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Nummulite Biozonation of Dammam Formation During the Eocene Epoch from Samawa and Nasiriya Cities, Southwestern Desert of Iraq

Falah H. Maziqa[1], **Maher M. Mahdi** [2*], **Abbas H. Mohammed** [3]

[1]*General Directorate of Education in Holy Karbala Province, Karbala, Iraq.*

[2,3] *Department of Geology, College of Science, University of Basrah, Basrah, Iraq.*

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Correspondence:
Name: Maher M Mahdi

Email: maher.mahdi@uobasrah.edu.iq

ABSTRACT

The lithology of the Dammam Formation is limestone, dolomitic limestone, and dolomite rocks, which are also used as raw materials in the manufacture of cement. It is characterized by shallow marine environment. The Eocene succession is described and illustrated in two complete sections in the Samawah and Nasiriyah regions. Determining the age of the formation accurately is in the form of multiple biozones. Biostrtigraphically, the Dammam Formation is divided into six main biozones including: 1. *Nummulites deserti*- *Nummulites fraasi* range zone: Early Eocene (E. Ypresian age), 2. *Nummulites lucasanus* range zone: Early Eocene (L. Ypresian age), 3. *Nummulites globulus*- *Nummulites Zettie*: Middle Eocene (E. Lutetian age), 4.*Nummulites gizehensis*- *Nummu-lites discorbinus*- *Nummulites planulatus* Assemblage Zone: Middle Eocene (L. Lutetian) age; this zone is divided into three subbiozones: a) *Lockhartia alveolata* Interval subzone: Middle Eocene (early Late Lutetian age); b) *Nummulites milacaput* range subzone: Middle Eocene (middle Late Lutetian age); c) *Nummulites elevate* range subzone: Middle Eocene (late Late Lutetian) age, 5. *Nummulites striatus* range Zone Middle Eocene (Bartonian), and finally 6. *Nummulites incressatus* range Zone: L. Eocene age (Priabonian). The study emphasizes the different sedimentation times of the Dammam Formation during the Eocene epoch across various sections in Iraq. It identifies in details the biozones in E. Eocene (Ypresian) and M. Eocene (Lutetian) ages, along with the lack of precise age determination for the Bartonian and Priabonian ages. The study suggests that the Bartonian age may start with the appearance of *N. striatus* and transition to the Priabonian age with the presence of *N. incressatus.*

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التنطق الحياتي النيوملايتي لتكوين دمام خلال حقبة الايوسين في مدينتي السماوة والناصرية، الصحراء الجنوبية الغربية من العراق

فلاح حسن حسين [1]، ماهر منديل مهدي [2*]، عباس حميد محمد [3]

[1] المديرية العامة للتربية في محافظة كربلاء المقدسة، كربلاء، العراق.

[2،3] قسم علوم علم الارض، كلية العلوم، جامعة البصرة، البصرة، العراق.

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المراسلة:
الاسم: ماهر منديل مهدي
Email: maher.mahdi@uobasrah.edu.iq

الملخص

صخارية تكوين دمام عبارة عن صخور جيرية وصخور جيرية متدلمتة ودولومايت، والتي تستخدم أيضا كمواد خام في تصنيع الاسمنت. يتميز التكوين بالبيئة البحرية الضحلة. تم وصف وتوضيح تعاقب الأيوسين في مقطعين كاملين في منطقتي السماوة والناصرية. حُدد عمر التكوين بدقة على شكل انطقة متعددة، واعتمادا على الطباقية الحياتية فقد قُسم تكوين دمام إلى ستة انطقة حياتية رئيسة وهي: 1. *Nummulites deserti*- *Nummulites fraasi* range zone: Early Eocene (Early Ypresian age), 2. *Nummulites lucasanus* range zone: Early Eocene (Late Ypresian age), 3. *Nummulites globulus*- *Nummulites Zettie*: Middle Eocene (Early Lutetian age), 4. *Nummulites gizehensis*- *Nummulites discorbinus*- *Nummulites planulatus* Assemblage Zone: Middle Eocene (Late Lutetian) age. وقسم هذا النطاق الى ثلاثة انطقة ثانويه وهي: a) *Lockhartia alveolata* Interval subzone: Middle Eocene (early Late Lutetian) age; b) *Nummulites milacaput* range subzone: Middle Eocene (middle Late Lutetian) age; c) *Nummulites elevate* range subzone: Middle Eocene (late Late Lutetian) age, 5. *Nummulites striatus* range Zone Middle Eocene (Bartonian), 6. *Nummulites incressatus* range Zone: Late Eocene age (Priabonian). تؤكد الدراسة على اختلاف أزمنة الترسيب لتكوين دمام خلال العصر الأيوسيني في مختلف أقسام العراق. وهو يعرض تفاصيل تحديد المناطق الحياتية في العصور الأيوسينية المبكرة (Ypresian) والإيوسينية الوسطى (Lutetian) إلى جانب عدم التحديد الدقيق لعمر العصرين البارتوني والبرابوني. تشير الدراسة إلى أن العصر البارتوني قد يبدأ بظهور *N. striatus* والانتقال إلى العصر البريابوني مع وجود *N. incressatus*. يتميز هذا التحول بالتغيرات في مجموعات النيوملايت، والتي ربما تكون مرتبطة بتقلبات مستوى سطح البحر بسبب الأحداث التكتونية.

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Introduction

The primary biogenic element present in the Eocene shallow-water carbonate succession from the western desert is Dammam Formation, which is of large benthic foraminifera (LBF). The studied borehole includes four Late Paleocene-Eocene strata: they are from top to bottom: the Euphrates, Dammam, Rus, and Umm Er Radhuma formations, which Sander is the first who mentioned that in 1952. Bramkamp (1941) and Van Bellen *et al.* (1959) used the type section on the SE flank of the Dammam dome in eastern Saudi Arabia to discover the Rus Formation for the first time. While in Iraq, it was discovered at the Zubair-3 well in the Mesopotamian Zone of southern Iraq, where the formation is mostly made of anhydrite and contains a small quantity of un-fossiliferous limestone. Dolomites, marls, shales, and chalky, organoderital, or dolomitic limestone made up the Dammam Dome in eastern Saudi Arabia, according to Van Bellen *et al.* (1959). The Dammam Formation was initially described by Bramkamp (1941). According to

Owen and Nasr (1958), the added type section of the Mesopotamian Zone's Zubair-3 well in Iraq was made of a light gray, porous, dolomitized, and sporadically chalky limestone. Eocene foraminiferal fossils are particularly useful for biostratigraphy and paleo-environmental reconstructions due to their abundance and sensitivity to environmental changes. According to Martín-Martín *et al*. (2020), the Eocene deposits in Iraq suggest a warm, tropical to subtropical climate with a diverse marine ecosystem. The presence of *Nummulites* and other marine fossils indicates the existence of shallow marine environments, lagoons, and marginal marine areas. During the Eocene epoch, significant parts of the Earth's landmass were submerged under shallow seas. Fossils of *Nummulites* have been discovered in various regions worldwide indicating their wide distribution (Alqudah *et al.*, 2019). *Nummulites* are large, lens-shaped foraminifera that were particularly abundant during the Eocene epoch. They reached their peak diversity and abundance during the middle and upper Eocene making them important index fossils for this period, *Nummulites* are primarily marine organisms, inhabiting shallow tropical and subtropical waters. They thrived in warm, clear, and well-oxygenated environments, commonly found in shallow seas and lagoons (Roozpeykar *et al.*, 2019). According to Pomar et al. (2017), Nummulites inhabited the shallow marine realm, typically found in water depths ranging from a few meters to a few hundred meters. Their abundance and diversity are highest in relatively shallow regions. The vast majority of the neritic shoal limestone in the Dammam Formation is recrystallized and/or dolomitized, with nummulitic in the lower half and miliolid-bearing in the top half. Al-Wa'ely (2016) distinguished between the dolomitic limestone unit at the top of the formation and the Nummulitic limestone unit at the bottom of the studied formation in Al-Muthana Governorate. The Dammam Formation from several Eocene shallow-water portions of Iraq becomes the subject of the most thorough investigations by several researchers such as Al-Jibouri (2003), Al Samarraie and Al-Dulaimy (2015), Al-Wa'ely (2016), Jassim et al. (2018), Tamar-Agha (2021), in addition to several researchers in the GEOSURV (in Maziqa et al., 2023) and there are numerous hydrologic-related studies concerning this formation, as it is considered a significant water reservoir for Iraq, such as Awadh et al. (2021) and Taka (2023).

Aim of study

The study aims to analyze the integration of biostratigraphy with other geological studies, such as local and regional biozones, as well as to determine the important fossils that exist in the studied formation to formulate a comprehensive bio-stratigraphic framework for the Dammam Formation.

