Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org

Stratigraphic Analysis and Depositional Environment of the Newly Recorded Umm Er Rhadhuma Formation (Paleocene) from the Borehole K.H12/7, South Anah City, Western Iraq

Anwar K. Mousa[1, *], Ibrahim Q. Mohammed[2], Salam I. Al-Dulaimi [1] and Fadhil A. Lawa[3]

[1] Department of Geology, College of Science, University of Baghdad. Baghdad, Iraq
[2] Al Maaref University College, Al-Anbar, Iraq
[3] Department of Geology, College of Science, University of Sulaimani, Kurdistan, Iraq
* **Correspondence**: anwar.mousa@sc.uobaghdad.edu.iq

Received: 22 July 2022

Accepted: 13 October 2022

Published: 31 March 2023

Abstract

The Paleocene benthic foraminiferal zonation of the Umm Er Rhadhuma Formation from the borehole (K.H 12/7**)**, South Anah City (Western Iraq), has been re-studied and re-analyzed precisely based on the large benthic foraminifera (LBF). They are represented by two biozone *Rotorbinella hensoni* Partial Range Zone, recorded from the Lower and middle parts of the Umm Er Rhadhuma Formation and *Lockhartia praehaimei* Partial Range Zone determined Uppermost of this unit, and dated to be the Selandian – Thanetian stage. Almost all the biogenic (micro and macro) and non-biogenic constituents, including large benthic foraminifera, Algae, Echinoderm, Bryozoans, Oyster, Gastropod fragments, and peloids, in addition to lithofacies types, indicate that this succession belongs to the Umm Er Rhadhuma Formation. Furthermore, the Paleocene shallowing upwards succession is recognized from seven identified microfacies (MF1 to MF7), which suggests three significant facies associations. A broad inner ramp represents them and is warm shallow open normal marine water (FA1). In contrast, the second facies association represents by the predominated bioclastic sand shoal facies association (FA2) and finally reaches the semi-restricted lagoon facies associations (FA3). The interaction between the local tectonic disturbance along Rutba high and eustatic sea level mainly controls the development of two sequence boundaries of Type-1 (SB1) that occurred respectively at the Cretaceous /Palaeogene K- Pg boundary and Paleocene /Eocene boundary. The Paleocene depositional system starts with major transgression during the Selandian above a sequence boundary of type one (SB.1), that separates the Late Cretaceous (Maastrichtian) successions of the Tayarat Formation from the overlying Paleocene succession with a significant gap, covering the whole Danian age (That is the top of Tectonic Megasequence AP. 9). The predominance of retrogradation staking tract indicated the transgressive system tract during the late Selandian and early Thanetian as a result of an increase in the sea level rise and expanded accommodation space. The highstand system tracts show aggradational and then change to a progradational stacking pattern by the end of the Thanetian and mark significant sea level drawdown with a new sequence boundary of type one between them.

Keywords: Paleocene; Umm Er Rhadhuma; Selandian; Thanetian; Western Iraq

DOI: 10.46717/igj.56.1C.7ms-2023-3-18

1. Introduction

The Paleocene lithostratiographic unit in Iraq represent by several units (Umm Er Rhadhuma, Akashat, Alaja , Kolosh and unit A and B of Swaiss Group G) manifesting lateral and vertical facieal changes within Mesopotomian – Kurdistan Foreland Basin (Lawa , 2018; Mohammed et al ., 2022). The Yogoslavia Team (1977) excuited a hydeogeological exploration program for underground from the Iraqi Western Desert. The studied borehole (K.H12/7) is one of the several drilled wells, which is located at coordination Longitude 42°00' 42.3"E, Latitude 34°00'0.8"N with a total depth of 3672meters.

The lithological properties, boundaries, thickness and paleogeographic distribution of the Umm Er Rhadhuma Formation in those boreholes is the matter of contravenes between several previous studies Yogoslavian Team (1977); Basi et al., (1987); Al-Mutwali & Abawi, (2001) and Yousif and Raje (1989).

The Yogoslavian Team (1977)reported planktic and benthic foraminifera – rich Upper Paleocene – Lower Eocene lithostratigraphic succession of the Umm Er Rhadhuma Formation at 106 to 163 meters (57 m thickness) underlined by Maastrichtian Tayarat and overlain by Eocene Jaddala formations. Based on the Yogoslavia Team (1978) the Umm Er Rhadhuma Formation is composed of foraminiferal dolomitic limestone deposited within a subtidal shallow marine high energy environment upward graded to the planktic foraminiferal marly limestone deposited within a deep marine low energy, reducing environment. Later Iraqi Geosurvey Teams ruled out the presence of Paleocene deposits between 106 to 163 m. and proposed that the top of the Maastrichtian Tayarat Formation at a depth the of 133 m, delineated the base of the Eocene Jaddala Formation at a depth of the 131 m. They suggested the depth from 133 to 131 m., probably of Paleocene age, in the absence of samples for these two meters (Basi et al., 1987). Later other paleontological studies believed that there were no Paleocene deposits in the stratigraphic successions of the K.H12/7(Al-Mutwali & Abawi, 2001). Steineke and Bramkamp first identified the Umm Er Rhadhuma Formation (1952) from Saudi Arabia territories and is composed mainly of dolomitic limestone and evaporite, ranging in thickness between 30-100 meters of the Selandian – Thanetian age. Owen and Nasr (1958) proposed a supplementary type section in drill hole Zubair-3 with 458 m in Iraq, underlain by Maastrichtian Tayarat Formation and overlain by the Eocene Rus Formation. It’s mainly composed of benthic foraminifera bearing- dolomitic limestone, dolomite, and anhydrite lithofacies with chert nodules at the top. The formation crop out in the southern part of the Iraqi Western and Southern Desert (Al-Mubarak and Amin, 1983). This unit consists of chalky limestone, dolostone, shelly limestone, and sandstone , sporadically rich in large benthic foraminifera in the Al-Nakhaib area, Mohammed and Jassim (1991) recognized phosphorite and phosphatic beds intercalated with oyster limestone, chert and dolomitic limestone within the carbonate succession of the Umm Er Rhadhuma Formation, while (Tamar-Agha, 2021) suggested shallow marine lagoon and sabkha for the dolostone and evaporite in subsurface boreholes in the Southern Desert. In the western part of the Western Desert, Al-Bassam & Karim (1992) introduced Akashat Formation for phosphorite-rich succession instead of Umm Er Rhadhuma Formation. The current work aims to identify precisely the proper lithology of the mentioned formation and to re analyzed its position, and boundaries and take into considerations the diagnostic lithological properties, the biostratigraphic data, and facies association indications. This study could add to our understanding of the Rutbah High's differential tectonic activity at the end of the Cretaceous and the beginning of the Paleogene, as well as expand our knowledge of the Cretaceous – Paleogene boundary (CPB) or K-Pg and Paleocene – Eocene boundary (PEB) in the carbonate–dominant east Rutbah basin.

2. Geological Setting and Stratigraphy

The Rutbah Basin is located north of the Arabian Platform, at the passive southern margin of the Tethyan Ocean. It plays an essential role in the architecture of the sedimentary deposits within the paleo-Tethys and new-Tethyan oceans, which are characterized by siliciclastic and carbonate, phosphorite;

porcellanite; and black shale in the Latest Cretaceous – Early Paleogene time (Jassim and Buday, in Jassim and Goff, 2006). Significant biostratigraphic and lithological changes characterized the CPB boundary in the Eastern segment of the Iraqi Western Desert; the Danian age was missing, unlike the western part of the Western Desert, which was characterized by more continuous deposition of the Paleocene successions. Since the late Maastrichtian, the Rutbah Basin was subdivided into two sub-basins, the Western sub-basin with the predominated Phosphatic facies and the Eastern sub-basin with the carbonate prevailed facies, completely separated from each other (Mohammed et al., 2022). In the Danian to Thanetian interval, the Western Phosphatic Basin was characterized by mixed phosphorite, shale, porcellanite, carbonate, and sandstone lithofacies of the Tarifawi, Hiri, and Duwima Members of the Akashat Formation (Al-Bassam & Karim, 1992), where's (Mohammed, 1993) and Mohammed et al., (2022) suggested that the Danian Tarifawi Member can be considered as the upper member of the Maastrichtian –Danian Jeed Formation, which represented the eastern periphery of the East Mediterranean phosphorite Belt, indicating deep to shallow open marine deposits at the western flank of the Rutbah High.

