية عالية, من خلال خلق وتحسين المسامية والنفاذية, هذا ادى الى تحسين جودة المكنن. السمنت والانظباط لها تأثيرات مدمرة, من خلال تقليل وتدمير المسامية والنفاذية هذا ادى الى تقليل جودة المكنن. العمليات الاخرى مثل المكرتة, الدلمتة, الفعاليات الاحيائية, واعادة التشكل كانت ليس لها تأثير عالي على جودة المكنن. بالاعتماد على التصنيف الوراثي للمسامية, اغلب المسامية ضمن تكوين اليمامة في هذا الحقل تكونت بالعمليات التحويرية, لذلك مكنن اليمامة هو مكنن تحويري.

## 1. Introduction

Yamama Formation is one of the giant reservoirs in southern Iraq. It is a heterogeneous carbonate reservoir, deposited during the Lower Cretaceous period within the main retrogressive depositional cycles (Berriasian - Aptian). Yamama Formation is the main lower Cretaceous carbonate reservoir in southern Iraq and it fits to the "Late Berriasian-Aptian cycles", represented from the shore to the deep basin by Zubair, Ratawi, Garugu, Yamama, Shuiaba, Sarmord and Lower Balambo Formations [1]. Yamama Formation mainly consists of carbonate rocks, with few dolomitic limestone and shale intervals in the south-western portion of Yamama basin. Yamama and Sulaiy Formations are underlain conformably, and the latter is uppermost Jurassic [1]. Consist of mud confirming argillaceous limestone with calcispheres and benthic Foraminifera. The Sulaiy, Yamama, Ratawi and Zubair formations represent a regressive carbonate cycle terminated by clastic invasion of the Zubair fluvial deltaic facies. Yamama Formation comprises the neritic litho facies of the cycle [2].

## 2. Area of Study

Faihaa Oil Field is located in southern Iraq, approximately 50 km north of Basra Governorate, at the border with Iran. The region is situated in the north-eastern part of the block 9. The structure of Faihaa Field is the same structure as the Yadavaran oil field in Iran (Figure-1).

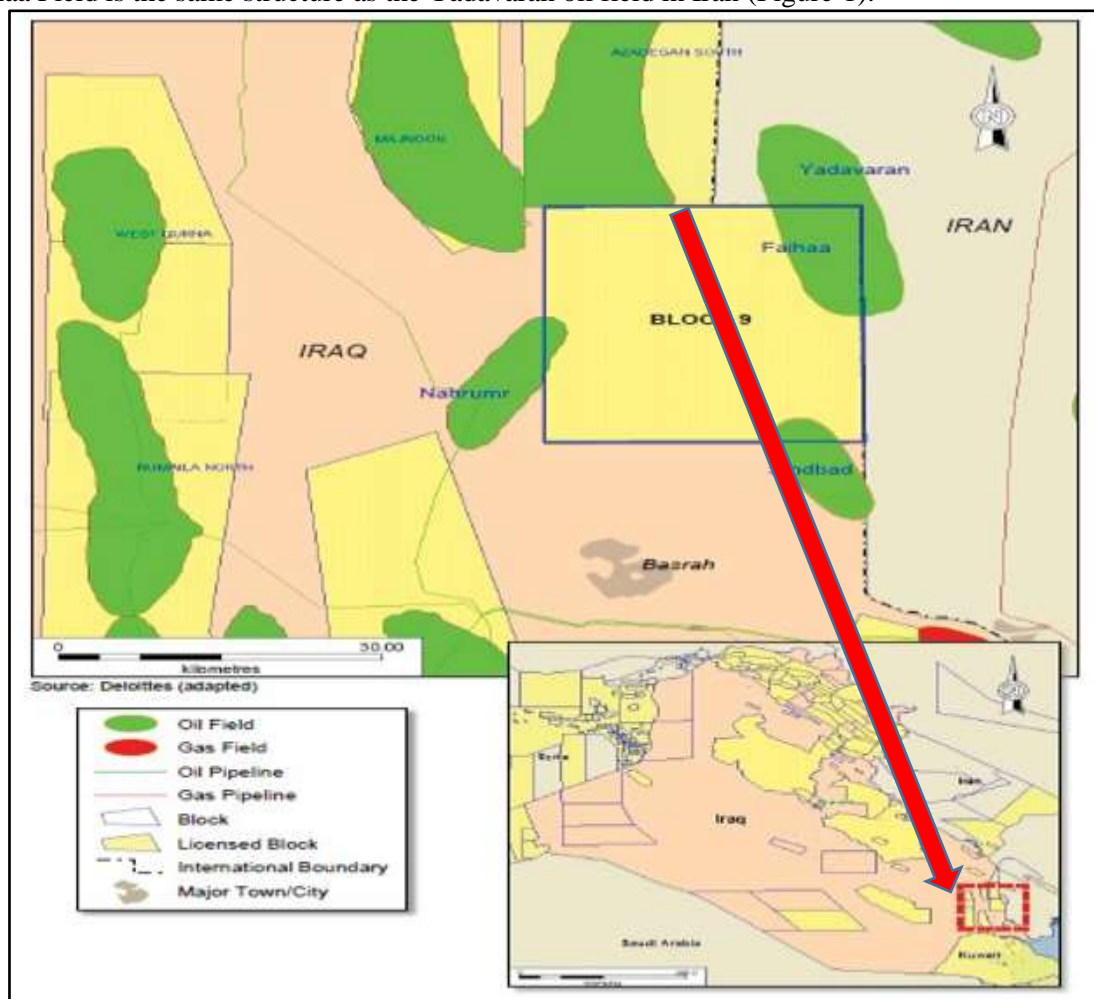


Figure 1-The study area.

