Biostratigraphy and Paleoecology of the Sinjar Formation (Late Paleocene-Early Eocene) in the Dokan and Sinjar Areas, Iraq

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Abstract

Biostratigraphy of the Sinjar Formation is investigated in two sections (Dokan and Sinjar) from northeastern and northwestern Iraq, respectively. Two hundred samples from all the limestones and marl that form the main lithological components of the studied sections were collected. The studied limestones and marl are rich in microfossils. Through thin sections, we were able to identify thirty species of benthic foraminifera and fifteen species of other microfossils (coral, algae, mollusca, bryozoa, and echinoids) at Dokan section, and fifty-one species of benthic foraminifera and thirty species of other microfossils at Sinjar section. Three biozones were distinguished from both sections 1- Biozone A: Kathina sp.-Lockhartia hunti Assemblage zone (SBZ 5) (Dokan section); (Kathina pemavuti - Lockhartia hunti Assemblage zone (Sinjar section), 2-Biozone B: Idalina sinjarica Total Range zone (SBZ 6-7) and 3-Biozone C: Alveolina globosa- Alveolina pasitisilata Concurrent Range Zone (SBZ8-10). These zones indicate the Late Paleocene–Early Eocene age of the Sinjar formation. The biostratigraphic correlations in the studied sections are based on benthic foraminiferal zonations. Showed the correlation comparison between the biostratigraphic zones of the commonly used benthic zonal scheme around the Late Paleocene -Early Eocene in and outside of Iraq. paleoecological studies suggest that the carbonate sedimentation of the Sinjar Formation thrived in 18-25ºC, with mesophotic to oligophotic light, under an oligotrophic to mesotrophic middle ramp environment with normal marine to slightly saline and at water depths from 40 - 80 m. Stable isotopic carbon (δ¹³C) and oxygen (δ¹⁸O) data revealed generally hot conditions with high productivity during the deposition of the Sinjar Formation accompanied by an abrupt change in paleoenvironmental conditions across the Paleocene-Eocene contact.

Keywords: Benthic foraminifera; Biostratigraphy; Paleoecology, Sinjar Formation; Paleocene-Eocene; Iraq

1. Introduction

The Formation is the least prominent unit in the Paleocene-Lower Eocene, mainly found in the foothills and southern parts of the High Folded Zone of Iraq. Limestone recrystallized limestone in the algal reef and miliolids of lagoonal and shoal continuous nummulitic facies have been recognized in the Sinjar Formation (Keller, 1941; Bellen et al., 1959).
Keller (1941) described the Sinjar Formation from the area of Jabal Sinjar, Mannista village (Buday, 1980). The Sinjar Formation in the type area comprises 176 m thick limestone of the algal reef, lagoonal miliolid (back reef), and Nummulitic shoal facies (fore-reef), (Bellen et al., 1959).

The structure of the Sinjar Formation appears to be a narrow belt at the border between high and low folded areas of Zagros collision of rang in Sulaymaniyah, Erbil, and Duhok in Iraq. Khanaqa et al., (2023) clarified that the Sinjar Formation exposed the mountains of Sarta-Bamo, Haibat Sultan, Baranan, Berke, and the southwestern limb Pirat and Bekkher anticlines.

Ghafor (1988) and Al-Shaiban et al., (1993), studied the biostratigraphy of Early Eocene strata in the Well in Tel –Hajar (No.1), Sinjar area, NW in Iraq. Surdashy (1988) studied lithological, facies, and environmental studies of the Sinjar Formation in selected sections from the Sulaimaniyah area, Northeastern Iraq. The Eocene rocks were described from Sartak-Bamo, northeastern Iraq (Ghafor and Karim, 1999). Ghafor (2000), described spores and pollen of Late Paleocene–Early Eocene deposition in the Shaqlawa area. Daoud (2009, 2012) studied carbonate microfacies and large benthic foraminifera in the Sinjar Formation, Northeastern Iraq. The Eocene deposits in North, Northeastern Iraq were described by Sharbaziheri et al., (2009, 2011) and give the Early Eocene age by using planktic and benthic foraminifers. Ghafor and Qadir (2009) have described larger foraminifera in three groups from the Eocene rocks in the Chwarta, Northeast Iraq. Al- Nuaimy et al., (2020) discussed planktic with benthic foraminifera of Eocene sediments from Northeastern Iraq. Early Eocene (Ypresian) age was recorded in the Chawrta area by Al-Qayim et al., (2014). Al Fattah et al., (2017, 2018, 2020a-b), studied benthic and planktic foraminifera from Early Eocene rocks in Sinjar, Shaqlawa, and Duhuk areas. Stratigraphy, tectonics, and boundary conditions of Eocene Bulfat Ophiolite Complexes and Mawat, Kurdistan Region, Iraq, studied by Karim and Ghafor (2021). Ghafor and Al-Qayim (2021) studied planktic foraminiferal biostratigraphy of Eocene rocks in the Western Desert, of Iraq. Karim and Ghafur (2021) clarified that the metamorphic greywackes during the Eocene sediments in Walash-Naoperdan Series, northeastern Iraq, were buried deeply during the Eocene age. Biostratigraphy and paleoenvironments of Ecene strata have been studied by Al-Qayim and Ghafor (2022) in the Western Desert, of Iraq. Finally, Ghafor and Muhammad (2022) studied the systematic description of the benthic foraminifera for the first time from Early Eocene rocks in the Chwarta area, NE Iraq.

