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Microfacies Analysis and Stratigraphic Framework of Yamama Formation in Sindbad, Halfaya and Ad'daimah Oil Fields, Southern Iraq

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Abstract

The Yamama Formation represents a part of the Late Berriasian-Aptian sequence, deposited during the Early Cretaceous period within the main shallow marine depositional environment. The studied area covers three oil fields; Sindbad oil field, Halfaya and Ad'daimah oil field, located in southeastern Iraq. Six major microfacies were recognized in the succession of the studied area represented by the Yamama Formation to determine and recognize depositional paleoenvironments. These microfacies are; Peloidal Packstone, Algal Wackestone to Packstone, Bioclastic Wackestone – Packstone, Foraminiferal Bioclastic Wackstone, Packstone, Peloidal – Oolitic Grainstone and Mudstone Microfacies. These microfacies are classified into three standard microfacies and three Facies Zones MFS-18/FZ- 8, SMF 15/FZ-6 and SMF-10/FZ-7, representing the restricted marine, shoal and shallow open marine associations facies, respectively.

The Yamama succession in the studied area is divided into three cycles representing three depositional stages of highstand system tracts. These three cycles are characterized by shallowing upward depositional mode where they are deposited in the shallow open marine shoal with semi-restricted associations facies for each cycle.

To the northeast of the study area near Halfya-5 well, the shoal association appeared in the lower and middle part of the Yamama succession, and in Da-1 and Sn-2 were three cycles. This case suggests that the paleo high was developed north of the study area, while the open marine was extended to the southern part. The presence of shallow open marine association facies between the Sulaiy and Yamama successions refers to continuous deposition during the same depositional stage in all studied wells. It may mark the end of the Sulaiy succession with the maximum flooding surface (MFS). This first depositional stage is started with the shallow open marine association facies underlain by shoal facies association and then semi-restricted association. The repetition of this cycle in the studied sections symmetrically indicates the harmonic oscillation in sea level during the second and third depositional stages of this sequence.

The Halfaya oil field within the Mesopotamian Block and Ad'daimah and Sindbad oil fields within the Basra Blok explain the significant variation in the thickness for this succession between the Halfaya oil field and the other oil fields. This may suggest the occurrence of high depositional subsidence in Basra Blok and uplifting during the Yamama depositional stages. The fact that the studied sections are distinguished by the same cycles, albeit roughly, indicates that the lifting and sit-down processes synchronized sedimentation.

Keywords:- Microfacies Analysis, Stratigraphic Framework, Yamama Formation, Sindbad oil field, Halfaya oil field, Ad'daimah oil Fields, Southern Iraq.

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تحليل السحنات الدقيقة و الهيكلية الطباقية لتكوين اليمامة في حقول نفط السندباد و الحلفاية و الديما / جنوب شرق العراق

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الخلاصة

ينتمي تكوين اليمامة إلى تتابع برياسيان–أبتيان المتأخرة ، والتي ترسبت خلال العصر الطباشيري السفلي ضمن بيئة الترسيب البحرية الضحلة الرئيسية ، وتغطي المنطقة المدروسة ثلاثة حقول نفطية ؛ حقل نفط السندباد وحلفاية وحقل الديمة النفطي الواقع جنوب شرق العراق.

تم التعرف على ستة سحنات دقيقة رئيسية في تتابع المنطقة المدروسة والممثل بتكوين اليمامة لتحديد والتعرف على ابيئات الترسيب القديمة. هذه السحنات الدقيقة هي

Peloidal Packstone, Algal Wackestone to Packstone, Bioclastic Wackestone – Packstone, Foraminiferal Bioclastic Wackstone, Packstone, Peloidal – Oolitic .Grainstone and Mudstone Microfacies

تم تصنيف هذه السحنات الدقيقة إلى ثلاث سحنات قياسية قياسية وثلاث انطقة سحنية هي MFS-18 / FZ- 8 و SMF 15 / FZ-6 و SMF-10 / FZ-7 ، والتي تمثل مترافقات سحنية بيئية هي:- البحرية الضحلة المحجوزة و الحاجز الرملي الكاربونايتي و البحرية الضحلة المفتوحة ، على التوالي .

ينقسم تتابع اليمامة في منطقة الدراسة إلى ثلاث دورات تمثل ثلاث مراحل ترسيبية لمسارات نظام الوثبة العالية. تتميز هذه الدورات الثلاث بتضحلها نحو الاعلى حيث ترسبت على التوالي من مترافقة بيئة بحرية مفتوحة والحاجز الرملي الكاربونايتي مع بيئة بخرية شبه محجوزة.

إلى الشمال الشرقي من منطقة الدراسة بالقرب من بئر حلفاية-5 ظهرت مترافقة الحاجز الرملي في الجزء السفلي والوسطى من تتابع اليمامة ، بينما في ديما والسندباد كانت ثلاث دورات. يشير هذا إلى أن المرتفعات القديمة نشأت في شمال منطقة الدراسة ، بينما امتد البحر المفتوح إلى الجزء الجنوبي. يشير وجود مترافقة البيئة البحرية المفتوحة الضحلة بين تكوينات السلي واليمامة إلى الترسيب المستمر خلال نفس المرحلة في جميع الآبار المدروسة ، وقد يشير إلى نهاية تكوين السلي بأقصى مستوى لسطح البحر (mfs). بدأت المرحلة الأولى للترسيب باعتلاء المترافقة السحنية البحرية المفتوحة الضحلة للمترافقة السحنية للحاجز الرملي ثم المترافقة شبه المقيد. إن تكرار هذه الدورة في المقاطع المدروسة بشكل متناظر يشير إلى التذبذب التوافقي في مستوى سطح البحر خلال مرحلتي الترسيب الثانية والثالثة من هذا التسلسل.

يفسر موقع حقل حلفايا النفطي ضمن كتلة بلاد ما بين النهرين وحقل الديمة والسندباد النفطي داخل بلوك البصرة التباين الكبير في سمك هذا التتابع بين حقل حلفايا النفطي وحقلي النفط الآخران. قد يشير ذلك إلى حدوث هبوط ترسيبي عال في بلوك البصرة ورفعها خلال مراحل ترسيب اليمامة. حقيقة أن المقاطع المدروسة تتميز بنفس الدورات ، وإن كانت تقريبية ، تشير إلى أن عمليات الرفع والجلوس متزامنة مع الترسيب.

