IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

*IBGM (**2025**, Vol 21; Issue 1)* *307-322*

CONTRIBUTION TO THE BIOSTRATIGRAPHY AND MICROFACIES ANALYSIS OF THE OAE2 FROM THE KURDISTAN REGION (NE IRAQ)

Abdulrahman Bamerni[1], Arkan O. Sharazuri[2], Bzhar A. Delizy[2*], Goran F. Hassan[2], and Fabrizio Frontalini[3]

[1] Department of Geology, University of Duhok, Duhok, Kurdistan Region, Iraq.
[2] Department of Petroleum Geosciences, Soran University, Soran, Kurdistan Region, Iraq.
[3] Department of Pure and Applied Sciences (*DiSPeA*), Urbino University, Italy.
***** *Corresponding author email: bzhar.kheder@soran.edu.iq*

Type of the Paper (Article)
Received: 19/ 08/ 2024
Accepted: 20/ 02/ 2025
Available online: 27/ 06/ 2025

Abstract

The Cenomanian/Turonian Boundary sediments of the Gulneri Formation are characterized by a 1.5 m thick organic-rich calcareous black shale that can potentially represent the lithostratigraphic expression of the global Ocean Anoxic Event 2 (OAE2). It is bounded by double unconformities, with the underlying dolomitic limestone of the Cenomanian Dokan Formation and with the overlying white-weathered, thinly bedded limestone of the Turonian Kometan Formation. The high-resolution planktic foraminiferal biostratigraphic investigation of the Gulneri Formation reveals three main biozones: *Whiteinella archaeocretacea* Partial-Range Zone, *Helvetoglobotruncana helvetica* Taxon-Range Zone, and *Dicarinella primitiva-Marginotruncana sigali* Interval Zone that constrains it from Latest Cenomanian to late Turonian in age. The characteristics of the planktic foraminiferal lime mudstone, wackestone, and packstone microfacies suggest that the Gulneri Formation was deposited in an euxinic, stagnant, open marine environment of the middle shelf. The occurrence of fish detritus, the increased abundance of the low-oxygen tolerant species belonging to the *Heterohelix* genus, surface dweller *Muricohedbergella*, and the disaster opportunist *Guembelitria cenomana* all indicate that the organic-rich calcareous black shale of the Gulneri Formation is correlated with the OAE2 that is observed widely across the Tethys realm.

Keywords: Foraminifera; Microfacies; Biostratigraphy; Gulneri; Cretaceous; Iraq.

ISSN 1811-4539, EISSN 3005-3714
https://doi.org/10.59150/ibgm2101a17
IBGM: http://ibgm-iq.org/
Academic Scientific Journals: www.iasj.net

1. Introduction

The Cretaceous Period (143.1 – 66.04 Ma) is known as a greenhouse interval where global high temperatures prevail (Gale *et al.*, 2019). The complex interplay of high pCO_2 in the atmosphere, the palaeogeographical configuration, high oceanic crust formation, the eruption of large igneous province, and warm ocean conditions constituted the background for the unique paleoclimatic conditions of the Cretaceous (Huber *et al*., 2018). This period was intermittent by episodes of widespread burial of organic-rich sediments on the seafloor under oxygen-deficiency conditions known as oceanic anoxic events (OAEs) associated with a perturbation in the carbon cycle (Leckie *et al*, 2002; Herrle *et al*., 2004; Leandro *et al*., 2022). The most significant episodes, today lithologically identified as black shale layers, are OAE1a in the early Aptian, OAE1b in the Aptian/Albian boundary, and the OAE2 in the Cenomanian/Turonian (C/T) boundary (Jenkyns, 2010). The OAE2, also known as Bonarelli in Italy or Thomel in France, falls in the *Whiteinella archaeocretacea* planktic foraminiferal zone (Coccioni and Premoli silva, 2015) and is associated with a significant carbon perturbation as evidenced by a marked positive $\delta^{13}C$ excursion as well as to biotic changes (e.g., planktic foraminifera and radiolaria) (Musavu-Moussavou et al., 2007).

A Late Cretaceous (Early Turonian) 1.2 m thick interval, black bituminous, finely laminated calcareous shale similar to the Gulneri Formation, has been described by Lancaster Jones (1957) in (Bellen et al., 1959) from the Dokan Dam northeastern of Iraq. Abawi et al., 2006 confirmed the description in the Gulneri Formation. From the type section sediments basically consist of organic-carbon-rich black shale with an Early Turonian age based on planktic foraminiferal assemblage that might therefore represent the OAE2. Keller et al., 2021 revealed that the OAE2 was started at the latest Cenomanian-Early Turonian age. AL-Lhaebi et al., 2020 investigated three sections in northern Iraq and concluded a Cenomanian-Turonian age for this interval as well as (AL-Salmani and AL-Badrani, 2023) based on calcareous nannofossil data from the Dokan and Pushen areas (northern Iraq). Lawa and Al-Khafaf, 2022 studied the biostratigraphy of the formation at the NE of the Dokan Dam and concluded the Early Turonian age of the formation.