Materials and Methods

Measurements and samples have been taken from two litho-stratigraphic sections, namely Borehole No. (S-3) close to Samawa City and Borehole (Ns-24) in the Southern Desert of Iraq (Figs. 1). Based on the variance in lithology, bed thickness, contacts, and distinctive fossil contents, 89 representative samples from the 270-meter-thick series are taken from the Dammam Formation at intervals ranging from 1.5 to 5 meters. Additionally, several samples of the inter-fingering within the examined formations and contacts with the Dammam Formation are selected, where the formation is connected to multiple formations including Umm Er Radhuma, Rus, and Euphrates. Around 150–400 grams of dry rock were soaked overnight in a solution of 30% diluted H_2O_2 or 40% acetic acid for benthic samples. This procedure, according to Al-Shawi *et al.* (2019) and Al-Ali *et al*. (2020), continues until full breakdown and then washed through a 63-micron sieve. The residue was then dried and selected after repeating this procedure in a mild water stream. A binocular microscope with magnifications of 10, 20, and 40X is used to identify foraminifera.

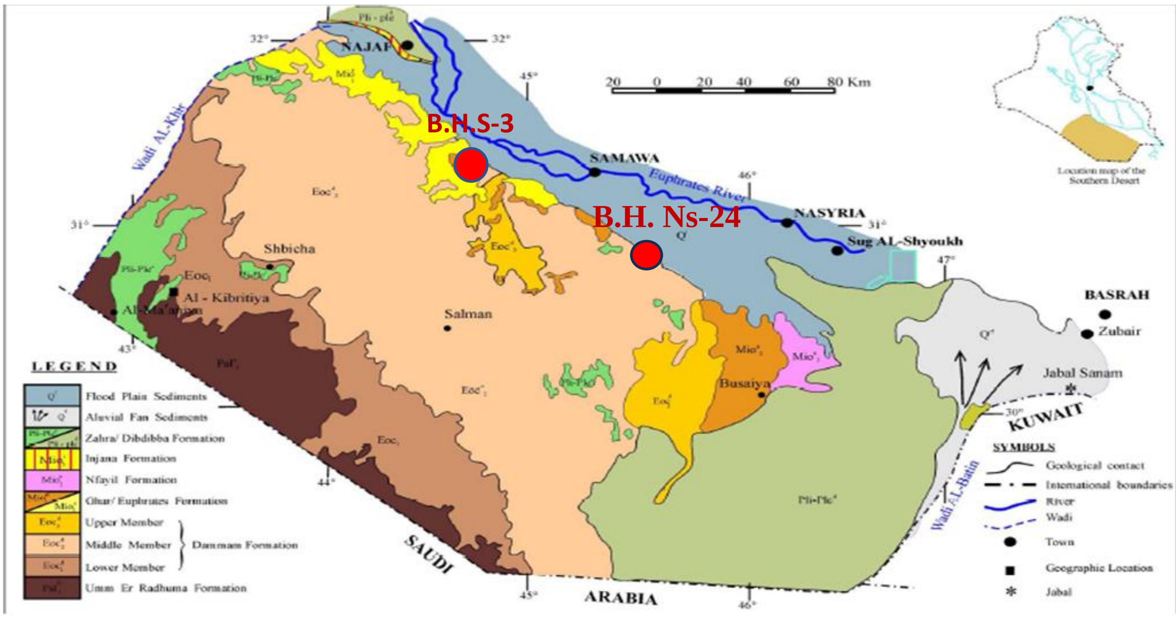

Fig. 1. Location of the investigated borehole and a geological map (Sissakian et al., 1997)

15 samples are prepared for the picking procedure in addition to the 108 thin-section samples needed for this investigation. Some of the thin sections (6 cm× 8 cm, 2.5 cm× 7.5 cm, and 7.5 cm ×7.5 cm) are examined using binocular microscopes and digital photography. The identification of the Larger Benthic Foraminifera (LBF) of the Eocene is mostly based on taxonomic descriptions provided by Loeblich and Tappan (1988), Sirel and Acar (2008), Benedetti (2015), and Bou Dagher-Fadel (2018).

Geological setting

The Eocene epoch lasted approximately 56 to 33.9 million years ago, which is a time of globally significant geological changes. However, this period represents the meeting point of the Arabian Plate, which is being pushed underneath, and the Turkish and Iranian plates, which are moving over it due to continental plate collision, resulting in ending of the Neo-Tethyan Ocean (Numan, 1997). Iraq may be divided into many tectonic regions. Three zones are identified in one important categorization done by Buday and Jassim in 1987 and later by Jassim and Goff in 2006: the folded zone of the Zagros, the stable shelf, and the Mesopotamian zone. Iraq is divided into two sections by Fouad (2015) in a more recent classification known as the Inner and Outer Platforms. The region under investigation, which includes the Euphrates and Tigris Subzones, is part of the Mesopotamian zone, where the studied wells are located in the Euphrates subzone (Al-Kaabi *et al.*, 2023). The research region is bounded by longitudes of (44° 57' 35.5" and 45° 27' 44") and latitudes of (31° 07' 00" N and 30° 42' 26" N) (Fig. 3-1). The initial indication of an imminent collision during the Eocene era is observed as the edge of the Arabian continental plate rises and elongates while curving around the outer swell, just before being pulled into the subduction system by the descending slab (Al-Muturi and Alasadi, 2008; and Handhal and Mahdi, 2016). This collision affected the growth and distribution of the different stratigraphic succession.

Results

Biostratigraphy of the Dammam Formation

Larger benthic foraminifera can be used to evaluate the bio-stratigraphic and palaeo-environmental data (Zoeram *et al*., 2015; Papazzoni *et al.,* 2017; Sallam *et al.,* 2018; Hanif *et al.,* 2021). Occasionally, during the Early Paleogene, the bigger benthic foraminifera have generated enormous accumulations in western, central, and eastern regions of Neo-Tethys. They also significantly contributed to shallow marine sediments in tropical and subtropical areas.

The genus *Nummulites* is the most common and evenly distributed among the bigger foraminifera in the Dammam Formation. There are 37 species of foraminifera from 12 different genera that make up the Dammam Formation's biostratigraphy. It is adequately distinguished, particularly in perpendicular sequences, according to micropaleontological investigations allowing to be categorized into the four mains proposed biozones. These biozones suggest that the Dammam Formation dates from the Early to Late Eocene. These biozones vary in thickness and appearance depending on the section:

1- *N. deserti- N. fraasi* Range Zone: Early Eocene (Early Ypresian) age.

The Eocene succession's lowest point in the Dammam Formation is defined by this zone. The Paleocene-Eocene boundary is located on the low presence of *Ranikothalia* sp. and the first appearance of *N. deserti* (DE LA HARPE), N. *fraasi* (DE LA HARPE), and *Orbitolites* sp.; the uppermost boundary matches with the line of the vanishing of its guide fossils. The thickness of the zone is 7 meters only when S-3 well appears. The distinctive feature of this period is the prevalence of diminutive and early-stage *Nummulites* species, such as *N. fraasi* (DE LA HARPE) (Fig. 6;1), *N. deserti* (DE LA HARPE) (Fig. 6;3), and *Operculina libyca* (SCHWAGER) (Fig. 6;4) are also of common occurrence, other associated benthonic foraminifera are *Nummulites planulatus* (LAMARCK), *Nummulites globulus* (LEYMERIE), *Lockhartia* sp. According to Al-Hashimi and Amer (1985), the lower Dammam Formation (Lower Eocene) sediment is significant and contains foraminiferal indices such as *Nummulites deserti*, *Nummulites fraasi*, *Nummulites globulus*, *Nummulites akashensis*, *Nummulites exilis, Operculina libyca*, and *Assilina spira*. The *Nummulites fraasi* is one of the earliest species of *Nummulites,* assigned to the Ypresian and its Standard Shallow Benthic Zones according to Serra Kiel *et al.* (1998). *Libyan Operculina* (SCHWAGE) according to Al-Hashimi (1972), these species are found in the upper beds of the Umm Er-Radhuma Formation and the lowermost layers of the Dammam Formation (Early Ypresian). In the Early Eocene (Early Ypresian) in south Ankara, central Turkey, Deveciler (2010, 2014), Sirel (2015), and Sirel and Deveciler (2017) detected *N. fraasi* (DE LA HARPE), *N. exilis*, and *Nummulites planulatus* (LAMARCK*). N. exilis - N. deserti* zone of Iraq at that age (Early Ypresian) are recognized by Al-Hashimi (1972) and Al-Hashimi and Amer (1985) respectively, and *N. distans - N. deserti* range zone with age Early Eocene at Egypt also recorded (Fahmy *et al.,*1969).