In the current work, two sections of the Sinjar Formation at Dokan and Sinjar section were chosen for biostratigraphy and paleoecological studies (Figs. 1 and 2). The study is based on the benthic foraminifera and other microfossil fauna supported by stable isotopic carbon and oxygen data aims to investigate the biostratigraphy and paleoecology of the Sinjar Formation from northeastern and northwestern Iraq.

2. Geologic Setting

The Sinjar Formation extends within the Zagros Collisional Zone in Sulaimaniyah and is the boundary between Low – High Folded Zones, Erbil, and Duhok areas N and NE Iraq (Fig. 1). located Dokan section is at the boundary of the High-Low Folded Zones (Buday 1980, Jassim and Goff, 2006). The Dokan section is located in northeast Iraq and lies on Lat. 36°43’31” N and Long. 45°36’27” E on the Imbricate/Thrust Zone (Fig. 3).

During the Early Cretaceous, the area consisted of a shallow basin on the Northeast Passive Margin of the Arabian Plate (Fig. 2a) in which the Qamchuqa and Kometan formations were deposited (Karim 2020). During the Paleocene, a deep Zagros Foreland Basin prevailed in which turbidities of the Kolosh Formation were laid down. During the Middle Eocene, paleoheight separated the Tertiary Foreland Basin into two basins, northern and southern basins (Karim et al., 2022).

The studied area is located within different two zones, Sinjar Formation at the Dokan section which consists of pale grey massive and fine crystalline limestone 147 m thick, and its upper boundary with
the Gercus Formation and its lower boundary with the Kolosh Formation. The Sinjar section is located in northwest Iraq, and lies on Lat. 36° 22'33." N. and Long. 41° 41’ 23" E (Fig. 2). It consists of limestone, that is usually recrystallized, white in color, and shows elements of algal reef facies and shoal nummulitic facies. (Bellen et al., 1959; Al-Sadeki, 1958). The Dokan section with 125 m thick, its lower boundary with the Kolosh Formation, its upper boundary with the Gercus Formation, and the Sinjar section with 172m thick its lower boundary with the Shiranish Formation, the upper boundary with the Jaddala Formation (Bakkal et al., 1993), the fieldwork investigation and lithologic description, are shown in Figs. 4 and 5.

Fig.1. Location map of the studied areas.
Fig. 2. (a) Tectonic map of the Middle-East (modified from Al-Husseini (2000) In Ziegler (2001) showing the location of the Dokan area; (b) Geological map of northeastern Iraq (modified from Sissakian (2010)). The red circle represents the study area.

Fig. 3. Geological cross-section of the Dokan area (modified from Khanaqa et al., 2023).
Fig. 4. The lithostratigraphic column of the Dokan section shows conventional lithologic constituents.
### 3. Materials and Methods

The method of work included field study and laboratory work. The first part included the field study description of 266 rock samples, (150 samples from the Dokan section and 116 samples from the Sinjar section), microfossils were identified from the thin sections by polarized microscope. The identification of microfossils and biostratigraphic study were done according to (Schlumberger and Douville, 1905; Rahaghi, 1980; Loeblich and Tappan, 1988; Hottinger, 2007 and Sirel, 2015), while the paleoecological interpretations, the concept of (e.g., Geel 2000; Romero, et al., 2002), Brandano et al. (2009), and Flügel (2010) are used.

For stable isotopic analysis, $\delta^{13}C$ and $\delta^{18}O$ values were measured using an automated carbonate preparation device (KIEI-III) and a Finnegan MAT 252 isotope ratio mass spectrometer at the University of Arizona. The isotope ratio measurement is calibrated based on repeated measurements of NBS-9; NBS-18; and CAR2, an in house carbonate standard. Following isotope ratios are assigned to these standards ($\delta^{18}O$) followed by ($\delta^{13}C$); NBS-19; -2.20, +1.95: NBS-18; -23.00, -5.01; CAR2, -1.41, +2.03. Analytical precision is $\pm 0.10\%$ for $d^{18}O$ and $\pm 0.08\%$ for ($\delta^{13}C$) (1 sigma). Powdered samples were reacted with dehydrated phosphoric acid under vacuum at $70^\circ$C. based on repeated measurements.

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**Fig.5.** The lithostratigraphic column of the Sinjar section shows conventional lithologic constituents.
of internal standards. Analysis was achieved at the Environmental Isotope Laboratory, University of Arizona, USA.