Consequently, the eastern side of Rutbah High is characterized by shallow lagoonal deposits (anhydrite; dolomite, and limestone) of the Selandian – Thanetian stage and known as Umm Er Rhadhuma Formation (Bellen et al., 1959 and Al-Naqib, 1967). The mixed carbonate and anhydrite facies were also recorded from several wells in southern Iraq, Kuwait, and Saudi Arabia (Bellen et al., 1959; Power et al., 1966) deposited within a shallow marine depositional environment (Tamar-Agha, 2021; Menshed and Al-Zaidy, 2021). In the Arabian Peninsula, including western Iraq, the lower boundary of the formation is unconformable in contact with the Late Campanian – Late Maastrichtian Aruma/Tayarat Formation (Al-Naqib, 1967).

3. Material and Methods

A total of 45 core samples were collected at regular intervals throughout the K.H12/7 well of the Paleocene succession. This well is located ten Km east of the desert development station, the site called Khelseai, which belongs to Nahia Haditha northeast of Rutbah City, southern Anah City, Western Iraq, at coordinates (Longitude 42°00' 42.3"E, Latitude 34°00'0.8"N; Fig. 1). Thin sections were prepared from each sample for foraminifera and microfacies identification. Benthic foraminifera are often well preserved and abundant and is used to classify the studied interval into two biozones based on Boudagher Fadhil classification (2015). Microfacies' texture was determined using Dunham's (1962) classification modified ,and the carbonate microfacies were grouped in three facies associations (Table 1) based on the Burchette & Wright, (1992), modified by Schlager (2005) and Flugel (2010).

4. Biostratigraphy

Examination of the paleontological datum in the studied section showed that the K.H 12\7 well contains numerous foraminiferal species; the Latest Maastrichtian lower boundary represented by *Lepidorbitoides socials* Partial Range Subzone and Middle Eocene upper boundary defined by *Globigerinatheka kugleri* of Total Range zone. Twenty-three benthic foraminifera species belonging to eighteen genera were documented, and two biozones were distinguished to indicate Paleocene age (Fig 2); the explanation and discussion of the biozones are shown below. In addition, ten Rotaloidean foraminifera were documented related to the Paleocene Umm Er Rhadhuma Formation. Therefore, it can be categorized into two Paleocene biozones following vertical distribution as shown below.

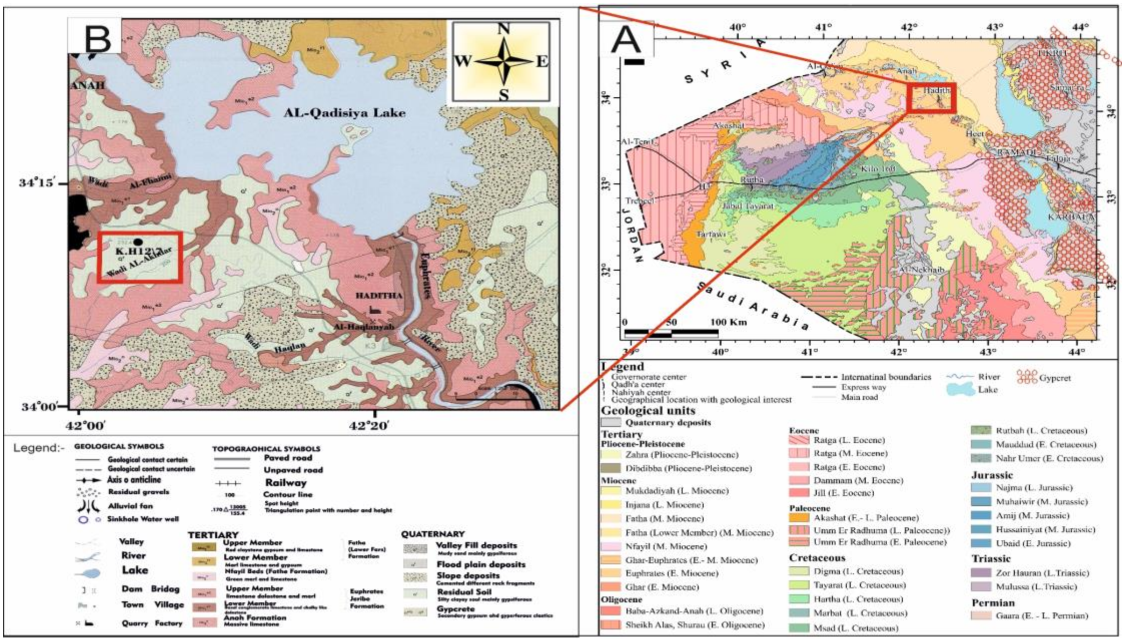

Fig. 1. Map of Iraq and location of studied well, A) Geological map of Iraq after Sissakian and Fouad, 2015; B) Geological map of Haditha after Sissakian & Hafidh (1994)

4.1. *Rotorbinella hensoni* Partial Range Zone

This biozone is specified from the first occurrence of *Rotorbinella hensoni* (Pl.1, Fig. A) to the first occurrence datum (FAD) of *Lockhartia praehaimei* (Pl.1, Fig. B), representing the Early to Middle Selandian age. This zone is about 8 meters thick and recorded from the lower part (Fig 2). The associated foraminifera is *Biloculina* sp., *chrysalidina* sp, *Miliolid* sp., *Plumokathina dienii* ,*Pseudochrysalidina conica* , *Pyrgo* sp. ,*Quinqueloculina* sp. *Quinqueloculina sphaera*, *Textularia* sp. ,and *Valvulina* sp. (Pl.1, Figs. C, D, E, F, H, I, J and K.).

The previously assigned age of the Umm Er Rhadhuma Formation. in Iraq extends from the Paleocene to the Early Eocene based on fossil content and correlation with Saudi Arabia (Bellen et al.,1959). In this study, an abrupt faunal change between the Cretaceous and Paleocene is represented by *Lepidorbitoides social* Total range subzone and identified as the highest deposits attributed to the Cretaceous, including a robust Maastrichtian age fossil. On the other hand, the *Rotorbinella hensoni* range zone suggests the lowermost beds of the overlying middle Paleocene age. The Rotaloidean foraminifera's well distribution, abundance, high evolution rate, and biostratigraphic importance for the Palaeocene have recently been described (Hottinger and Bassi, 2014). The *Rotorbinella hensoni* Zone is defined from the Paleocene in Qatar (Smout, 1954) and matches with the SBZ2 Zone of the Early to middle Selandian age (Hottinger and Bassi, 2014).

4.2. *Lockhartia praehaimei* Partial Range Zone

This biozone is specified as the Partial Range zone of the *Lockhartia praehaimei*. Uppermost Selandian – Thanetian determines this biozone's age, and this zone has a thickness (23 m) within the middle and upper part of the Umm Er Rhadhuma Formation (Fig. 2).

Lockhartia prehaimei Zone is reported previously from the lower part of the Paleocene Umm Er Rhadhuma Formation in Qatar's Dukhan oil field (Hewaidy & Al-Hitmi, 1994; Hewaidy, 1994). It is reported from the upper Paleocene SBZ3 and SBZ 4 Zones of the Uppermost Selandian-Lower Thanetian and Upper Thanetian, respectively (Hottinger & Bassi, 2014). The associated fossils in this subzone are represented by *Bolivina* sp., *Biloculina* sp., *chrysalidina* sp., *Daviesina danieli* Smout (Pl.2,

Fig.L), *Gavelinella* sp., *Kathina aquitanica* n. sp. (Pl.2, Fig.M), *Kathina pernavuti* Sirel (Pl.2, Fig.N), 1972, *Lockhartia conica* Smout (Pl.2, Fig.O), *Lockhartia conditi* Nuttall, 1926 (Pl.2, Fig.P), Miliolid sp., *Pseudochrysalidina conica*, *Quinqueloculina* sp., Quinqueloculina *sphaera* , *Pyrgo* sp., *Redmondina henningtoni* Hasson,1985, *Rotorbinella skourensis* Pfender, 1954, *Textularia* sp., *Valvulina* sp.(Pl.2, Figs. L, M, N, O, P, Q, R). In addition, other fossils can be identified: Bryozoa, *Clypeina* sp., Corallina algae, Dasycladacean, Echinoids fragments, Gastropoda, Ostracoda, Pelecypods.

