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Microfacies Analysis and Stratigraphic Evolution of Garagu Formation in Selected Oil Fields, Northern Iraq

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Abstract

The Garagu Formation represents a part of the Late Tethonian-Middle Valanginian sequence, which was deposited during the Early Cretaceous period within the main carbonate open marine environment. The studied area covers three oil fields; Jambur (Ja-46), Khabaz (Kz-1), and Qara Chauq (Qc-2) oil fields which are located in the north part of Iraq within the Low Folded Zone.

Eight major microfacies were recognized in Garagu Formation within the area of study to determination and recognition the paleoenvironments. The major microfacies for this carbonate succession are; Lime mudstone microfacies, Orbitolinid and Nezzazata wackestone with bioclast microfacies, Foraminifera wackestone-packstone microfacies, Bioclast wackestone – packstone microfacies, Algal wackestone-packstone with bioclast microfacies, Oolitic packstone-grainstone with bioclast microfacies, Coral bioclast packstone - grainstone microfacies, Planktonic wackestone-packstone microfacies and Peloidal (pellets) packstone - grainstone microfacies. These microfacies are deposited in restricted marine, shoal and open marine, Mid ramp, and outer ramp associations facies.

The Garagu succession in the studied area is divided into two depositional cycles (C1 and C2) of highstand system tracts (HST) in Ja-46 well. In the Khabaz oil field (Kz-1), the succession is divided into three cycles of HST (C1, C2, and C3). While in the Qara Chuaq oil field (Qc-2) the succession is divided into four depositional cycles of HST (C1, C2, C3, and C4) with conformable underlying Makhul Formation and conformable overlying of Ratawi Formation. In both oil fields, the Sarmord Formation is conformable underlying of Garagu Formation and conformable overlying of Ratawi Formation.

Keywords: - Microfacies analysis, stratigraphic development, Garagu Formation, Low Folded Zone.

تحليل السحنات الدقيقة والتطور الطباقي لتكوين كاراكو في حقول نفطية مختارة ، شمال العراق

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الخلاصة

يمثل تكوين كاراكو جزءًا من تتابع التيثوني المتأخر الى الفالنجيني المتوسط ، والذي تم ترسيبه خلال فترة العصر الطباشيري المبكر داخل بيئة الترسيب البحرية المفتوحة الرئيسة. تغطي منطقة الدراسة ثلاثة حقول

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نفطية وهي حقل نفط جمبور (Ja-46) وحقل خباز (Kz-1) و حقل قره جوق (Qc-2) التي تقع في نطاق الطيات المنخفضة في العراق.

تم التعرف على ثمان سحنات دقيقة رئيسة في تكوين كاراكو ضمن منطقة الدراسة لتحديد البيئات القديمة والتعرف عليها. وهذه السحنات هي:-

سحنة الحجر الجيري الطيني و سحنة الحجر الجيري الواكي الحامل للاوربتيولنيا والنزازاتا مع المكسرات الحياتية و سحنة الحجر الجيري الواكي – المرصوص الحامل للفورامنيفيرا و سحنة الحجر الواكي – المرصوص الحامل للمكسرات الحياتية و سحنة الحجر الواكي – المرصوص الحامل للطحالب و للمكسرات الحياتية و سحنة الحجر المرصوص – الحبيبي الحامل للسرئيات و المكسرات الحياتية و سحنة الحجر المرصوص – الحبيبي الحامل لمكسرات المرجان و سحنة الحجر الواكي – المرصوص الحامل للطافيات و سحنة الحجر المرصوص – الحبيبي الحامل للدمالق والمكورات.

يتم ترسيب هذه السحنات الدقيقة ضمن مترافقات البيئة البحرية المحجوزة والحاجز الضحل والبيئة المفتوحة ، والمسطبة متوسطة وخارجية.

تم تقسيم تتابع كاراكو ذو التتابع ثلاثي الرتبة في المنطقة المدروسة إلى دورتين ترسيبيتين (د1 و د2) لمسارات نظام عالية المستوى (HST) في بئر جمبور- 46. في حقل نفط خباز (بئر خباز- 1) ينقسم التعاقب إلى ثلاث دورات من (د1 و د 2 و د3) لمسارات نظام عالية المستوى (HST) ، في كلا حقلي النفط ، يقع تكوين سارمورد اسفل تكوين كاراكو ويعلوه تكوين رطاوي بشكل متوافق. بينما في حقل نفط قره جوق (بئرقرة جوق- 2) ينقسم التتابع إلى أربع دورات ترسيب (د1 و د 2 و د3 و د4) لمسارات نظام عالية المستوى (HST) مع اعتلاء التتابع ايضا لتكوين مكحول وتغطيته بواسطة تكوين رطاوي بشكل متوافق ايضا.

1. Introduction

Due to global temperature rise, the Cretaceous period in northern Iraq is considered one of the most suitable locations for depositing carbonate rocks, and the best carbonate factory and reservoir rocks during the Jurassic and Cretaceous periods are made [1]. The Yamama/Garagu succession, a heterogeneous carbonates reservoir, is one of the most widespread and important reservoirs in southern Iraq for oil production and the adjacent area within the main retrogressive sedimentation cycle (Berriasian-Aptian). It was deposited during the Lower Cretaceous Period [2]. Within its stratigraphic location, an age group from the Late Berriasian to the Early Hauterivian stage, as expected by[3], and assigned a Valanginian age[1].

The Garagu Formation is a typical unit of the lower Cretaceous in northern Iraq, where it crops out and occurs in the subsurface on the area of the Unstable Shelf, roughly to the northwest of a line connecting Awasil - Kirkuk and the Ru Kuchuk[2].

The Garagu Formation is a carbonate-siliciclastic unit that consists of an alternation between bedded, yellow to brown, shale, marl-marly limestone and limestone from the middle part and limestone, oolitic limestone, shale, and sandstone beds from both the upper and lower parts [1].

The formation can be a good reservoir in the subsurface[2][4]. Therefore, it offers a good opportunity to study and identify the depositional environments and palaeogeography because of their vast outcrop-area and well-recognized succession in terms of succession thickness and observed lower and upper boundaries. The formation was first described from the Chia Gara anticline, Gali Garagu, Amadia district, High Folded Zone of northern Iraq by [5]. Since then, few detailed studies have been conducted on the Garagu Formation, either in the outcrops or subsurface sections.

The studied area includes three oil fields, Qara Chuq, Khabaz and Jambur, located in the northern part of Iraq within the Low Folded Zone [6].
Aims of the current study are microfacies analysis and their distribution to interpret the depositional evolution and stratigraphic development of this succession.