### 3. Stratigraphy

The Yamama Formation comprises three main depositional cycles in southern Iraq. Cycle tops consist of oolitic grain stone, with an inner ramp passing down into fine-grain peloidal facies, a middle ramp made of bioclastic/ coral/ stromatoporoid packstone-wackstone, and an outer ramp cycle base comprising a thin bed from shale with string of chalky micrite [2]. The Yamama Formation is an up to 400 m thick carbonate reservoir of Lower Cretaceous age that is deposited in shallow marine conditions on a regionally extensive carbonate platform (Figure-2) [2].

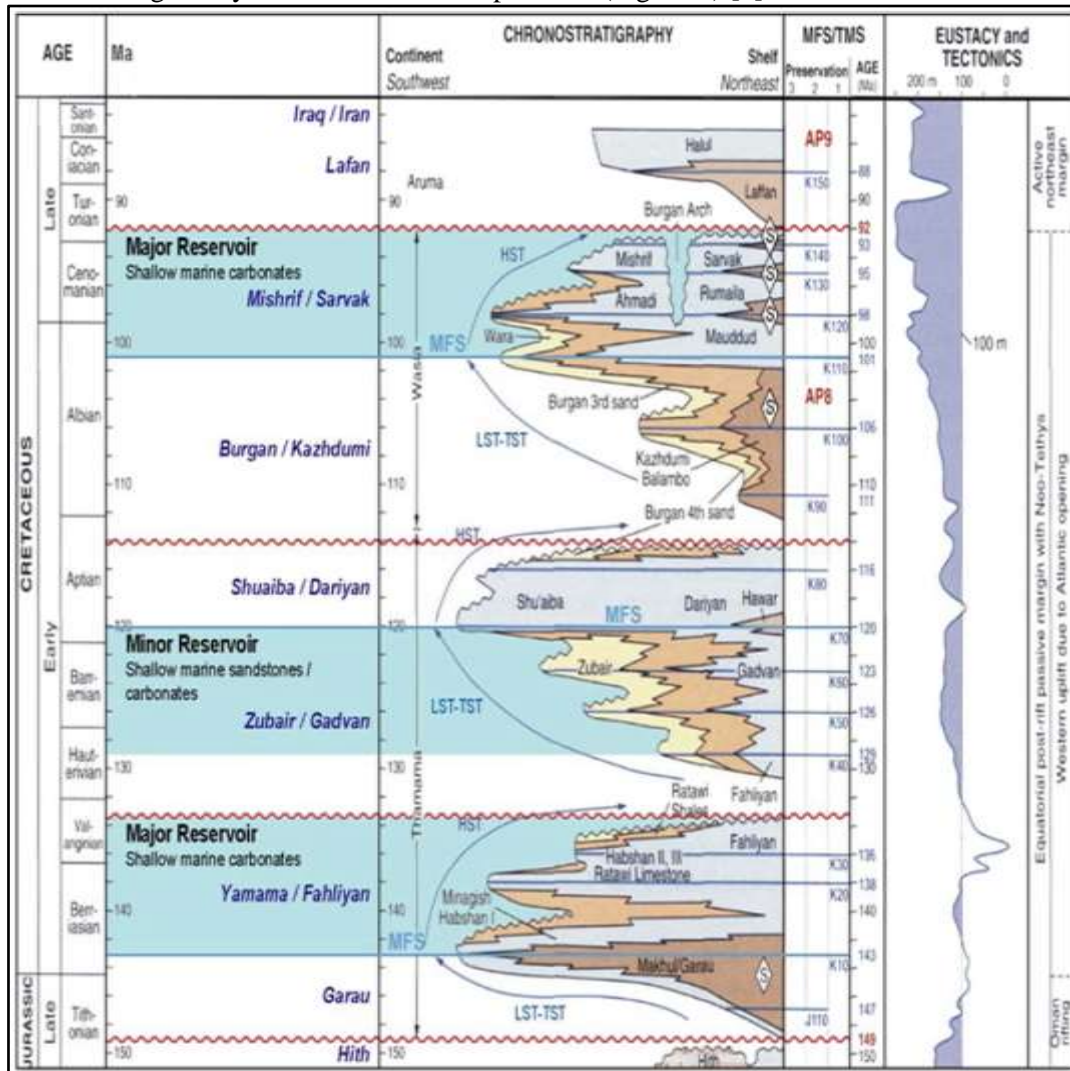


Figure 2-Sequence Stratigraphy and main reservoir of Cretaceous age [3].

### 4. Geological Setting

Faihaa Oil Field is situated at the southern part of Iraq within the Mesopotamian basin in the Zubair subzone of the stable zone (Figure-1). The Mesopotamian zone was possibly uplifted through the Hercynian deformation. The Mesopotamian basin consists of three subzones: The Zubair subzone in the south with a structure trend N-S, the Euphrates subzone in the west, and the Tigris subzone in the north [4].