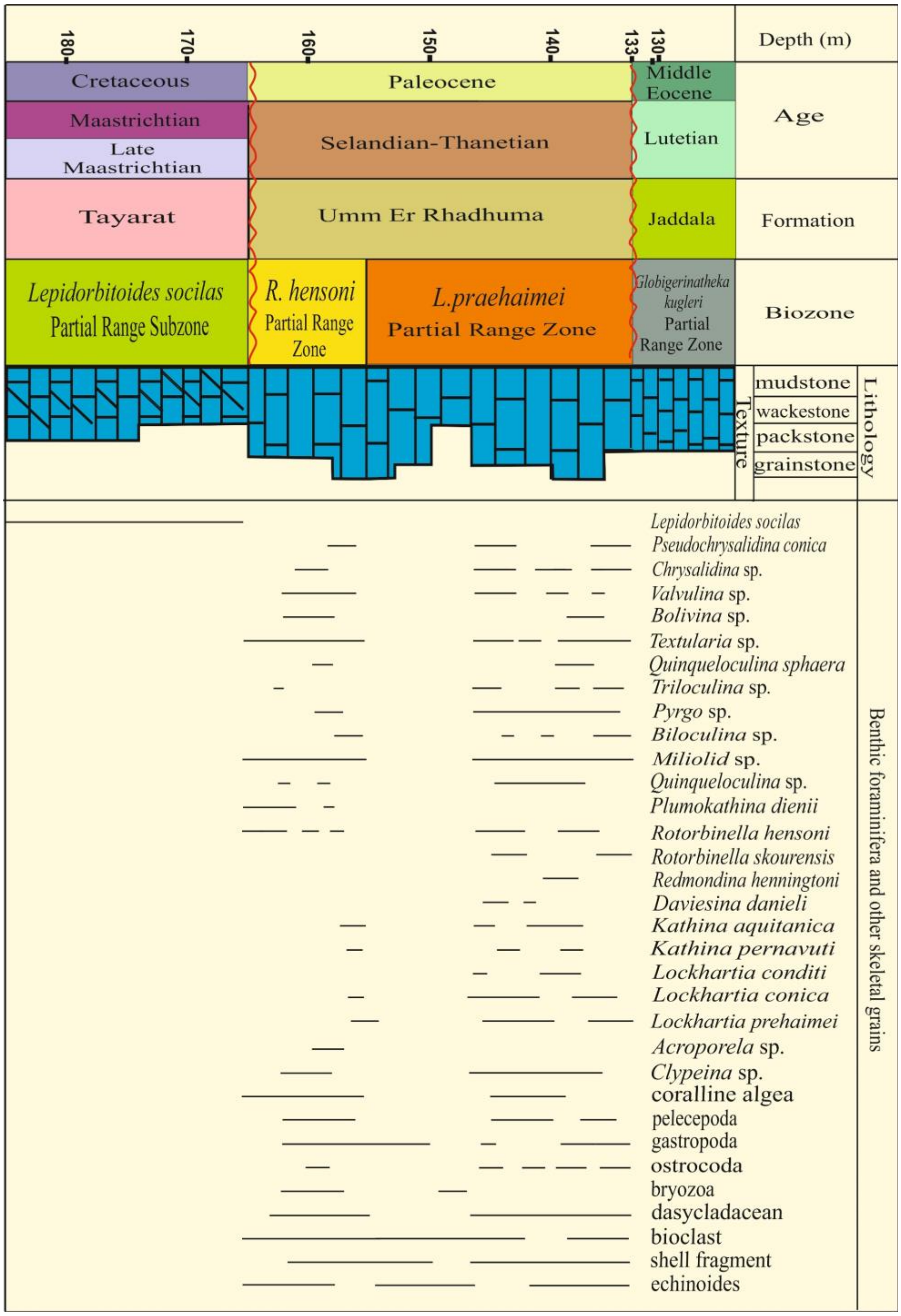

Fig.2. Biozone and biostratigraphic distribution of Foraminifers and skeletal grain of Umm Er RadhumaFormation in K.H 12\7 section.

5. Facies Associations

From the core analysis, about seven microfacies (MF1–MF7) were identified based on the skeletal, non-skeletal, and texture. These seven microfacies are grouped into three facies associations (FA1-FA3) (Table-1) and represent a broad, shallow, homoclinal ramp sedimentary system. FA1 to FA3 from the distal to the proximal inner ramp. The arenitic grain size, moderate sorting and rounding within wackestone texture, and gradual microfacies and facies associations between FA1, FA2, and FA3 indicate a broad homoclinal ramp.

Long the Selandian– Thanetian vertical succession of the K.H12/7 displays stacking patterns of the microfacies types and their sedimentary environment due to retrogradation of the system.

5.1. Facies Association 1 (FA1): Shallow Open Marine Inner Ramp

FA1 contains biota of normal open marine water (echinoderm and bryozoan) with peloids in a mud-support wackestone texture (MF1 and MF2), representing a shallow open marine inner ramp within the euphotic zone and low energy currents above fair-weather wave-base (FWWB) and within the fore-shoal seaward environment (James and Dalrymple, 2010; Wilson, 1975; Schlager, 2005).

5.2. Facies Association 2 (FA2): Shoal Inner Ramp

Grainstone microfacies (MF3, MF4, and MF5) dominate FA2 and contain various arenitic skeletal grains of green algae, large benthic foraminifera, echinoderm, bivalve Gastropoda and other bioclasts. Grain-support texture, sparite cement, well-sorted, and moderate to well rounding suggest moderate – to -high energy current, probably shallow subtidal to intertidal submarine shoal in the inner ramp (Hohenegger, 1999).

5.3. Facies Association 3 (FA3) Semi-Restricted Lagoon Inner Ramp

FA3 is represented by packstone texture (MF6 and MF7) with porcelaneous and calcareous benthic foraminifera, algae, shell fragments, subordinate peloid grains, fine-grained dolomite, and less anhydrite cement. The micrite matrix, grain types, and well-sorted fabric of the foraminiferal grains, including small miliolid foraminifers, suggest moderate tidal water energy within the semi-restricted lagoon (Scholle and Ulmer-Scholle, 2003). Miliolid is widespread mainly in muddy lagoonal zones (Haig, 1988; Flügel, 2004; Villalonga et al., 2019; Consorti & Köroğlu, 2019). In contrast, highly dolomitization and scattered anhydrite cement indicate the dominance of a semi-arid climate. Vugs and fenestral porosity with ghost fossils constrain gradation from semi-restricted subtidal to intertidal and probably supratidal. Similar supratidal or sabkha to restricted lagoon facies association types have been interpreted as the anhydrite–dolomite interbedded within the Paleocene succession of southern Iraq. The studied borehole and compared with published work in the eastern part of the western in addition to south Iraq revealed a broad, widespread, highly dolomitic and evaporitic–rich large benthic foraminifera granular limestone developed typical of an epeiric carbonate – evaporite homoclinic ramp type system with semi-to closed basins in a hot -arid climate and high salinity (Tucker & Wright, 1990; Wilson, 1975).