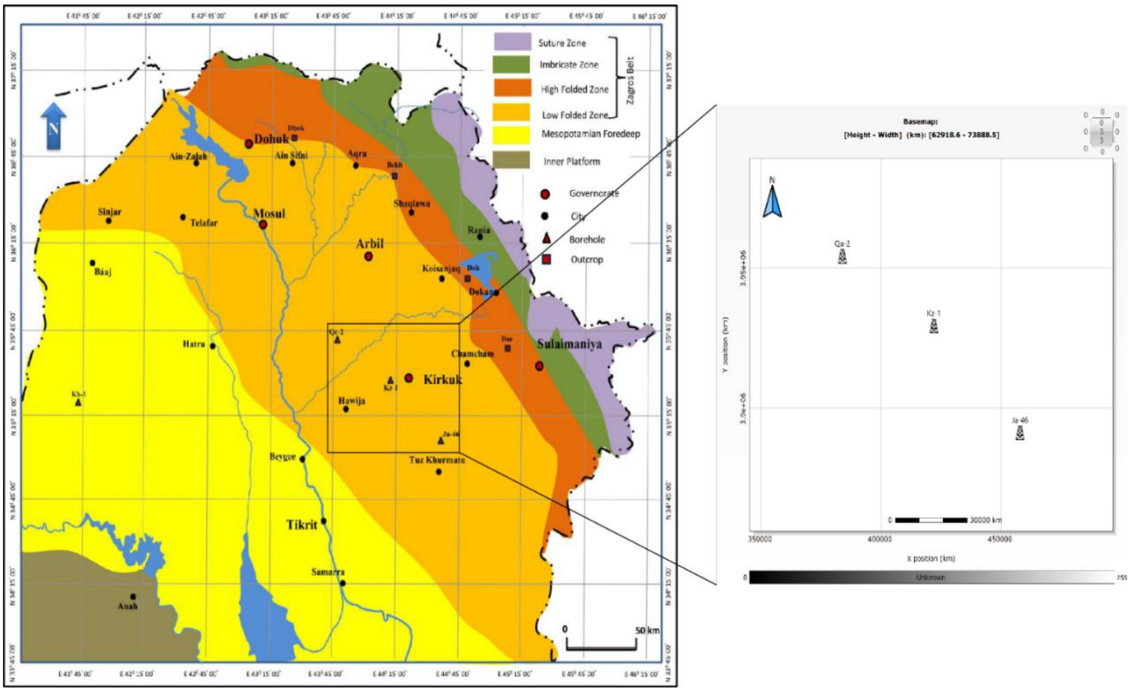


Figure 1: Location map of the studied area with the tectonic subdivisions based on [6]

2. Methodology:

- Field Work
- Sampling and describing selected boreholes using cutting and core samples collected at various intervals (Table 1).
- Laboratory Work

1- Preparing 150 thin sections for the selected cutting and core samples in the laboratory of the Department of Geology, University of Baghdad.
2- Petrographic description of the preparing thin sections by transmitted light microscope.
3- Study the available well logs (GR and Sonic logs) and relate the log response to facies and stratigraphic patterns.

Table 1: Shows the coordinates of studied wells with Garagu thickness and the number of samples

Well No.	Coordinates	Top	Bottom	Thickness in (meter)	Sample number
Kh-1	E:422 049.36 N:3929 239.86	3305	3415	110	65
Qc-2	E:383 941.9 N:3954 033.6	1230	1290	60	30
Ja-46	E:457 830.36 N:3891 115.02	3087	3181	94	55

3. Geological setting: -

The Garagu succession was initially identified by [5] from the Gali Garagu of the Chia Gara anticline in the High Folded Zone of Northern Iraq. According to[5], the succession has three subdivisions. The middle division consists of marls and marly limestone with limestone beds. The lower and upper oolitic parts are comprised of limestone, oolitic limestone and sandstones.

The Garagu succession is believed to have been deposited in a shallow water environment contemporaneously with the Yamama/Zangura Formation of Central Iraq [5]. [7]described the formation as an independent unit, including the beds comprising it into the Yamama. This practice was not accepted by [8], who used the name Yamama for the Zangura Formation of the Late Berriasian age of the Awasil area only and retained the Garagu Formation for the oolitic limestones conformably overlying Yamama (Zangura). The Yamama/Garagu Formation have a wide distribution in southern Iraq, containing a relatively thick section of porous oolitic and skeletal limestones[9].In the Northern Thrust Zone at Banik, similar to Gara Mountain, the Garagu Formation unconformably overlies the Chia Gara Formation. In Central Iraq, the Yamama Formation is unconformably overlain by the Zubair Formation in Awasil-5 and Kifl-l [10]. The Garagu Formation has no proved facies and age equivalents in and outside Iraq. In age and partly in facies too, the lower parts of the neritic Fahliyan Formation of southwestern Iran[11], Yamma Formation from Saudi Arabia [12] [1], and Minagish Formation in Kuwait [1] might be correlated with the Garagu Formation.
[13] studied the microfacies analysis and paleoenvironments of Garagu succession (Valanginian-Hauterivian) in the Gara Mountain in Gali Garagu within the High Folded Zone, Sarsang District, and northern Iraqi Kurdistan. They suggested that eight microfacies were recognized, and subdivided based on their environmental identification into two basic association facies; shelf margins (shoal) and shelf lagoonal association. Generally, the Garagu succession represents a shallow water environment with two high-energy belts in the lower and upper successive parts.

[14]and [15] suggested that the Late Berriasian-Aptian succession was deposited during three depositional cycles of highstand system tracts within the Mesopotamian Zone. These three depositional cycles are characterized by shallowing-upward mode where they are deposited within the shallow open marine (shoal) and semi-restricted facies associations for each cycle. And then, [16] mentioned that the basin in this area stretches from the southeast direction to the southwest direction with major single depocenters. It was extended to the southeast of the study area near wells Mj-2, Mj-3.NR-8 and WQ-15 stretched to another position at the southwest near wells NR-7, RU-131, RU-158, ZB-47 and ZB-49.

[17] the stratigraphic development and diversity of Garagu succession fossils assemblages were explained, indicating the Hauterivian-Barremian stage of the Garagu succession. Shallow marine settings with local transitions to continental, shelf lagoonal and open platform associations facies characterize the fossil assemblages in the Garagu succession.

4. Microfacies Analysis

Include lithofacies analysis (determination of the depositional texture of rocks, the composition of the grains and the background material) and biofacies analysis (examination of fossil associations). Since similar lithofacies can occur in a variety of depositional environments and the diagenetic processes can significantly modify the original texture (e.g., compaction can transform a wackestone into a packstone or background micrite can be replaced by sparite etc.), biofacies data are especially important to interpret the depositional settings [18].

The major microfacies types which used in Garagu facies association based on [18], compared with [19] in different parts of the homoclinal carbonates ramp.

A- Lime mudstone microfacies

This microfacies reflects the deposition in quiet water, preventing the organisms from accumulating [20]. It is similar to RMF 2, according to [18], which is deposited in a distal mid-ramp environment. There are two types of mudstones microfacies: -

1- Argillaceous lime mudstone is made up of a micritic matrix and is black with significant amounts of siltstone and shale. It does not contain any fossils (Plt.1A).

2- Lime mudstone is distinguished by having less than 10% of planktonic foraminifera (Plt.1B). This microfacies has appeared within the middle and lower part of the Garagu Formation at well Ja-46 only.