The structures of Zubair subzone are long and relatively constricted anticline separated by the wider syncline, especially to the east. Zubair subzone is the best prolific petroleum region in Iraq (Figure-3).

The Tectonics of Yamama basin extend over two tectonic zones; the part of the western basin is located within the stable shelf of the Arabian platform, particularly within Salman subzone of the belt, and the other part of the eastern basin is situated within the Mesopotamian foredeep [2].

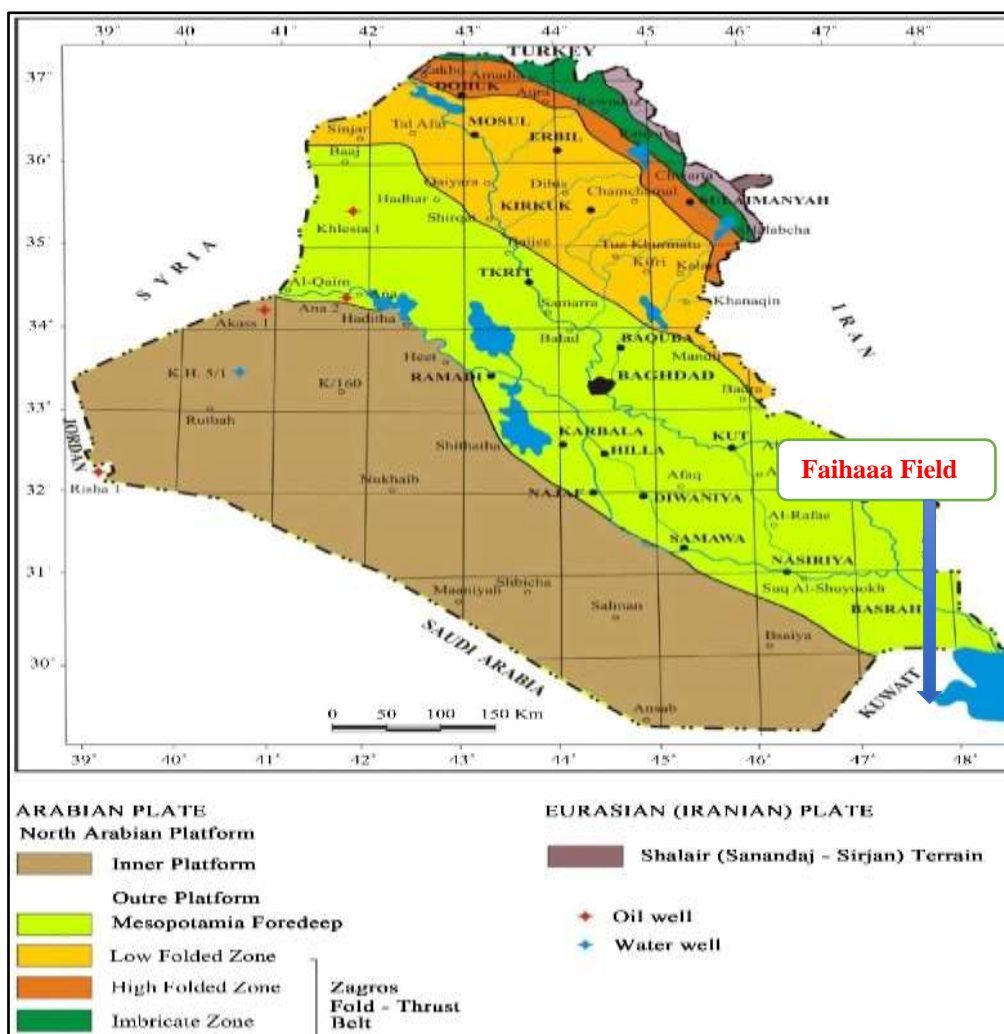


Figure 3-Tectonic map of Iraq [5].

## 5. Methodology

Six wells were studied using full sit logs, and two wells were used to study thin sections. The diagenesis processes of Yamama Formation components were analyzed depending on the examination of more than 250 thin sections of core samples from two wells.

## 6. Diagenesis Processes

Diagenesis is a process that includes physical, chemical, and biological changes of sediments leading to changing the original sediments and are compaction, cementation, recrystallization and other changes [6].

Diagenetic processes are divided into two stages, early diagenesis and late diagenesis; early diagenesis process takes place nearly after deposition or after burial of sediments, whereas late diagenesis process occurs after deposition, when the sediment was previously more or less compacted into a rock willing to burial processes performed in the subsurface over along geological period [7].

Diagenesis can improve or destroy porosity and permeability. However, with increased time and depth, the porosity and permeability were reported to be reducible [8].

The most common diagenetic processes in Yamama Formation were micritization, cementation, dissolution, neomorphism, dolomitization, bioturbation and compaction; the most effective diagenetic processes that highly affect the Yamama Formation were cementation and dissolution.

### Micritization

Micritization is a primary diagenetic process characteristic of the shallow marine environment. This process leads to completely destroying the original structures of the grains. Continual micritization results in the construction of carbonate muds [7].



Micritization may reduce permeability by filling pore throats or reducing the size. Otherwise, early micritization may prevent porosity decrease throughout burial compaction [9].

Micritization strongly affects the formation through destroying the entire skeletal and bioclastic grains, making them lose their internal structures and develop include micritic envelopes, occur this process can be attributed to the effect of microbial activity. (Plate-1 A).