2- *Nummulites lucasanus* Range zone: Early Eocene (Late Ypresian)

The assemblage zone of the first appearance of the excellent index fauna *N. lucasanus* (D'ARCHIAC) (Fig. 6; 2) is typical of this zone, and the initial record of the index fauna *N.gizehensis* zeitteli (DE LA HARPE) and *N. globulus* (LEYMERIE) both date from the Middle Eocene and the end presence of *N. lucasanus* (D'ARCHIAC) its limited upper zone. The zone seems to be 10.5 meters thick in borehole S-3. It is characterized by the occurrence of *Nummulites* (not too large) including *N. lucasanus* (D'ARCHIAC), *Nummulites planulatus* (LAMARCK), *N. atacicus* (LEYMERIE), *Assilina granulosa* (D'ARCHIAC), *Assilna globausa* (D'ARCHIAC and *Assilina* sp.*;* the first specie is restricted in this zone. The range of *Nummulites lucasanus* defines the lower and upper bounds of this zone. In this assemblage, *N. lucasanus* is the most significant species. It has a broad global distribution; however, the *N. lucasanus* Zone's narrow stratigraphic span is just the (Late Ypresian). For the Late Ypresian of the Akashat and Ratqa formations recognized by Al-Hashimi (1972), as well as south Ankara, Turkey by Deveciler (2014); Sirel (2015) and Sirel and Deveciler (2017), *Nummulites planulatus* is regarded as a reliable index fossil. Al-Hashimi (1972) recognized in the Samawa section of southwestern Iraq with age Late Ypresian, according to Al-Hashimi and Amer (1985) who recognized *N. planulatus -N. globulus* zone with age Late Ypresian. Globally, Nummulites *laevigatus* Range Zone is diagnosed with age Early Eocene of Turkey (Sirel, 2003). The Late Ypresian, or Early Eocene sequence is defined by this zone.

3- *N. gizehensis Zeitteli*- *N. globulus* Interval Zone: Middle Eocene (Early Lutetian)

The Early Middle Eocene duration or the first appearance of the guide fossil *Nummulites gizehensis zeitteli* (DE LA HARPE) (Fig. 6;5) and *Nummulite* globulus (LEYMERIE) marks the bottom contact of this zone, while the first presence of *N.gizehensis* (FRSKAL) and *N.discorbinus* (SCHLOTHIEM) (Figs. 8;4-5 and Fig.9;10) marks the top contact of this zone. In well S-3, the zone thickness is 9 meters at intervals between 97.5 and 106.5 meters, whereas, in well Ns-24, the zone thickness is 13.5 meters at intervals between 104 and 117.5 meters. The Middle Eocene sequence (L. Lutetian) is defined by this zone. Large and highly evolved *Nummulites*, such as *N.gizehensis zeitteli* (DE LA HARPE), *N.bayhariensis* (CHECCHIA-RISPOL) (Fig. 7;1), *N.planulatus* (LAMARCK) (Fig.9;9), *N.murchisoni* (RUTIMEYER), *N.atacicus* (LEYMERIE) (Fig. 9;4-6), *N.globulus* (LEYMERIE), *N.beaumonti* (D'ARCHIAC), *Nummulites* sp., *Assilna globausa* (d'Archiac), *Assilina* sp., *Alveolina* sp., *Coskinolina* sp., *Linderina* sp., with other Rotaliids, Miliolids, gastropods, pelecypods, ostracods, algae, echinoids, bryozoa, and shell fragments.

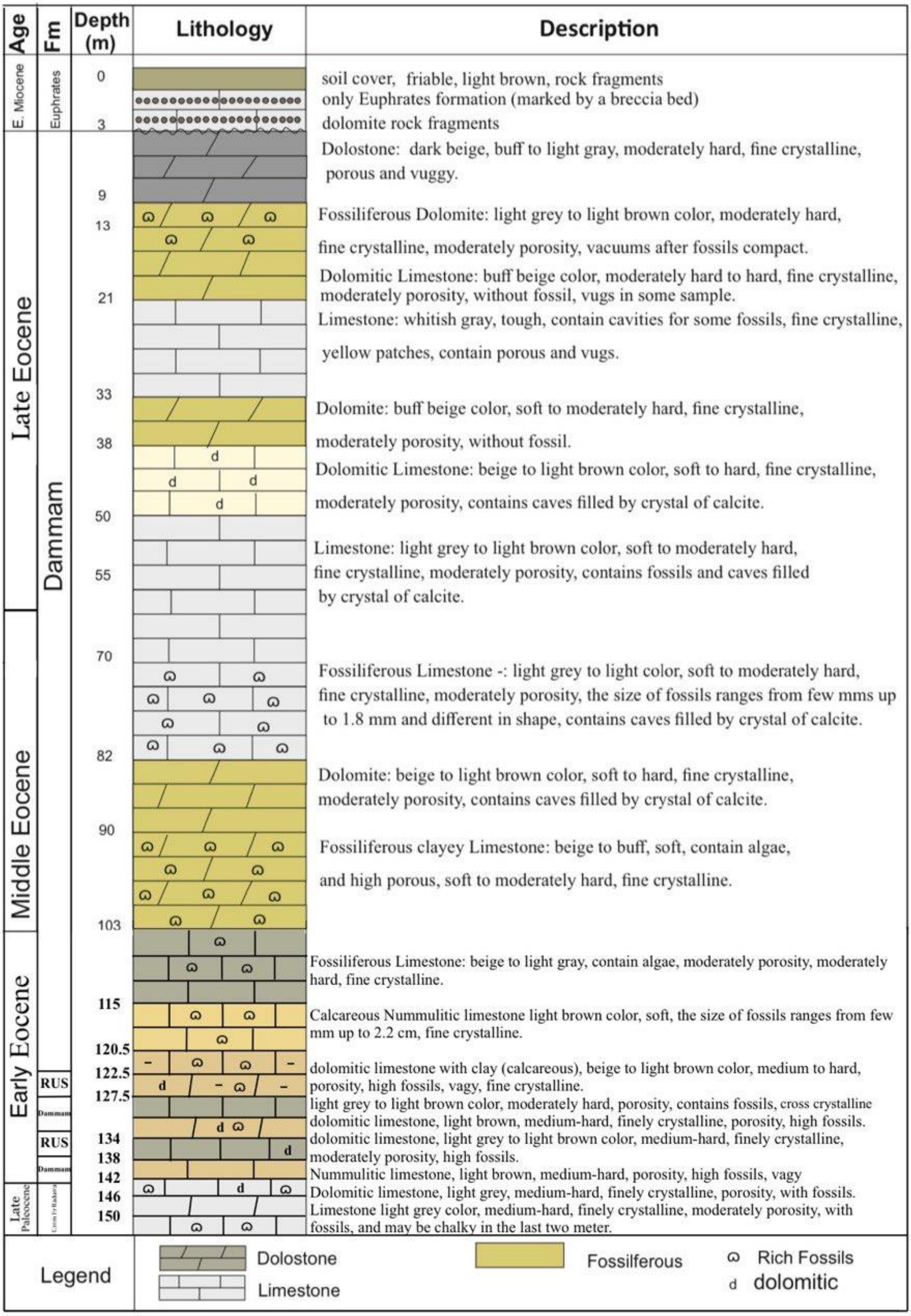

Fig. 2. Dammam Formation stratigraphic column in the investigated borehole, Samawa (S-3).