Recently a detailed examination of the condensed Cenomanian-Turonian succession from the Dokan Dam and Khalakan areas (Sulaimani, northeastern Iraq) showed that the C/T boundary is characterized by a hiatus given the absence of the *Globigerinelloides benthonensis* and *Dicarinella hagni* subzones, and the lack of the positive $\delta^{13}C$ excursion during the OAE2 (Lawa et al., 2023). Twelve microfacies and four submicrofacies were identified, which led to the identification of the five facies-depositional paleoenvironments spanning from peritidal to basinal settings (Lawa et al., 2023).

This study aims to investigate the Qallat section across the C/T boundary by using high-resolution planktic foraminiferal biostratigraphy, and microfacies analyses.

2. Geological Setting

During the Cenomanian-Turonian, the Kurdistan region of Iraq formed the distal NE margin of the Arabian Plate, where the deformation occurred and the C/T sequence deposited as the upper part of the Late Tithonian – Early Turonian 8th Tectonostratigraphic Megasequence Arabian Plate (TMSAP8). During this period, the Austrian orogenic event started to affect the northeastern margin of the Arabian Plate and resulted in a tectonic instability that formed several structural deep settings. In such settings, the organic-rich calcareous black shale of the Gulneri Fm. Deposited as a thin, highly condensed unit that is locally preserved at the top of the Cenomanian/ Early Turonian sequence associated by two stratigraphic breaks occurring at the base and top of the formation with high bitumen content and dwarfed fossils which indicate an euxinic depositional environment.

The Gulneri Formation of the Qallat section (Long. 44°54'26.29" E and Lat. 35°58'11.31" N) is exposed on the southeastern limb of the Kosrat anticline near the main road of Sulaimani-Dokan-Khalakan areas, about 62 km to the northern-west of Sulaimani city (Figure 1). The Kosrat anticline is an asymmetrical fold with a SW limb steeper than the NE one, including rock units from Aptian-Albian to Miocene-Pliocene in age (Barno, 2017; Zarraq, 2021). The study area is part of the High Folded Zone of the Outer Platform of the Western Zagros Fold Thrust Belt (WZFTB) according to the tectonic divisions of Iraq by Fouad, 2015 (Figure 1).