B- Bioclastic-foraminiferal wackestone microfacies

The microfacies consists of foraminifera such as Miliolid, *Nautioculina* sp., *Orbitiolina* sp. and *Nezzazata* sp. in addition to echinoderms, algal and coral bioclasts (Plt.1C and D). This microfacies refer to the Low-energy environments below the wave base [18]. This represents RMF 13, which is deposited in a proximal open marine environment. This microfacies appeared in the middle and lower parts of Graragu Formation at Qc-2 and Kz-1, while in Jambur oil field, it showed within the upper part only associated with shoal facies.

C- Foraminifera wackestone-packstone microfacies

This microfacies consist of rocks ranging from wackestone to packstone in texture and containing large benthic foraminifera, such as Textularia, Choffatella, & Pusedocyclammina (Plt.1E and F). This microfacies is similar to RMF 13, deposited in the distal open marine environment according to [18] and [19]. It appeared in the lower part of the Garagu Formation within Qc-2 (near the lower boundary) and Jambur oil field association with mid-ramp facies (Fig.).

D- Bioclast wackestone – packstone microfacies

This microfacies includes a lot of fragments of echinoderm and Mollusca, with fewer bioclasts of foraminifera and calcareous algae (Plt.1G and H). It may correspond to RMF 7, which is deposited in a restricted environment. This microfacies has a minimal appearance in studied succession, which appeared at Ja-46 (middle part) and Kz-1 (upper part) (Fig.2).

E- Algal wackestone-packstone microfacies

Algal wackestone-packstone microfacies is observed in the studied succession within the middle part at Kz-1 and upper part at Qc-1 (Fig.3, 4). This microfacies have green algal (Charophyta) with bioclast it, consists Echinoderms, algae fragments and benthic foraminifera (Textularia sp.) (Plt.2A and B). This facies matches RMF 17, which indicates an open marine environment [18, 19].

F- Oolitic packstone-grainstone microfacies

Ooids are the most essential non-skeletal grains for defining the depositional environment**.** This microfacies consists of oolite, intraclasts and bioclasts of benthic foraminifera, in addition to quartz grains at some times (Plt.2C and D). The oolitic packstone – grainstone is matching to RMF 29 and RMF 30 when bearing quartz grains, which are deposited in shoal environments. This microfacies is abundant in Garagu Formation at Qc-1 and Kz-1, and very limited appearance at Ja-46 (upper part) (Fig.4, 3 and 2)

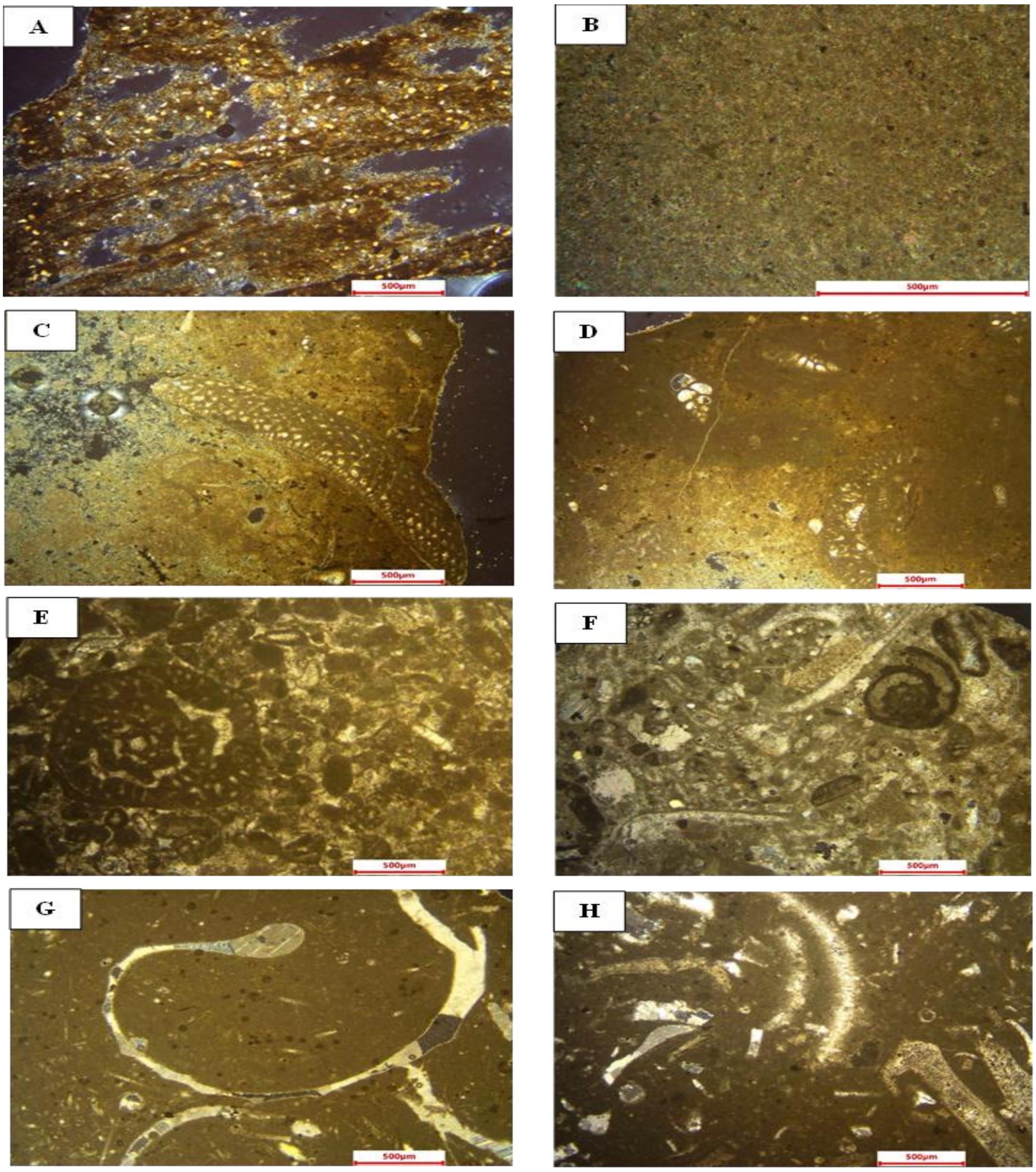
G- Planktonic wackestone-packstone microfacies

The planktonic bioclast wackestone to packstone is characterized by planktonic foraminifera (Hedbergella) being the main skeletal component, with few calcispheres and sponge spicules (Plt.2E and F). This microfacies represents below the fair-wave base within or just below the euphotic zone, with good circulation, mostly highly fossiliferous microfacies [18]. This microfacies may represent RMF 5, which was deposited in the outer ramp environment and appeared in Sarmord Formation at Ja-46 (Fig.2).

