



ISSN: 0067-2904

Depositional Environment and Microfacies Analysis of Yamama Formation in North Rumaila Oil Field, South Iraq

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Received: 12/6/2021

Accepted: 26/7/2021

Abstract

Yamama Formation is an important sequence in southern Iraq. Petrographic analysis was used to determine and analyze the microfacies and pore types. The diagenetic processes and the impacts on the petrophysical properties of the rocks were also identified. The petrographic identification was based on data of 250 thin sections of cutting and core samples from four wells that were supplied by the Iraqi Oil Exploration Company (O.E.C). The present study focuses on the depositional environment and the microfacies analysis of Yamama Formation. The results revealed several types of microfacies, including peloidal wackestone-packstone, algal wackestone-packstone, bioclastic wackestone-packstone, foraminiferal wackestone, bioclastic wackestone, and mudstone. The latter was divided into two submicrofacies, namely argillaceous lime mudstone and sparse fossiliferous lime mudstone. The study showed that Yamama Formation was deposited through various settings within the carbonate platform; these comprise inner ramp, middle ramp, and outer ramp settings. The inner and middle ramp settings, characterized at the top and middle Formation, have high effective porosity and low clay volume, due to dominant packstone.

Keywords: Microfacies, Yamama Formation, Depositional Environment, North Rumaila, South Iraq

البيئة الترسيبية والسحنات الدقيقة لتكوين اليمامة في حقل الرميلة الشمالي جنوب العراق

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الخلاصة

تكوين اليمامة من التتابعات المهمة في جنوب العراق، حيث يستخدم التحليل البتروغرافي لتحديد السحنات الرسوبية ونوع المسام في التكوين ومعرفة العمليات التحويرية وتأثيرها على الخصائص البتروفيزيائية للصخور. تم خلال هذه الدراسة فحص حوالي (250) شريحة صخرية من اللباب والفتات الصخري زودت من شركة الاستكشافات النفطية. هذه الدراسة اختصت في معرفة السحنات الرسوبية والبيئة الترسيبية لتكوين اليمامة في اربعة ابار . حيث اظهرت النتائج بأن هناك عدة انواع مختلفة من السحنات الرسوبية وهي كالتالي : الحجر الجيري الواكي المرصوص الدملي والحجر الجيري الواكي المرصوص - الطحلي و الحجر الجيري الواكي المرصوص الفتاتي العضوي و الحجر الجيري الواكي الحاوي على المنخريات و الحجر الجيري الواكي الفتاتي العضوي و الحجر الجيري الطيني والتي قسمت بدورها الى سحنتين ثانويتين هما سحنة الحجر الجيري

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الطيني الصلصالي و سحنة الحجر الجيري الطيني الحامل للمتجترات المتناثرة. وتم الاستنتاج من خلال هذه الدراسة بأن تكوين اليمامة مترسب ضمن المنحدر الداخلي و الوسط والخارجي. الرصيف الداخلي والوسط يتميز بتركيزه عند اعلى و وسط التكوين والذي يكون ذو مسامية ونفاذية بسبب هيمنة سحنة الحجر الجيري الواكي المرصوص.

Introduction

The Cretaceous rocks represent good oil potential rocks within the stratigraphic column in southern Iraq. The main oil reservoirs are of the Cretaceous age, in addition to some important reservoirs from the Tertiary and upper Jurassic ages at most of the hydrocarbon within this point of view were confined to Suitable deposits for reserve especially in the lower and middle Cretaceous Formations in the south of Iraq [1, 2, 3]. This study targets Yamama Formation due to its good oil potential which attracted the interest of many researchers [4].

The Yamama paleogeography is represented by the Late Tithonian-Valanginian time at the Southern Neo-Tethys opened with the separation of the Bisitoun (Avroman) microplate from Arabia. The Upper Berriasian to Lower Valanginian palaeogeography (Yamama Formation) is summarized in (Figure 1) [5].

The Mesopotamian Zone witnessed repeated open marine incursions, leading to the deposition of alternating shallow water carbonates and outer shelf marls. Sedimentation began with the deposition of the transgressive Sulaiy and Yamama formations and ended with deposition of the Ratawi Formation during the high stand stage [5]. In southern Iraq, The Yamama Formation comprises outer shelf argillaceous limestones, as well as oolitic, pelloidal, pelletal, and pseudo-oolitic shoal limestones.

Oolitic reservoir units are present in several NW-SE trending depocentres [5]. The formation is of the Berriasian-Valanginian age. From its stratigraphic position, it can be implied that the age range of the Upper Berriasian to Lower Valanginian is likely 140 to 136 Ma.

The Yamama Formation was deposited in alternating oolitic shoal and deep inner shelf environments, probably controlled by subtle structural highs within a carbonate ramp [5].