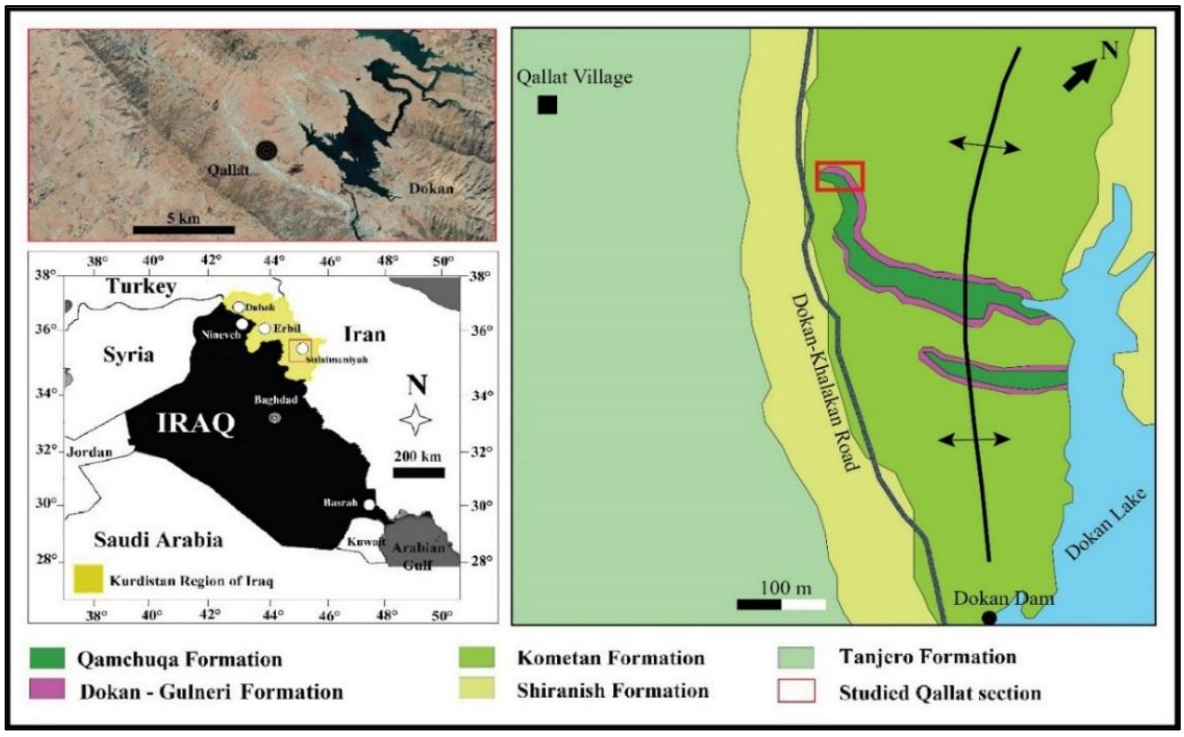

Figure 1. a) Map of Iraq showing the studied area, b) Google image of the Qallat section; and c) geological map of the studied area.

3. Materials and Methods

The Gulneri Formation exposed in the Qallat section was examined in the field for lithological change, bioturbation, macrofossils, hardgrounds, erosional surface, glauconite occurrence, and other physical characteristics. The Gulneri Formation was measured, described, and sampled. A total of 15 fresh rock samples were collected at 5 – 10 cm intervals. The identification of the planktic foraminifera and the determination of the biozonation follows the basic zonation of Bolli et al., 1994 as well as the most up-to-date classification catalogs of Petrizzo and Premoli-sliva (2011), and Coccioni and Premoli-silva (2015). The recorded microfacies were described and classified according to the classification of Embry and Klovan, (1971) modified after Dunham's (1962) classification of the carbonate microfacies.

4. Results

4.1. Lithostratigraphy

The Gulneri Formation was initially described by Lancaster Jones (1957) as cited in Bellen et al., (1959). It was characterized as a 1.2 m thick interval of black, bituminous, finely laminated calcareous shale, containing glauconite and cellophane in its lower section. It is bounded by the Dokan Limestone Formation and the Kometan Formation, both marked by erosional unconformities at the type section near the Dokan Dam in the Sulaimani region.

In the studied Qallat section, the Gulneri Formation aligns closely with the lithological and contact features documented in the type section. It comprises a 1.5 m thick sequence of laminated, organic-rich, calcareous black shale with minimal bioturbation and lower resistance to physical erosion compared to the underlying Dokan Formation and the overlying Kometan Formation. Field observations confirmed the presence of cellophane material, including fish bones and teeth (Figure 2), in the lower part of the formation, as well as increasing glauconite concentrations toward the upper contact with the Kometan Formation (Figure 3). Additionally, the occurrence of small pyrite nodules suggests euxinic (sulfidic and anoxic) conditions prevalent during the OAE-2 event.

In the Qallat section, the Dokan Formation underlies the Gulneri Formation and consists of robust, light grey, thin-to-medium-thick beds of brecciated dolomitic limestone, enriched with iron oxides, especially near the contact surface. Notably, no faunal assemblages were identified within one meter directly below the contact. The upper contact is distinctly marked by the onset of stylolitic, thin, white limestone beds belonging to the Kometan Formation, which displays an abundance of glauconite at its base (Figure 4).