Table 1. The microfacies and facies associations of the shallow marine Umm Er Rhadhuma Formation

Facies associations	**Microfacies types**	**Petrographic descriptions**	**Thicknesses, stratigraphic locations**	**Sedimentary environments**
Distal shallow open marine FA1	***Echinoderm peloidal wackestone MF1** ***Echinderm bryozoa wackestone MF**	Echinoderm fragments, peloid, bryozoans fragments. Arenitic size within micrite matrix in a moderately sorted and rounding.	MF1:Two m. at depth 148-150 m, within the middle part. MF2: one meter at a depth of 147 m. middle part.	Low energy, euphotic zone, Fore-shoal, Shallow open marine, distal inner ramp.
Shoal FA2	***Alge miliolid bioclastic grainstone MF3** ***LBF echinoderm alge bioclastic grainstone MF4** ***Bioclast rotalia miliolid grainstone MF5**	Algae (Dasycladacean, Clypeina sp., Coralline algae), miliolid, bioclastic of oyster, echinoderm,Gastropoda, and Ostracoda, LBF (*Rotalia* sp., *Textularia* sp., *Bolivina* sp., *Chrysalidina* sp., *Valvulina* sp., *Gavelinella* sp.,) and peloids.Sparite and microsparite. Arenitic size of a well sorting and moderately to well rounding.	MF3:six m at depth 140-147 m. middle part. MF4: four m at depth 136-140 m. upper part MF5: eight m at depth 153-158 m. middle part.	Moderate to high energy, euphotic zone. Shallow subtidal to intertidal shoal, central inner ramp.
Semi-restricted lagoon FA3	***Algae bioclastic miliolid packstone MF6** ***Shelly rotalia miliolid packstone MF7**	Porcelaneous benthic foramimifera (Miliolid sp., *Quinqueloculina sp., and Pyrgo* sp.,) and calcareous foram (*Rotalia* sp., *Textularia* sp., *Bolivina* sp., *Chrysalidina* sp., *Valvulina* sp., *Gavelinella* sp.) algae (Dasycladacean, Clypeina sp., Coralline alae) echinoid	MF6:3 m at depth 133-136 m. Uppermost and 3m at depth 162 -165 m. lowermost part. MF7: 4m at depth 158-162 m. lower and middle part.	Moderate energy, euphotic zone, proximal inner ramp.

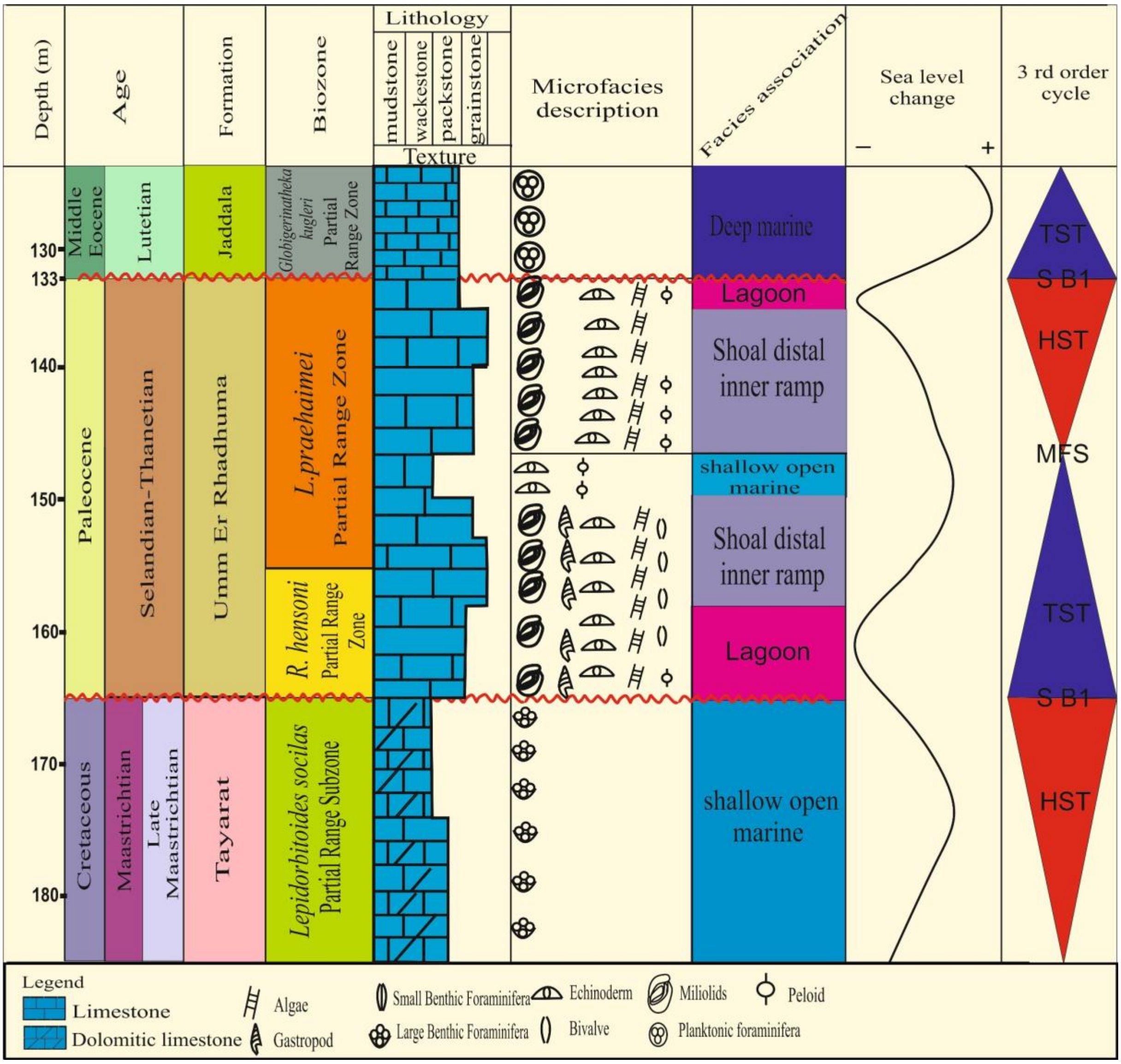

Fig. 3. Microfacies, facies associations, and sequence stratigraphic analysis of Umm Er Radhuma Formation in K.H 12\7 well.