### **Cementation**

Cementation is a process by which voids and pores are filled by cement materials, either during the deposition via filling the primary voids or after deposition by filling the voids formed by dissolution processes or the fractures and joints formed by compaction [7].

This process has a destructive effect on reservoir's properties, especially porosity and permeability. Several kinds of calcite cement in Yamama formation have been recognized, which are described below:

#### **A- Syntaxial Cement**

In this type of cement, the crystals are composed of both calcite and aragonite, and its early diagenetic origin refers to early fresh water phreatic cement [10].

This type is formed around the echinoderm fragment and observed in different microfacies. This type of cement destroys the interparticles and is associated with vuggy porosity (Plate 1 B).

#### **B- Granular (Blocky) Cement**

Blocky cement is composed of comparatively equi-dimensional filling small crystals that are abundant in intergranular pores. This type of cement is found in meteoric-vadose, meteoric-phreatic and with the burial environments, while originating from re-crystallization of preexistent cements [7].

Blocky cement is common in different Microfacies of the Yamama Formation, filling the voids between and within the structural grains.

This type is characterized by large subhedral crystals without a distinct direction for their growth. The large crystals and pure appearance indicate slow recrystallization below saturated solutions and formation at late diagenetic processes, leading to reduced- destroyed porosity (Plate-1 C).

#### **C- Druzy mozaic cement**

Druzy mosaic calcite cement consists of anhedral and subhedral calcite crystals filling vugs and pores in different sizes and represented by crystals showing an increase in sizes towards the center of these pores (Plate-1D, E). This type of cement is common and highly effective downwards, being increased with the increase in depth, especially in lower Yamama Formation. Formation of drusy cement leads to decreased and destroyed porosity and permeability and, thereby, reducing reservoir quality. Drusy cement forms as a late diagenetic process indicating meteoric phreatic zone [11].

#### **D- Saddle (Baroque) dolomite cement**

Saddle (baroque) dolomite, defined as a coarse-crystalline dolospar with regularly to irregularly curved crystal boundaries and sweeping extinction, has been described from numerous diagenetically altered carbonates and sandstones in hydrocarbon reservoirs [12].

This type of cement fills some of the voids and fractures, while its formation increases with the increase of temperature and compaction due to the increased depth. Therefore, forming saddle dolomite leads to decreased porosity and permeability. Saddle dolomite is mostly found in burial environments where temperatures of water exceed 60° C [13](Plate-1 G).

### **Neomorphism**

Neomorphism is a diagenetic process that leads to changes in mineralogical composition and/or crystals as well as crystal fabrics. Neomorphic processes lead to crystal magnification or diminution [13].

In Yamama Formation, neomorphism process affects skeletal grains and micritic matrix. Their impact on skeletal grains renders them difficult to determine while in the bioclastic. Also, it influences micrite via transforming it to microspar, finally resulting in pseudospar (Plate-1 D, 2 B).

### **Bioturbation**

Bioturbation is typically a small-scale but potentially significant geologic process that might occur anywhere in plants or animals live. Bioturbation can take several shapes, comprising displacement of soil by plant's roots and tunnels formed by burrowing animals and footprints [14].

Bioturbation process has a big influence on reservoir quality and flow behavior and is efficient either in increasing or decreasing reservoir quality.

Destructive effects of bioturbation on reservoir quality occur through reducing the porosity and permeability.. This process can lead to enhancing reservoir properties, but later, due to filling of voids with cement, it causes damages to the reservoir properties and decreases its quality (Plate-1 F).

### Dolomitization

Dolomitization process occurs when limestone or its precursor sediments are totally or partly converted to dolomite via replacement of the original  $\text{CaCO}_3$  by magnesium carbonate, during the action of Mg bearing water. This process might improve porosity by creating large pores, or it might reduce it by the growth of interlocking mosaics of dolomite crystals.

Two types of dolomitization were recognized within the Yamama succession formed by different mechanisms:

**A-** Limpid euhedral crystals of dolomites created within and about the stylolite (Plate-1 H). Limpid dolomite is formed after forming stylolite, leading to the conclusion that stylolite acts as channels for transient dolomitizing fluids.

**B-** Xenotopic, limpid, coarse crystals of dolomite with ripple extension (Plate-1 G). This dolomite is named saddle dolomite which fills pores and fractures and has bad influences on reservoir quality. It is formed within deep burial environments with temperature of 50-160°C and represents a good indicator for oil window [15].

Generally, the dolomitization process within Yamama Formation didn't clearly affect reservoir quality, because most of the dolomite formed was associated with stylolite.