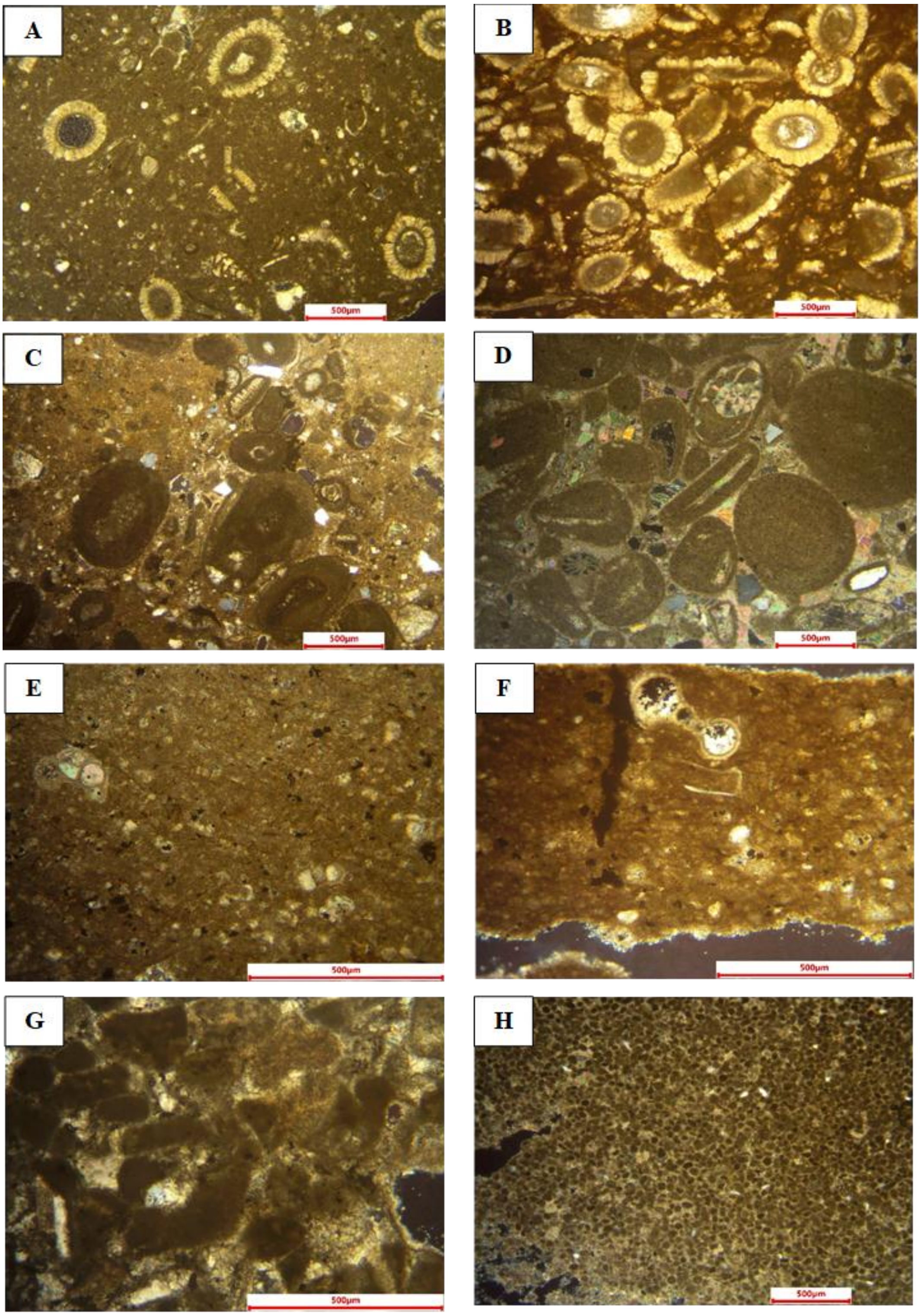
H- Peloidal (pellets) packstone -grainstone microfacies

This microfacies consists of peloidal and pellets with bioclasts and intraclasts (Plt.2G, H). The peloidal packstone - grainstone microfacies are characterized by the well-stored due to the high energy of waves**.** While the pellets bearing facies is formed in a low-energy sheltered environment[18]. This microfacies matches RMF 16, deposited in a restricted environment and appeared at Kz-1 and Qc-2 oil fields (Fig.3, 4).

Plate 1



A. Argillaceous lime Mudstone (Well Qc-2, depth 1285 m)
B. Planktonic Lime Mudstone (Well Ja-46, depth 3187m)
C. Bioclastic-foraminiferal wackestone microfacies (Well Qc-2, depth 1370 m)
D. Wackestone with bioclast microfacies (Well Qc-2, depth 1200 m)
E. Foraminifera wackestone-packstone microfacies (Well Qc-2, depth 1280 m)
F. Foraminifera wackestone-packstone microfacies (Well Qc-2, depth 1300m)
G. Bioclast wackestone – packstone microfacies (Well kz-1, depth 3406m)
H. Bioclast wackestone – packstone microfacies (Well Qc-2, depth 1315m)



A. Algal wackestone-packstone microfacies (Well kz-1, depth 3400m)
B. Algal wackestone-packstone microfacies (Well kz-1, depth3401.5m)
C. Oolitic packstone-grainstone microfacies (Well kz-1, depth 3395.5 m)
D. Oolitic packstone-grainstone microfacies (Well kz-1, depth 3390m)
E. Planktonic wackestone-packstone microfacies (Well Ja-46, depth 3114m)
F. Planktonic wackestone-packstone microfacies (Well Ja-46, depth 3152m)
G. Peloidal (pellets) packstone -grainstone microfacies (Well kz-1, depth 3360 m)
H. Peloidal (pellets) packstone -grainstone microfacies (Well Qc-2, depth 1330 m)

5. Facies association and depositional setting

The analysis of thin sections indicates that the microfacies of the Garagu Formation can be classified into facies associations representing various depositional settings. This is based on comparable depositional textures and faunal composition that refer to distinct depositional circumstances. The deposition of the Garagu succession is characterized by a complex of detrital limestones and containing peloidal packstone, oolitic grainstone, foraminifera bioclast and other types of facies.

The carbonate ramp term was used to characterize a gently-sloping depositional surface that transitions from a shallow, high-energy environment to a deeper, low-energy environment without breaking the slope [20]. Carbonate ramp progradation begins with mudstones and wackestones microfacies at the outer ramp depositional environment and progresses to packstones and wackestones at the mid-ramp environment and grainstone and packstone of the inner ramp environment. This shallowing-upwards progradation and succession indicate higher energy in shallow water environments [21].

The carbonate ramp has been identified by the advent of a shallow, gentle surface which grades from the shoreline to the basinal environments[22].

The shallowest water environments in the back ramp area are to the western part, which is comprised of the Garagu Formation, while deep-basin environments appear at the studied area's eastern part. A region between the shallow ramp and the deep ramp is known as the mid ramp, and the limits between them are typically established at the lower limit of the fair-weather wave base (FWWB).