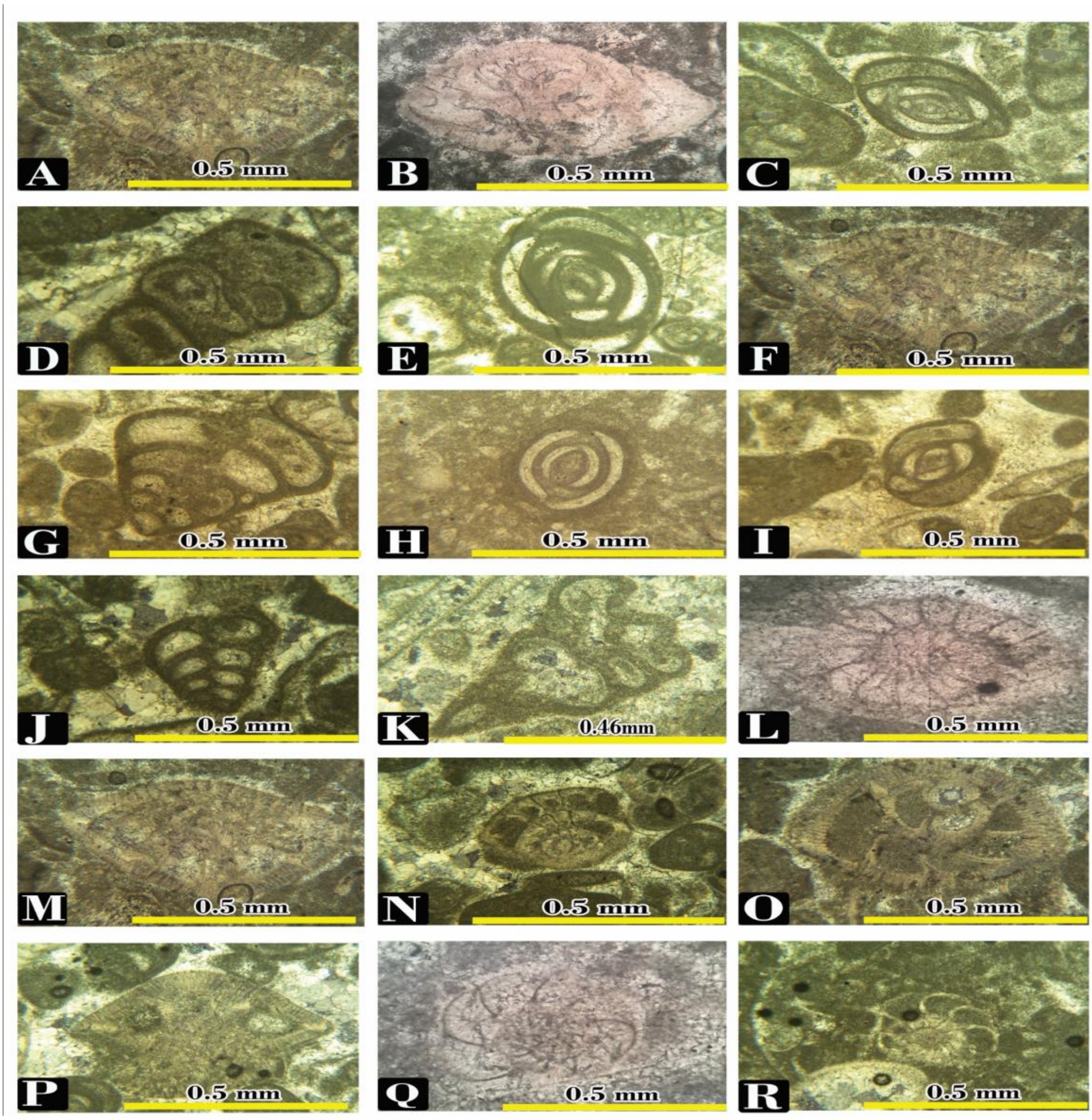

Plate 1. all figures are from Umm Er Rhadhuma Formation (Paleocene). A- *Rotorbinella hensoni* Smout, 1954; Axial section(162m)B- *Lockhartia prehaimei* Smout; Axial section(142m) C- *Biloculina* sp.; Equatorial section(138m)D- *Chrysalidina* sp.; Axial section (134m)E- *Miliolid* sp.; Axial section (146m)F- *Plumokathina dienii* n. sp.; axial section (162m) G- *Pseudochrysalidina conica*; axial section (145m)H- *Pyrgo* sp.; axial section (142m) I- *Quinqueloculina* sp.; Subaxial section (145m) J- *Textularia* sp.; Axial section (134m) K- *Valvulina* sp.; Axial section (138m) L- *Daviesina danieli* Smout; Equatorial section (145m) M- *Kathina aquitanica* n. sp; Axial section (139m) N- *Kathina pernavuti* Sirel; Subequatorial section (144m) O- *Lockhartia conica* Smout; Subequatorial section (146m) P- *Lockhartia conditi* Nuttall; Axial section (139m) Q- *Redmondina henningtoni* Hasson,1985; Subequatorial section (144m) R- *Rotorbinella skourensis* Pfender ,1954; Equatorial section (137m).

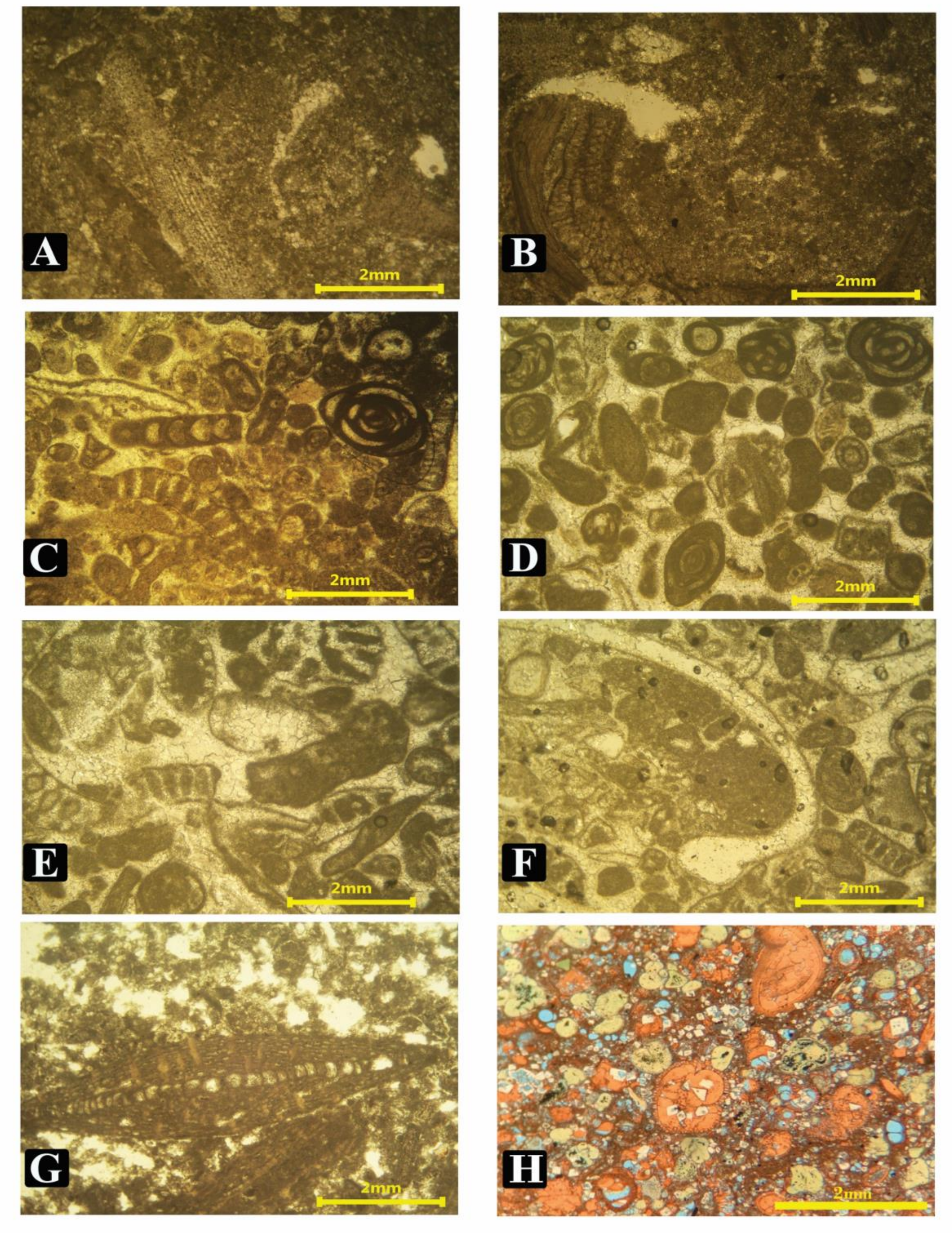

Plate 2. A- MF1 Echinoderm peloidal wackestone (148m); B-MF2 Echinoderm bryozoa wackestone (147m); C- MF3 Algae miliolid bioclastic grainstone (143m); D- MF5 Bioclast Rotalia miliolid grainstone (154m); E- MF6 Algae bioclastic miliolid packstone (134m); F-MF7 Shelly Rotalia miliolid packstone (158m); G- Orbitoidal bioclastic wackestone Maastrichtian microfacies (Tayarat Fm) (166m); H- Planktonic glauconitic grainstone (Jaddala Fm) - Middle Eocene microfacies (132m).

6. Discussions

6.1. Age Assignment

In Western Iraq, the upper part of the Tayarat Formation consists of dolomitic limestone with Orbitoides – large benthic foraminifera, and the boundary between Tayarat and Umm Er Rhadhuma Formation was taken at the change from *Lepidorbitoides socialis* Partial Range Subzone, to *Rotorbinella hensoni* Partial Range Zone – bearing dolomitic limestone of the middle Paleocene age, with the absence of the Danian age (Mousa *et al*., 2020). This hiatus is known in the Arabian Peninsula as " Pre – Cenozoic Unconformity (PCU) (Sharland et al., 2001). The long break of the PCU is probably linked with the subduction of the northeastern margin of the Arabian Plate and ophiolite obduction (Al-Husseini and Matthews, 2005). The top of the Umm Er Rhadhuma Formation in the studied borehole is unconformable in contact with the Eocene Jaddala Formation. The boundary is placed at the appearance of the planktic-rich limestone *Globigerinatheka kugleri* of the Range zone of the Middle Eocene basinal facies in the association of the Jaddala Formation (Al-Mutwali and Abawi, 2002) with the missing of the lower Eocene sediments and probably part of the upper Eocene.