4. Results

4.1. Biostratigraphy

In this work study, the biozonation of two sections was founded on the apportionment of the benthic foraminifera and other microfossils (Plates 1-9) that applied to the Sinjar Formation, three biozones have been recognized depending on the benthic foraminifera and other microfossils that discussed below:

4.1.1. Biostratigraphy of Sinjar Formation in Dokan area

Thirty species from twenty-one genera of benthic foraminifera and fifteen species from ten genera of other microfossils have been identified in the Dokan section (Plates 1-3). Based on the stratigraphic ranges of the recognized species, three biozones have been recognized and were arranged from older to younger (Fig. 6).

- Biozone A: *Kathina* sp.- *Lockhartia hunti* Assemblage zone (SBZ 5)

  This biozone is rich in benthic foraminifera and other microfossils. The association of the taxa *Kathina* sp. and *Lockhartia hunti* is the main continent of this zone, in which, the lower part of the zone shows the First Appearance Datum (FAD) of these two genera. Thickness is about 42m, from the samples (58-100), recorded at the lower layers of the section, and the most important species including *Alveolina globosa*, *Alveolina pasticilata*, *Rotalia trochidiformis*, *Rotalia* sp., *Dictyoconus* sp., *Lokhartia* sp., *Textularia* sp., *Quinqueloculina* sp., *Biloculina* sp., *Assilina* sp., *Valvulammina globularis*, *Lockhartia hunti*, *Alveolina rutimeyeri*, *Bigenerina* sp., Miliolina, this zone also include these fossils of non-foraminifera, *Rostroporella oviformis*, *Lithophylum* sp., *Lithoporella* sp., *Archaeolithothamnium* sp.

  This Biozone (Biozone A) has been identified at the lower layers of the section. It corresponds in the Zagros Basin to the biozone (43) Wynd (1965), it was defined by BouDagher-Fadel et al., (2015) corresponds to biozone (TP4), (SBZ5) and the lower of (SBZ6 as), it is equivalent to the *Kathina – Lockhartia* zone of Amirshahkarami and Zebarjadi (2019), to the SBZ 5 of Zhang et al., (2013).

- Biozone B: *Idalina sinjarica* Total Range zone (SBZ6-7)

  The second assemblage biozone in this section contains benthic foraminiferal and other microfossils, It is characterized by the total range zone of *Idalina sinjarica*, the lower part of the zone shows the First Appearance Datum (FAD) of the species *Idalina sinjarica* and the upper layers of the zone by the last. Appearance Datum of the same taxon, . The thickness of this zone is about 11 m, from the samples (100–111), at the lower layers of the section, and the important species including *Alveolina globosa*, *Alveolina pasticilata*, *Rotalia trochidiformis*, *Rotalia* sp., *Dictyoconus* sp., *Lockhartia* sp., *Textularia* sp., *Quinqueloculina* sp., *Valvulina* sp., *Miliolina*, *Biloculina* sp., *Assilina* sp., *Valvulammina globularis*, *Lockhartia hunti*, *Alveolina rutimeyeri*, *Bigenerina* sp., *Triloculina trigonula*, *Opercinala subsasalia*, *Opercinala* sp., *Assilina* sp., *Periloculina* sp., *Alveolina rutimeyeri*, *Daviesina longhani*, *Miscelleina miscella*, *Miscelleina meardina*, this zone also includes other microfossils, *Cymopolia kurdistanensis*, *Cymopolia elongata*, *Cymopolia* sp., *Penachaias glynnjones*, *Rostroporella oviformis*, *Clypeina* sp., *Ovulites* sp., *Indopolia styovati*, *Lithophylum* sp., *Lithoporella* sp., *Archaeolithothamnium* sp.
This biozone (B) of the Early Eocene has been identified in the upper-middle part of this section. Biozone (B) corresponds to biozone (44) Wynd (1965), and corresponds to the lower part of SBZ 6-10 of Zhang et al., 2013 to biozone 6-9 as pinpoint by BouDagher-Fadel, et al., (2015). It was equivalent to Alveolina and Operorbitolites zone of Amirshahkarami, Zebarjadi, (2019), and corresponds to the lower part of Nummulites gizhensis-Nummulites moculatus zone as defined by Al-Qayim and Ghafor (2021).

- **Biozone C: Alveolina globosa-Alveolina pasitisilata, Concurrent Range Zone (SBZ 8-10)**

  This biozone in this section contains benthic foraminiferal and other microfossils. The biostratigraphic interval of this zone was characterized by the concurrent range of the nominate taxa (Alveolina globosa and Alveolina pasitisilata). This biozone started by the First Appearance Datum (FAD) of Alveolina globosa, in sample number 6, and ended by the Last Appearance Datum (LAD) of Alveolina globose-Alveolina pasitisilata.

  Thickness is about 18 m, from the samples (111–120), at the lower layers of the section, and the important species including Nummulites chavannensis, Nummulites antacicus, Nummulites sp., Nummulites globulus, Rotalia trochidiformis; Rotalia sp., Dictyoconus sp. Lokhartia sp., Quinqueloculina sp., Textularia sp. Biloculina sp., Valvulina sp., Triloculina trigonula, Triloculina sp., Operculina subsasalia, Operculina sp., Discocyclina varians, Assilina sp., Pyrgo. sp., Lockhartia hunti, Periloculina sp., Alveolina rutimeyeri, Daviesina longhami, Miscelleina miscella, Miscelleina meardina, this zone also includes other microfossils, Cympolia kurdistanensis, Cympolia elongata, Cympolia sp., Penachaia glynnjones, Rostroporella oviformis, Clypeina sp., Ovulites sp., Indopola styovati., Lithophylum sp., Lithoporella sp., Archaeolithothamnium sp.