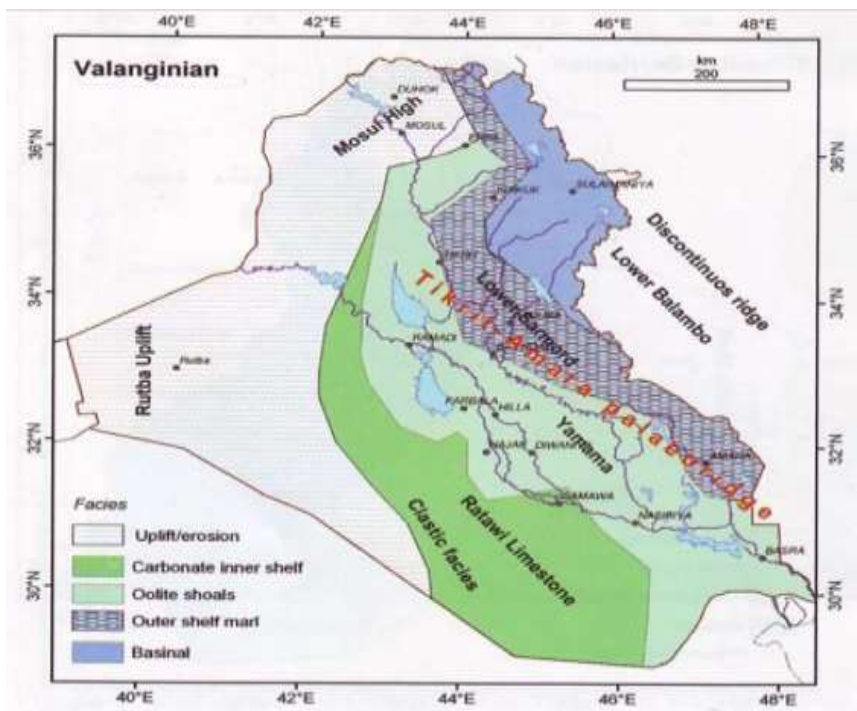


Figure 1- Palaeogeography of the Yamama Formation [5]

This study is intended to complement previous studies of the relationship between sedimentary environments and diagenetic processes and their effects on the petrophysical properties in north Rumaila oil field. The Yamama Formation occurs in the upper Berriasian-Aptian rock package. This package comprises the environments from shallow tidal flat to the deeper basin environments represented by the Shuiaba, Zubair, Ratawi, Yamama, Sarmord, and Lower Balambo formations .Yamama Formation is composed generally of limestone, with some thin dolomitic intervals, as well as narrow shale lamina [5].

Yamama Formation overlies the underneath Sulaiy Formation in a conformable manner. The latter is made of Jurassic-Lower Cretaceous carbonates composed of mud-dominated argillaceous limestone and contains the small-size benthic foraminifera. Yamama Formation changes upward gradually into Ratawi Formation (Figures 2 and 3). Ratawi Formation is a heterogeneous package of dirty limestone, shale, siltstone, and sandstone. The Ratawi Formation can be considered as a seal interval of the Yamama reservoir rocks [5].

The studied oilfield is the North Rumaila which is located about 70 km west of Basra, forming a convex asymmetrical sub-surface, with a slight slope and axis towards the north and south .The field is about 41 km long and 15 km wide and has a structural closure of approximately 110 meters (Figure 4).

This field represents the northern extension of North Rumaila field. The formation is widely distributed in Iraq and represents reservoirs in the southern parts.

The Yamama Formation, in southern Iraq, comprises an outer shelf argillaceous limestones, in addition to oolitic, peloidal, pelletal and pseudo-oolitic shoal limestones [6]. Sadooni [6] suggested that, in SE Iraq, the formation comprises three depositional cycles. Cycle tops contain oolitic grainstone inner-ramp facies which pass down into finer-grained peloidal facies and middle-ramp bioclastic/coral/stromatoporoid pack-wackestones. Outer-ramp cycle bases comprise thick grey shales with stringers of chalky micrite (Figure 5).

The main goal of this study is to find a relationship between the reservoir properties and sedimentary environments in carbonate rocks, concerning the effects of the diagenesis processes.

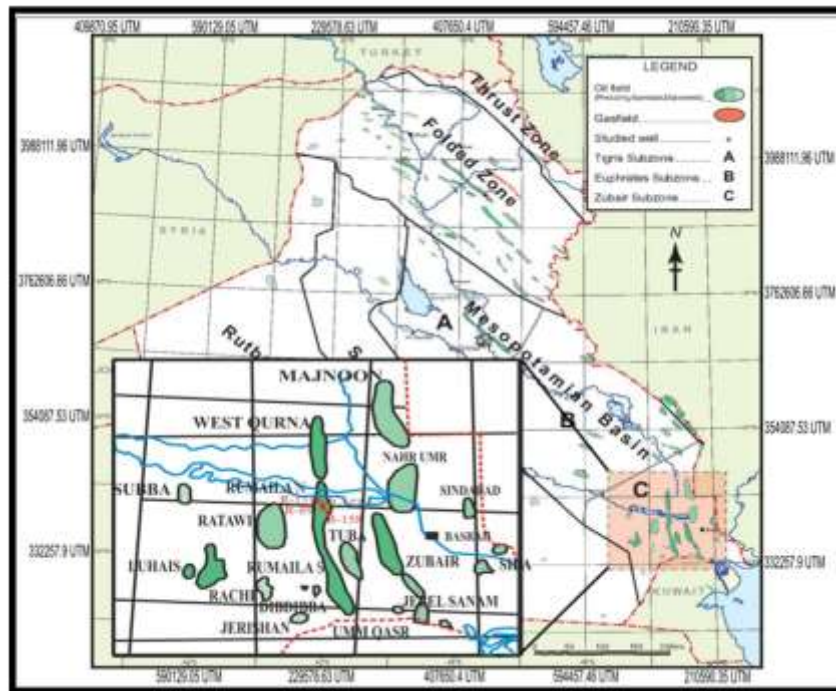


Figure 2-North Rumaila oil field and the Wells location map [6]