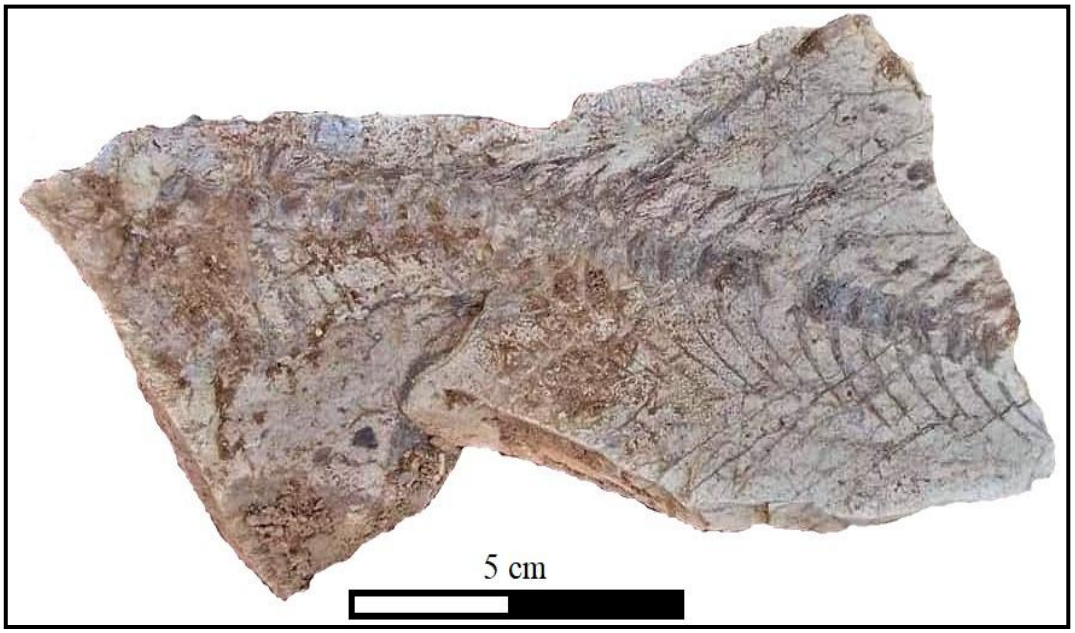

Figure 2. Cellophane material (fish skeleton) from the Gulneri Formation of the Qallat section (Sulaimani area, Kurdistan Region of Iraq).

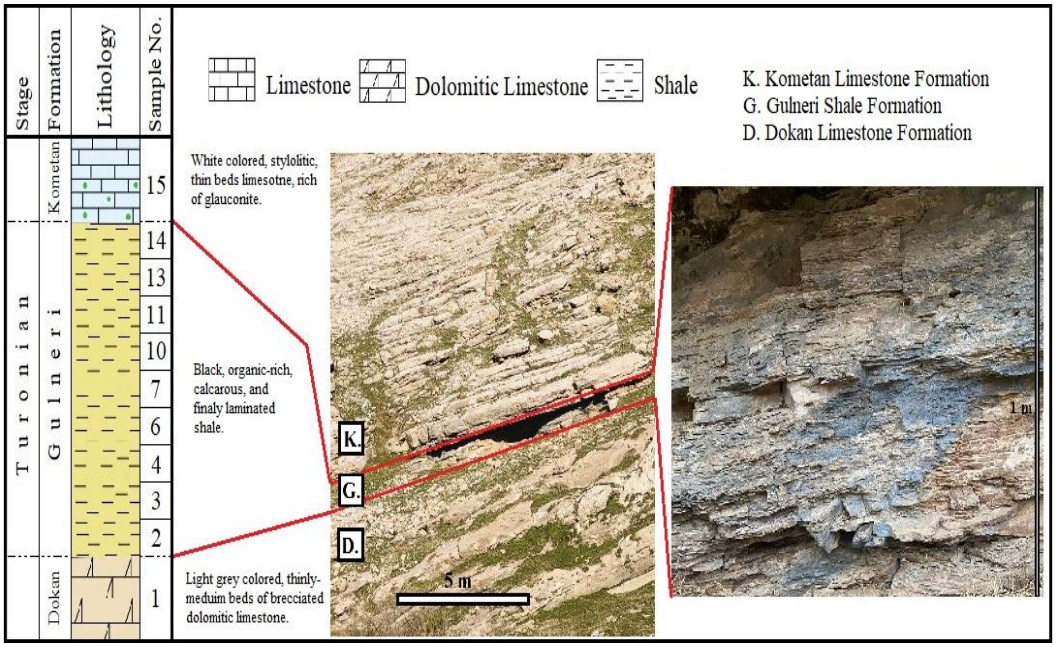

Figure 3. Lithostratigraphy of the studied Gulneri Formation of the Qallat section (Sulaimani area, Kurdistan Region of Iraq).