  In the Early Eocene, the Assemblage of biozone (C) was identified in the upper layers of the Sinjar Formation. In the Zagros Basin Biozone (C) corresponds to biozone(44) (upper part) of Wynd J (1965), and corresponds to the upper layers of SBZ 6-10 of Zhang et al., (2013), to the biozone TP10-12 as pinpointed by BouDagher-Fadel et al., (2015), it is equivalent to Nummulites –Alveolina-Orbitolites Zone of Amirshahkarami and Zebarjadi (2019), and corresponds to the upper of part of Nummulites gizhensis-Nummulites moculatus Zone as defined by Al-Qayim and Ghafor (2021).
Fig. 6. Biostratigraphic range chart of the microfossils within the Dokan section.
Plate 1. Dokan section (a) Nummulite chavannesi de la Harpe, 1878. sample no. 2, (b) Rotalia trochidiformis (Lamarck 1804), sample no. 5, (c) Triloculina trigonula (Lamarck 1804), sample no. 39, (d) Ovulites sp. sample no. 36, (e) Textularia sp. sample no. 95, (f) Daviesina longhami sample no. 2, (g) Rostroporella oviformis sample no. 8, (h) Gastropoda sample no. 32, (i) Idalina sinjarica Grimsdale., sample no. 52, (j) Penachais gynniones sample no. 5 (k) Miliolina sample no. 32 (l) Valvulina sample (m) Quinqueloculina sample no. 33.
Plate 2. Dokan section (a) *Alveolina globosa* Leymerie, 1846, sample no. 2, (b) *Kathina* sp., sample no. 12, (c) *Indopoliya styovavti*, sample no. 18, (d) *Valvulina* sp., sample no. 23, (e) *Ovalites* sp., sample no. 23, (f) *Pycnoporidium* sp. sample no. 23, (g) *Miscellanea meardinas*, sample no. 25, 8. (h) *Valvulina* sp., sample no. 31, (i) *Miliolina*, sample no. 31, (j) *Biloculina* sample no. 31, (k) *Triloculina trigonia*, (Lamarck, 1804) sample no. 32, (l) *Textularia* sp., sample no. 35, (m) *Pyrg* sp., sample no. 35, (n) *Quinquloculina* sp., sample no. 35, (o) *Cympolia* sp., sample no. 35.
Plate 3. Dokan section (a) Valvuulina sp., sample no. 35, (b) Textularia sp., sample no. 35, (c) Bigenerina sp., sample no. 18, (d) Ovalites sp., sample no. 42, (e) Alveolina pasticillata Schwager, 1883, sample no. 42, (f) Idalina sp., sample no. 37, (g) Nummulites sp., sample no. 39, (h) Rotalia sp. sample no. 25, (i) Quinquiloculina sp., sample no. 32.

4.1.2. Biostratigraphy of Sinjar Formation in Sinjar area

Fifty-one species from twenty-four genera of benthic foraminifera and thirty species from ten genera of other microfossils have been identified in the Sinjar section (Plates 4-9). Based on the stratigraphic ranges of the recognized species, three biozones have been recognized (Figs. 7, 8), the recognized biozones in this study were correlated with biozones of different locations (Fig. 9).

- **Biozone A: Kathina pemavuti - Lockhartia hunti Assemblage zone (SBZ5)**

This biozone contains foraminiferal assemblages of the taxa Kathina and Lockhartia that are characterized by the First Appearance Datum (FAD) of Kathina - Lockhartia. The zone thickness is about 107 m, between the samples (3–70), it was recorded from the bottom of the section, and the most important microfossils includes:

- Textularina sp.; Valvulammina globularis; Lockhartia hunti; Lockhartia lipperi; Lockhartia altispira; Lockhartia conditi; Lockhartia sp., Kathina pemavuti; Kathina nammalenthis; Alveolina globosa; Alveolina pasticillata, Alveolina rutimeyeri, Rotalia trochidiformis, Rotalia sp., Dictyoconus sp., Lockhartia spp., Dictryokathina simples, Assilina sp., Kathina sp, Biloculina sp., Textularia sp., Quinquiloculina sp., Pseudocrysalidina sp., Bigenerina sp., this zone also includes other microfossils, Lithophyllum sp., Cympolia kurdistanensis; Cympolia sp., Pseudolithothamnium sp., Parkerell sp., Rostroporella oviformis, Trinocladius sp., Solennmeris o"ogormang, Crdelites sp., Dissocladella sp., Lithoporella sp., Trinocladius sp., Pagodaporella wetzeli, Cympolia elongata, Acroporella sp., gastropods, pelecypods, cephalopods, ostracods, bryozoan, and dasyclades.
This Biozone (biozone A) has been recorded at the bottom part of the studied section. Biozone A equivalent to biozone 43 which was studied in the Zagros Basin by Wynd (1965), and corresponds to biozone (TP4), (SBZ5), and the lower part of the zone (SBZ6) of BouDagher-Fadel et al., (2015). It is equivalent to Kathina – Lockhartia zone, Amirshahkarami and Zebarjadi (2019), also equivalent to the SBZ 5 of Zhang et al., (2013).