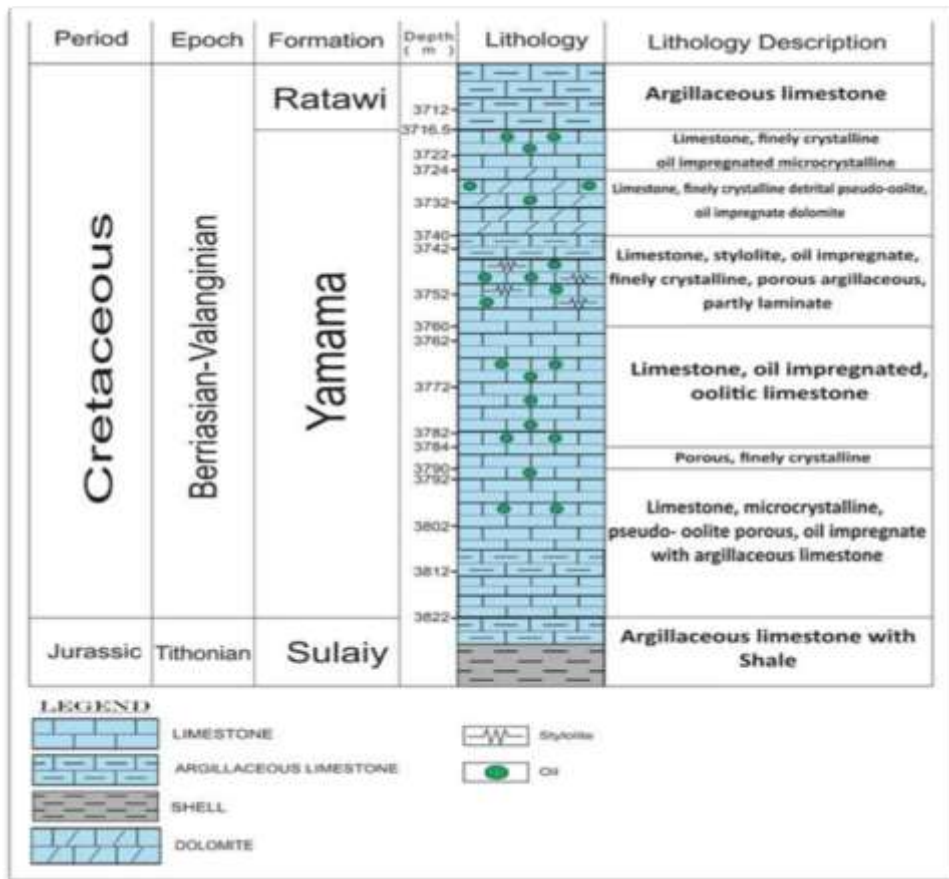


Figure 3-Stratigraphy section and lithology of Yamama Formation of well R-89 in North Rumaila field [6].

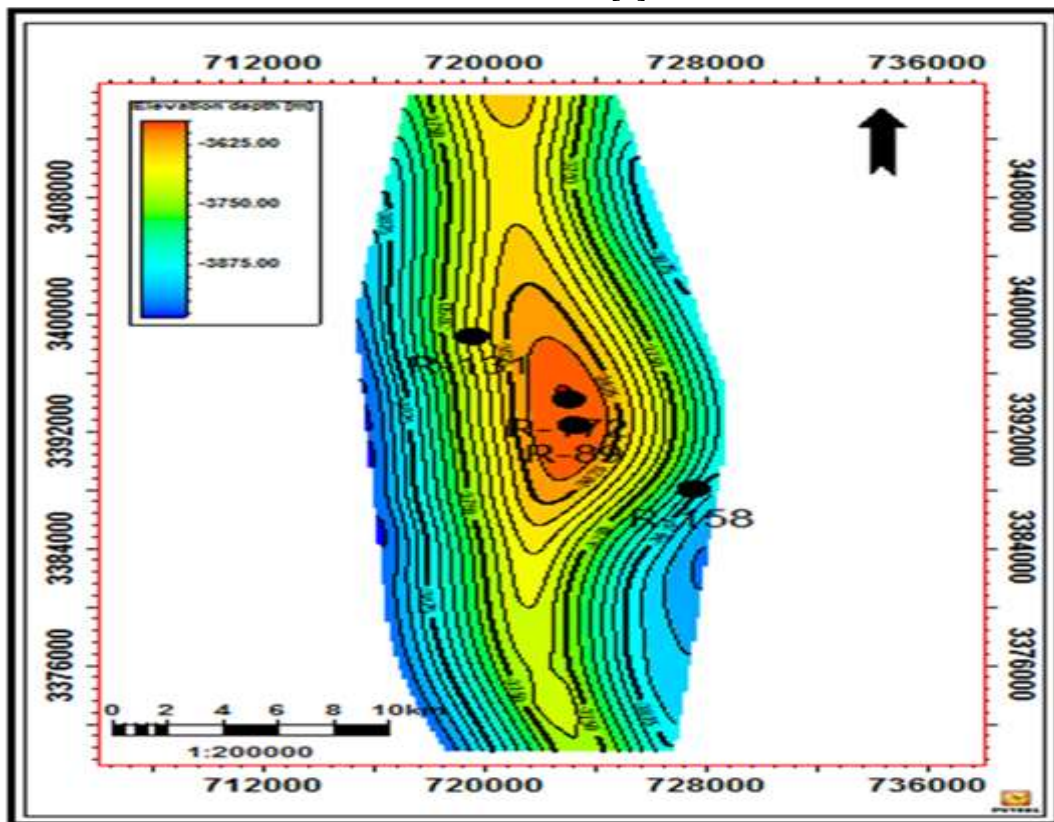


Figure 4- Structural contour map of the top of Yamama Formation (O.E.C)