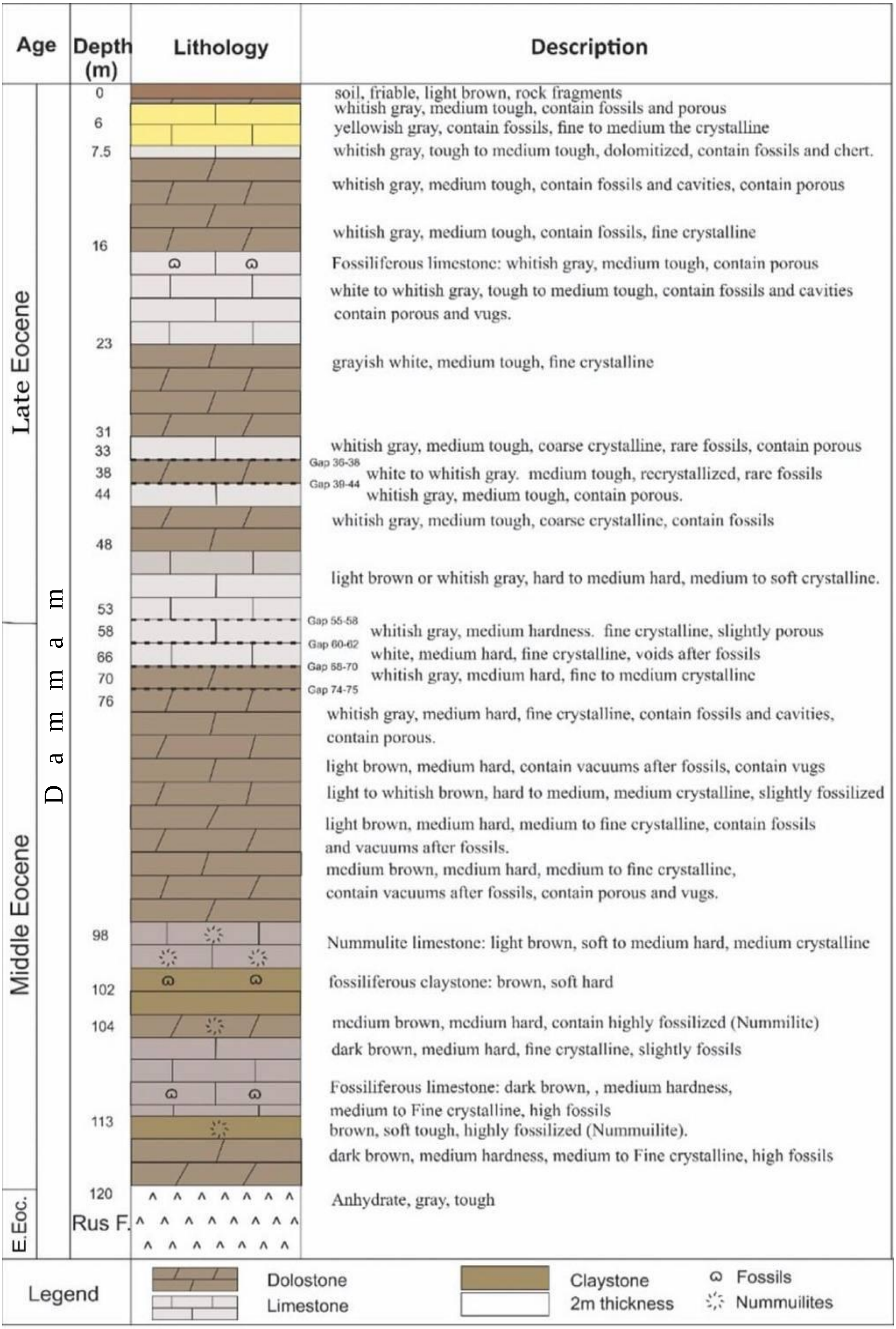

Fig. 3. Dammam Formation stratigraphic column in the investigated borehole, Nasiriya (Ns-24).

The *N.gizehensis zeitteli* (DE LA HARPE) characterizes a good guide species of Middle Eocene period (Early Lutetian) according to Al-Hashimi and Amer (1985). Other species known so far solely from the M. Eocene are *Nummulites atacicus* (LEYMERIE) and Alveolines (Bozorgnia and Kalantari,1965) in the Bahariya Depression in Oman, *Nummulites beaumonti* was discovered in the early and middle Lutetian (Afify *et al.*, 2016).

4- *N. gizehensis- N. planulatus -N. discorbinus* Assemblage Zone: Middle Eocene (Late Lutetian)

The first appearance of the guide fossil *Nummulites gizehensis* (FRSKAL) marks the bottom contact of this zone, while the end presence of *Nummulites gizehensis* and *Nummulites discorbinus* (SCHLOTHIEM) along with the disappearance of all the larger Foraminifera mark the upper limit. In borehole S-3, the zone thickness is 39 meters at intervals between 65 and 104 meters, whereas, in well Ns-24, the zone thickness is 64.5 meters at intervals between 53 and 117.5 meters. The Middle Eocene sequence (L. Lutetian) is defined by this zone. Large and highly evolved *Nummulites*, such as *N.gizehensis zeitteli*, *N. gizehensis* (FRSKAL) (Fig. 6;6), *N.bayhariensis* (CHECCHIA-RISPOL) (Fig. 7;1), *N.elevata* (AL-HASHIMI AND AMER) (Fig. 7;4), *N.planulatus* (LAMARCK) (Fig. 9;9), *N.preforates* (MONTEORT) (Fig. 6;7 and Fig.9;1+2), *N.murchisoni* (RUTIMEYER), *N.atacicus* (LEYMERIE) (Fig. 9;4-6), *N.globulus* (LEYMERIE), *N.millecaput* (BOUBEE) (Fig. 6;8), *N.beaumonti* (D'ARCHIAC), *N.yelli* (D'ARCHIAC) (Fig. 7;10), *Nummulites* sp., *Assilina* sp., *Alveolina elliptica unttalli* (Davies) (Fig. 7;7), *Alveolina* sp., *Coskinolina* sp., *Linderina brugesi* (SCHLUMBERGER), *Linderina* sp., *Lockhartia alveolata* (SILVESTRI), with other Rotaliids, Miliolids (*pyrgo* sp.) (Fig.7;8), gastropods, pelecypods, ostracods, algae, echinoids, bryozoa, and shell fragments. Numerous authors from the Tethyan Province and the late Middle Eocene (L. Lutetian) of Iraq identified this zone. Al-Hashimi (1972), and Al Samarraie and Al-Dulaimy (2015) mark the top of this zone as the border between the Middle and Late Eocene. According to Ben smail-Lattrache *et al.* (2014), Izadighalati and Ahmadi (2017), and Maziqa *et al.*, (2023), the *N.gizehensis* (FRSKAL) characterizes a good guide species of M. Eocene period (Late Lutetian). It is distinguished by the richness of enormous *N.gizehensis* (could reach 25 mm long), but distantly related to *N.planulatus*; as a result, the search estimates the Middle Eocene age of the examined formation's Middle Member based on the existence of this biozone. Other species known so far solely from the M. Eocene are *Nummulites atacicus* (LEYMERIE), *Nummulites discorbinus* (SCHLOTHIEM), and Alveolines. Bozorgnia and Kalantari (1965), Ellis and Messina (1966). Only the Middle Eocene has been used to define these species. According to Afify *et al.* (2016), *Alveolina elliptica nuttalli*, *Coskinolina perpera*, and *Orbitolites complanatus* are also indicative of the Middle Eocene (Robinet *et al.*, 2013). The genus *Alveolina* is first appeared during the Paleocene/Eocene transition and went extinct in the Oligocene. *Alveolina elliptica nuttalli* and *N. perforates* according to Deveciler (2010) and BouDagher-Fadel (2018) have only been pronounced from the M. Eocene. The assemblages of fossils mentioned above are closer to the M. Eocene (Late Lutetian) than to any other fossil record found in the research area. They have been discovered in the L. Lutetian of Iraq's *Nummulites gizehensis* range Zone Al-Kubaysi (2014), Egypt's Late Lutetian (Fahmy *et al.*, 1969). As a result, this article suggests that the Middle Member of the Dammam Formation is M. Eocene (Late Lutetian) in age based on the occurrence of the *Nummulites gizehensis*-*Nummulites planulatus*-*Nummulites discorbinus* Assemblage Zone. These sub-bio-zones are separated into:

a) Lockhartia alveolata Interval subbiozone (early Late Lutetian) age: The first records of the *N.gizehensis* FRSKAL in the lower limit and the last apparent *Lockhartia alveolata* (SILVESTRI) in the subzone's and the first appearances of *N. milacaput* (BOUBEE) in the subzones represents upper limit. The subzone's thickness is 12.5 m in borehole S-3 and while thickness is 24 m in borehole Ns-24.

b) Nummulites milacaput Range subbiozone (middle Late Lutetian) age: The recorded *N. milacaput* (BOUBEE) is in the lower limit, the start appearances of *N. elevate* (AL-HASHIMI AND AMER), and the end presence of *N. milacaput* this species presents as the high contact for this subzone with a thickness 9.5 m in borehole S-3 and 16 m in borehole Ns-24. These features distinguish this subzone.

c) *Nummulites elevate* Range subbiozone (late Late Lutetian) age: This subzone can be identified by the occurrence of *Nummulites elevate* for the first time and the disappearance of *Nummulites gizehensis zeitteli*. In addition to first record of *N. Striatus* (BRUGUIERE) and the complete disappearance of larger foraminifera, which are the upper limit with a thickness of 7 m in borehole S-3 and not recorded in borehole Ns-24 clearly to lose of core samples at those depths.

5-*Nummulites striatus* –Range Zone: Middle Eocene (Bartonian) age.

The bottom contact of this zone is marked by the initial recording of the smaller benthonic foraminifera that associate with *N. striatus* (BRUGUIERE), its index fauna of this zone. The uppermost boundary is marked by the first appearance of *N. incrassatus* (DE LA HARPE). In well S-3, the zone thickness ranges from 60 meters to 69 meters, while in borehole Ns-24, it ranges from 52.5 meters to 63 meters. The most important benthic species recorded in this zone include assemblages of the *N. striatus* (Bruguiere) (Fig. 7;3), *N. preforates* (MONTEORT), *N. beaumonti* (D'ARCHIAC), *N. yelli* (D'ARCHIAC), *N. discorbinus* (SCHLOTHIEM), *Nummulites* sp., *Alveoline elipitica unttalli* (Davies), *Alveoline olongat* (Terquem), *Alveolina* sp., *Lockhartia alveolata* (SILVESTRI), Coskinolina sp., *Amphistegina* sp., *Rotalia* sp., gastropods, ostracods, algae, and pelecypod fragments, shell fragments, and corals. Similar assemblages of larger benthic foraminifers including *Dictyoconus*, *Alveolina*, and *Orbitolites* have been reported from different mid-Eocene (Bartonian) sedimentary successions in the Arabian, African, and Middle East platforms (Fig. 4 and 5) including the Observatory, district in northeastern Egypt Boukhary and Abdelmalik (1983), Bignot and Strougo (1994, 2002). According to Serra-Kiel *et al.* (1998), *N. perforates* and *Alveoline olongat* (Terquem) indicate the early Bartonian age. Likewise, *Alveoline elipitica unttalli* (Davies) was reported from the Bartonian Sirel (2010) and in south Ankara, central Turkey by Deveciler (2010). The latter species is associated there with *Alveolina elongata* (D'Orbigny) of Bartonian age Sirel and Acar (2008). Because of the foregoing paleontological datum, the *N. perforatus, and A. elipitica nuttalli are* located at the top of (M. Eocene) Deveciler (2010). *N. striatus* is found with *N. fabianii retiatus* in the Bartonian to Priabonian Zakrevskaya *et al.* (2014). The assemblage's fauna is similar to the *N. striatus* range zone of the upper Middle Eocene of Egypt by Fahmy *et al.* (1969). Accordingly, the study suggests that the Member of the Dammam Formation is Middle Eocene (Bartonian) in age.