The microfacies analysis was used to discriminate between the following sedimentary environments:

5.1 Inner Ramp Environment

The wide range of microfacies reflecting inner ramp environment, such as shoal (RMF 29, 30), open marine (RMF 13, 17), restricted marine (RMF 7, 16) environments. Development of shoals requires wave action or strong tidal currents in a zone of high carbonate production that dominates with shoals, organic barriers, shoreface deposits and back-barrier. Inner ramp association facies consists mostly of oolite, peloids or bioclastic components. These components build-up of shoal, barrier, and back-barrier sediments and shoreface sediments that migrate or prograd fast, a lagoon depositional environment[23].

This is observed through the dominion of some types of foraminifera like Miliolid, open marine environment is distinct by echinoderm and bioclastic debris. These components indicate shallow open marine deposition with relatively moderate energy and open water circulation[18].

The associations of this environment are varied in appearance in the different studied wells, whereas the open marine association appeared in all studied wells. The shoal facies association is very limited in Ja-4 and predominant in others. While the restriction was least prevalent in Ja-46 and Qc-2, it dominates in the upper part of the studied succession within Kz-1.

5.2 Mid Ramp Environment

The mid-ramp is the depositional zone between the fair-weather and storm wave bases. This depositional environment form under the fair-weather wave base and therefore reflects storm deposition in these sediments, only affected by storm wave-graded beds. Water depth reaches some tens of meters, and storm waves and swells frequently reworking the bottom sediments. The sediments reflect varying degrees of the storm influence based on the water's depth and bottom relief [20]. A range of sub-environment characterizes the Middle ramp, comprising beach, barrier bar, stand plain, and shoal, and may also comprise a variety of reef facies association. The primary environmental control on this depositional condition is the predominance of high-energy wave oscillation which agitate the water on a regular basis [22]. This association facies are predominant as RMF 2 in Ja-46 and less in Kz-1 within the lower part of the studied succession, while Qc-2 was absent.

5.3 Outer ramp

The outer ramp facies association is distinguished by mud-dominated microfacies, predominately composed of planktonic foraminifera with argillaceous carbonate and terrigenous mud, sponge spicules, and shell fragments. Planktonic mudstone and wackestone are characteristic of this microfacies. The assemblage of the mud-mounds and thin shales inter-bedding which result from the background sediments assemblage throughout low-energy settings via a variety of settling processes, including the suspension settling, flocculation and pelletization [22] [18], stated that planktonic mudstone- wackestone microfacies reflects outer ramp environment.

This association facies represent the deeper part of the basin, which refers to the Sarmord Formation, which appeared only in well Ja-46.

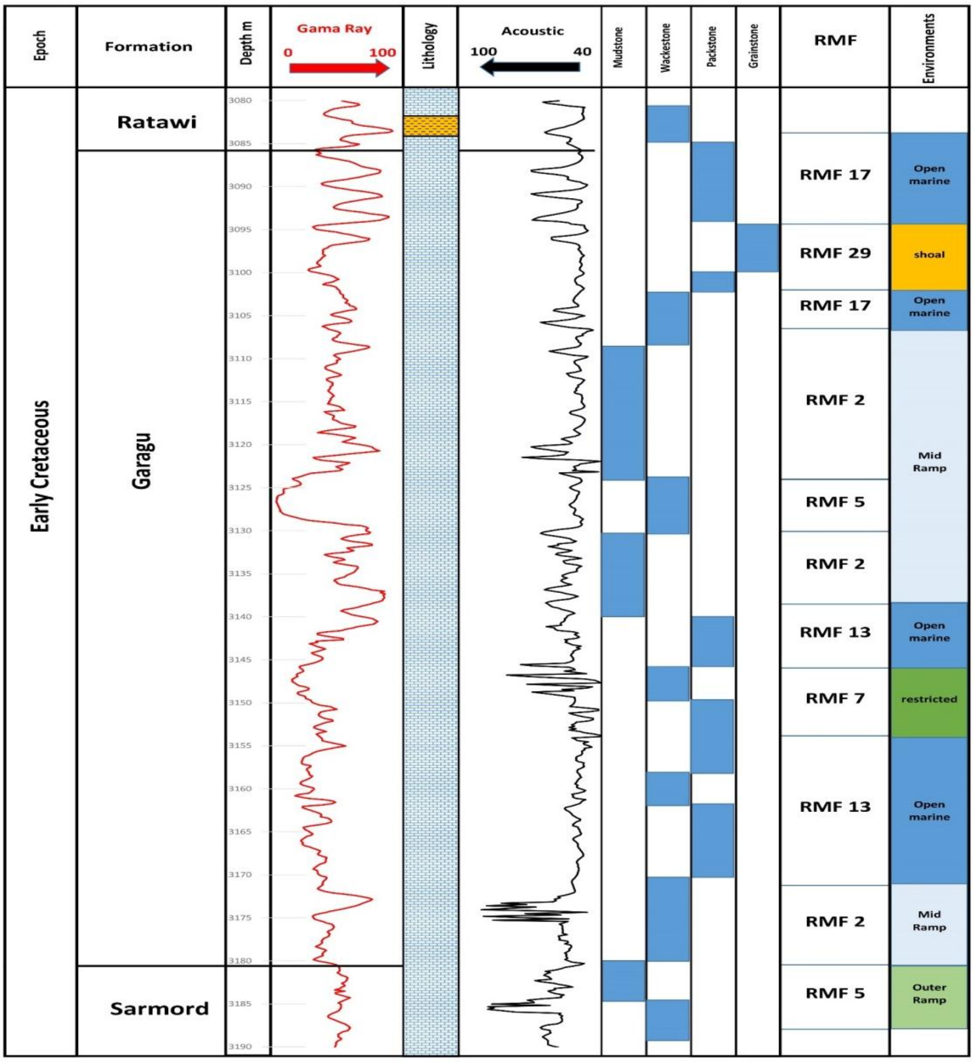


Figure 2: Microfacies and depositional environments distribution of Garagu Formation in well Ja-46.