- **Biozone B: Idalina sinjarica Total Range Zone (SBZ6-7)**

  It is characterized by the total range zone of Iddalina sinjarica, the lower part of the zone shows the First Appearance Datum (FAD) of the species Idalina sinjarica, and the upper layers of the zone by the Last Appearance Datum (LAD) of the same taxon. The thickness of this zone is about 27 m, from the samples (70-95), it was diagnosed within the middle part of the section, including these microfossils: Alveolina sp., Alveolina globosa, Alveolina pasticilata, Alveolina rutimeyeri, Alveolina shwageri, Valvulammina globularis, Lockhartia hunti, Idalina sp., Saudia sp., Rotalia sp., Kathina sp., and miliolids, Daviesina longhami, Miscelleina miscella, Miscelleana meardina, Penachaias glynnjones, Rstroporella oviformis, Triloculina trigonula, Operculina subsalsa, Opeculina sp., these other microfossils are abundant in this zone including, Lithothamnium sp., Lithophylum sp., Parachaetes sp., Ditchoplax biserials, Indopolia styovavti, Mesophylum sp., Clepeina meriema, Solenmmeris o’ogormang, Archaeolithothaminum sp., gastropods, pelecypods, cephalopods, ostracods, bryozoan, and dasyclades., The Early Eocene has been identified as an assemblage of biozone B in the middle layers section of the Sinjar Formation. Wynd, (1965) said biozone B corresponds to the biozone (44) of in the Zagros and corresponds to the lower part of the SBZ 6-10 of Zhang et al., 2013 and to the biozone 6-9 as pinpointed by BouDagher-Fadel, et al., (2015), it is equivalent to Alveolina-Operorbitolites zone of Amirshahkarami and Zebarjadi, (2019) and corresponds to the lower part of the Nummulites gichensis-Nummulites moculatus zone as defined by Al-Qayim and Ghafor, (2021).

- **Biozone C: Alveolina globosa-Alveolina pasitisilata, Concurrent Range Zone (SBZ 8-10)**

  This biozone in this section contains benthic foraminiferal and other microfossils. The biostratigraphic interval of this zone was characterized by the concurrent range of the nominate taxa (Alveolina globosa and Alveolina pasitisilata). This biozone started by the First Appearance Datum (FAD) of Alveolina globosa, in sample number 6, and ended by the Last Appearance Datum (LAD) of Alveolina globosa-Alveolina pasitisilata. The thickness of the zone about 35 m, between the samples (95–115), it was diagnosed within the middle part of section and associated with these fossils of benthic foraminifera, including:- Nummulites chavannesi, Nummulites anticus, Nummulites chavannesii, Nummulites sp., Textularina sp., Valvulammina globularis, Lockhartia hunti; Alveolina pasticilata, Alveolina rutimeyeri, Rotalia trochidiformis, Dictyoconus sp., Assilina sp., Pyrgo sp., Biloculina sp., Textularia sp.; Triloculina trigonula, Triloculina sp.; Quinqueloculina sp.; Miliolids sp.; Rstroporella oviformis, Opretorbitolites complanatus, Opretorbitolites transitorius, other microfossils are distributed in this zone, Lithothamnium sp., Lithophylum sp., Parachaetes sp., Ditchoplax biserials, Indopolia styovavti, Mesophylum sp., Clepeina meriema, Solenmmeris o’ogormang, Archaeolithothaminum sp., gastropods, pelecypods, cephalopods, ostracods, bryozoan, and dasyclades., biozone C of the Early Eocene has been identified in above part of the studied section. Biozone C corresponds to the biozone 44(upper layers) of Wynd (1965) in the Zagros Basin, and corresponds to the upper layers of SBZ 6-10 of Zhang et al., (2013), to the biozone TP10-12 as pinpointed by BouDagher-Fadel et al., (2015). It is equivalent to Nummulites –Alveolina-Orbitolites zone in Amirshahkarami, Zebarjadi (2019), and
corresponds to upper layers *Nummulites gizhensis-Nummulites moculatus* zone as defined by Al-Qayim and Ghafor (2021).