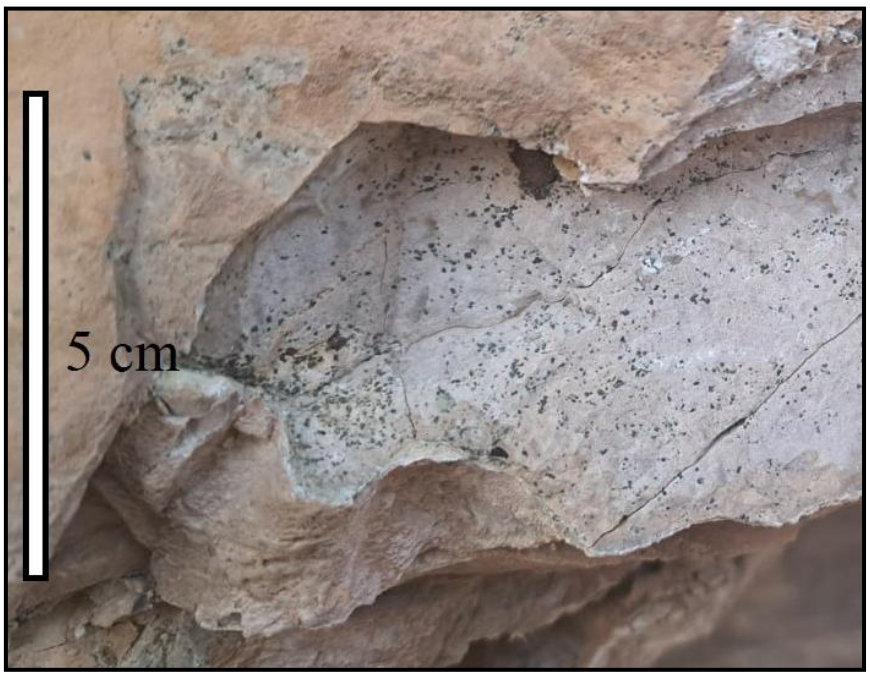

Figure 4. The field photo shows the richness of the glauconite at the base of the Kometan Formation of the Qallat section (Sulaimani area, Kurdistan Region of Iraq).

4.2. Biostratigraphy

Thinsections showed moderate to good preservation of the foraminiferal assemblage. The planktic foraminiferal assemblages across the studied interval showed a low diversity with a total of 18 species belonging to 12 genera with abundant small biserial species belonging to *Heterohelix* and *Laeviheterohelix* genera, triserial *Guembelitria cenomana* (Keller), and low trochospiral *Muricohedbergella holmdelensis* (Olsson). A detailed distribution of the recorded planktic foraminiferal species is shown in Figure 5.

4.3. Planktic Foraminifera Biozonation (from bottom to top)

4.3.1. Whiteinella archaeocretacea Partial-Range Zone (p.p.)

Author and Definition: This zone is defined by Bolli (1966) as the interval from the highest occurrences (HO) of *Rotalipora cushmani* (Morrow) to the lowest occurrences (LO) of the *Helvetoglobotruncana helvetica* (Bolli).

Remarks: This study did not record the *Rotalipora cushmani* (Morrow) from the Gulneri Formation, even from the dolomitic limestone of the underlying Dokan Formation. This interval is similar to the global zone of Petrizzo and Premoli-sliva (2011) and is characterized by a poorly diversified foraminiferal assemblage related to the widespread deposition of organicrich sediments. The foraminiferal assemblages from this interval beside the taxon species of this zone are *Whiteinella archaeocretacea* Pesango, *Heterohelix globulosa* (Ehrenberg), *Hx. reussi* (Cushman), *Hx. carinata* (Cushman), *Guembelitria cenomana* (Keller), *Muricohedbergella*

holmdelensis (Olsson) (Figures 6a, b, c, d, and f), that match the global description of this zone according to Petrizzo and Premoli-sliva (2011) and Coccioni and Premoli-silva (2015) (Figure 5). According to Coccioni and Premoli-silva (2015), the *Whiteinella archaeocretacea* zone is known globally as the zone that records at its base the Bonarelli level (OAE2) that consists predominately of organic carbon-rich sediments alternating with carbonate accumulation- rich in fish debris as in the base of the Gulneri Formation of this study.

Age: latest Cenomanian – earliest Turonian.