1. Introduction

The Yamama Formation, a heterogeneous carbonate reservoir, is one of the most important oil-producing reservoirs in southern Iraq and neighbouring areas, which was deposited during the Lower Cretaceous within the major retrogressive depositional cycle (Berriasian - Aptian), [1]. From the stratigraphic position of this succession, the age ranges from Late Berriasian to Early Hauterivian stage is expected [2] and assigned the Valanginian age [3].

The Yamama Formation was defined for the first time by Steinke and Bramkamp in 1952 [4] from outcrops in Saudi Arabia. They suggested that the Yamama succession represents the Thamama Group.

The Formation is underlain conformably by the Sulaiy Formation and grading upward into the Ratawi succession, which is considered the Yamama reservoir cap rock.

The Yamama Formation in southern Iraq is comprised of outer shelf argillaceous limestones with oolite, pelloids, pellets and pseudo-oolitic shoal limestones. The Oolitic reservoir units are present in several NW-SE trending depocentres [5].

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

The studied area covers three oil fields; the Sindbad oil field is situated in Basra city, southeast of Iraq, adjacent to the Iraq- Iran border and approximately 16 km southwest of the center of Basra governorate (Figure 1). The Halfaya field is located in southern Iraq near Messan governorate, about 35 km southeast of Amara city (Figure 1). Structurally, which is composed of two structural domes laying from northwest to southeast direction and a gentle slope of elongated anticline about 38km long and 12km wide. The Ad'daimah oil field is located in southeast Iraq, Messan Governorate, about 80 km SW of Al'emara City (Figure 1) as a continuation of Hoor Al-Baghdadiyah (a local term for a wetland part filled with water in all seasons).

The present study involves microfacies analysis and diagenetic development of the Yamama succession in the Sindbad, Halfaya and Ad'daimah oil fields.

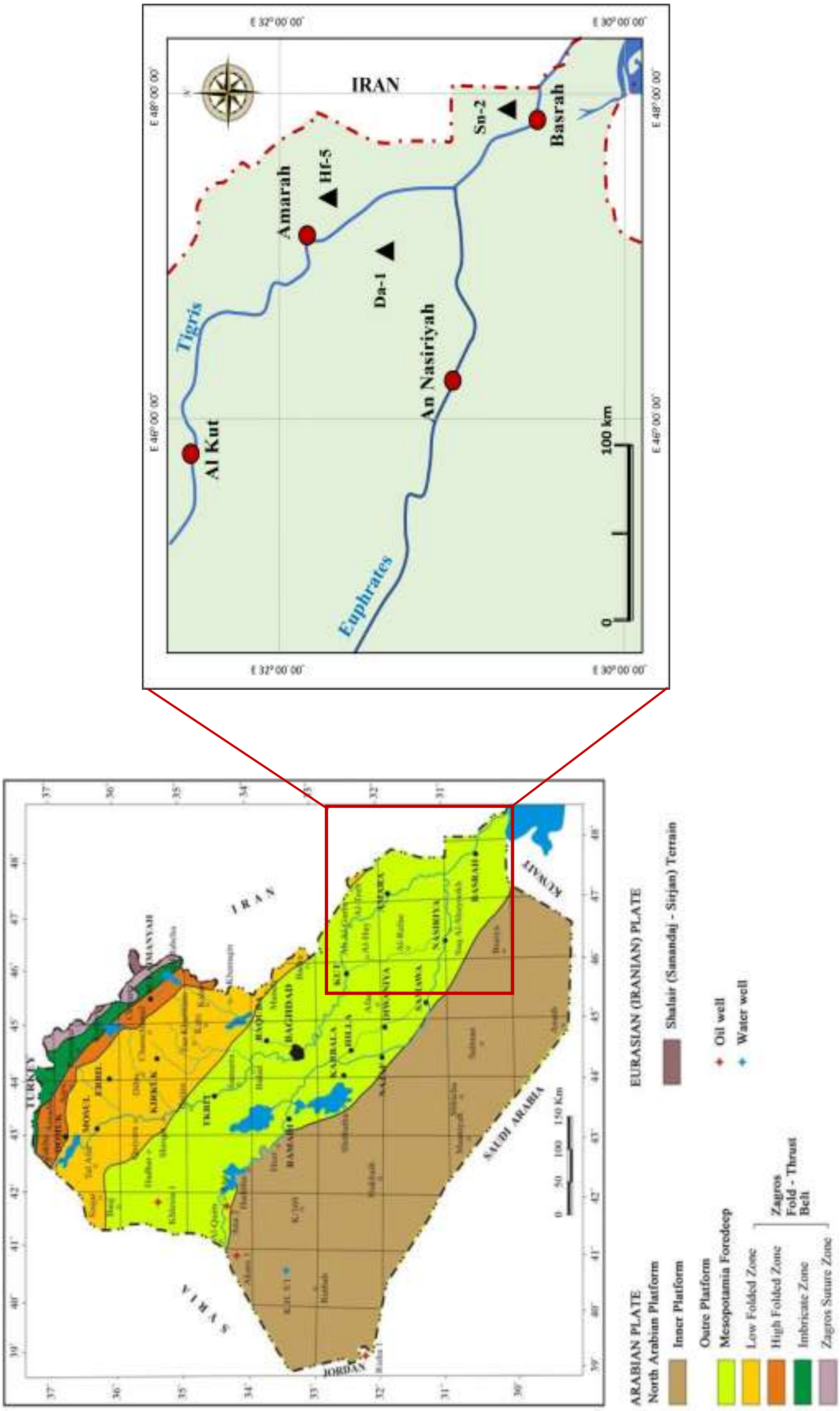


Figure 1 : Shows a map of study area with the tectonic subdivisions according to [6]

2. Methodology:

- **Fieldwork**

1. Three boreholes in three oil fields were selected for this study that contains more than 600 thin sections, and then the description is made to identify the texture, grains size, and type of microfacies, and determine the depositional environments.
2. The Sampling stage was made by taking rock samples from the available cuttings and cores to the Yamama succession and then making a thin section; the sampling was done one slide per meter.