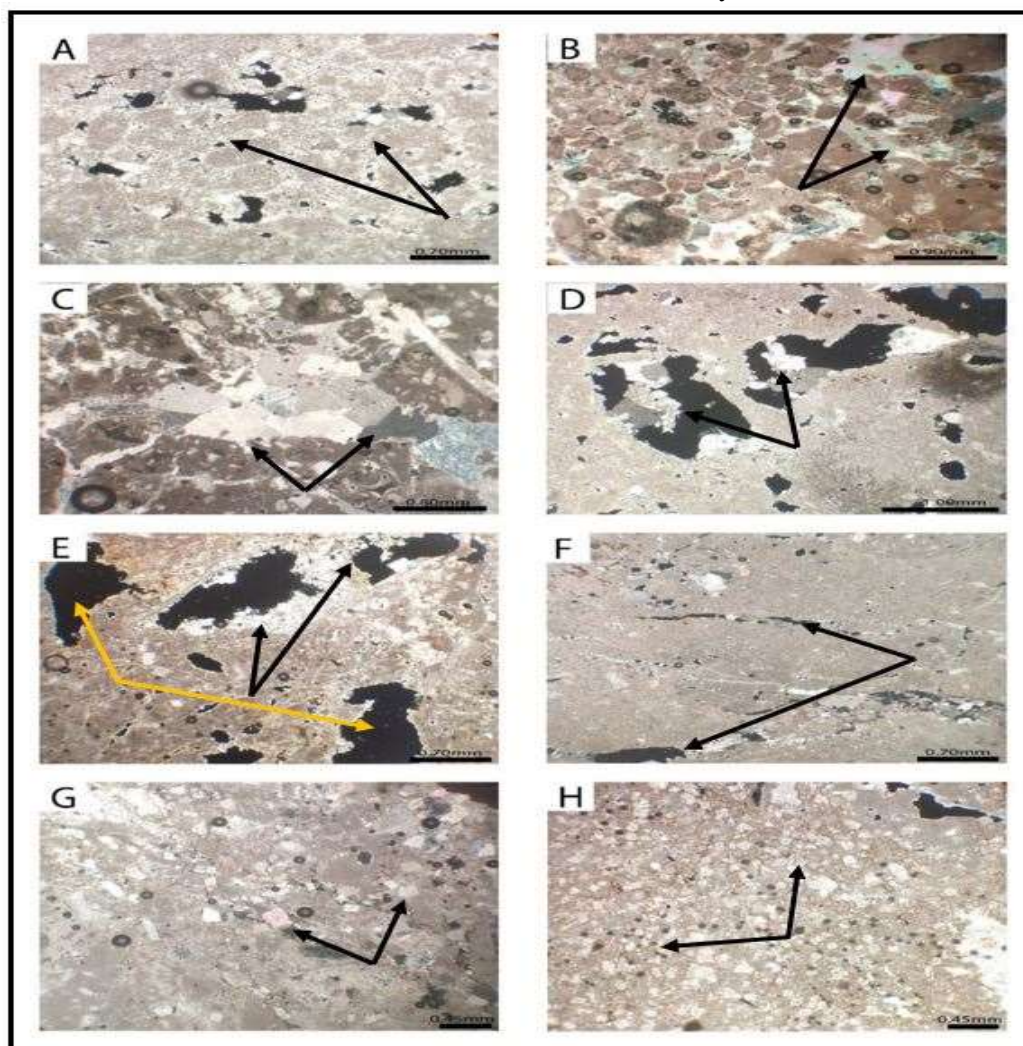


Plate-1.Types of diagenesis processes: (A) Mictitization with dissolution PPL. (B) Syntaxial cement around skeletal grain- PPL. (C) Blocky Cement PPL. (D) Druzymosaic cement PPL. (E) Drusy cement with dissolution PPL. (F) Bioturbation process partially by cement PPL. (G) Saddle dolomite cement PPL. (H) Dolomite associated with stylolite PPL.

### **Dissolution**

Dissolution can happen at any time in burial history of carbonate series, after stability of minerals. It is characterized by non-fabric-selective dissolution, where the resultant voids cut across the whole fabric fundamentals like grains, matrix, and cement [8].

This process happens when the water system of rocks is out of balance. In this case, water is under-saturated with esteem to  $\text{CaCO}_3$ . Dissolution process has the greatest influence in the formation of secondary porosity forms, such as vugs and moldic pores as a result of cement dissolution. Dissolution is supposed to have occupied a place in the meteoric- fresh water zone and intermittently in the mixed marine-fresh water zone [16].

Dissolution is a very important process within Yamama Formation, highly enhancing reservoir quality by creating various sizes of secondary porositities, which is an indicator of enhanced reservoir characteristics (Plate-1 E, 2 F).

### **Fracturing**

Fracturing processes are naturally occurring in rocks due to deformation or physical changes in sediments, and they are possibly formed as the result of brittle failure below differentials stress but pliable fractures happen. Fractures in reservoirs, especially in carbonates, are brittle fractures. Brittle failure means that rocks are unsuccessful in breaking the application of differential stresses overridden their elastic limit [6].

In this study, fractures process had a positive effect on reservoir properties, through improving porosity and permeability. Therefore, this process has led to enhancing reservoir quality (Plate-2 H).

### **Compaction and Pressure Solution (Stylolization)**

Compaction of sediments through burial includes reduction of the bulk volume, occurring mainly via progressive drop in porosity with growing depth and/or temperature. Whole sediments contribute to greater mechanical and thermodynamically stabilization. In General, compaction is divided into two kinds: mechanical and chemical [17].

#### **A- Mechanical Compaction**

Mechanical compaction begins nearly after deposition due to the influence of stress applied on the sediments. It is a main diagenetic process formed by the overburden sediments. In a general decreasing porosity and volume of rock, thickness of overburden necessary to yield compaction structures is convertibly, overburden results in the mechanical failure of grains [7]. Mechanical compaction involves re-orientation, with tangential, point, and concavo-convex contacts of grains (Plate-2 C), with these processes leading to destruction of porosity and permeability.