**Fig. 7.** Biostratigraphic range chart of benthic foraminifera at the Sinjar section.
**Fig. 8.** Biostratigraphic range chart of other microfossils in the Sinjar section
Plate 4. Sinjar section: (a) Rotalia sp., sample no.3, (b) Nummulites chavannes de la Harpe, 1878, sample no.3, (c) Discocyclina ranikotenensis sample no. 3, (d) Somalina sp. sample no. 3, (e) Indopolia styovati sample no.3, (f) Rostroporella oviformis sample no.11, (g) Pseudolithothamnium sp. sample no. 23, (h) Coral, sample no. 23.
Plate 7. Sinjar section: - (a) Bivalve., sample no. 43, (b) Alveolina cf. munieri. sample no. 44, (c) Alveolina aragonensis sample no. 44, (d) Biloculina sp., sample no. 46, (e) Valvulammina globulari sp., sample no. 46, (f) Trinocladus, sample no. 49, (g) Lithothamnium sample no. 49, (h) Parkerella sp, sample no. 51, (i) Bryozoa, sample no. 51.
Plate 8. Sinjar section: (a) *Lockhartia*, sample no. 56, (b) *Kathina mammalensis*, sample no. 58, (c) *Lockhartia condita*, sample no. 5, 8, (d) *Quinqueloculina* sp., sample no. 61 (e) Deformed form of *Pyrgo* sp., sample no. 61, (f) *Lithoporella melobesioides*, sample no. 61, (g) *Pyrgo* sp., sample no. 61, (h) *Locohartia huntii* sample no. 61, (i) *Alveolina pasiticilata*, sample no. 63, (j) *Rotalia* sp., sample no. 65, (K) *Nummulites* sp., sample no. 67, (l) *Lockhartia* sp., sample number no. 68, (m) *Textularia*, sample no. 69, (n) *Olsonia* sp., sample no. 63, (o) *Lithophylum* sp., sample no. 85, (p) *Idalina sinjarica* sample no. 8.
Plate 9. Sinjar section: (a) Rotalia sp., sample no. 94, (b) Nummulites sp., sample no. 94, (c) Nummulites chavannesii, sample no. 94, (d) Nummulites sp., sample no. 97, (e) Nummulites sp., sample no. 97, (f) Nummulites sp., sample no. 97, (g) Pelecypods sample no. 97, (h) Textularia sp., sample no. 97, (i) Bryozoa, sample no. 93, (j) Nummulites sp., sample no. 92, (K) Bryozoa, sample no. 92, (l) Bryozoa, sample no. 93.

Fig. 9. Biostratigraphic correlation of the Sinjar Formation (Dokan section) with other studies.
4.2. Paleoeccological Study

The most important factors are light, temperature, depth, substrate, salinity, nutrients, and Oxygene in shallow shelves, where primary production is most pronounced (Duxbury and Duxbury, 1997). This is because the bathymetric distribution of benthic fauna shows obligate dependence on light penetration into the water column on a shallow carbonate platform.

In the current study, isotopic carbon and oxygen data are used to support other paleoeccological evidence. The relationship between the carbon and oxygen isotope values shows a weak positive correlation that indicates weak influence by diagenesis, and represents the initial imprint of the environment in which these sediments were deposited (Fisher et al., 2005; Hennhoefer et al., 2018).

4.2.1. Physical factors

• Temperature

According to Wilson and Vecsei (2005), Larger benthic foraminifera are typically found in tropical and subtropical marine environments. The preferred water temperatures generally range from 14°C to 25°C.

The presence of Nummulites and Operculina, from the Sinjar Subtropical - tropical environments reflects the environment of the formation, whereas, imperforate, large-benthic-foraminiferas like miliolids of the Sinjar Formation reflect the presence in the tropical environment. The association of coral and red algae indicates temperatures (18 - 22)°C in tropical environments Wilson and Vecsei (2005). (Flugel, 2010) clarified that Lithoporella, Lithophyllum, Lithothaminium, show subtropical-tropical environments in depths between 20 to 80 m During the sedimentation process, carbonates form from aqueous solutions, and the oxygen isotopes present in these minerals reflect the temperature of the surrounding seawater at that time. In addition, subsequent reactions between carbonate minerals and atmospheric and metamorphic waters can also influence oxygen isotope formation. These exchanges can be caused by fluid flow, decomposition, or other geological processes and can lead to modifications to the original $\delta^{18}$O values of carbonate rocks (Higgins, et al., 2012; O'Neil, et al., 1969).

The values of the oxygen isotope ($\delta^{18}$O) range in the samples of the Dokan section between (% - 8.07 - %0.71) at a rate of (% -3.25), (Table 1, Fig. 10). These values are negative in the Sinjar Formation and vary in the area of overlap with the Kolosh Formation looked at the environmental variability, and it was noted that they are negative values in most models. It also shows a large anomaly (excursion) in the values of the oxygen isotope for some values, and the values are distributed unevenly, with the presence of some sites in which the values increase or decrease slightly due to the change of some environmental conditions. The negative values in general reflect increasing temperature in the studied rocks Scott et al., (2013).

To estimate the paleotemperature values for the studied Sinjar limestone, the equation of Shackleton and Kennett (1975) is used, $T =16.9-4.38(\delta^{18}O - \delta^{18}O) + 0.1(\delta^{18}O - \delta^{18}O)$. This equation is an expression of the isotopic equilibrium between water and calcite, where, $\delta^{18}O$ = Oxygen isotopic composition of limestone (vPDB), $\delta^{18}O$ =Oxygen isotopic composition of seawater (vsMOW), (which is assumed to be $\delta^{18}O = \delta^{18}O(VSMOW) - 1.00$%; Shackleton and Kennett, 1975; Kim et al., 2015).