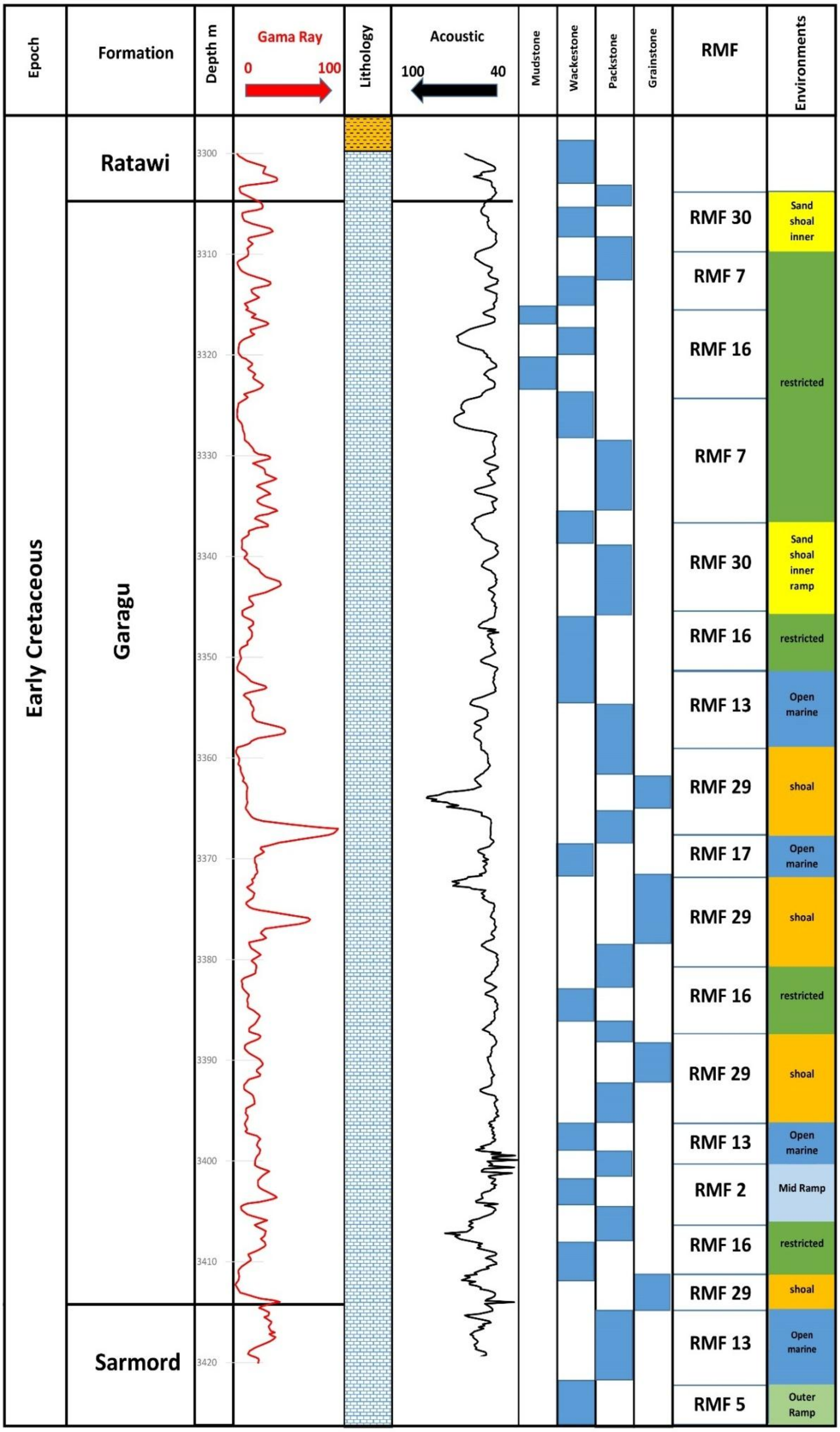


Figure 3: Microfacies and depositional environments distribution of Garagu Formation in well Kz-1.

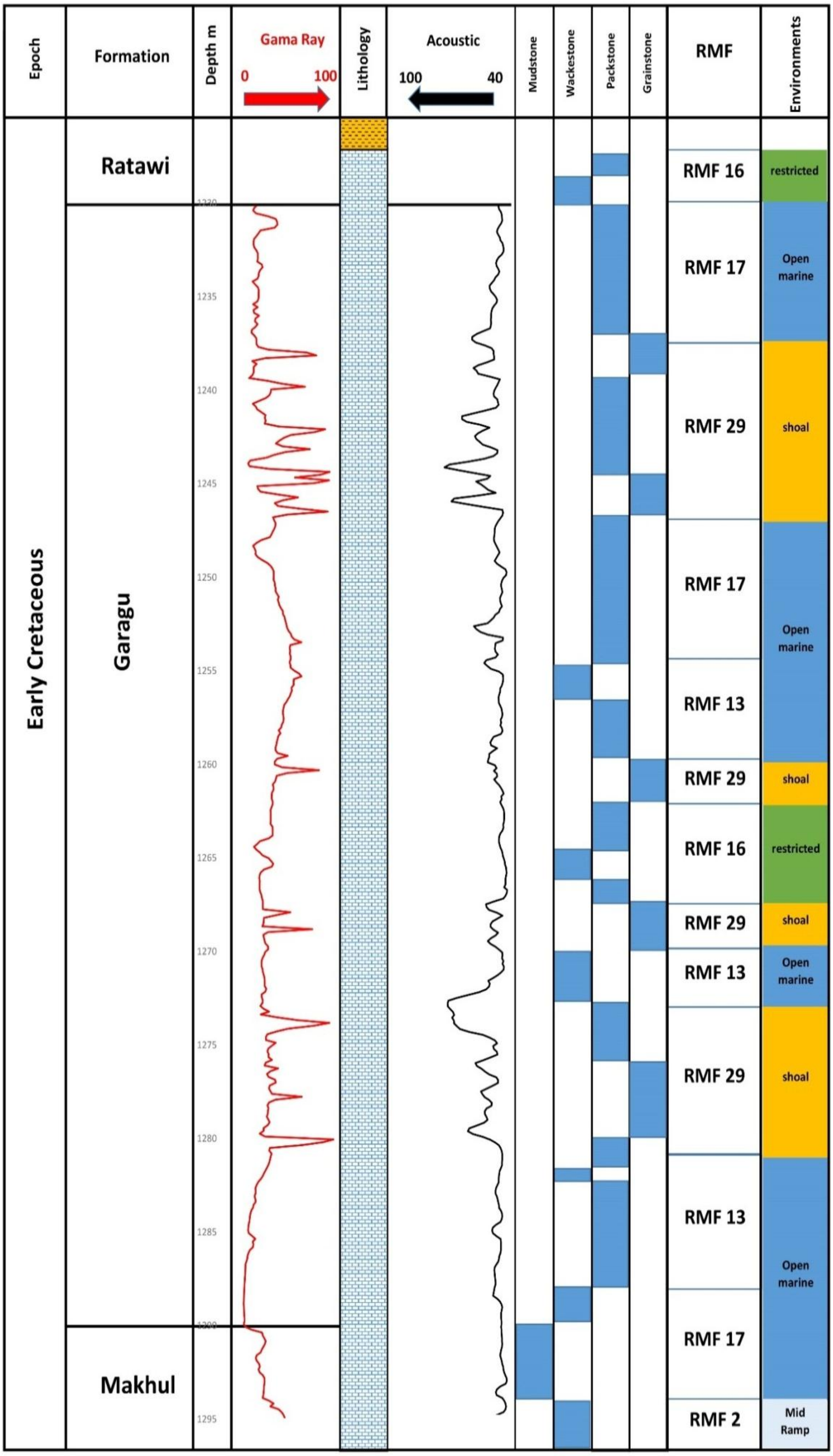


Figure 4: Microfacies and depositional environments distribution of Garagu Formation in well Qc-2.

6. Stratigraphic evolution

The sequence stratigraphy is the sedimentary rocks relationships (carbonates and clastic) within a chronostratigraphic framework of repetitive genetically related stratal, which is bounded by the sequence boundary (unconformity surfaces), and/or their correlative conformity surfaces [24] [25]. The stratigraphy configurations and stratal patterns of the sedimentary successions record result from the interactions of the tectonic evidence, eustatic sea level, and climatic parameters[26].