#### **B- Chemical Compaction.**

Thermodynamic and dynamic interactions of rock fluids are controlled by chemical compaction, dissolution, transformation of aragonite to calcite, and cementation processes that happen at shallow depth. Pressure solution is reduced after major active processes during chemical compaction. Chemical potential differences between the stressed and unstressed parts of the sediments [18] are as follows;

- along contact occur dissolution of minerals
- spread toward the voids
- Precipitation at less-stressed surfaces of grains.

According to the Koepnick (1988) and Sadd and Alsharhan (2000) and as shown in Figure-4, three classification of stylolite appeared within Yamama formation. The stylolite are abundant in most of the microfacies, with various types of a stylolite such as Rectangular, Dissolution seams and Wispy seams (Plate-2 A, B, D, E).

Stylolitization process may enhance reservoir quality through creating a tight barrier to prevent vertical fluid flow, whereas it may reduce the reservoir quality by partly or completely filling the pores due to the precipitated cement nearby the stylolite. This phenomenon affects the reservoir quality since the pore space is reduced as the cementation occur due to stylolitization.

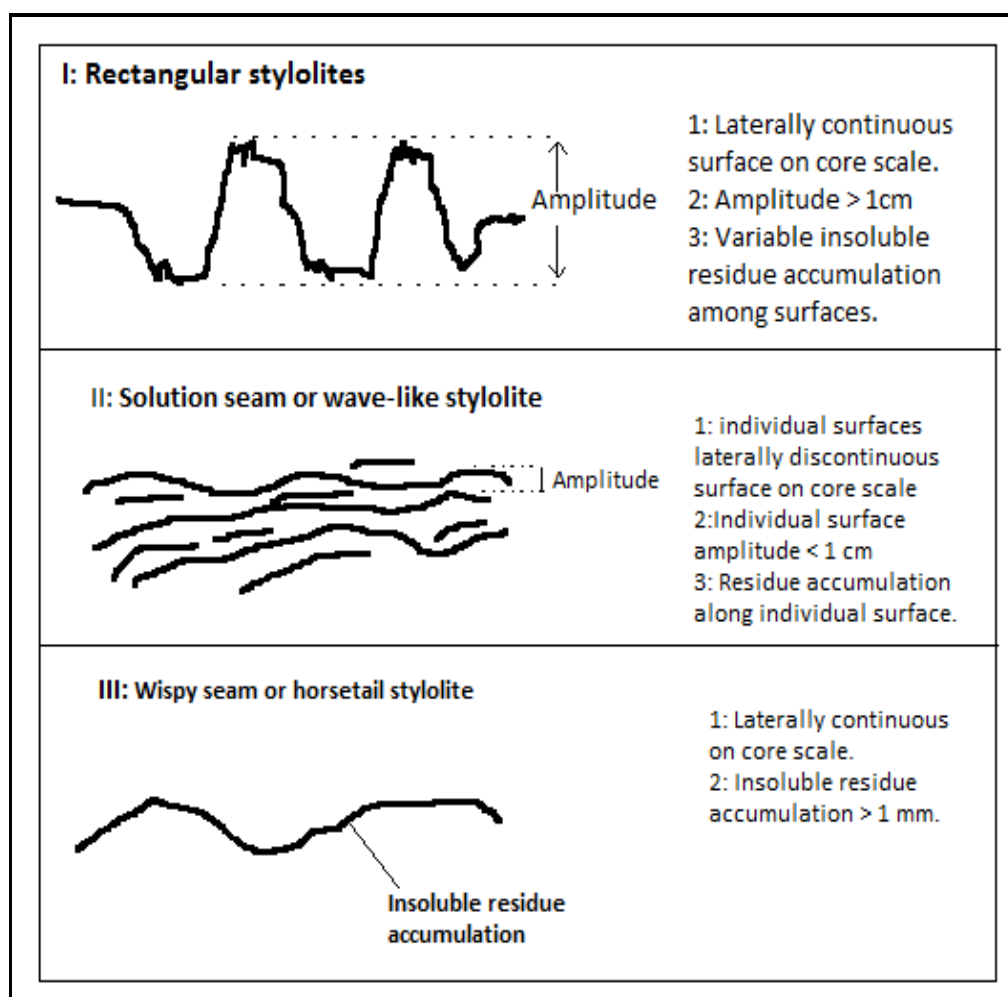


Figure 4-Three types of Stylolite with various in the lower cretaceous is reproduced from [18].

### Diagenetic History

Depending on the petrographic details, there are three diagenetic environments that have major effects on the Yamama Formation. These diagenetic environments were marine environments. Micritization of allochems by some skeletal grains takes place in the early phase of diagenesis at sea floor. At first, micrites are created around grains, with the development of the actions of the whole allochems are changed via micrite.