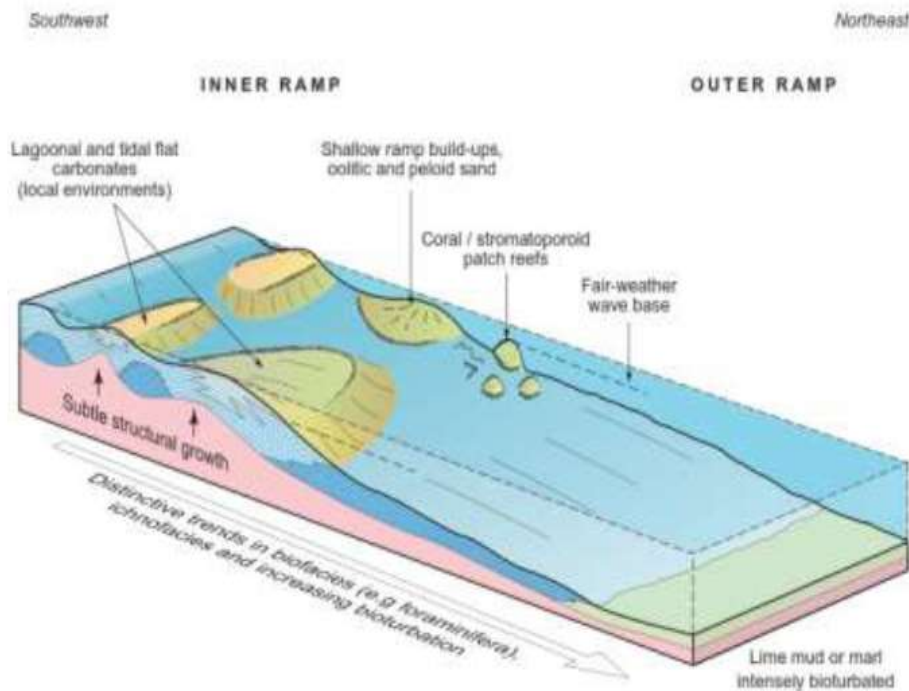


Figure 5- Facies model for the Yamama Formation ramp system in SE Iraq [6].

Materials and Methods

This study was based on subsurface data approved by the Iraqi Petroleum Exploration Company. Four wells were selected at the North Rumaila field structure, which are R-131, R-172, R-89, and R-158. The core data were collected from the final geological reports of the studied wells, which contain the plugs and thin sections that were identified.

Thin section analysis, by using polarized microscope, resulted in the petrographic description, identification and classification of microfacies, as well as identification of diagenetic processes to determine and reconstruction of the depositional environment of the Yamama Formation. The study involved more than 250 slides of cores and cuttings that were described and interpreted, together with several hundreds of thin sections previously prepared by the Iraq Oil Exploration Company and studied petrographically by applying the modified Dunham (1962) classification by Embry and Klovan (1972) [7, 8].

Well logs analysis was used to predict the relationship between the porosity and permeability, along with the effects of the sedimentary environments and diagenesis in terms of decreasing or increasing the reservoir properties. Many of the characteristics of the limestone of Yamama Formation were recognized using cutting samples, which were utilized to choose samples for thin section preparation. The cutting investigation was accompanied by the use of geological well reports, including data on the depths to which oil showed up. Fossil dissolution pores were used to distinguish the limestone units (vugs and molds), cementation, nodular fabrics, pyritization, bioturbation, fractures and stylolite. In addition, microfacies analysis depended on the study of thin sections of cutting samples, from the Oil Exploration Company labs, for selected wells for Yamama Formation in North Rumaila. Well logs were digitized using NeuraLog software. Furthermore, available well log responses were related to facies changes for the studied succession intervals.

Results and discussion

1 Microfacies of the Yamama Formation

Six facies were determined in the Formation of Yamama; (1) Peloidal wackestone-packstone, (2) Algal wackestone-packstone, (3) Bioclastic wackestone-packstone (4)

Foraminiferal wackestone, (5) Bioclastic wackestone Microfacies, (6) Microfacies of Mudstone .

1.1 Peloidal wackestone-packstone Microfacies

In a low-energy sheltered area (plt. 1-I), these facies are often prevalent in the upper portion of the studied well. They could correspond to the Wilson Standard Microfacies Types (SMF-17) and (FZ-8) of the Standard Facies Zones, according to the Flugel Classification (2010) [9], suggesting an internal ramp setting with minimal water circulation.

1.2 Algal Wackestone to Packstone Microfacies

The algal debris facies can be divided into two subfacies according to algae types, as described below.

A- The subfacies of dasycladacean wackestone

These are primarily composed of green algae from the Dasycladacean group. Most of their skeletons were dissolved by sparry calcite cement in order to be filled. In most cases, algae are mixed with shell fragments (mainly pelecypods).

The most favorable areas for green algae development are typically sheltered lagoons and protected reef flats [9] (Plt. 1-A, B).

B- Permocalculus.

This is the largest group of red algae preserved as fossils. These microfacies can represent open-circulation shallow marine waters (Plt. 2-M). Wilson Standard Microfacies Types (SMF-12), (FZ-7) can correspond to it [10].

1.3 Bioclastic Wackestone Packstone Microfacies

Echinoderms and algae fragments are mixed in this microfacies as an indication of open marine environment without reef or that confined to the circulation of water (plt. 1-E, F). Wilson Standard Microfacies Types (SMF-10), (FZ-2) can correspond to it [10]. Because of the abundance of wackestone packstone, this suggests a shallow open sea climate.

1.4 Foraminifera Wackestone Microfacies

These facies consist of rocks ranging from wackestone to packstone in texture and containing large benthic foraminifera, such as Miliolid and Trocholin (Plt. 1-C, D). It may correspond to Wilson's (SMF-8) (FZ-2), which suggests a circulating shelf lagoon [10]. Environments of low energy below the wave base.

1.5 Mudstone Microfacies

The mudstone microfacies are divided into two main submicrofacies: Argillaceous lime mudstone and Fossiliferous lime mudstone.

A The argillaceous lime mudstone submicrofacies

This submicrofacies is similar to Wilson's (SMF-23) facies zone (FZ-8), indicating open-restricted lagoon environment and shallow open marine. (Plt-2, A)

B Fossiliferous lime-mudstone submicrofacies

This submicrofacies is similar to Wilson's (SMF-23), facies zone (FZ-9), which indicates tidal flats and restricted-protected lagoon climate (Plt.2-H, 1-G).