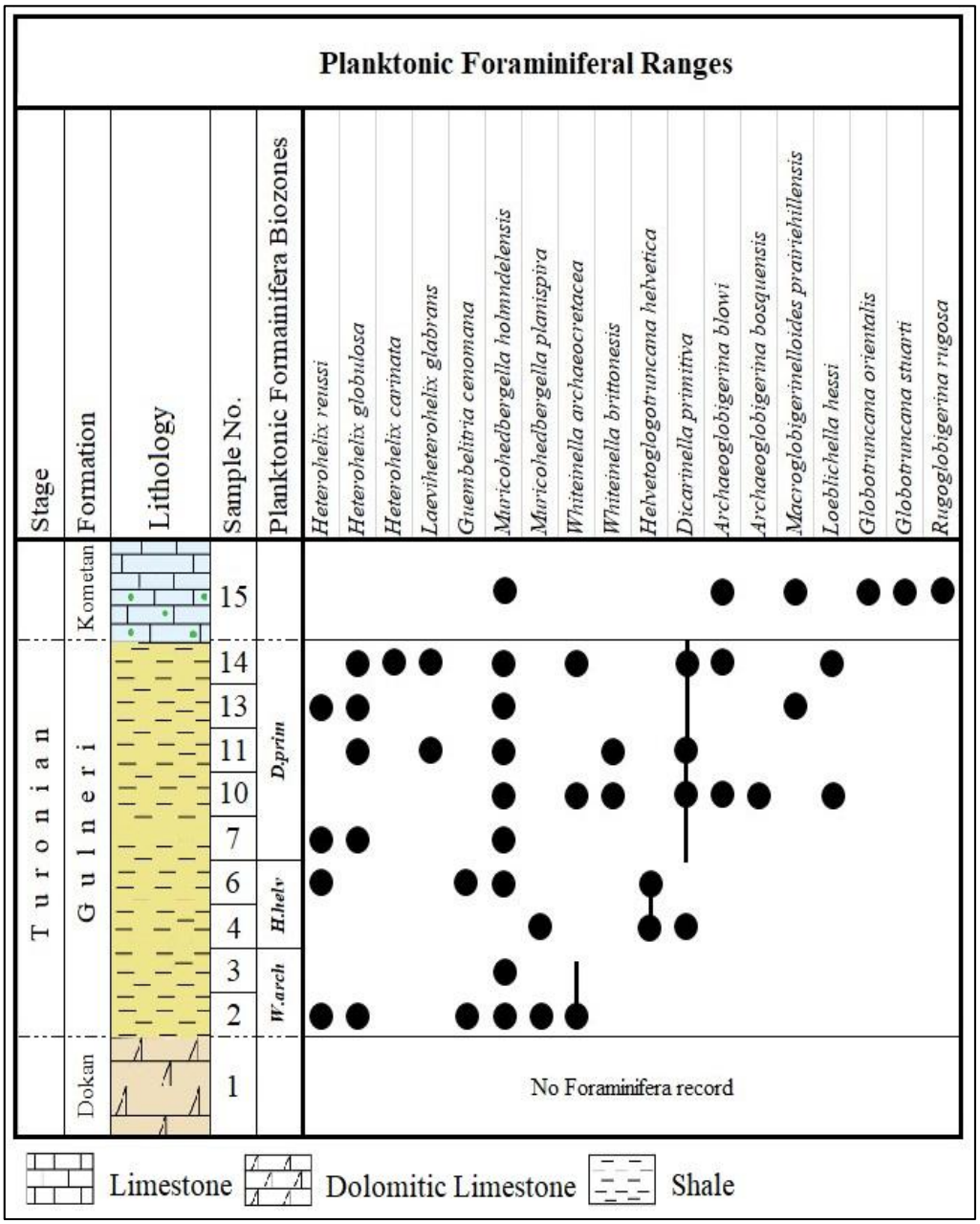

Figure 5. Biostratigraphic range chart of the planktic foraminifera of the Gulneri Formation of the Qallat section (Sulaimani area, Kurdistan Region of Iraq).