- **Laboratory work**

1. The current petrography and microfacies investigations were according to the Dunham (1962) classification [7] using a transmitted light microscope. The petrographic study was based on about 600 thin sections from cores and/or cutting of the study wells.
2. The well-logging tried to compare the microfacies extracted from the laboratory work as electrofacies, diagnostic of the horizontal and vertical changing facies.
3. Location map and columnar sections for the studied wells were drawn using the Corel Draw X7 and Rock work 16 programs.

3. Geological and stratigraphic settings

Late Tithonian to early Turonian Megasequence was represented deposit in intra-shelf of a wide area in the basin that will coincide with the new tectonic phase of ocean floor spreading in the Southern part of Neo-Tethys that cause a differential in subsidence due to change in thickness along the transverse fault. The axis of intra shelf basin shifted toward the eastern Mesopotamian position in the Salman zone and western Mesopotamian zone.

According to the tectonic subdivision of Jassim and Joff (2006), the Sinbad, Addaimah and Halfaya are located near the platform flank of the Mesopotamian basin within the stable zone (Figure 1). The Addaimah and Halfaya oilfield is located in the Mesopotamian block. The Sinbad oilfield is located in the Basra block.

This sequence is comprised of Sulaiy, Makhul, Chia Gara (including Karimia), Yamama (including Garagu and Zangura), Ratawi and Lower Sarmord formations. Although geologists in Iraq and Kuwait dropped the Sulaiy Formation in favour of the Makhul Formation [8, 9], the two formations represent two distinct facies. The Sulaiy Formation is an inner shelf facies deposited in the Salman Zone; the Makhul Formation is a deep inner shelf facies deposited in the Mesopotamian Zone.

The Yamama Formation consists of 12m of gray and brownish detrital limestone with thinly bedded shale overlaying by 191 micritic limestone and oolitic limestone, the isopach map of Yamama Formation indicates the formation thickness south of the Mosul high. Four isolated depocenters occur in Mesopotamian, with a small depocenter near Kirkuk. The Formation thickness is 400m thick in the Euphrates area near Najaf, southeast Iraq [10].

The Yammam succession in Southern Iraq comprised of outer shelf argillaceous limestone and Oolitic limestones presenting in the northwest to southeast trending depocenter, while the Formation deposited as a transgressive cycle in the inner shelf environment held Berriaisian-Valangiain age [11].

In Iraq, the Yamama succession is assigned a Berriasian to valanginian stage [12]. The upper and lower boundaries of the succession are conformable with the overlying Ratawi succession and underlying Sulaiy succession [11].

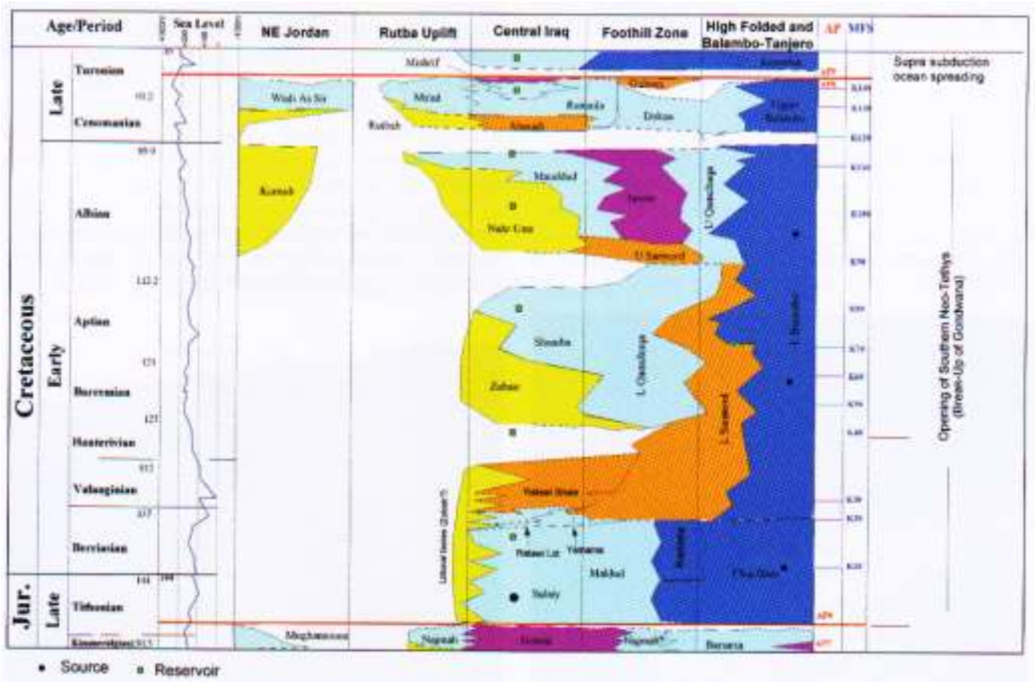


Figure 1: Stratigraphic correlation of Late Tithonian-Early Turonian of Megasequence [11]

4. Microfacies Types

Six major microfacies were recognized in the succession of the studied area represented by the Yammama Formation depending on Dunham classification (1962) [7] of Carbonate rock which deals with a depositional texture that is used to determine their properties of grain types and the depositional textures which enabled the recognized the paleoenvironment.

- **Microfacies (A):- Peloidal Packstone**

Some sections of the Yamama succession consist of peloids-bearing limestone. The peloid particles are characterized by different sizes, shape modes, and sorting degree. This microfacies is mostly common in the upper part of the studied wells formed in a low-energy sheltered environment **(Pl.1-D, Sindbad) (Pl.1-B, Pl.2-E, Pl.3-A, Daimah)**.
Two generated mechanisms are suggested to explain the origin of these grains. These may be where either fecal pellets or they were originally ooidal particles but were transported by the marine currents and/or waves from the oolite shoals and distributed over the depositional basin. They accumulated in local depressions and underwent diagenetic processes such as micritization and borings. The presence of the peloid particles in sufficient quantities, their relative depletion of clay materials, and their grading of vertical and horizontal changes into oolitic facies support the second interpretation [5].