6- *Nummulites incressatus* range Zone: Late Eocene (Priabonian) age.

The bottom contact of this zone is marked by the last recording of the benthonic foraminifera that associate with *N.striatus* (BRUGUIERE) and the first appearance of *N. incrassatus* (DE LA HARPE). The uppermost boundary is marked by the last appearance of *N. incrassatus* (DE LA HARPE), and the top of this zone represents the boundary between the Late

Eocene and Lower Miocene (Euphrates Formations), where the end of Late Eocene is limited by the complete disappearance of *Alveolina* sp., and the appearance of breccia lithofacies and *Miogypsina* sp. The Miogypsinidae are superior index fossils for the Middle Oligocene to Early Miocene time period, conferring to Van Bellen *et al.* (1959), who proposed the top contact with Ghar or Euphrates strata which could be unconformable contact. In well S-3, this zone thickness ranges from 3 to 60 meters, while in borehole Ns-24, it ranges from 0.5 to 52.5 meters. The most important benthic species recorded in this zone include: *Peneroplis* sp. (Fig. 7;5), Miliolid, *N. incrassatus* (DE LA HARPE), *Nummulites* sp., *Coskinolina* sp., *Dentalina* sp., *Amphistegina* sp., *Elphidium* sp., *Textularia* sp., *Alveolina* sp., *Rotalia* sp., gastropods, ostracods, algae, and pelecypod fragments, shell fragments, and corals. The L. Eocene *Nummulite* faunas are substantially little varied than recorded in the Middle Eocene, and they are made up mostly of small animals that have a tiny megalospheric proloculus. These fossils were identified by Al Hashimi (1972) as being from the Late Eocene (Priabonian) and located in the upper region of Dammam. A notable extinction of the planktonic foraminifera was linked to the decline in eustatic sea level that occurred at the end of the Late Eocene (Berggren *et al.*, 1995). According to Abdelghany (2002) tectonic disturbance and decrease in sea level may be to blame for this widespread retreat. As a result, the study put the Upper Member of the Dammam Formation with the same age.

N. incrassatus is found in Southern Armenia from the early Bartonian to Priabonian (Zakrevskaya *et al*., 2020). Depending on the faunal assemblage, the Upper Member of the Dammam Formation is thought to be Late Eocene (Early Priabonian) in age (Jassim and Goff, 2006). According to Al-Hashimi (1973), the upper portion of the Dammam Formation, which is considered a miliolid and peneroplid faunal assemblage in abundance, represents the final stage of the Middle-Late Eocene sedimentary cycle. Based on the existence of assemblage fossils that are comparable to those found in the Miliolids - Peneroplid Assemblage Zone, Al-Hashimi and Amer (1985) suggested that the Upper Member of the formation dates the Late Eocene.

The study suggests that the Upper Member of the Dammam Formation is Late Eocene in age. In the Middle and Far East, it is typically believed that the last appearance of genera like *Discocyclina, Pellatispira, Alveolina*, and *Addilina* marks the end of the Eocene and the first appearance of *Nummulites intermedius* signifies the start of the Oligocene (Ejel, 1969).

The study was able to identify several primary benthonic foraminiferal zones for the Lower-Late Eocene successions based on the stratigraphic distribution of the identified benthonic foraminiferal species (Figs. 4 and 5). These zones are defined and compared to those observed locally (Iraq) and worldwide (Tables 1 and 2).

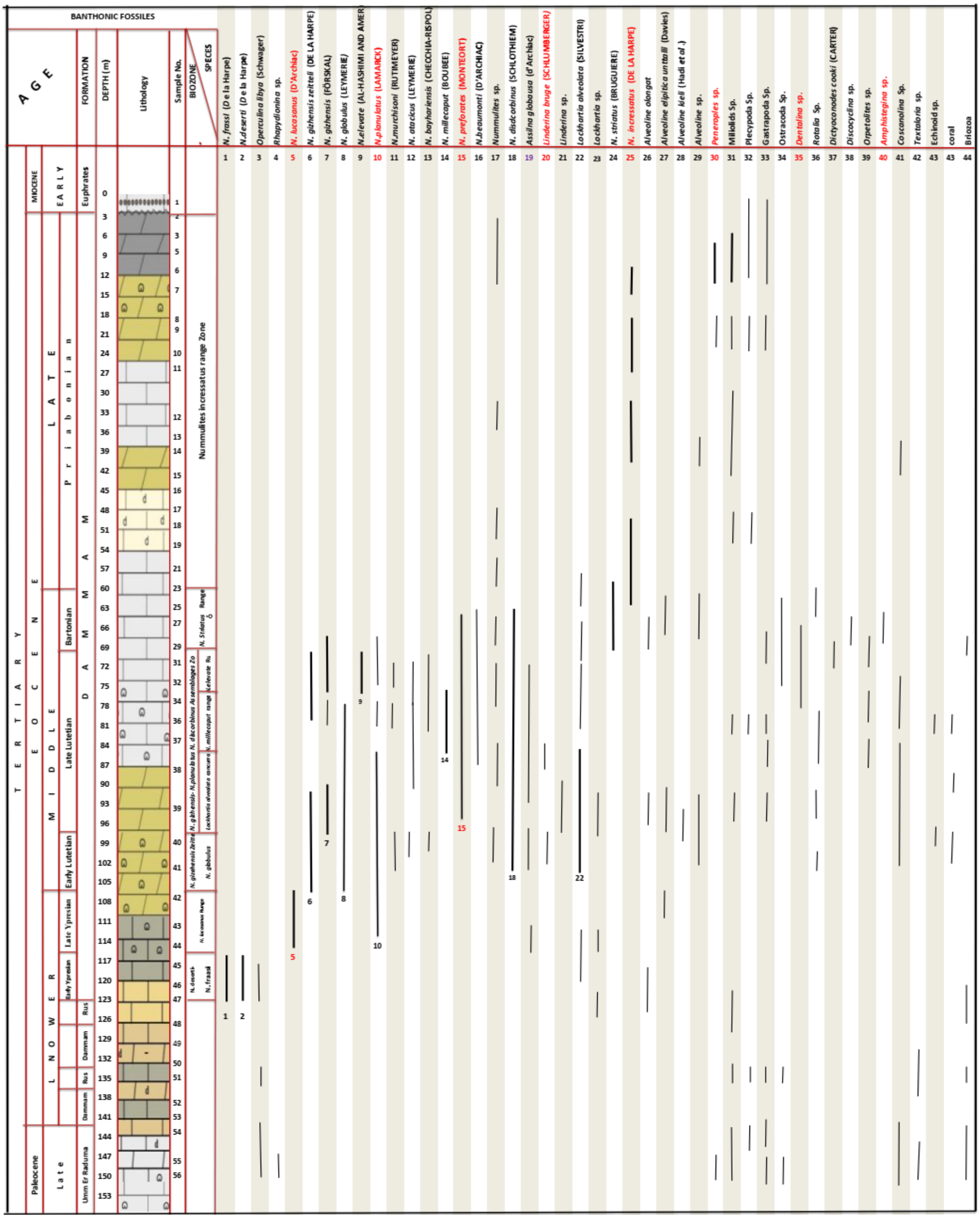

Fig. 4. Stratigraphic range and biozonation of Benthonic Foraminifera within Dammam Formation in well (S-3).