The estimated temperature ranges between 17°C to 47°C (Table 1). Higher temperatures were recorded in samples from 100-113 which correspond to strong negative values in $\delta^{18}$O (Table 1) and may relate to the Paleocene-Eocene transition.
Table 1. Stable C and O isotopic data for the Sinjar Formation (S samples), the transition zone between Sinjar and Kolosh formations (S-K samples), and the upper Kolosh Formation (K- samples) in the Dokan section, with estimated temperature for the limestone units only from the present study.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>δ¹³C (% VPDB)</th>
<th>δ¹⁸O (% VPDB)</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>S120</td>
<td>-0.53</td>
<td>-5.18</td>
<td>42.5</td>
</tr>
<tr>
<td>S119</td>
<td>-0.01</td>
<td>-1.61</td>
<td>24.2</td>
</tr>
<tr>
<td>S117</td>
<td>0.58</td>
<td>-1.52</td>
<td>23.8</td>
</tr>
<tr>
<td>S113</td>
<td>-9.99</td>
<td>-5.99</td>
<td>47.0</td>
</tr>
<tr>
<td>S112</td>
<td>2.66</td>
<td>-5.05</td>
<td>41.8</td>
</tr>
<tr>
<td>S110</td>
<td>3.28</td>
<td>-4.76</td>
<td>40.2</td>
</tr>
<tr>
<td>S108</td>
<td>1.43</td>
<td>-5.36</td>
<td>43.5</td>
</tr>
<tr>
<td>S100</td>
<td>-0.82</td>
<td>-5.32</td>
<td>43.3</td>
</tr>
<tr>
<td>S95</td>
<td>2.99</td>
<td>-4.19</td>
<td>37.2</td>
</tr>
<tr>
<td>S90</td>
<td>2.40</td>
<td>-4.99</td>
<td>41.4</td>
</tr>
<tr>
<td>S85</td>
<td>2.84</td>
<td>-3.47</td>
<td>33.4</td>
</tr>
<tr>
<td>S84</td>
<td>3.69</td>
<td>-1.05</td>
<td>21.6</td>
</tr>
<tr>
<td>S80</td>
<td>2.22</td>
<td>-4.12</td>
<td>36.8</td>
</tr>
<tr>
<td>S77</td>
<td>0.66</td>
<td>-3.61</td>
<td>34.2</td>
</tr>
<tr>
<td>S71</td>
<td>1.75</td>
<td>-4.61</td>
<td>39.4</td>
</tr>
<tr>
<td>S66</td>
<td>2.60</td>
<td>-4.74</td>
<td>40.1</td>
</tr>
<tr>
<td>S63</td>
<td>2.14</td>
<td>-2.70</td>
<td>29.5</td>
</tr>
<tr>
<td>S58</td>
<td>0.60</td>
<td>-3.54</td>
<td>33.8</td>
</tr>
<tr>
<td>S52</td>
<td>-1.86</td>
<td>0.52</td>
<td>14.6</td>
</tr>
<tr>
<td>S46</td>
<td>-0.33</td>
<td>-0.03</td>
<td>17.0</td>
</tr>
<tr>
<td>S37</td>
<td>-5.86</td>
<td>0.39</td>
<td>-</td>
</tr>
<tr>
<td>S-K35</td>
<td>0.70</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>S-K34</td>
<td>1.11</td>
<td>-3.73</td>
<td>-</td>
</tr>
<tr>
<td>S-K24</td>
<td>0.42</td>
<td>-3.92</td>
<td>-</td>
</tr>
<tr>
<td>K15</td>
<td>-3.57</td>
<td>-8.07</td>
<td>-</td>
</tr>
<tr>
<td>K14</td>
<td>-2.44</td>
<td>-4.88</td>
<td>-</td>
</tr>
<tr>
<td>K12</td>
<td>-10.30</td>
<td>0.71</td>
<td>-</td>
</tr>
<tr>
<td>K9</td>
<td>-19.29</td>
<td>-4.40</td>
<td>-</td>
</tr>
<tr>
<td>K6</td>
<td>0.05</td>
<td>0.59</td>
<td>-</td>
</tr>
</tbody>
</table>
Fig. 10. The vertical distribution of the isotope values of carbon ($\delta^{13}$C) and oxygen ($\delta^{18}$O) for the Sinjar Formation in the Dokan section

- **Light**
  
  BouDagher-Fadel (2008) interpreted that when the shape of the test changed and affected to the light levels at greater depths. According to the previous studies, the studied sections have been shown from mesophotic-to-oligophotic conditions.

- **Depth**

  Rasser et al., (2005) clarified that some of the species of foraminifera have developed and become thick and others with conical forms and secondary cells. The thick hard substrate has been identified in the Sinjar Formation based on the abundance of the genera Nummulites and Operculina, which have very large shells.

- **Substrate**

  Based on previous studies, the deposition of genera *Operculina* and *Nummulites* within the Sinjar Formation is good evidence for solid sediments.