It may correspond to Wilson's Standard Microfacies Types (SMF - 18) and (FZ -8) according to Flugel classification (2004) [13] of standard facies Zones, which indicate inner ramp setting with restricted water circulation.

- **Microfacies (B):- Algal Wackestone to Packstone**

The microfaces B is equivalent to the algal debris facies described by Elliott (1958) [14] and may be divided into two sub-microfacies according to algae types.
***A* —** Dasycladacea wackestone to packstone sub-microfacies is mainly composed of green algae from the Dasycladacean group. Most of their skeleton parts were dissolving to be filled by sparry calcite cement. In most cases, the algae are mixed with shell fragments which are composed mainly of pelecypods. This sub-microfacies may also contains minor large benthic

foraminifera, such as *Pseudocyclammina spp* **(Pl.4-D, F/Pl.5-A, B, C, Daimah) (Pl. 2E, Sindbad).**

The skeletal debris or grains were scattered in a slightly argillaceous matrix. Green algae are known to prefer normal marine waters but may be found in isolated lagoon waters. Green algae favoring the tropical to subtropical conditions and flourish in subtidal depths of 3-5 m and ranging in depths to about 30 m. The water is usually low energy, and the algae live below the wave base. Generally, sheltered lagoons and protected reef flats are the most suitable areas for producing green algae [16].

***B* —** Red algae wackestone to packstone consists of Permocalculus, representing the red algae group preserved as fossils [16].

These microfacies may generally reflect shallow marine waters with open circulation **(Pl.5D , Daimah)**. It may correspond to Wilson's (SMF - 18), (FZ - 8).

- **Microfacies(C):-Bioclastic Wackestone – Packstone Microfacies**

This facies is mainly composed of bioclasts of mollusc and Echinoderm. Such microfacies reflect shallow open marine. Facies associated include bioclastic mudstone. The main facies compose of bioclastic of Mollusca and Echinoderm **(Pl. 6E, Daimah)(Pl. 4E, Sindbad) (Pl.6A, 9E, Daimah)(Pl.4C, Sindbad).**

It may correspond to Wilson's (SMF - 10), (FZ - 7). Because of the abundance of packstone over wackestone, which indicates a shallow open marine environment.

- **Microfacies (D):-Foraminiferal Bioclastic Wackstone, Packstone Microfacies**

The microfacies comprise foraminifera bioclasts such as Miliolid and other benthic foraminifera bioclasts in addition to Echinoderm **(Pl.9C Daimah) (Pl.4B, D Sindbad)**.

It may correspond to Wilson's (SMF - 18), (FZ - 8), which indicates a shelf lagoon with circulation. Low-energy environments below wave base.

- **Microfacies (E):-Peloidal – Oolitic Grainstone Microfacies**

Oolite Grainstone is a grain-supported carbonate rock that contains less than 1% of muddy compound materials. Recently, This definition has been clarified as carbonate-dominated rocks that do not contain carbonate muds, less than 10% [7] **(Pl.2F Daimah)**.

When comparing this microfacies with Wilson's Standard Microfacies Types, it indicates that it is similar to (SMF - 15) and (FZ - 6) according to Flugel classification [13] of standard facies Zones, which indicates a shoal environment.

- **Microfacies(F):- Mudstone Microfacies**

This microfacies is classified into two main sub-microfacies: Aargillaceous lime mudstone and Fossiliferous lime mudstone.

Fossiliferous Mudstone sub-microfacies

This microfacies was used here based on Dunham [7] identified to indicate rocks made up of pure lime muds. Sadooni [16] described this facies as being made of well-sorting micrite grains with good matrix porosities and chalky texture **(Pl.1A, Sindbad).** This sub-microfacies is similar to Wilson's (SMF- 10) facies zone (FZ - 7).