1.6 Bioclastic Wackestone Microfacies

This microfacies in features dissolved most of bioclasts and leaved effect stamps of bioclasts (Plate-2, N). It occurs as a shallow lagoon with open circulation at or just below the fair-weather wave base (FZ 7) and deep shelf (FZ 2); i.e. outer and mid ramp settings [9, 10].

Hence, the Yamama Formation was deposited through various settings within the carbonate platform; these comprise the inner ramp, middle ramp and outer ramp setting.

SEDIMENTARY ENVIRONMENTS

2 Depositional Environments of the Yamama Formation

The carbonate ramp environments in Yamama Formation are classified into three categories:

(1) inner ramp, (2) middle ramp, and (3) outer ramp [10] (Figure 4). The Mesopotamian Basin, which is built on a gently dipping slope of the Arabian Platform and considered a passive edge on a ramp setting, deposited the Early Cretaceous Yamama Formation [6].

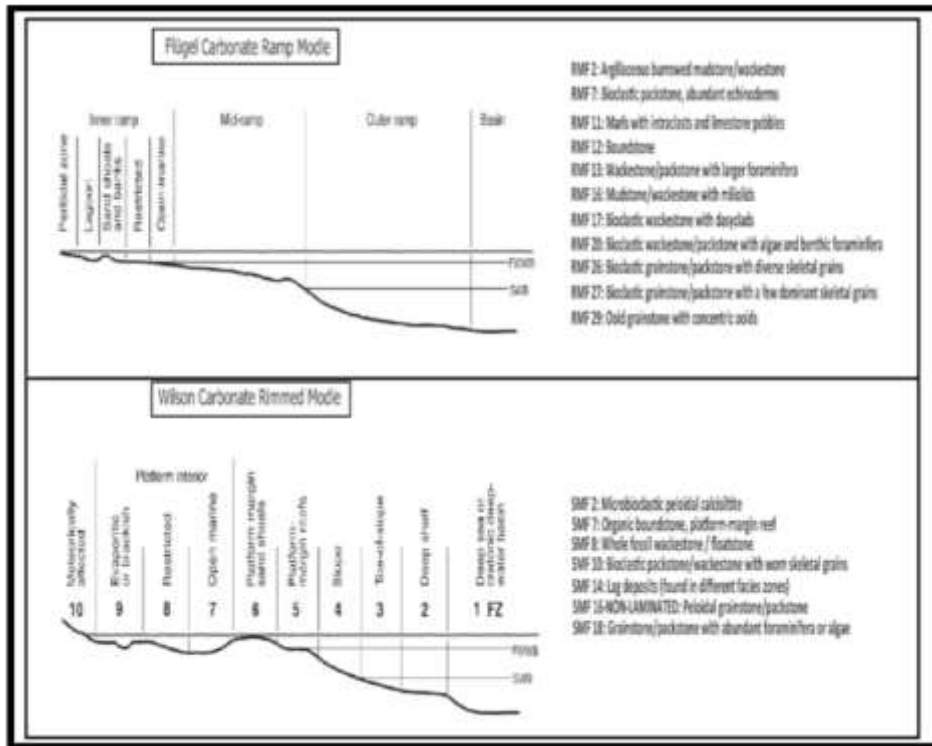


Figure 6-Main microfacies types used in Yamama facies association according to Flügel, 2010, [9], compared with Wilson, 1975, [10] in different parts of homoclinal carbonate ramp and rimmed platform.

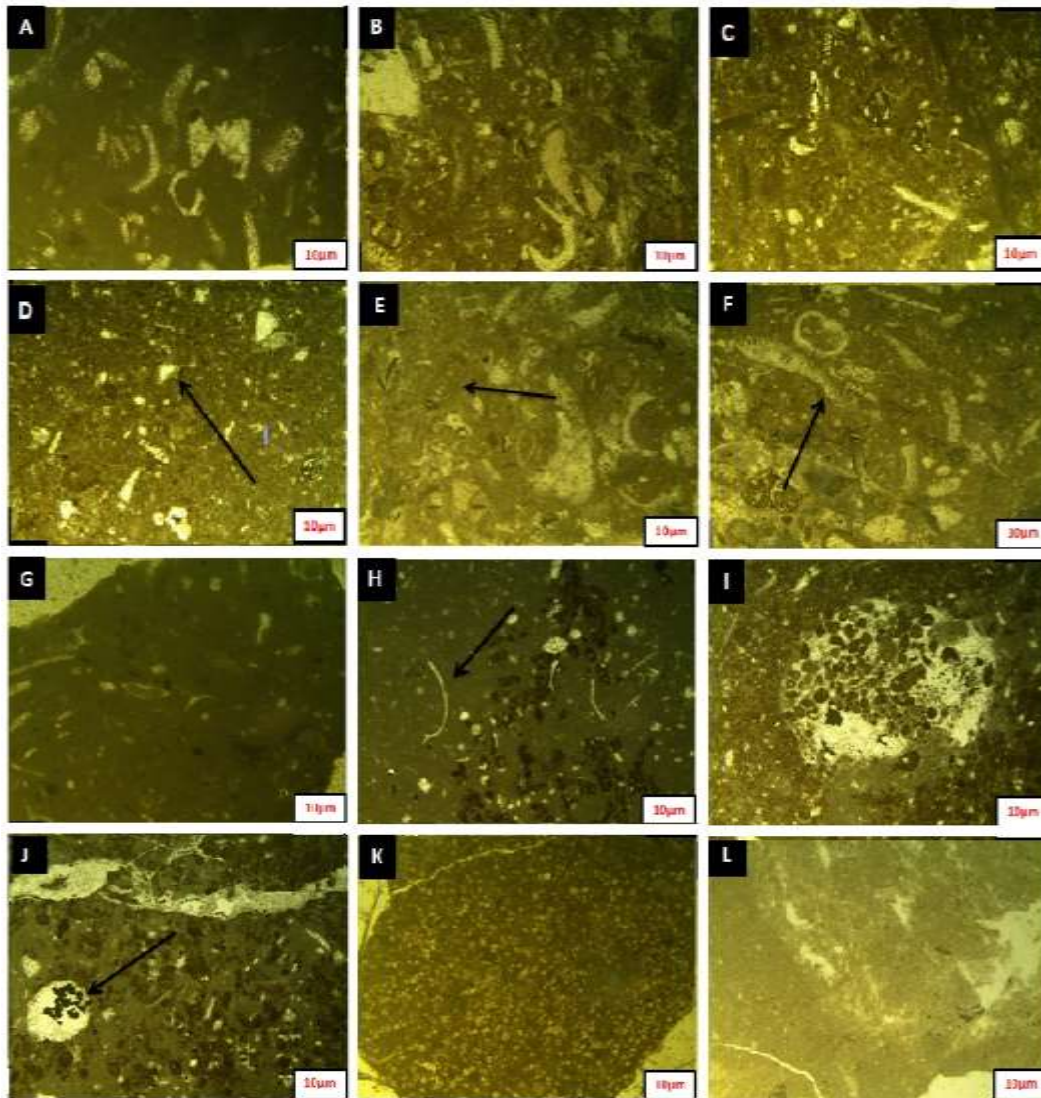
In Yamama Formation, this diagram is arranged with shallowest water environments to the right side of the back ramp area, through deep basin environments to the left. In between, there is an intermediate area that indicates shallow ramp and deep ramp, with the confines between them being established approximately at the lower limit of the fair weather wave base (FWWB).