The following larger rotaliid species Rotorbinella hensoni, Lockhartia prehaimei, Daviesina danieli, Kathina aquitanica, K. pernavuti, Lockhartia conditi, Lockhartia conica, Plumokathina dienii, Redmondina henningtoni, Rotorbinella skourensis were recorded for the first time in K.H12\7 in the present study (see Basi et al., 1987; Al-Mutwali, 1992). The hiatus time is marked by the absence of Danian forms, such as Laffitteina cf. bibensis Marie and Rotorbinella detrecta Hottinger, which correspond to SBZ 1 (Danian). In the absence of plankton foraminifera, it is impossible to draw a sharp line between the Late Maastrichtian and the Paleocene in the studied samples. Here, it is notable to sign that the K/Pg boundary is characterized by a break as indicated by the absence of Danian age, and the Middle and Late Paleocene zones was recorded in the first time, represented by Rotorbinella hensoni Partial Range Zone and Lockhartia praehaimei Partial Range Zone. Where the Lepidorbitoides socialis Partial Range Subzone reported from the uppermost part of the Tayarat Formation refers to latest Maastrichtian, followed directly by the Rotorbinella hensoni Partial range zone of Selandian age, The Middle Eocene represented by Globigerinatheka kugleri total Range zone of Jaddala Formation overlying the Lockhartia praehaimei Partial Range Zone of the Umm Er Rhadhuma Formation., indicating the significance of gap at the Paleocene /Eocene boundary

6.2. Hiatuses

The Maastrichtian to Eocene litho- and biostratigraphic investigations of the studied borehole reveal two significant hiatuses that indicate intensive tectonic activity. The earlier hiatus is the complete missing of the lower Paleocene (Danian) age, and the other one is the missing of the lower Eocene (Ypresian) age.

6.2.1. Cretaceous / Paleogene (K/Pg) Hiatus

In the Western Desert of Iraq, the transition between the Maastrichtian and Paleocene is recorded in the outcrop surfaces within the Western Rutbah Phosphatic Bain (WRPB) (Bellen et al., 1959) and not exposed in the Eastern Rutbah Carbonate Basin (ERCB). Published data of the WRPB claimed excellent K-Pg transition with the Latest Maastrichtian – Danian succession of a deep open marine shale, porcellanite, phosphorite, phosphatic sandstone, and oyster limestone cycles in the Late Maastrichtian Safra Member and approximately, the same lithofacies are repeated in the Danian Trefawi Member of the Jeed Formation well exposed in their type area southwestern Rutbah in the Trafawi area (Ezmalat Houran)(Mohammed, 1993)(Mohammed et al., 2022). However, Danian sediments were recorded on a different surface and subsurface of the western part of the Iraqi Western Iraq (Al-Bassam et al., 1990;

Mohammed, 1985; Mousa et al., 2020; Karim and Al-Kubaysi, 2020). However, in the ERCB, the present study has identified large benthic foraminifera *Rotorbinella hensoni* Partial Range Zone rich dolomitic limestone of the Selandian age of the Umm Er Rhadhuma Formation overlain *Lepidorbitoides socialis* Partial Range Subzone the latest Maastrichtian large benthic foraminifera - rich dolomitic limestone of the Tayarat Formation. All index fossils of Danian forams are absence such as large benthic foraminifera *Laffitteina cf. bibensis* Marie and *Rotorbinella detrecta* Hottinger that correspond to SBZ 1 and absence of all index fossils of Danian planktic zone such as *Guembelitria cretacea* that correspond to Earliest Danian P0 and *Parvularugoglobigerina eugubina* and subsurface of southwestern Iraq (Mohammed and Jassim, 1991; Tamar-Agha, 2021).

6.2.2. Paleocene / Eocene (P/E) Hiatus

The absence of the Ypresian fauna marks the transition from the Paleocene to the Eocene in the studied borehole and borehole (B.H7/7) south of the studied area within the ERCB previously studied (Al-Badrani, 2011; Al-Mutwali and Abawi, 2002; Mousa et al., 2020). In contrast, the outcrop succession in the WRPB is rich in the Lower Eocene (Ypresian) foraminifera such as *Anomalimoides granosa* (Hantken), *Bulimina quadrata* (Plummer), *Globorotalia aragonensis* (Nuttal), *Globorotalia cf. velascoensis* (Cushman), *Marsonella oxycona* (Reuss), *Quadrimorphina allomorphinoides* (Reuss) Bellen et al., 1959; *Nummulites deserti* (Dela Harpe), *Assilina placentula* (Deshays), *Operculina lypica*, *Rotalia trochidiformis* (Al-Bassam & Hagopian, 1983). Furthermore, the occurrence of glauconitic facies marks this unconformity/ hiatus–rich planktic packstone of middle Eocene Jaddala Formation *Globigerinatheka kugleri* Total Range zone overlain the large benthic foraminifera – rich Thanetian carbonate of the Umm Er Rhadhuma Formation., indicating the significance of gab at the P-E transition.

6.3. Hiatuses Interpretation

The K-Pg and P-E unconformity in the studied section of the ERCB shows a long-time interval missing; it differs from the WRPB, which is characterized by the presence of the Danian and Ypresian age. These two stratigraphic discontinuities and the subdivision of the Rutbah Basin to a deep open marine WRPB and shallow marine ERCB are linked with the tectonic activity of the Rutbah High in the central Rutbah Basin. Like these structural and stratigraphical features was a regional existing in the Arabian and Nubian Plate in the Late Cretaceous and Paleogene; folding of the Syrian Arc System and Ha'il – Rutbah Arc, and the extension of the normal fault of the Euphrates Fault System. These large-scale geological features are contemporaneously related to the change of the passive – margin of the Arabian Platform to the flexural basin when the Arabian – Nubian Plate subduction beneath the Iranian (Sanandaj-Sirjan) in the northeast and Anatolian microplates in the north (Berberian & King, 1981; Stern & Johnson, 2010; Lawa et al., 2013; Bar-On et al., 2018).

7. Depositional Environments

Facies associations recognized in the study Borehole (KH12/7) indicates shallow to the subtidal semi-restricted lagoon, shoal, and shallow open marine setting, above the fair-weather wave Base (FWWB). Shallow normal marine water condition is manifested by the predominance of the green calcareous algae Dasycladacean, clypeina, and coralline algae, within ten meters water depth and euphotic zone (Zwaan et al.,1990). The Porcelaneous and calcareous benthic foraminifera species, in combination with Oyster, Echinoderms, Bryozoans, Gastropoda, and Ostracoda shell fragments, in addition to peloids and without planktic foraminifera, almost point to slight fluctuation in sea-level bounded by long two hiatus within the shallow marine environment. Therefore, they are reflecting the deposition in uplifted area, on the contrary, from the WRPB, which was characterized rapid subsidence and deposition open marine shallow to deep facies associations (Mousa et al., 2021; Karim and Al-Kubaysi, 2020 , Mohammed et al ., 2022) under the impact of the tectonic activity of the Rutbah High. The gradational change s from facies associations to another in semi-closed to open shallow carbonate basin, suggesting that the Umm Er Rhadhuma Formation was deposited with inner broad homoclinal ramp system along with the eastern margin of the Rutbah High, with lagoon, grainstone (MF3 , MF4 and MF5) shoal, and shallow open fore-shoal facies association, which related with the Selandian sea-level rise of the Arabian Platform, and transgressive over the ERCB, which opened to the north and east and changed to the outer – ramp and basinal facies of the Aaliji Formation within borehole Anah-1 (Al -Mutawli and Abawi, 2001) in the north and Fallujah -1 in the east.