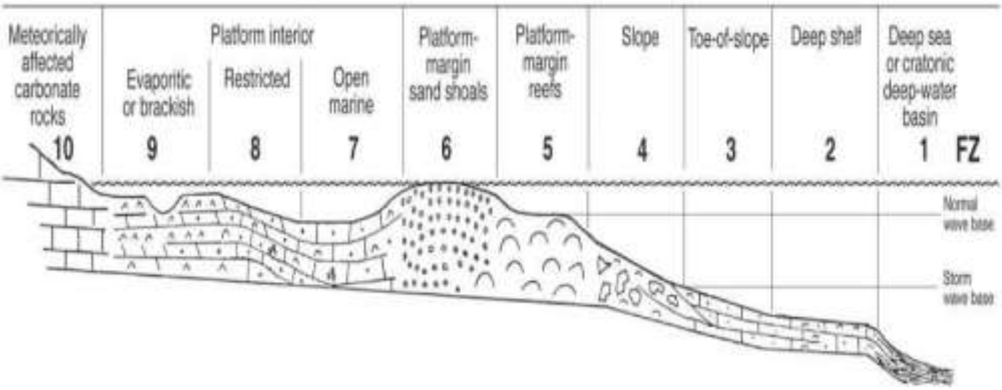
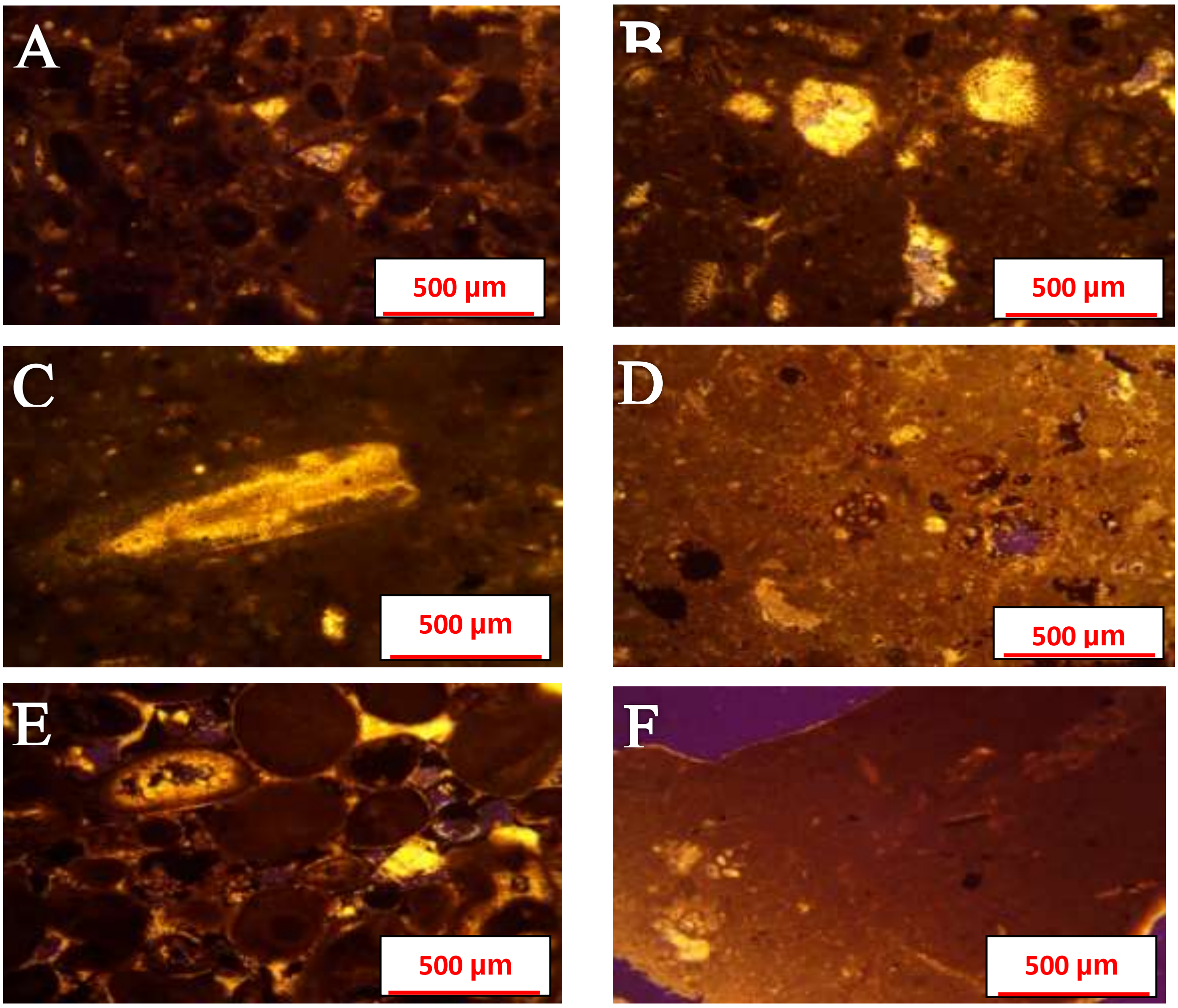


Figure 3: A model of carbonate rimmed platform showing the Standard Facies Zones modified after the Wilson model [17].

Plate1



A.Peloidal Packstone with peloids, (well sindbad-2,depth 4052m,x40X).
B.Dasycladacean Algal wackestone (Dasycladacean) (well Ad Daimah-1 ,depth 3971.60 m,x40X).
C.Bioclastic Wackestone-Packstone Echinoderm wackestone microfacies (well Ad Daimah-1 ,depth 3985.50m ,x40X).
D.Miliolid foraminifera Wackestone (well Ad Daimah-1 ,depth 4050m ,x40X).
E.Peloidal – Oolitic Grainstone Microfacies (well Ad Daimah-1 ,depth 3880.50m ,x40X).
F. Fossiliferous lime mudstone Sub-microfacies(well Sindbad-2 , depth 4037 m , x40X)