The absence of any reef margin development, the lack of primary slope break from the shoreline to deeper water, and the existence of high-energy grainstone facies were reported by an earlier work [11]. These findings are consistent with prior investigations of facies relationships, which revealed facies organization along carbonate ramps and differences in hydrodynamic energy, depositional texture, sedimentary structures, and fossil content. The Yamama Formation's inner ramp develops the microfacies of lagoon, shoal, open marine, and restricted marine facies associations.

On a homoclinal ramp setting, lagoon ecosystems are also extensively formed. The degree of barrier restriction and permanence affects the organisms that live in lagoons, as well as the sediments that accumulate in this mostly quiet water environment [12]. Lagoonal, open marine, and restricted marine environments of Yamama Formation microfacies are rich in lime mud and dominated by benthic Foraminifera and green algae in the studied fields. Carbonate shoal distribution is one of the characteristics that describe inner ramp habitats with peloids, ooids, and intraclasts coated by micrite in Yamama Formation microfacies in the studied area. These microfacies are classified as shoal facies, meaning that they have a lot of energy [12]. Open marine environments with sponge spicule, echinoderm, bioclastic

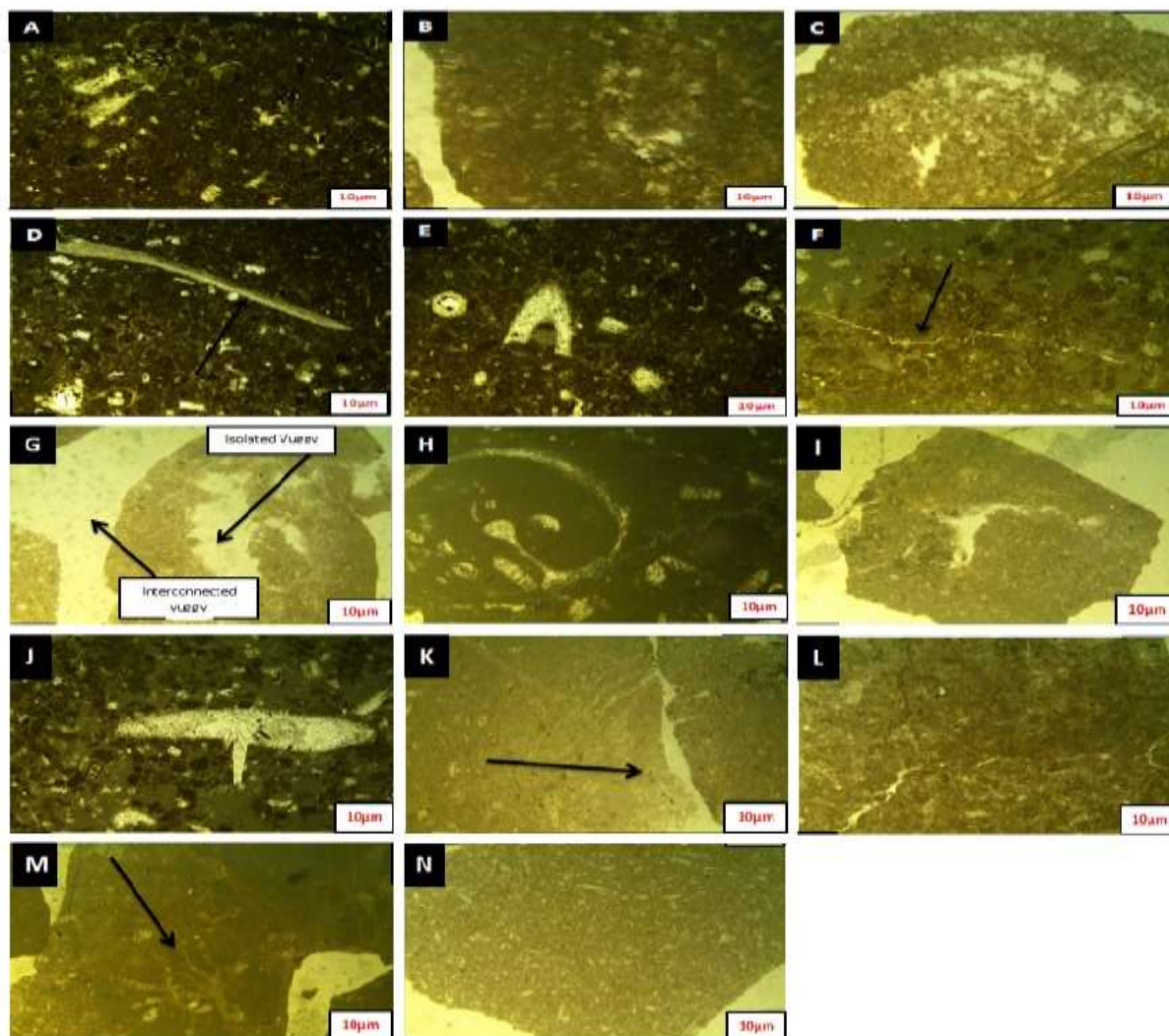
Foraminifera, algal debris, and peloid grains in the microfacies make up the inner ramp. Mudstone and occasional wackestone microfacies are present in the mid-ramp setting.