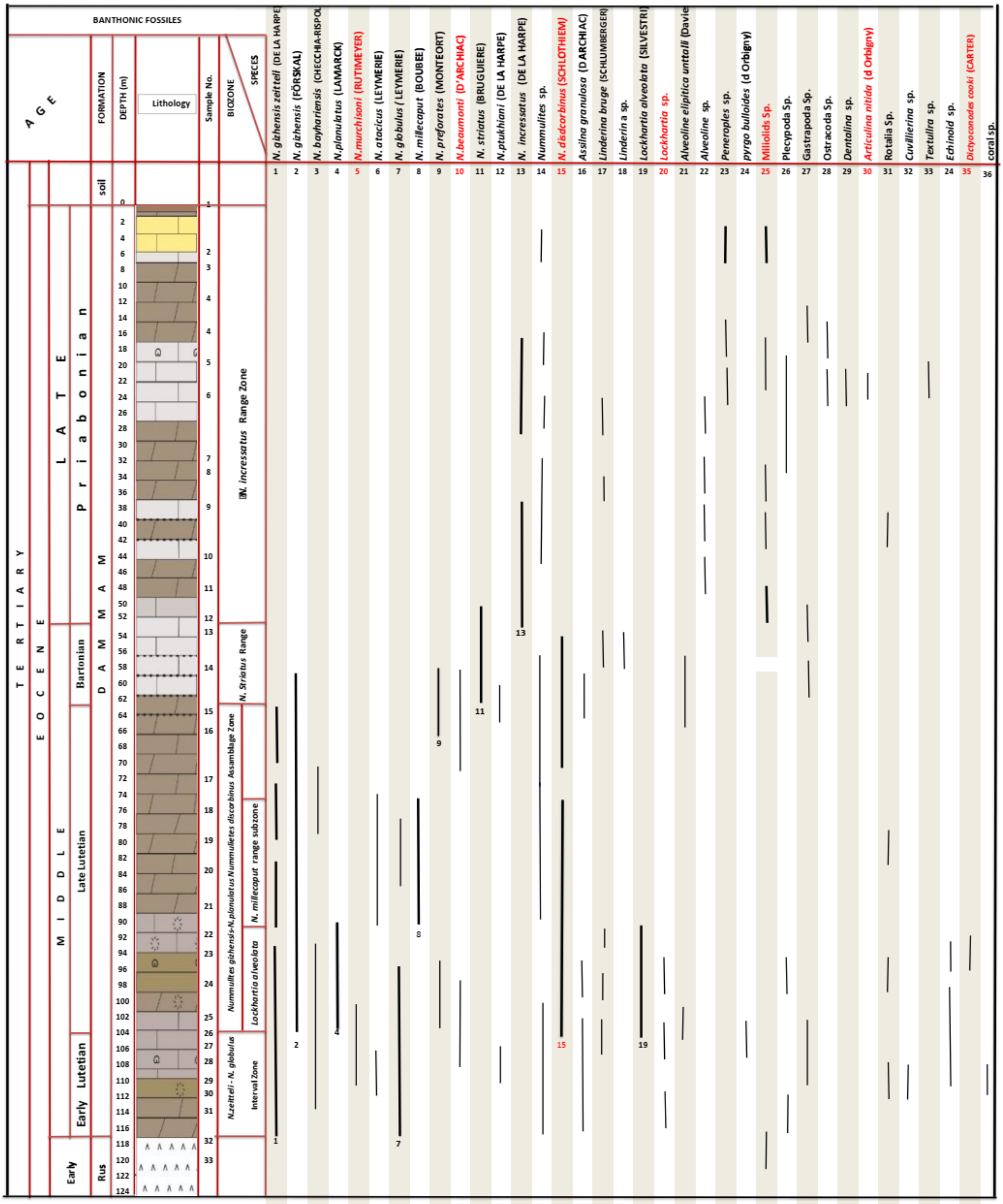

Fig. 5. Stratigraphic range and biozonation of Benthonic Foraminifera within Dammam Formation in well (Ns-24).

Table 1. Correlation of Dammam biozones with local biozones in Iraq

Epoch	Age	EGYPT Fahmy *el. at*, 1969	North Oman Racey, 1995	Egypt Boukhary et al., 2002	Turkey Sirel, 2003	Iran Gravand and Golgir, 2014	Egypt Abd El-Gaied *et al.*, 2019	North Mediterranean Papazzoni, et. al. 2017	Present study
Late Eocene	Priabonian	*N.striatus*	*N.fabianii-N.striats*	*incrassatus Zone*	*N.bouillei N.incrassatus N.gamieri N.fabianii*	*N.fabianii,*	*Pyrgo elongate*	*N.fabianii N.striats*	*N. incressatus* Range Zone
			India Samanta, 1968		North Turkey Kaya *et.al*, 2014	Iran Mousavian M. *et.al*, 2010	Iran Roozbahani and Alp, 2011		
Middle Eocene	Bartonian					*Assilina granolusa Range Zone*			*Nummulite striatus Range Zone*
	Late Lutetian	*N.beamonti- N. gizehensis – Dictyoconus, Aagyptiensis- N. obesa*	*Nummulites. gizehensis- Nummulites. discorbinus Assemblage zone*			*Nummulites aturicus, Nummulites globulus* Assemblage Zone	*N. autricus- Orbitolites - Fabiania* Assemblage Zone	*N. gizehensis- N. discorbinus*	*Nummulitegizehensis - Nummulitediscorbinus- Nummuliteplanulatus Assemblage zone*
	Early Lutetian	*N,distans Assilina Praespira*			*Nummulites laevigatus Range Zone*				*N. gizehensis Zeitteli- N. globulus* Interval Zone
Early Eocene	L. Ypresian	*N. distans N.deserti*	*Southern Europe Serra-Kiel et al 1998*						*N. lucasanus Range Zone*
	E. Ypresian		*N. distans N.deserti*						*N. deserti- N. fraasi Range Zone*

Table 2. Regional correlation of the studied biozones with other worldwide studies.

Epoch	Age	Al-Hishimy, 1972	Al-Hishimy and Amer, 1985	Van Bellen, 1959 (north Iraq)	Al-Kubaysi and Karim, 2014	Sattam, 2005	Al-Wa'aly, 2016	Present study
Late Eocene	Priabonian	*N.bouillei- N. incrassatus*	*N.bouillei- N. incrassatus*	*N.bouillei- N. incrassatus*	*Miliolids – Peneroplid* Assemblage Zone			*N. incressatus Range Zone*
				Al-Samarraie, and Al-Dulaimy (2015).				
	Bartonian		*N.striatus- N.praefabinai*					*Nummulites striatus Range Zone*
Middle Eocene	Late Lutetian	*N. discorbinus - N. gizehensis*	*N.gizehensis- N. lyellei*	*N. gizehensis- N. discorbinus* Range zone	*Nummulites gizehensis* Zone	*N. discorbinus* Range zone	*N. gizehensis* Range zone	*Nummulites. gizehensis- N.discorbinus- N. planulatus -* Assemblage zone
	E. Lutetian		*N.gizehensis zeiteli*			*Nummulites laevigatus* Range Zone		*N. gizehensis Zeitteli- N. globulus* Interval Zone
Early Eocene	L. Ypresian	*N. lucasanus Rung Zone*	*N.planulatus- N.giobulus*					*N. lucasanus Range Zone*
	E. Ypresian	*N. deserti- N. fraasi*	*N.exilis-N.deserti*					*N. deserti- N. fraasi*