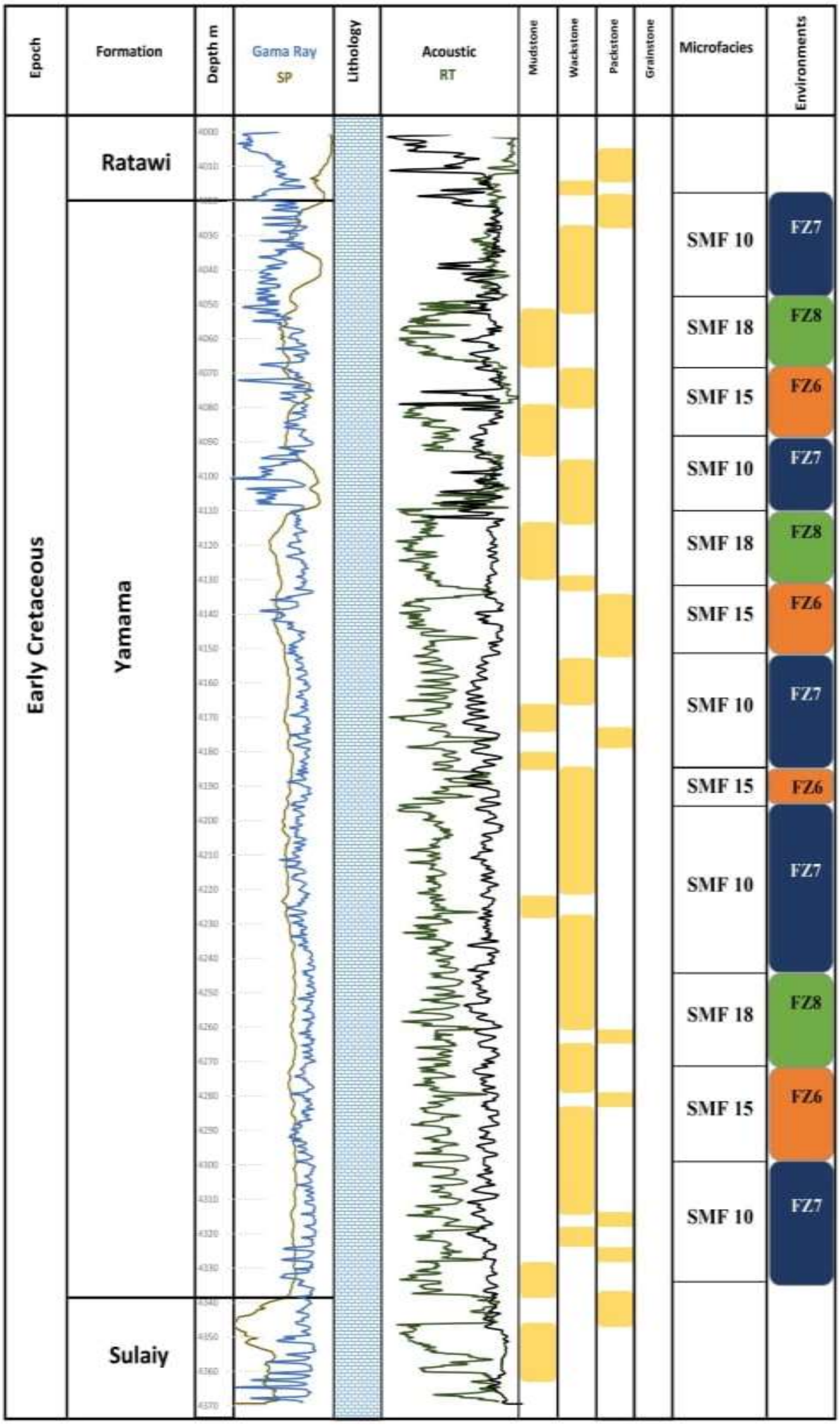


Figure 4: Lithology and Microfacies distribution of well Sindbad-2.

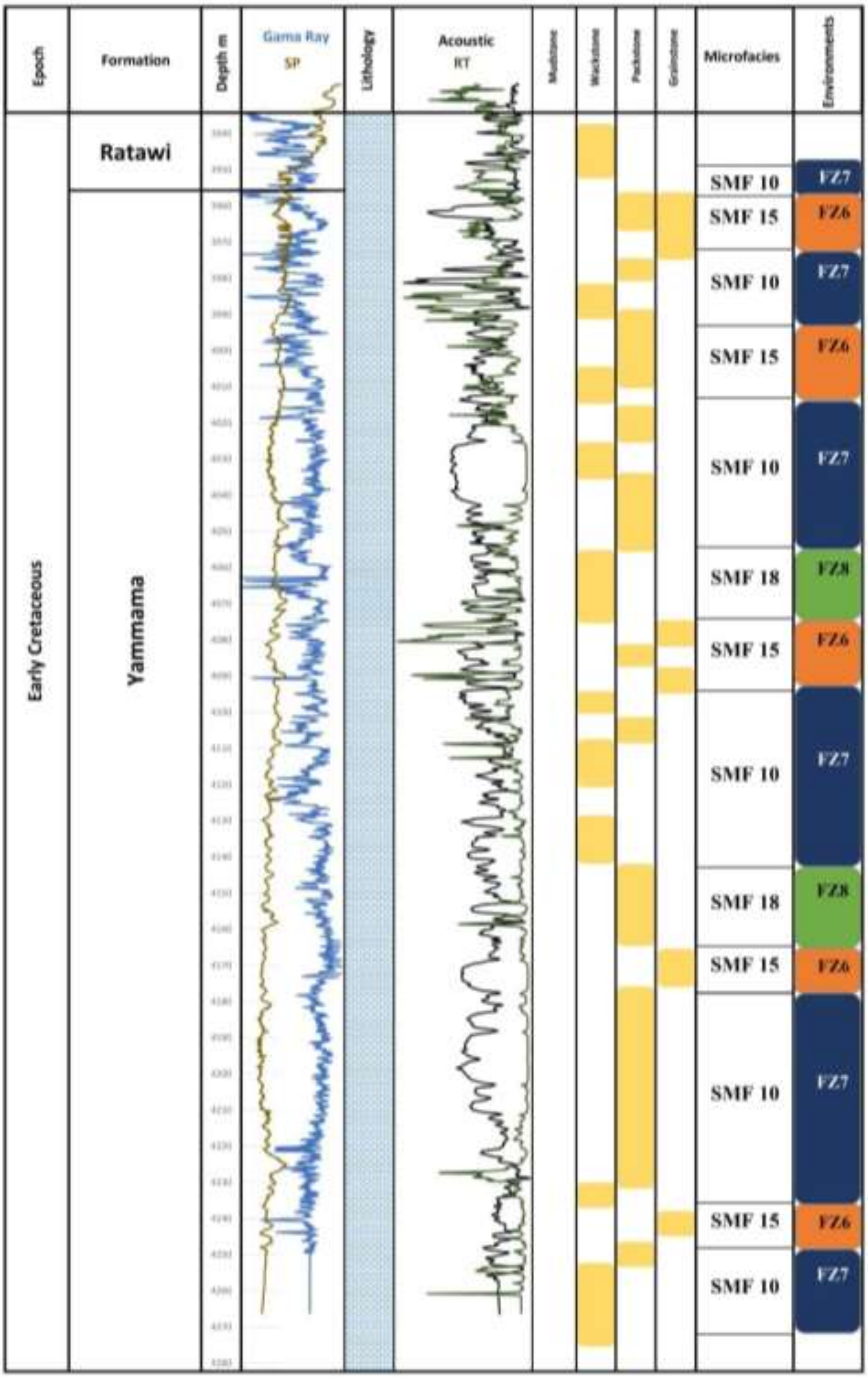


Figure 5: Lithology and Microfacies distribution of well Ad daimah-1.