8. Sequence Stratigraphy

Vertical facies associations display retrogradation of shallow – to - deep – to shallow marine within inner homoclinal carbonate ramp (transgressive – regressive cycle), suggesting sea-level rise through the middle-late Paleocene, which coincided with the significant transgression in the northern Arabian platform (Lawa, 2004; Haq, 2014; Farouk et al., 2019). The lower and upper boundary of the Umm Er Rhadhuma Formation in the studied borehole is bounded by two unconformity surfaces with a long duration hiatus, characterized by total missing of the Danian age in the lower hiatus and Ypresian age of the upper hiatus. These two unconformity surfaces are considered lower and upper sequence boundary type-1 (SB – K/Pg and SB-P/E), and a long time is missing within K/Pg, and P/E boundaries in the ERCB suggests that the local tectonics of the Rutbah High had a significant impact on the non-deposition of these two intervals in the ERCB. The long hiatus/ unconformity surfaces, relatively small in thickness, during the subaerial exposure, a significant portion of the system tracts may be eroded, the water level is gradually rising, and facies associations are converging; in addition, the two sequence boundaries type -1, the Umm Er Rhadhuma Formation comprising one-third order depositional sequence. This sequence (Catuneanu, 2017; Mitchum and Wagoner, 1991) consists only of the transgressive system tract (TST) and Highstand system tract (HST) separated by a maximum flooding surface (MFS). The TST is marked by moderate energy semi-restricted lagoon (FA3), including MF7 and MF6, and higher energy shoal (FA2), including MF5, MF4, and MF3, displays the Deepening trend during the transgressive phase. In the middle of this succession, the transgressive phase is continuous and deepening -upward, represented by MFS, characterized by transition from shoal to shallow open normal marine water and low energy within euphotic zone, represented by MF1 and MF2. The upper succession was again represented by FA2 and FA3 and showing shoreward migration from MFS to the HST and displayed shallowing-regression phase, and in the top of the FA3 complete regression occurred, through forced regression after uplifting of the Rutbah High at the end of the Thanetian.

9. Conclusions

- Several larger rotaliid species of Rotorbinella hensoni, Lockhartia prehaimei, Daviesina danieli, Kathina aquitanica, K. pernavuti, Lockhartia conditi, Lockhartia conica, Plumokathina dienii, Redmondina henningtoni, Rotorbinella skourensis are reported for the first time in the borehole KH 12\7, from Umm Er Radhuma Formation (Paleocene), Iraq.
- Two biozones were established based on the vertical stratigraphic distribution of the main taxa, represented by (1) Rotorbinella hensoni Partial range Zone (the lower and middle parts of the Selandian) and (2) Lockhartia praehaimei Partial Range Zone (uppermost Selandian-Thanetian).
- Based on Large Benthic -Foraminifera, the Middle and Late Paleocene age belonged to the Umm Er Rhadhuma Formation, from 133 m to 165 m (32 m thicknesses),
- The K/-Pg and P/E - boundaries represent amajor huiatus manifested by the disappearance of the Danian and the Ypresian ages,

- Those gaps are indicated by the Lepidorbitoides socialis Partial Range Subzone reported from the uppermost part of the Tayarat Formation refers to the Latest Maastrichtian, followed directly by the Rotorbinella hensoni Partial range zone of Selandian age.
- These two hiatuses, representing two sequence boundaries type -1, were interrupted that result from the uplifting of Rutbah High.
- Boundaries are mentioned recognized as a long hiatus/unconformity surface, characterized by the Danian in the K/Pg and Ypresian in the P/E boundaries.
- Seven microfacies represent three facies' associations. The inner ramp model of the Umm Er Rhadhuma Formation: FA1 has been interpreted by MF1 and MF2, echinoderm bryozoa, and peloid–rich, low energy, euphotic, open shallow inner ramp above FWWB. FA2: moderate to high energy with arenitic bioclastic and foraminiferal grainstone (MF3, MF4, and MF5) was deposited within the inner ramp as a sand shoal. FA3, characterized by MF6 and MF7, is dominated by porcelaneous and calcareous benthic foraminifera, algae, other bioclasts, and peloids.
- One-third order sequence was recognized, bounded by type-1 lower and upper sequence boundaries (SB1 and SB2), consisting only of the transgressive system tract (TST) and Highstand system tract (HST) separated by a maximum flooding surface (MFS).

Acknowledgements

We want to express our gratitude to the Iraqi Geological Survey (GeoSurv-Iraq) for their general support and help with sampling and thin section preparation. We would also like to thank Prof. Sherif Farouk (Egyptian Petroleum Research Institute) and Dr. Felix Schlagintweit (independent consultant, Germany) for their assistance in validating parts of the large benthic foraminifera. Thank you for your thoughtful and informative comments, Prof Salih M. Awadh, Editor-in-Chief, and two anonymous reviewers.

References

Al-Badrani, O. , 2011. Nannobiostratigraphy of Jaddala Formation in Well (KH 12/7) West Iraq, Iraqi National Journal of Earth Sciences. Mosul University, 11(1), 71–84.

Al-Bassam, K. and Karim, S., 1992. Depositional history and paleogeography of the Upper Cretaceous–Paleogene phosphorite-bearing sequence, Western Desert, Iraq, Iraqi Geological Journal, 25(1), 142–167.

Al-Bassam, K. S., Karim, S. A., Hassan, K. M., Saeed, L. Yakta, S.,Salman, M., 1990. Report of the Upper Cretaceous–Lower Tertiary phosphorite bearing sequence, Western Desert, Iraq.

Al-Bassam, K. S. and Hagopian, D., 1983. Lower Eocene phosphorites of the western desert, Iraq, Sedimentary Geology. Elsevier, 33(4), 295–316.

Al-Husseini, M. and Matthews, R. K., 2005. Arabian orbital stratigraphy: Periodic second-order sequence boundaries?, GeoArabia, 10(2), 165–184.

Al - Mubarak , M. A. and Amin, R. M., 1983. Report on the regional geological mapping of the eastern part of the Western desert and the western part of the Southern Desert, SOM Library No. 1380 , Baghdad.

Al-Mutwali, M. M. A., 1992. Foraminifera, Stratigraphy and Sedimentology for Upper Creatceous – Lower Tertiary Succession within Selected Boreholes in khelesia- Anah- Rammadi, Unpublished Ph.D. Thesis, University of Mousl, 273.

Al-Mutwali, M. M. and Abawi, T. S., 2001. A study of the paleoclimate of the Eocene period on the basis of the planktonic foraminifera of the Jaddala Formation, Western Iraq, Iraqi Journal of Earth Science, 1(1), 31–37.

Al-Mutwali, M. and Abawi, S. T., 2002. Facies distribution and paleogeography of lower tertiary deposits in khleisia anah–Ramadi area western Iraq, Iraqi National Journal of Earth Sciences. Mosul University, 2(1), 14–27.

Al-Naqib, K. M., 1967. Geology of the Arabian Peninsula-South Western Iraq, Geological Survey-professional paper, no.560 G.1(United state Government Printing, Washington), 31-33.

Bar-On, Y. M., Phillips, R. and Milo, R., 2018. The biomass distribution on Earth, Proceedings of the National Academy of Sciences. National Acad Sciences, 115(25), 6506–6511.

Basi, M. A., Esho,W.Y., Younis,W.R., Odesho, H., 1987. Pertology, Paleontology and Geochmistry of key holes 12\7,W Desert of Iraq.

Bellen, R. C., Dunnington, H. V., Wetzel, R., Morton, D., 1959. Lexique stratigraphique international, Asie, Iraq, 3(10a).

Berberian, M. and King, G. C. P., 1981. Towards a paleogeography and tectonic evolution of Iran, Canadian journal of earth sciences. NRC Research Press Ottawa, Canada, 18(2), 210–265.

Burchette, T. P. and Wright, V. P., 1992. Carbonate ramp depositional systems, Sedimentary Geology, 79(1–4), 3–57.

Catuneanu, O., 2017. Sequence Stratigraphy: Guidelines for a Standard Methodology, Stratigraphy & timescales, 2, 1–57..

Consorti, L. and Köroğlu, F., 2019. Maastrichtian-Paleocene larger Foraminifera biostratigraphy and facies of the Şahinkaya Member (NE Sakarya Zone, Turkey): Insights into the Eastern Pontides arc sedimentary cover, Journal of Asian Earth Sciences, 183.