To study the evolution of the sedimentary cycle in the northeastern part of Iraq in more detail. The Mesopotamian fore-deep basin has experienced active syntectonic deposition, which led to generating giant structures that appeared to grow simultaneously during the Yamama succession deposition [9]. These tectonic structures were probably induced by diapiric warps caused by the Infra-Cambrian Hormuz Salt Series, which is believed to underline parts of southern Iraq[2]. The succession extends, and facies association distribution appeared the basin is characterized by one main depocenter to northeastern Iraq. The Garagu sequence in the studied area represents one 3rd-order sequence divided into two depositional cycles of highstand system tracts (HST) in Ja-46. In the Khabaz oil field (Kz-1), this sequence is divided into three HST cycles. In both oil fields, the Garagu Formation underlies Sarmord Formation and Ratawi Formation's overlying (Fig.5 & 6). While in the Qara Chuaq oil field (Qc-2), the sequence is divided into four depositional cycles of HST with conformable underlying of the Makhul Formation and conformable overlying of the Ratawi Formation (Fig.7).

In Ja-46, these two cycles are characterized by symmetrical shallowing upward depositional mode, representing outer and/or mid ramp underlying open marine and restricted or shoal associations facies.

At Khabaz oil field (Kz-1), the outer and mid-ramp environments were very limited and confined to the mid-ramp environment's appearance in the formation's lower part to indicate a distance from the basin's centre. This succession consists of three cycles of open marine/restricted and shoal facies associations (Shallowing upward) during the HST stage. The lower part is characterized by open marine-shoal association, while the upper part is appeared by restricted-shoal (quartz bearing) association (Fig.6).
To the western part of the studied area at Qara Chauq oil field (Qc-2), this succession consists of four cycles (shallowing upward) deposited during HST. These cycles is characterized by an alternative of open marine and shoal associations facies, except for the last cycle, which ended by Ratawi supratidal facies (Fig.7).

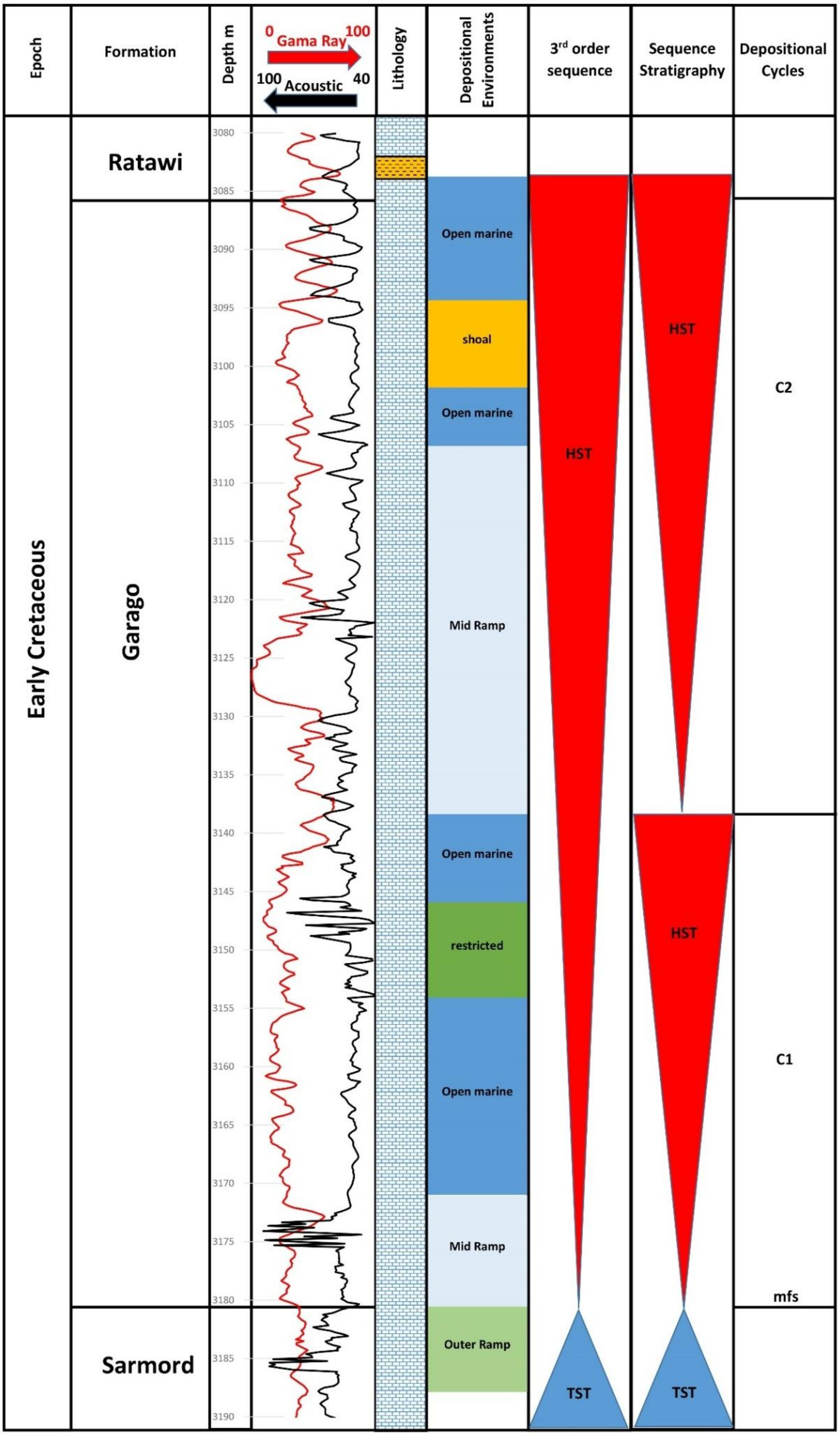


Figure 5: Stratigraphic and depositional distribution of Garagu sequence in well Ja-46.