Plate1



A. Algae (Dayscladales) (3785m), **B.** Green algae, Bioclastic Wackestone Microfacies (3730m), **C.** Foraminifera (Millioid), Foraminifera Wackestone Microfacies (3734m) **D.** Foraminifera (Trocholina), (3734m), **E.** Foraminifera (Oolithica), Bioclastic Wackestone-Packstone Microfacies (3730m) **F.** Mollusca (Gastropoda), Bioclastic Wackestone-Packstone Microfacies, (3730m), **G.** Other organism Fossiliferous lime-Mudstone submicrofacies), (3818m) **H.** Other organism (pelecypoda), (shall fragment), (3740m), **I.** Peloidal wackestone-packstone Microfacies, (3740m), **J.** Cement (Drusy cement), (3740m), **K.** Dolomitization, (3816m), **L.** Micritization & dissolution, (3769).

Plate 2



A .Neomorphis (3734m), **B**. The argillaceous lime Mudstone submicrofacies ,(3800m),**C**. Dissolution (3800m),**D**. Echinoderm (3734m), **E**. Dolomitization (3734m), **F**. Micro Fracture poros, Peloid , (3740m) **G**. Isolated Vagy & interconnected Vagy poros (3828m), **H**. Mollusca (Gastropoda), Fossiliferous lime-Mudstone submicrofacies (3785m) **I**. Isolated Vagy (3849m), **J**. Syntaxial cement:,Peloid, (3740m) ,**K** Channal poros (3769m), **L**. Stylolites, (3800), **M**. Red Alge , (3767m), **N** . Bioclastic wackstone , Mid-Ramp facies association (3854m) .

Moreover, three distinct depositional environments were identified. The arrangements of these environments range from semi-restricted to shallow open marine and deep open marine water conditions (Figures 1 and 7). Such results are in accordance with many researches [13 to 18]. Three major depositional cycles were determined. All the cycles exhibit normal sequential regression from the base upward. The upper part of the formation represents the fall of the sea level and marks the end of the regressive phase.

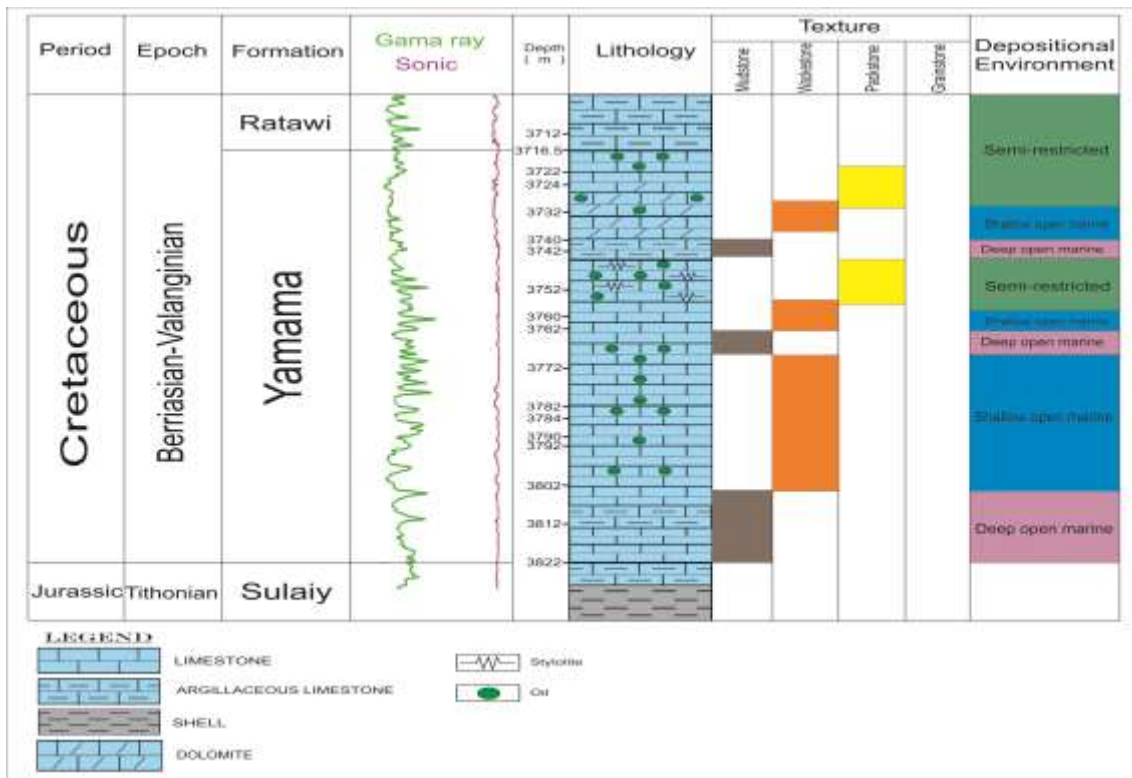


Figure 7- Variations in the depositional environments of Yamama Formation along with age and texture characterizations for R-89.