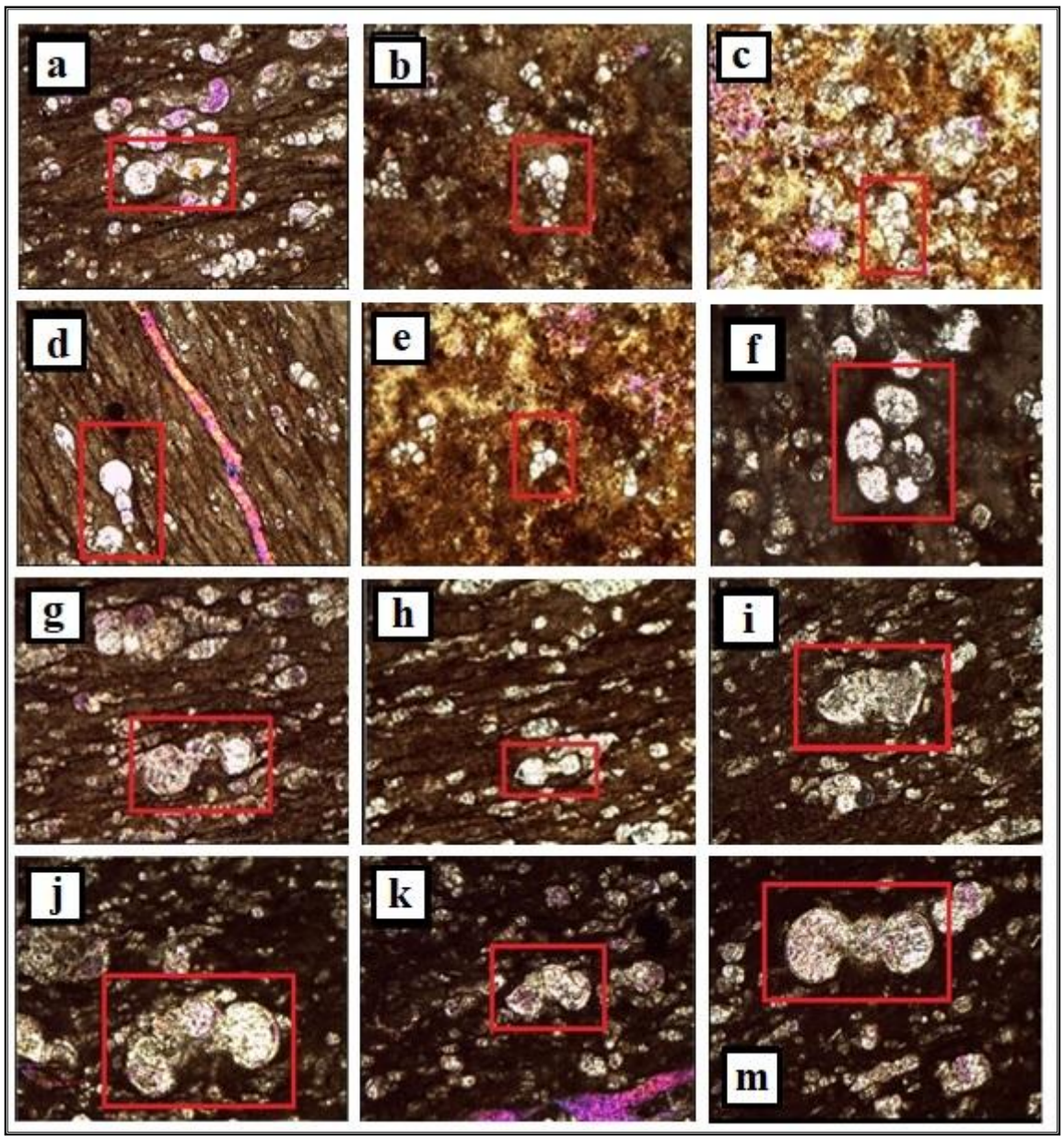

Figure 6. Photomicrographs of a) *Whiteinella archaeocretacea* (Pessagno), x100 (S.5a); b) *Hx globulosa* (Ehrenberg) x100 (S.4); c) *Hx. reussi* (Cushman) x100 (S.1); d) *Heterohelix carinata* (Cushman), x100 (S.7a); e) *Guembelitria cenomana* (Keller) x100 (S.1); f) *Muricohedbergella holmdelensis* (Olsson), x100 (S.7); g) *Helvetoglobotruncana helvetica* (Bolli) x100 (S.3a); h) *M. planispira* (Tappan) x100 (S.3a); i) *Dicarinella primitiva* (Dalbiez, 1955), x100 (S.5a); j) *Archaeoglobigerina bosquensis* (Pessagno), x100 (S.5a); k) *Arch. cretacea* (d'Orbigny), x100 (S.5a); m) *Loeblichella hessi* (Pessagno), x100 (S.5a).

4.3.2. Helvetoglobotruncana helvetica Taxon-Range Zone

Author and Definition: This zone is defined by Sigal (1955) as the interval containing the total range of *Helvetoglobotruncana helvetica* (Bolli) (Figure 6g).

Remarks: This zone is a very short interval and shows a lower diversity than the underlies and overlies zones, particularly in the lower part. The LO of *Muricohedbergella planispira* (Tappan) (Figure 6h) and the HO of *G. cenomana* (Keller) were recorded in this zone in this study. The *H. helvetica* zone of this study is equivalent to the *H. helvetica* zone defined in the Tethyan sections (Petrizzo and Premoli-sliva, 2011; Peryt et al., 2022) (Figure 5).

Age: early – middle Turonian.

4.3.3. Dicarinella primitiva-Marginotruncana sigali Interval-Range Zone (part)

Author and Definition: This zone is defined by Dalbiez (1955) and is also known as the *Marginotruncana schneegansi* zone (Sliter, 1989), later on; Robaszynski and Caron (1995) split this interval into two zones with the *Marginotruncana schneegansi* zone below and the *Dicarinella primitiva* zone above. In this study, this zone is defined as an interval from the HO of the *H. helvetica* (Bolli) to the LO of the species belonging to the double-keel genus *Globotruncana* recorded from the base of Kometan Formation.

Remarks: The aforementioned definition and subdivision were not applied to the biozonation of the Gulneri Formation because of the rarity of the zonal marker of planktic foraminifera in general and because of the absence of *M. schneegansi* (Sigal). This zone shows more variety of the identified genera as well as species diversity compared to the previous zones. Specific bioevents recorded in this zone are the LO of the genus D. primitive (Dalbiez), *Archaeoglobigerina* (*A. bosquensis* Pessagno, *A. blowi* Pessagno) (Figures 6i, j, and k), which is comparable to the bioevents recorded by Petrizzo and Premoli-sliva (2011) and Coccioni and Premoli-silva (2015). The rare occurrence of the very low trochospiral coiling *Loeblichella hessi* (Pessagno) (Figure 6m) is recorded from this zone (see Figure 5).