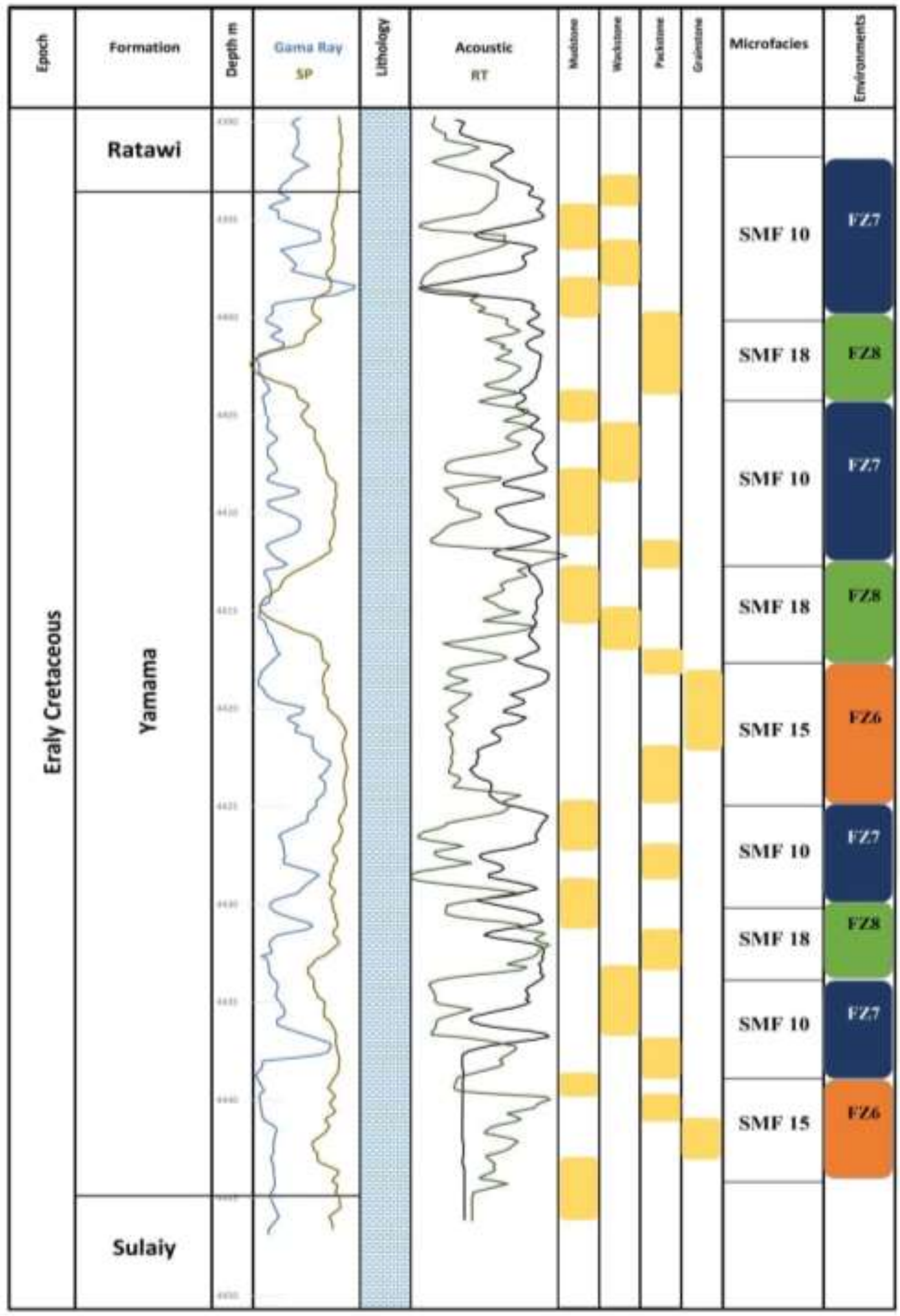


Figure 6: Lithology and Microfacies distribution of well Halfaya-5.

5. Stratigraphic development

The stratigraphic sequence is the relationships between the sedimentary rocks (carbonates and clastic) within a chronostratigraphic framework of repetitive genetically related strata bounded by the unconformity surface and/or their correlative conformity surfaces [18, 19]. The stratigraphic configurations and patterns of strata in the sedimentary succession record result from the interaction of tectonic evidence, eustasy sea level, and climates parameters [20].

In order to study the development of this cycle in southeastern Iraq in more detail, the Mesopotamian foredeep basin has experienced active syn-tectonic deposition leading to the forming of giant structures that were apparent simultaneously growing during the deposition of the Yamama succession [5]. These structures were probably induced by diapiric warping caused by the Infra-Cambrian Hormuz Salt Series, which is believed to underline parts of southern Iraq [1]. The succession extends, and facies association distribution appears the basin is characterized by one main depocenter to the southeastern of Iraq [21], and this appeared clearly in the present study (Figure 7).

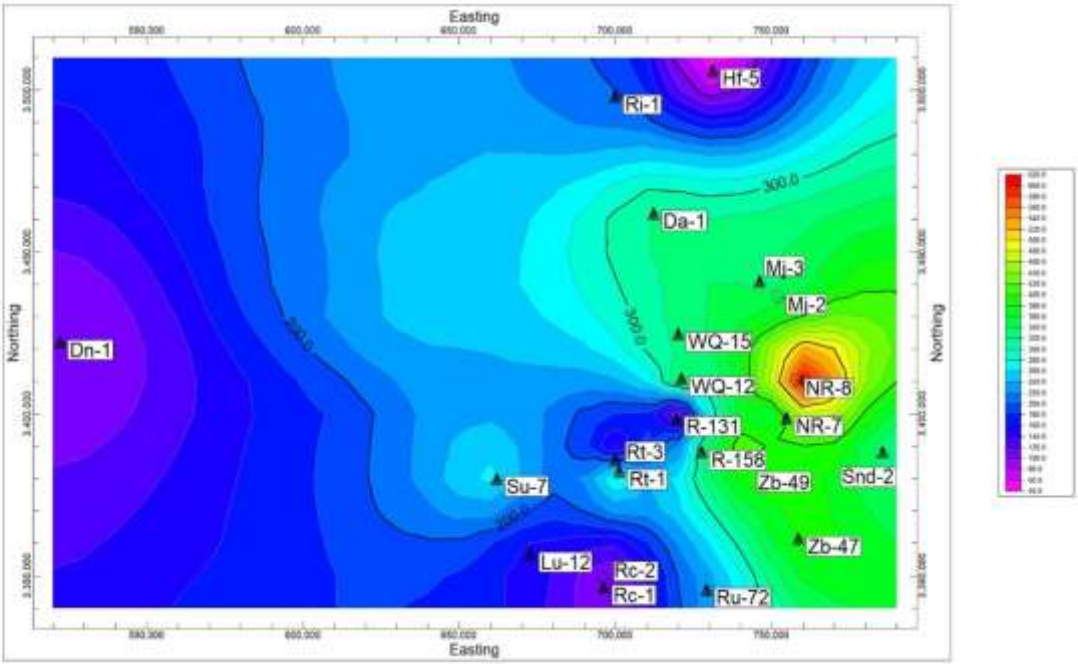


Figure7: Thickness distribution map shows the main depocenter of the Yamama basin.