Bioturbation occurs in marine environments, while cementation is found around and within skeletal grains and divided into two stages; early and late cementation. Compaction has a major effect by two kinds of processes; mechanical compaction due to overload pressures as result of drop in sea level, and dissolution via under-saturated connate water affecting the carbonate rocks of Yamama Formation and forming vuggy and moldic porosity, sparry precipitated calcite cement and decreased porosity (vuggy and moldic). The greatest possible source of calcite cement is the materials created as a result of degradation of carbonate in meteoric environments. Sea level increase results in precipitation of new sediments. Different diagenetic processes within deep environments affect formation, including cementation, compaction, fracturing, and dolomitization. Stylolite is formed at increasing depth and overburden pressure of solution seams. Fracturing is formed under pressure within these environments, depositing calcite cement within dissolution porosity, any types of porosity reduced pore volumes. Dolomite around stylolites is formed in burial environment, probably forming calcite cement in carbonate sediments which are dissolved through formation of solution seam and due to overburden pressure creating the stylolite. Dolomite around stylolite is created at burial environments, whereas saddle dolomite is formed through deep burial environments. Table-1 illustrates the relative time of different diagenetic processes.



**Table 1-**Paragenetic sequence of diagenetic processes of Yamama Formation in Faihaa Oil Fie

Diagenetic Processes	Diagenetic Environments		
	Marine	Meteoric	Burial
<u>Micritization</u>			
<u>Cementation</u>			
<u>Dolomitization</u>			
<u>Neomorphesum</u>			
<u>Fractures</u>			
<u>Dissolution</u>			
<u>Mechanical compaction</u>			
<u>Stylolite</u>			
<u>Bioturbation</u>			

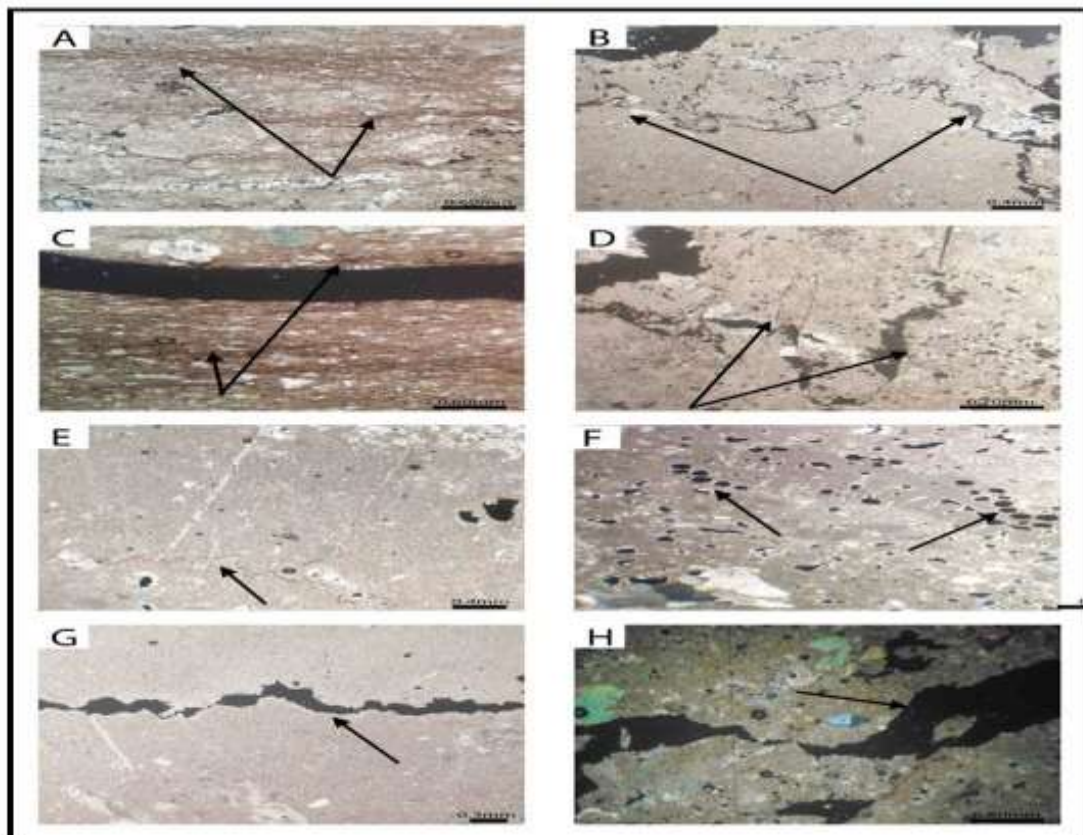


Plate-2 Diagenesis Processes: (A) Chemical compaction Wave stylolite PPL. (B) Medium amplitude stylolite PPL. (C) Mechanical compaction PPL. (D) High amplitude stylolite with insoluble fluid PPL. (E) Low amplitude stylolite PPL. (F) Dissolution PPL. (G) Fracturing in friable limestone PPL. (H) Fracturing with Cementation PPL.

### Diagenesis Effects on Reservoir Quality

Diagenesis processes had strong effects on Yamama Formation in Faihaa Oil Field. Dissolution had highly positive effects on this formation. Dissolution is the most important process through enhancement porosity and permeability. Allochems as well as matrix were effected intrusively, through forming a good interconnected porosity, especially in the upper part of Yamama Formation. The fracturing process also had a highly positive effect on improving reservoir quality. Most of the fractures were open and, therefore, led to improving reservoir quality.

Cementation and compaction processes had highly negative effects on reservoir properties. Most types of cement, especially calcite cement, filled partial and complete pore spaces. The compaction process negatively affected reservoir quality, leading to reduced and destroyed porosity due to increased overburden pressure. These processes occurred especially in the lower part of Yamama Formation.