- **Salinity**

  Sinjar Formation in the studied sections with a normal salinity from 34 to 50 ‰.
Nutrient and oxygen. Samankassou 2002 clarified that the alimentary provision has a non-positive relationship with temperature. Existence of large benthic foraminifera like Peneroplis, and Operculina, coral with red algae in the Sinjar Formation have mesotrophic-oligotrophic conditions. (Geel, 2000; Romero et al., 2002).

The paleoecological conditions of the Sinjar Formation could be interpreted as follows: Nummulitids and mollusca thrived in oligophotic to mesophotic mid-ramp environments at water depths from 40 to 80 m (Bosence, 1983; Hottinger, 1997). Distribution of benthic foraminifera such as (Nummulites, Operculina, coralline, algae, Alveolina, Lokhartia, Rotalia, miliolids, and mollusca (bivalves, cephalopods, and gastropods) in the section indicate normal to slightly saline (Flügel, 2010; Allahkarampour Dill et al., 2012; Taheri et al., 2017), (Table 2).

Table 2. Vertical distribution and palaeoecological elements such as temperature, light, depth, substrate, salinity, nutrient, and oxygen estimation from the Sinjar Formation in the studied sections.

<table>
<thead>
<tr>
<th>Age</th>
<th>Fossil's abundance</th>
<th>Temp.</th>
<th>Light</th>
<th>Depth (m)</th>
<th>Substrate</th>
<th>Sea water Salinity</th>
<th>Nutrients and Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paleocene</td>
<td>Larger Benthic Foraminifera (LBF), Nummulites, Operculina, Alveolina, Lokhartia, Rotalia, Peneroplis, with mollusca, coralline algae, coral, and miliolids.</td>
<td>18 - 25 °C</td>
<td>Mesophotic to oligophotic conditions</td>
<td>40 – 80</td>
<td>Hard sediments</td>
<td>Normal marine to slightly saline</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td>Lower Eocene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mesotrophic c</td>
</tr>
</tbody>
</table>

Modern geochemical techniques such as carbon isotope analysis have been used to elucidate the concept of PETM and other similar events. It was observed that in the current study, the values of the carbon isotope (\(\delta^{13}C\)) ranged in the samples of the Dokan section between (-19.29‰ to 3.69‰) at a rate of (-1.24‰), (Table 1). These values varied for this section in the contact area between the Sinjar - Kolosh formations. Positive values are indicative of the lagoon environment, according to (Silva and Boulvain, 2008), the deep regions of the lagoon environment have high and positive carbon isotope values due to the weakness of the effect of atmospheric water in them, while the carbon isotope values gradually reach lower and negative values towards the supratidal regions, leading to exposure to the surface. As the carbon isotope values reflect the original changes in the composition of seawater in terms of salinity and the influence of the mixing zone and atmospheric water, the carbon isotope values show a kind of lateral gradient within the secondary environments, which is reflected vertically through the section.

In general, the positive values of the most of transition zone at the lower layers of the Sinjar Formation may reflect high productivity, high input of marine organic matter rich in carbon (Higgins et al., 2012; Quan, et al., 2021), while the negative values in upper layers of Sinjar Formation across Paleocene-Eocene transition (sample 110 Fig.10, Table 1) reflects the sudden change in environmental conditions across P-E contact.

Biostratigraphic results along with data from isotopic analysis are compared with previous studies locally and regionally including those of GSSP at Dababiya, Egypt (Khozyem et al., 2014; Kasem et al., 2020; Al-Fattah et al., 2020 a,b).
5. Conclusions

Large benthic foraminifera and non-foraminifera of the Late Paleocene-Early Eocene sediments biostratigraphy of the Sinjar Formation in the Dokan area was divided into three assemblage biozones. These biozones are:

- **Biozone A-** *Kathina sp.-Lockhartia hunti* Assemblage Zone (Dokan Section); *Kathina pemavuti - Lockhartia hunti* Assemblage zone (Sinjar Section), which refers Late- Paleocene (L-Thanetian).

- **Biozone B-** including *Idalina sinjarica* Total Range Zone it renowned in (Early- Eocene) by the first occurrence of *Idalina sinjarica*.

- **Biozone C-** including *Alveolina globosa-Alveolina pasitisilata* Concurrent Range Zone (SBZ 8-10) is a guide of Early Ypresian (E. Eocene).

The pale sedimentary environment and variable thickness of the Sinjar Formation are in various areas of Zagros because of the subsidence and faulting during (Eocene). Paleoeconomically, the Sinjar Formation in these sections was deposited in normal to slightly water saline, with water depths ranging from 40 - 80 m, temperature, 18-25°C, and under oligotrophic to mesotrophic nutrient conditions. The abrupt changes in paleoenvironmental conditions across the Paleocene-Eocene contact. have been shown with high productivity during the deposition of the Sinjar Formation depending on the data of isotopic carbon (δ^{13}C) and oxygen (δ^{18}O).

References


Sissakian, V.K 2010; Neotectonic movements in Darbandi Bazian area, southwest of Sulaimaniyah city, NE Iraq, Iraqi Bulletin of Geology and Mining, 6(2) 57-69.