Farouk, S., Aaskalany, M., El-Sorogy, A., Youssef, M., Taha, S., 2019. Micropalaeontological and isotopic analyses of the middle Palaeocene succession at Gebel Nezzi (Luxor, Egypt): Implications for eustatic changes, Geological Journal, 54(3), 1435–1453.

Flügel, E., 2004. Microfacies of carbonate rocks: analysis, interpretation and application. Springer Science & Business Media.

Haig, D. W., 1988. Miliolid foraminifera from inner neritic sand and mud facies of the Papuan Lagoon, New Guinea, The Journal of Foraminiferal Research. Cushman Foundation for Foraminiferal Research, 18(3), 203–236.

Haq, B. U., 2014. Cretaceous eustasy revisited, Global and Planetary Change, 113, 44–58.

Hewaidy., A., 1994. Biostratigraphy of the Umm Er Rhadhuma Formation in South-East Qatar, Arabian Gulf, N.Jb. Geol. Palaont. Abh., 193(2), 145–164.

Hewaidy, A. and Al-Hitmi, H. H., 1994. Cretaceous-Early Eocene foraminifera from Dukhan oil field, West Qatar, Arabian Gulf, A: Suborder Textularina, Involutinina and Miliolina. Al-Azhar Bulletin of Science, 4(2), 469–494.

Hohenegger, J., 1999. Larger foraminifera-microscopical greenhouses indicating shallow-water tropical and subtropical environments in the present and past, (February).

Hottinger, L. and Bassi, D., 2014. Paleogene Larger Rotaliid Foraminifera from the Western and Central Neotethys.

Jassim, S.Z.and Goff, J., 2006. Geology of Iraq. Dollin and Moravian Museum, Prague, printing,Mosul ,Iraq, 341.

James, N. P., And Dalrymple, R. W., 2010. FACIES MODELS 4, Geological association of Canada.

Kriam, S. A. and Al-Kubaysi, K. N., 2020. Biostratigraphy and environmental reconstruction of the Akashat Formation (Paleocene phosphatic sequence), western desert, IRAQ, Iraqi Bulletin of Geology and Mining, 16(2), 1–20.

Lawa , F. A., 2004.Sequence Stratigraphic Analysis of the Middle Paleocene–Middle Eocene in the Sulaimani District (Kurdistan Region), Unpublished Ph. D. Thesis, University of Sulaimani, Kurdistan Region, Iraq.

Lawa, F. A., Koyi, H. and Ibrahim, A., 2013.Tectono-stratigraphic evolution of the NW segment of the Zagros fold-thrust belt, Kurdistan, NE Iraq, Journal of Petroleum Geology. Wiley Online Library, 36(1), 75–96.

Lawa, F. A., 2018. Late Campanian–Maastrichtian sequence stratigraphy from Kurdistan foreland basin, NE/Iraq. Journal of Petroleum Exploration and Production Technology, 8(3),713-732.

Menshed, M. A. and Al-Zaidy, A. A. H., 2021. Sedimentary basin reconstruction and tectonic development of paleocene-eocene succession, southern iraq, by geohistory analysis, Iraqi Journal of Science, 62(4), 1213–1225.

Mitchum Jr, R. M. and Van Wagoner, J. C., 1991. High-frequency sequences and their stacking patterns: sequence-stratigraphic evidence of high-frequency eustatic cycles, Sedimentary geology. Elsevier, 70(2–4), 131–160.

Mohammed, I. Q., 1985. Petrology and Geochemistry of Upper Cretaceous-Paleocene Phosphatic Rocks in the Rutba-H3 Area, Western Desert Iraq. M. SC. Thesis, University of Baghdad, Baghdad.

Mohammed ., I. Q., 1993. Mineralogy, Petrology and Depositional environments of clay and siliceous rocks in the Maastrichtian-Danian sequence in Western Iraq, Unpublished Ph.D., Thesis, University of Baghdad, 171.

Mohammed, I. Q, and Jassim, R. Z., 1991. Geology and Sedimentology of Nukhaib Phosphate deposit, Western Iraq, Iraqi Geological Journal, 24(1), 1–17.

Mohammed, I. Q., Farouk, S., Mousa, A., Lawa, F. A., 2022. Lithofacies types, mineralogical assemblages and depositional model of the Maastrichtian–Danian successions in the Western Desert of Iraq and eastern Jordan, Journal of African Earth Sciences. Elsevier Ltd, 186, 104397.

Mousa, A. K., Al-dulaimi, S. I. and Mohammed, I. Q., 2020. Biostratigraphy of the Late Cretaceous /Early Paleocene successions at k . h 5 \ 6 and k . h 5 \ 8 core interval , western desert of iraq, Iraqi Geological Journal, 53 (IE)(1986), 104–125.

Mousa, A. K., Al-Dulaimi, S. I. and Mohammed, I. Q., 2021. Microfacies analysis of the Late Maastrichtian-Danian phosphatic succession in the H3-Trebeel district, Western Desert of Iraq, Iraqi Journal of Science, 62(4), 1188–1203.

Owen, R.M.S. and Nasr, S. N., 1958. The stratigraphy of the Kuwiat-Basrah area., In: Weeks, G.L. (es). Habitat of oil a symposium. Amer. Assoc. Pet. Geol. Tulsa.

Power, R., Ramirez, L. F., Redmond, C. D., 1966. Geology of the Arabian Peninsula, Sedimentary Geology of Saudi Arabia., U.S.Geol.Surv., 560:147.

Schlager, W., 2005. Carbonate sedimentology and sequence stratigraphy. SEPM Soc for Sed Geology.

Scholle, P. A. and Ulmer-Scholle, D. S., 2003. A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis, AAPG Memoir 77. AAPG.

Sharland, P.R., Ratmond, A., Casey, D.M., Daris, R.B., Hall, S.H., Hewerd, A.P., Horbury A.D. and Simmons, M. D., 2001. Arabian Plate Sequence Statigraphy., Geo. Arabia, Specl. Pub.

Sissakian, V. K. and Fouad, S.. 2015. Geological map of Iraq , scale 1 : 1000 000 , 4 th edition , 2012 Geological Map of Iraq , scale 1 : 1000 000 , 4 th edition , 2012, 11, 8–17.

Sissakian, V. K. and Hafidh, S. Q., 1994. The Geology of Haditha Quadrangle, scale 1: 250 000, Baghdad, Iraq.

Smout, A. H., 1954. Lower Tertiary Foraminifera ofthe Qatar Peninsula. JSTOR, p. London: British Museum. (Natural History). 90.

Stern, R. J. and Johnson, P., 2010. Continental lithosphere of the Arabian Plate: a geologic, petrologic, and geophysical synthesis, Earth-Science Reviews. Elsevier, 101(1–2), 29–67.

Tamar-Agha, M. Y., 2021. Sedimentology of the Paleocene–Early Eocene sequence, Southwestern Iraq, Iraqi Bulletin of Geology and Mining, 17(2), 17–36.

Tucker, M. E. and Wright, V. P., 1990. Carbonate sedimentology. John Wiley & Sons.

Van der Zwaan, G. J., Jorissen, F. J. and De Stigter, H. C., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: constraints and applications, Marine Geology. Elsevier, 95(1),1–16.

Villalonga, R., Boix, C., Frijia, G., Parente, M., Bernaus, J. M., Caus, E., 2019. Larger foraminifera and strontium isotope stratigraphy of middle Campanian shallow-water lagoonal facies of the Pyrenean Basin (NE Spain), Facies. Springer, 65(3), 29.

Wilson, J. L., 1975. The lower carboniferous Waulsortian facies, in Carbonate Facies in Geologic History. Springer, 148–168.

Yosif, W., Raje, W.,1989. Biostratigraphy study and deposition environment of Key Holes 12\7 in the Western Desert of Iraq.

Zwaan, G. J., Jorissen, F. J. and De Stigter, H. C., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: constraints and applications, Marine Geology. Elsevier, 95(1), 1–16.