The bioturbation process did not affect reservoir quality. Most of the bioturbation was filled partially or completely by calcite cement. The dolomitization process did not develop and most of the dolomite was associated with stylolite. Other diagenesis processes had no clear effects on Yamama Reservoir in this field. Figure-5 illustrates the distribution of diagenesis process within Yamama Formation in Faihaa Oil Field/ well Faihaa-2.

According to Ahr classification (2008) the Yamama reservoir in Faihaa Oil Field is a type of diagenetic reservoir, because the main factors for enhancement of the reservoir quality were dissolution and fractures.

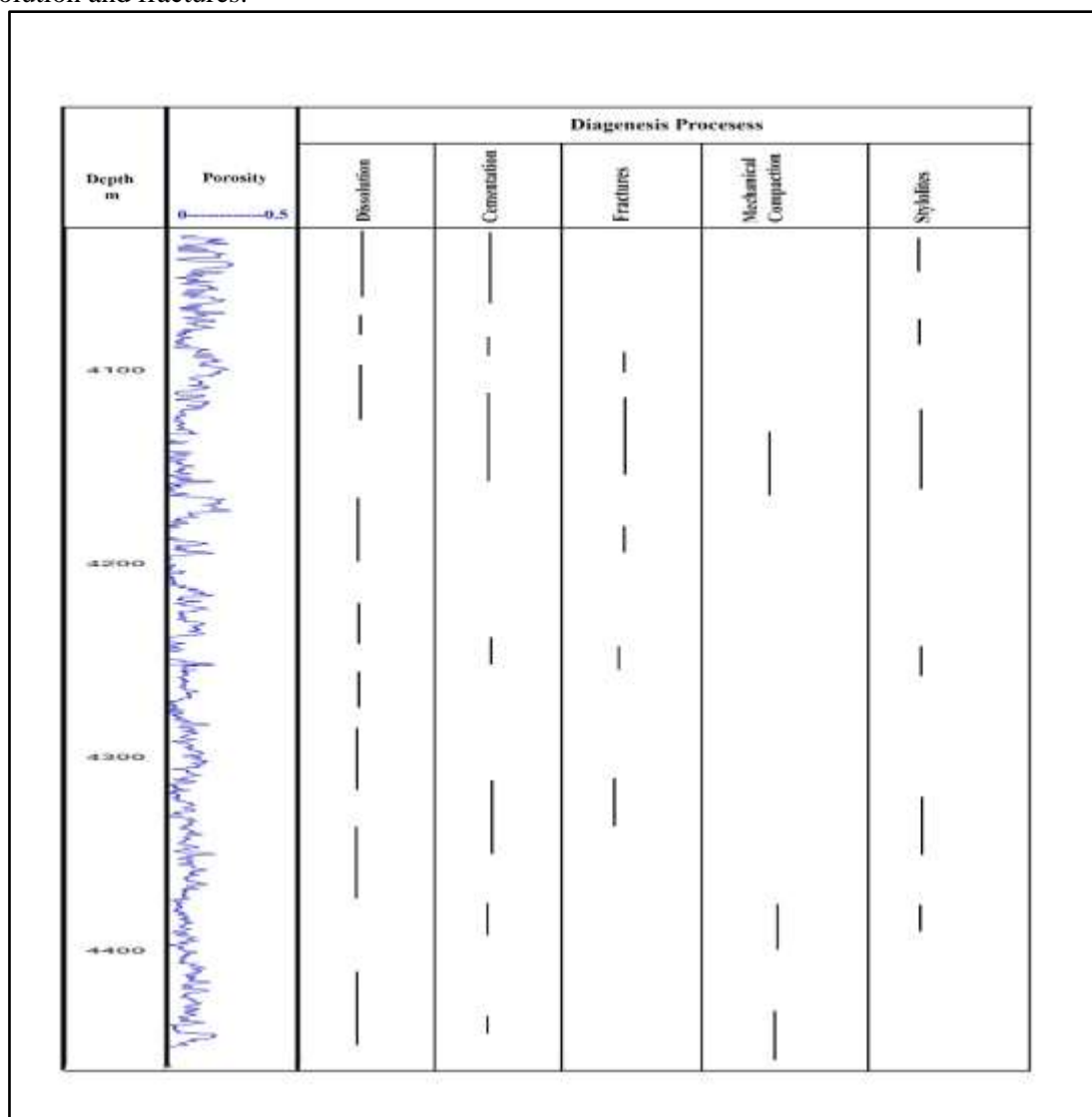


Figure 5-Distribution of the diagenetic processes' intervals in Yamama Formation, Faihaa-2

## Results and Conclusion

Based on the analysis and interpretations of thin section from core samples, three diagenetic environments were identified, represented by marine, meteoric and burial environments. The diagenesis processes controlled the reservoir properties, with many identified diagenesis processes affecting Yamama Formation. These processes included dissolution, cementation, fracture, compaction, dolomitization, micritization, neomorphism and bioturbation.

Dissolution and fractures showed highly positive effects on reservoir quality, through creating and improving porosity and permeability, especially in the upper part of Yamama Formation.

Cementation and compaction had highly destructive effects on reservoir quality, through filling most of the pore spaces. These processes led to reduced and destroyed porosity and permeability through partially or completely filling the pore spaces.

Other processes didn't have clear effects on Yamama reservoir in this field. From these details we could classify Yamama Reservoir as a diagenetic reservoir.

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