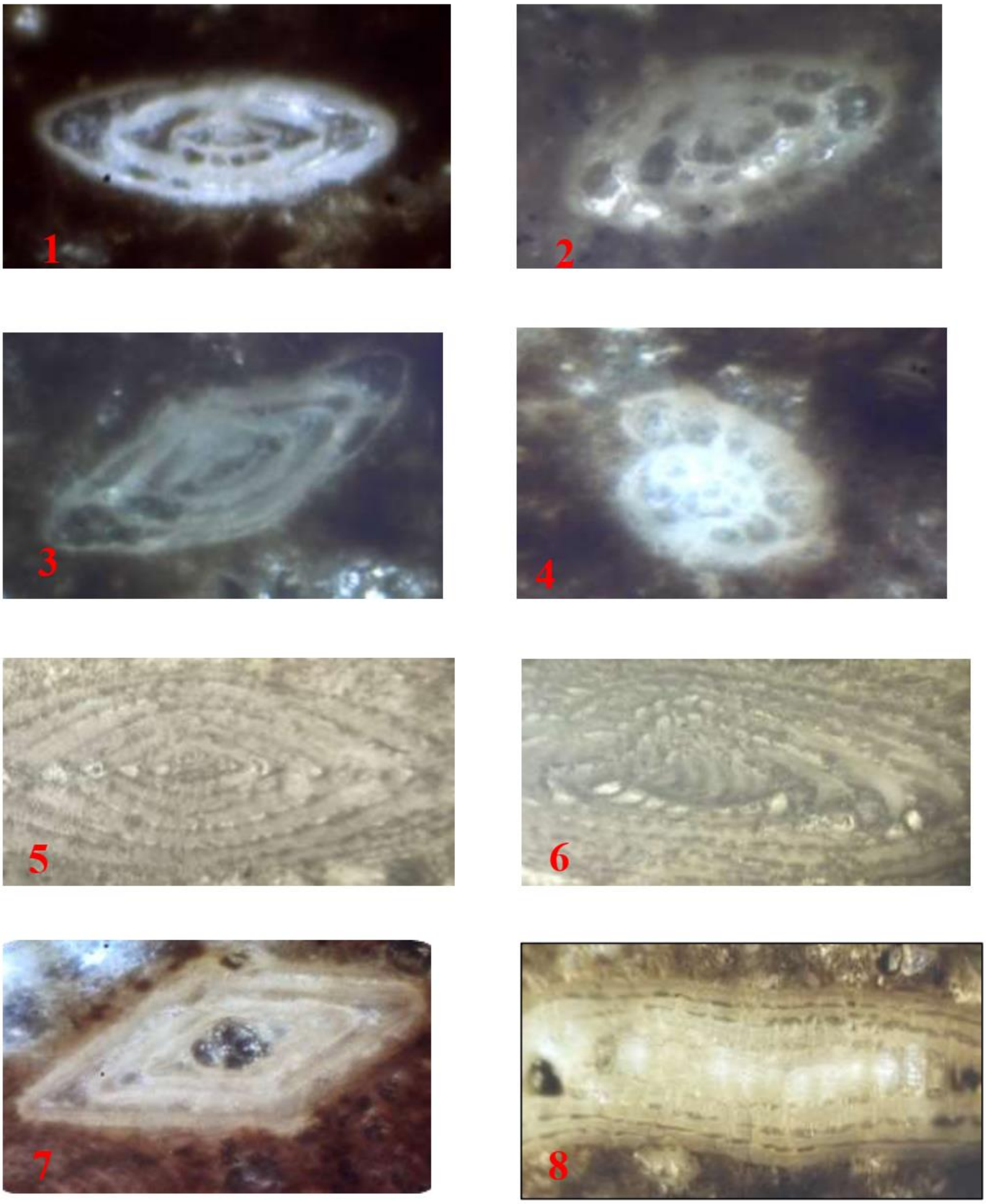

Fig. 6. 1- *N. fraasi* (DE LA HARPE) B.H. S-3 depth (119m); 2-*N. lucasanus* (D'Archiac) B.H. S-3 depth (119m); 3- *N. deserta* (DE LA HARPE) B.H. S-3 depth (120m); 4-*Oprealina libyea* (SCHWAGER) B.H. S-3 depth (122m); 5- *N. gizehensis zeitteli* (DE LA ARPE), X2 B.H. S-3 depth (89.5m); 6- *N. gizehensis* (FÖRSKAL), X4 B.H. S-3 depth (72.5m); 7- *N. preforates* (MONTEORT), X8 B.H. S-3 depth (75.5m); 8- *N. milacaput* (BOUBEE), X10, B. H. S-3 depth (81.5m).

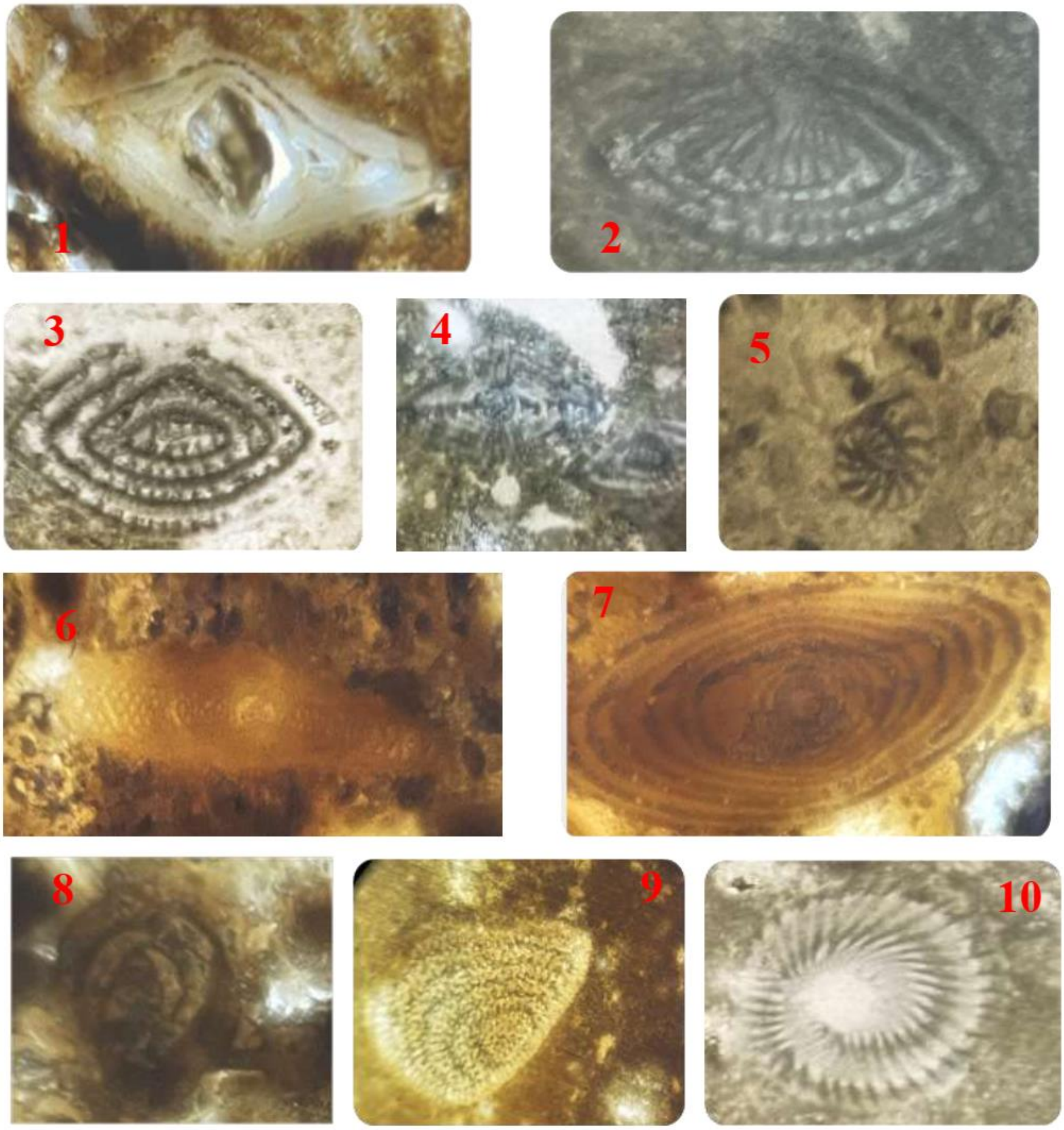

Fig. (7) 1- *Nummulites bayhariensis* (CHECCHIA- RISPOL), X2 B.H. S-3 depth (79.5m); 2- *Nummulites* sp., X4 B.H. S-3 depth (89.5); 3- *N. striatus* (Bruguiere) X8 B.H. S-3 depth (65.5m) 4- *Nummulites elevata* (AL-HASHIMI AND AMER), X4 B.H. S-3 depth (69.5m); 5- *Peneroplis* sp. X8 B.HS-3 depth (21.5m); 6- *linderina chapmani* (HALKYARD), X20; B.H. S-3 depth (94); 7- *Alveolina elliptica unttalli* (Davies), X20; B.H. S-3 depth (94); 8- *Quinqueloculina* sp., X30; 9- *Coskinolina balsilliei* (DAVIES); X 24 B.H. S-3 depth (85.5); 10-*N. lyelli* (D'ARCHIAC), X2 B.H. S-3 depth (65.5m).

Fig. (8) 1+2. *Nummulites planulatus*, X8; X10; equatorial section; axial section, B.H.Ns-24 depth (98.5m); B.H.Ns-24 depth (102.5m); 3. *N. chavannesi* (de la Harpe), X20; side view; B.H Ns-24 depth (99.5m). 4-5. *Nummulites discorbinus*; X8; X12; X10; sied view; axial section B.H. Ns-24; depth (102.5m), 6. *Nummulites myrchisone*; X8; axial section; B.H. Ns-24 depth (113m). 7. *Assilina sublaminosa* (Gill), X12; axial section; B.H. S-3 depth (94m). 8-9. *Nummulites partschi* (DE LA HARPE); X8; axial section; B.H Ns-24 depth (102m, 104m).