The Yamama succession in the studied area is divided into three cycles representing three depositional stages of highstand system tracts. The first and the last were interplays with the older succession of Sulaiy, and the younger succession of Ratawi Formation as a maximum flooding surface (MFS).

These three cycles are characterized by shallowing upward depositional mode where they are deposited in sequential shallow open marine and shoal with semi-restricted associations facies. To the northeast of the study area near Halfya-5 well, the shoal association appeared in the lower and middle part of the Yamama succession, and in Da-1 and Sn-2 were three cycles. This may be referring to paleo-high development to the north of the study area, while the open marine was extended to the southern part.

The tectonic setting contributed to the emergence of the passive margin in the east and northeast Arabian Plate and made it face the Neo-Tethys [22]. The Sulaiy Formation conformably underlies the Yamama Formation except in some parts of the Salman Zone, where it is unconformably overlain by the Zubair Formation [11].

The presence of shallow open marine association facies (Algal Wackestone to Packstone and Bioclastic Wackestone – Packstone Microfacies) between the Sulaiy and Yamama succession refers to continuous deposition during the same stage in all studied wells. The end of the Sulaiy succession may be marked by a maximum flooding surface (MFS). This first depositional stage started with deposited of shallow open marine sediments underlain by shoal sediments and then semi-restricted sediments. The repetition of this cycle in the studied sections symmetrically indicates the harmonic oscillation in the sea level during the second and third depositional stages.

The locality area of the Halfaya oil field within the Mesopotamian Block and Ad'daimah and Sindbad oil fields within the Basra Blok explain the significant variation in the thickness for this succession Between the Halfaya oil field on the one hand and the other two oil fields on the other. Al-Zaidy and Al-Mafraji [23] suggested the occurrence of high depositional subsidence in Basra Blok and uplifting during the Yamama depositional stage. The fact that the studied sections are distinguished by the same cycles, albeit roughly, indicates that the lifting and sit-down processes synchronized sedimentation.

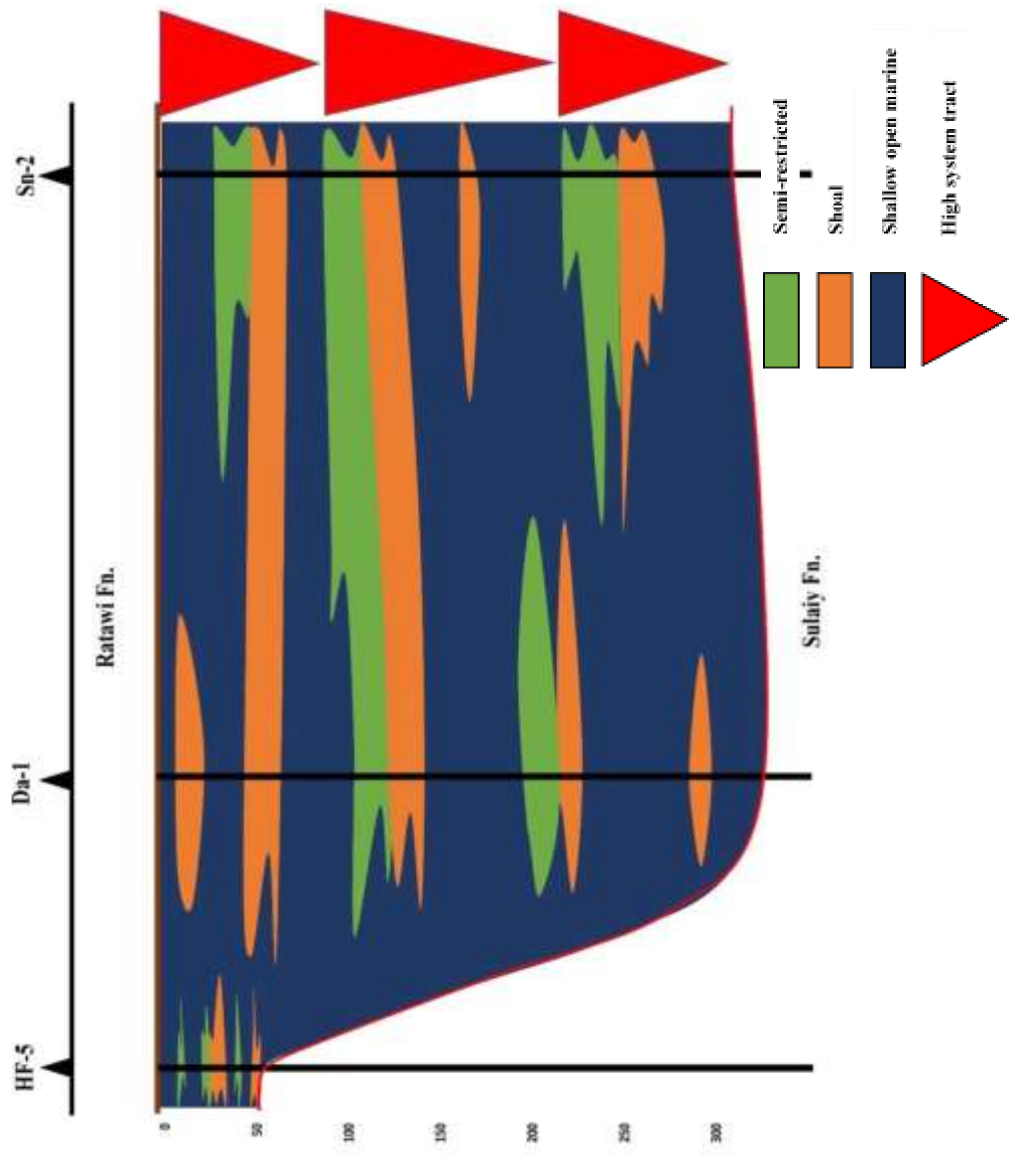


Figure 8: Cross section showing the facies associations distribution and stratigraphic cycles of Yamama succession in studied area

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