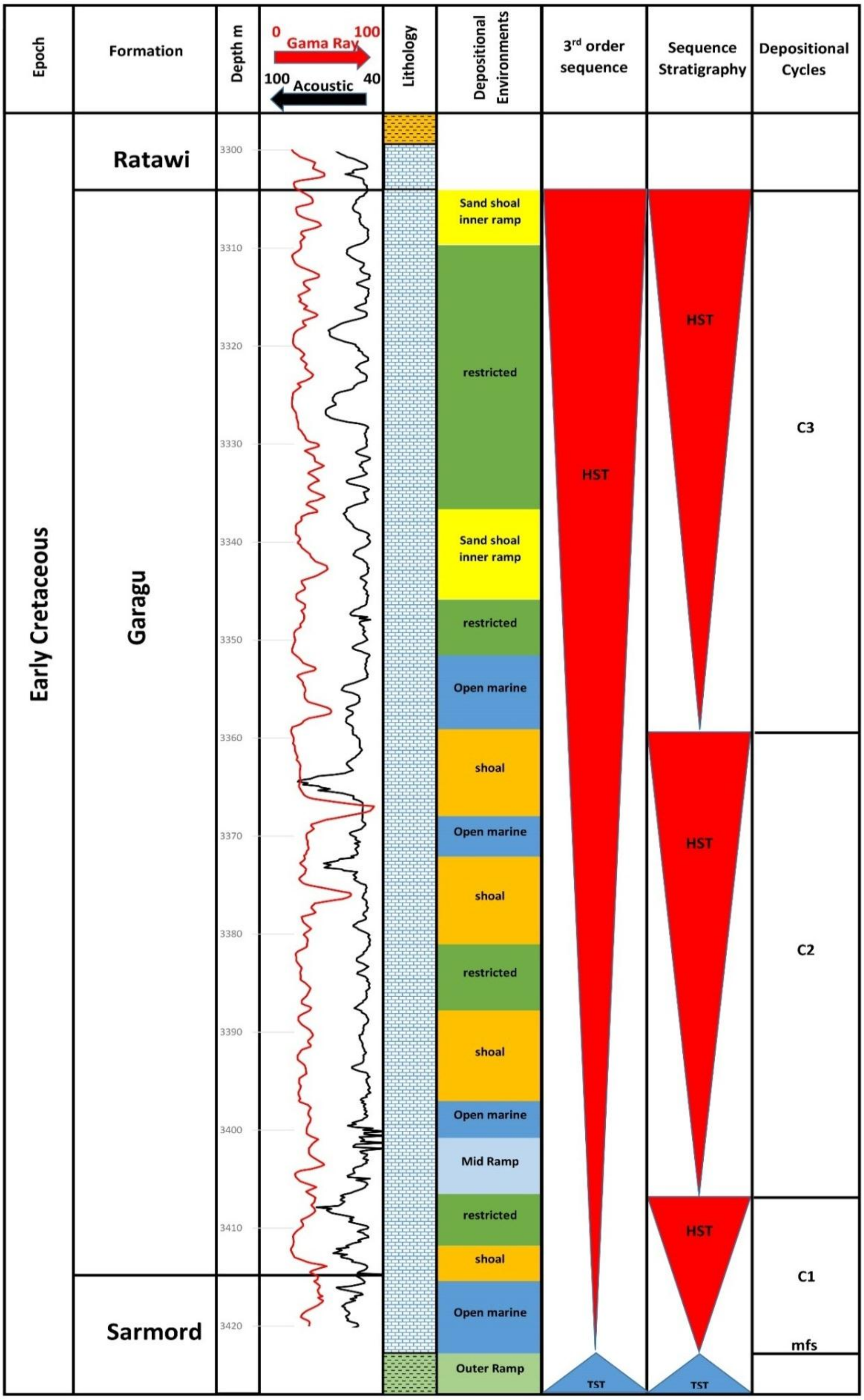


Figure 6: Stratigraphic and depositional distribution of Garagu sequence in well Kz-1.

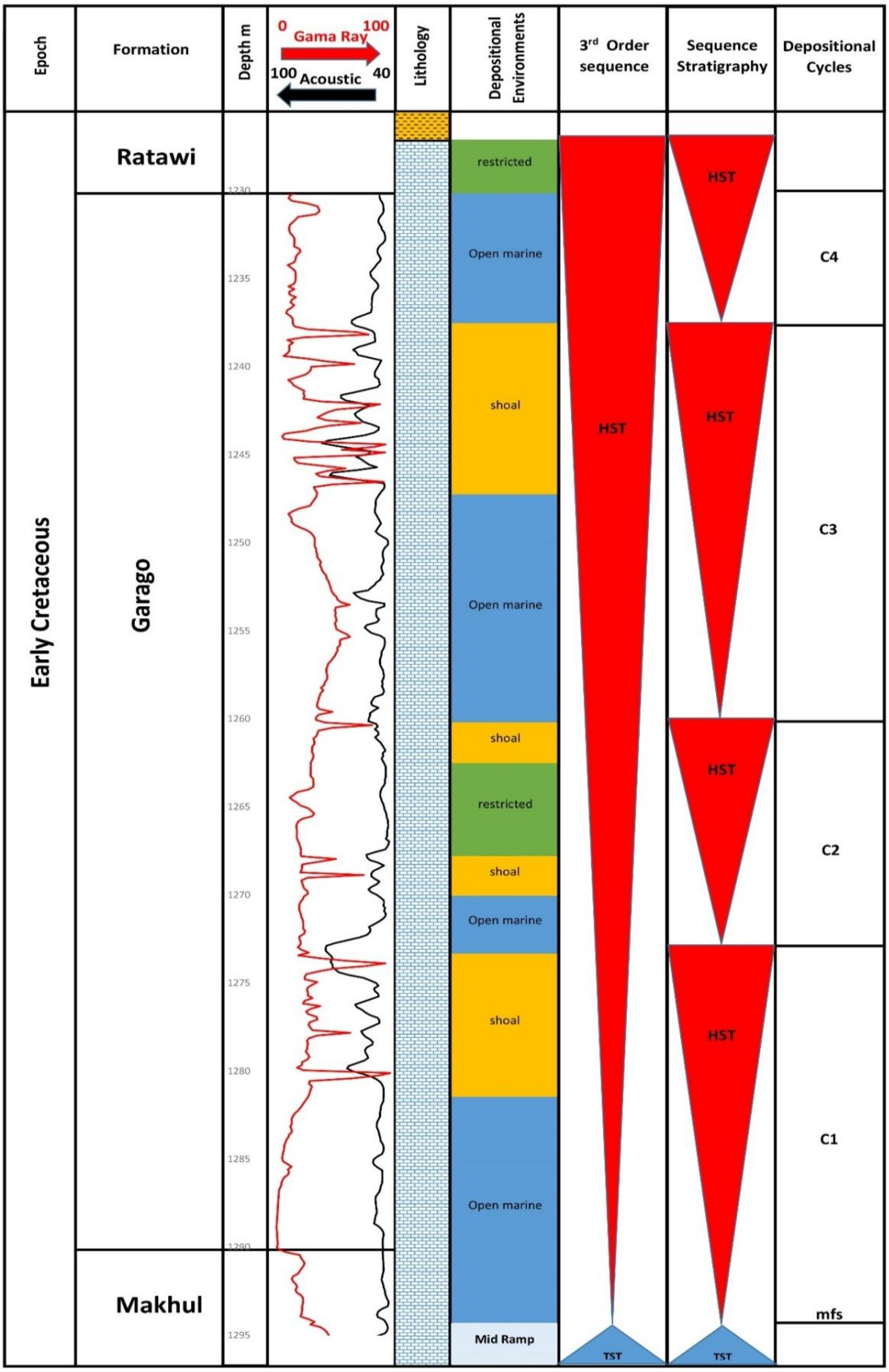


Figure 7: Stratigraphic and depositional distribution of Garagu sequence in well Qc-2.

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