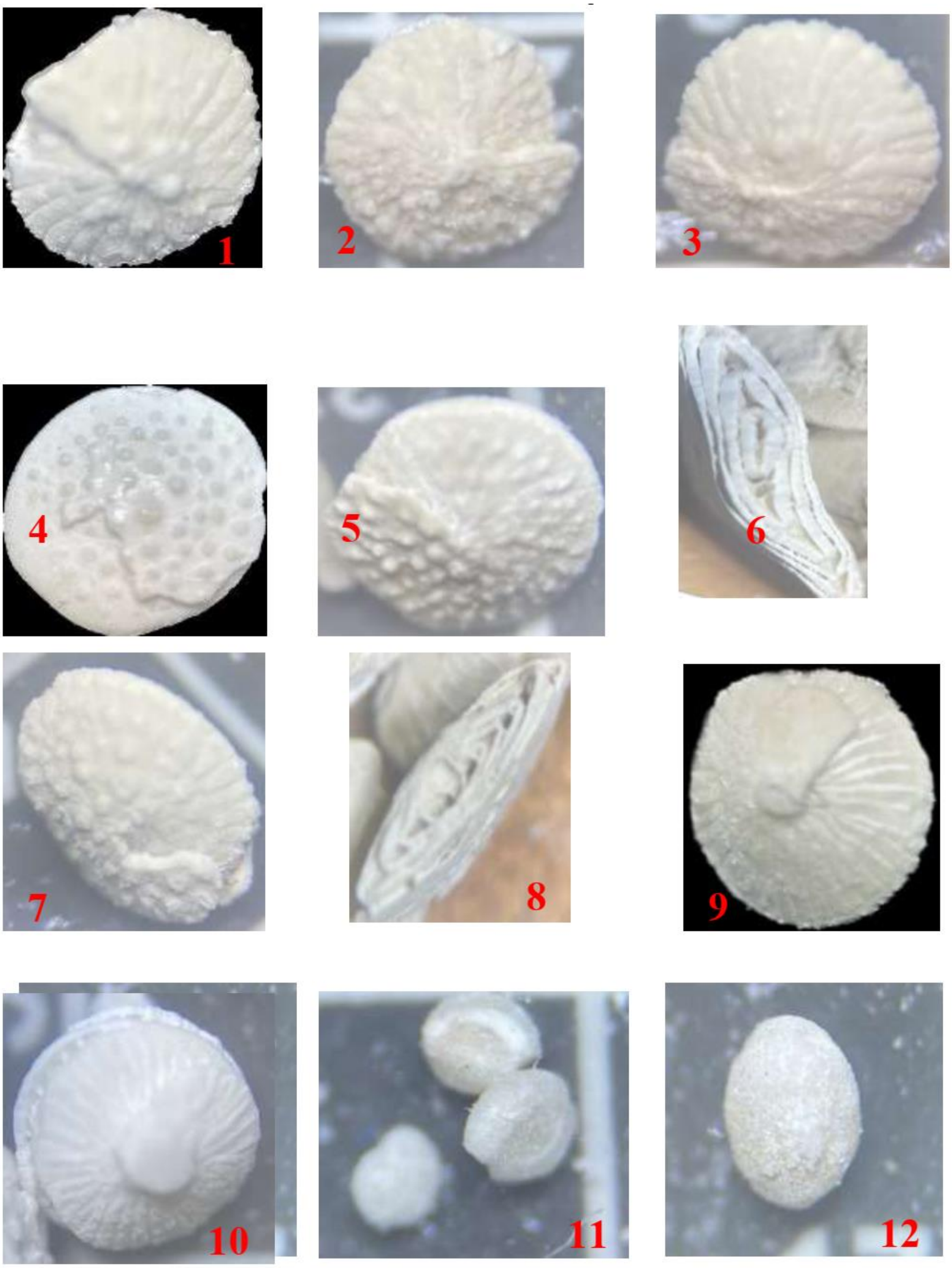

Fig. (9) 1-2 *N. perforates* X4 B.H. S-3 depth (115m). 3-*N. striatus* (Bruguiere), X20, B.H. Ns-24 depth (48m). 4-6 *N. atacicus* X2 B.H. S-3 depth (99m). 9- *N. planulatus* X6 B.H. S-3 depth (101m). 10-*N. discorbinus* X4 B.H. S-3 depth (99m). 11- miliolid X10 B.H. S-3 depth (19.5m).12- *Quinqueloculina vulgaris* (D ORBIGNY) X10 B.H. S-3 depth (19.5m).

Discussion

The Eocene epoch, spanning from around 56 to 34 million years ago, was a significant period in the Earth's history marked by notable climatic changes, the emergence of new life forms, and shifting geological landscapes (Bijl *et al.*, 2010; Boscolo Galazzo *et al.*, 2013). In the context of Iraq, the Eocene epoch left behind a rich geological record that provides insights into the ancient environments and ecosystems of the region. During the early Eocene, Iraq was part of a larger subtropical and tropical environment (Martín-Martín *et al*., 2020; Tamer-agha, 2021; and Maziqa, *et al.,* 2023). The Tethys Sea, a precursor to the modern-day Arabian Gulf, influenced the region's climate and biodiversity. Sedimentary deposits from this time, including limestone, shale, and marl, contain a variety of fossils that indicate a diverse marine life, including larger foraminifera, mollusks, and corals. Regarding of paleogeography, the Eocene epoch witnessed changing sea levels, leading to the deposition of marine sediments across different parts of Iraq.

The fossil record found in these sediments provides information about the evolution of marine life, climatic conditions, and the interplay between tectonic activities and the regional environment (Al-Waely, 2016). Generally, the middle and late Eocene succession is complete in the North of Iraq (Ghafor and Muhammad, 2022), but in the middle and southern Iraq is different. Al-Hashmi (1972) the first author emphasizes the lower Lutetian disappearance in the middle of Iraq. While several of the authors determine the age of the Dammam Formation without details of the Eocene age, just stating the middle and lower such as (Al-Kubaysi, 2014; Al-Wa’ely, 2016; Al-Dulaimi and Al-Wa’ely, 2016) ...etc. Differences in age-related sedimenta-tion time of the Dammam Formation have been observed. The formation is fully deposited during the Eocene epoch in section S-3, while there is a complete absence of the early Eocene age in section Ns-24.

This study is a detailed investigation on the region because of the availability of an integrated stratigraphic column, which was sampled accurately, the results indicate that the Early Eocene (Ypresian) was deposited in an integrated way in S-3 only, as two biozones are identified, namely *Nummulites deserti- Nummulites fraasi* interval zone: Early Eocene (Early Ypresian) age, and *Nummulites lucasanus* Range zone: Early Eocene (Late Ypresian) age.

As for the middle Eocene, it is also defined completely and clearly in both sections, it is divided into main and secondary biozones, namely: *Nummulites Zettie – Nummulites globulus*: Middle Eocene (early Lutetian) age, for the first time this age is recorded in the region. While the age of the Late Lutetian is determined accurately through a major range zone, namely, *Nummulites gizehensis- Nummulites discorbinus- Nummulites planulatus* Assemblage Zone: Middle Eocene (Late Lutetian) age, which is divided into two secondary biozones:(a) *Lockhartia alveolata* Interval subzone: Middle Eocene (early -Late Lutetian age); (b) *Nummulites milacaput* range subzone Middle Eocene (middle-Late Lutetian) age and (c) *Nummulites elevate* range subzone Middle Eocene (late-Late Lutetian) age.

The most mysterious part of this section of the study remains, for the Bartonian and Priabonian ages. The exact age has not been precisely determined by researchers. In northern Iraq, this age is clear (Ghafor and Muhammad, 2022), but in the south, it is possible to consider the onset of the Bartonian age with the appearance of the *N. striatus* (BRUGUIERE) as confirmed by Al-Hashimi and Amer (1985). This age ends with the disappearance of the *N. striatus*, and the Priabonian age starts with the appearance of the *N. incressatus* (DE LA HARPE); therefore, the rest of the Eocene epoch will integrate with the Dammam Formation through the two main biozones, these are *N. striatus range zone* (Bartonian) and *N. incressatus range zone* (Priabonian). It is worth mentioning that the gap between the two ages (Bartonian/ Priabonian) is evident due to a decrease in *Nummulites* and other populations (Wade *et al.*, 2011; Strougo *et al.,* 2013). Regression or elevation of the sea level linked to tectonic events (uplifting and subsidence of the Zagros mountains) (Salama *et al.* 2021). The Bartonian/Priabonian boundary in the study area has been established using these criteria (Haq *et al.*, 1987 and Boukhary *et al.*, 2005).

Conclusion

Based on the biostratigraphical study, the age of the Rus Formation is Early Eocene, and Early Eocene for the Late Eocene Dammam Formation, and for the Dammam Formation six main biozones and three subzones suggested that including 1-*Nummulites deserti*- *Nummulites fraasi* Interval zone: Early Eocene (Early Ypresian) age. 2-*Nummulites lucasanus* Range zone: Early Eocene (Late Ypresian) age. 3-*Nummulites globulus*- *Nummulites Zettie* Middle Eocene (Early Lutetian). 4-*Nummulites gizehensis*- *Nummulites discorbinus*- *Nummulites planulatus* Assemblages zone Middle Eocene (Late Lutetian) it is divided in to a) *Lockhartia alveolata* Interval subzone: Middle Eocene (Early Late Lutetian age). B) *Nummulites milacaput* subzone Middle Eocene (middle Late Lutetian) age. c)*Nummulites elevata* subzone Middle Eocene (late Late Lutetian) age. 5- *Nummulites striatus* Range zone Middle Eocene (Bartonian). 6-*Nummulites incressatus* Range Zone: Late Eocene age (Late Eocene (Priabonian).

The Rus Formation was formed in a shallow, confined (Lagoon) environment, whereas the Dammam Formation was deposited in a variety of settings, including a peritidal inner ramp, lagoon, shoals, a restricted-marine platform, and an open interior platform.

Conflict of Interest

The researchers state that there are no conflicts of interest on their part.

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