Diagenetic processes

Carbonates of the Yamama Formation have been affected by both early- and late-stage diagenesis. The most important diagenetic processes in the Yamama Formation are micritization, cementation, neomorphism, dolomitization, dissolution, and fractures (Plates 1 and 2). Mudstones and wackestone were principally altered by marine phreatic and later diagenetic processes. Cloudycentered, clear-rimmed dolomite rhombs and stylolites indicate later, burial diagenetic processes. Diagenetic features in the bioclastic wackestones, packstones, and grainstones indicate early and surface alteration in the meteoric phreatic and mixing zones. The development of moldic, vuggy, and channel porosity, particularly in packstones and grainstones, indicates a similar diagenetic environment. These processes are described briefly below.

Dolomitization

The limestone beds of the Yamama Formation have been affected by dolomitization process at various degrees. The fine grain size of the rhombs indicates their early diagenetic origin, whereas larger dolomitic crystals of clear-rimmed, cloudy-centered types were formed during later diagenesis [12, 13, 14].

The fine grain size of the rhombs and their occurrence within the mud-supported facies indicate their early- diagenetic origin, particularly those present within intertidal mudstone. The coarser dolomite crystals are formed during a later dolomitization process but before stylolitization. Dolomitization has highly enhanced the reservoir quality of most the microfacies, particularly with the formation of secondary intercrystalline micropores within muddy microfacies (Pl.1 K , Pl.2 E).

Neomorphism

The Yamama Formation carbonates have been affected by neomorphism, which commonly

affected the groundmass and particles (Pl.2 A). Micrite is often recrystallized and aggrading to microspar or pseudospar. It also affects the molluscan shell fragments, foraminifera, and other skeletal grains, leading to the inversion of aragonitic skeletal fragments to calcite by the presence of solution. In shallow marine environments, the neomorphism process intensifies greatly by the solution under higher temperature and pressure conditions [9].

Cementation

Cementation has been an effective diagenetic process in various microfacies, filling the intergranular and intragranular pores, cavities, fissure, and fractures and leading to the occlusion of primary porosity in the Yamama Formation carbonates. Many types of cements have been recognized: (1) micrite cement, (2) overgrowth cement, (3) displacement cement, (4) granular cements, (5) druzey mosaic cements, (6) syntaxial rim cement, and (7) blocky cement. These cements are believed to be of later diagenetic origin, although the mosaic cement and the syntaxial rim cement may have formed during two or more phases (Pl.1 J and Pl.2 J).

Micritization

It is the most common process affecting the skeletal fragments in the bioclastic packstones and bioclastic wackestones microfacies of the Yamama Formation. In a stagnant marine phreatic zone, the micritization process is affected greatly by blue-green algae or fungi [12]. Micritization is an early diagenetic process and micritized skeletal grains are very common in facies of the Yamama Formation (Pl.1 L).

Dissolution and Fracture

This process acts to destroy the internal structures for the skeletal grains, leaving the micritic envelope to form the moldic porosity or vuggy porosity (Pl.1 L, Pl.2 C,K,F,G,I and L). The results could distinguish the porosity and divided them into grain-dominated fabric and mud-dominated fabric. Also, interparticle porosity was distinguished and divided into grain-dominated fabric and mud-dominated fabric. In addition, interparticle porosity was distinguished and divided to grain-dominated fabric and mud-dominated fabric.1. 2.

The moldic porosity or vuggy porosity or enlarge the presenting vugs to form cavern porosity or channel porosity . Fracture porosity is found in mudstone and wackestone that are composed of soft mud, where the channel porosity is developed due to dissolution process.

Conclusions

Based on the analysis and interpretation of thin sections from the cut samples, Yamama Formation in North Rumaila oil field consists of six microfacies types: (1) Peloidal wackestone-packstone, (2) Algal wackestone-packstone, (3) Bioclastic wackestone-packstone (4) Foraminiferal wackestone, (5) Bioclastic wackestone microfacies, and (6) Microfacies of mudstone . Peloidal wackestone-packstone and algal wackestone-packstone microfacies are concentrated at the top and middle of the formation, while microfacies of mudstone are concentrated in the lower part.

In addition, Yamama Formation is effected by six diagenetic processes, namely the dolomitization, cementation, neomorphism, dissolution, fracture, and micritization. These processes may increase porosity, as in the cases of dissolution and fractures, or lead to a decrease in porosity, as in dolomite and cementation. The reservoir properties of the formation decrease towards the bottom due to the increase in mudstone microfacies.

On the basis of microfacies analysis, the deposit environment of the Yamama Formation was divided into (1) inner ramp, (2) middle ramp, and (3) outer ramp. The inner ramp setting is characterized by Peloidal wackestone-packstone microfacies that have high effective porosity and low clay volume. The packstone inner ramp is dominant in the top and middle Formation at depths between 3719 and 3790 m, which is characterized by high reservoir quality. The middle ramp setting is characterized by Bioclastic wackestone microfacies and Bioclastic wackestone-packstone. The outer ramp setting is composed of Mudstone and Algal

wackestone-packstone microfacies, characterized by a decrease in porosity and permeability due to the increase of clay volume. This results in a decrease in reservoir properties at the lower part of the Formation.

Acknowledgement

Deep thanks to my supervisors, Dr. Medhat and Dr. Moutaz Al-Dabbas, as well as and to the Miss Wafaa for helping me in arranging this research.

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