Age: late middle – late Turonian.

4.4. Microfacies Analysis

The major petrographic components and the presence of the significant index foraminiferal species in addition to other sedimentological and stratigraphical characteristics of the thin sections from the Gulneri Formation enabled us the identify three main microfacies.

4.4.1. Planktic foraminiferal lime-mudstone microfacies

The main components of this microfacies include planktic foraminifera, which is represented by minute ghosts of *Muricohedbergella* (Figure 7a). Dissolution and recrystallization in addition to micritization are the main diagenetic processes that affect the grains. All the grains are skeletal except few black spots of pyrite. These microfacies occur in a few beds of the lower part with highly recrystallized, dolomitized, and dissolved grains (Figure 7i).

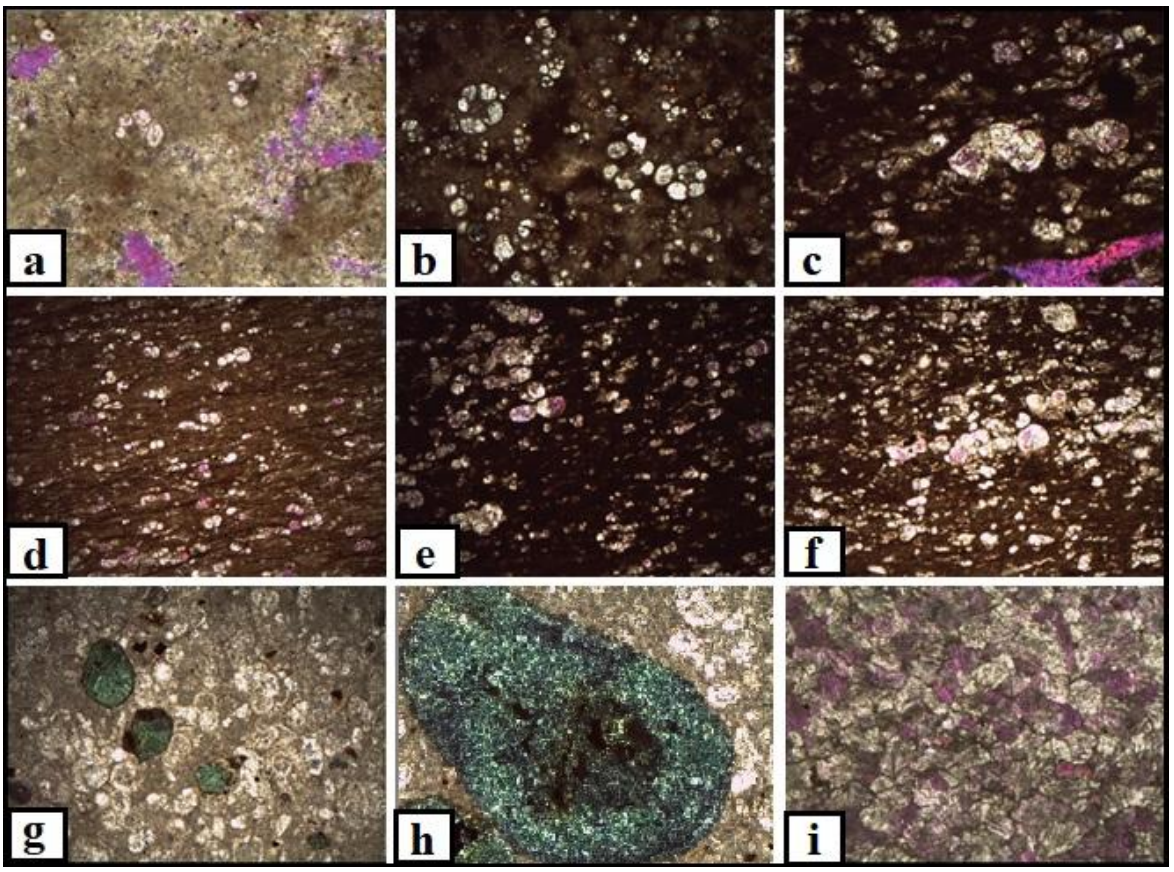

Figure 7. Photomicrophotographs of a) Planktic foraminiferal lime mudstone microfacies with minute ghosts of *Muricohedbergella* Gulneri Formation (40X), b) Planktic foraminiferal lime wackestone microfacies with *M. holmdelensis,* Gulneri Formation (40X), c) Planktic foraminiferal lime wackestone microfacies with *A. cretacea*, Gulneri Formation (40X), d) Planktic foraminiferal lime packstone microfacies with *Hx. globosa* and *H. carinata*, Gulneri Formation (40X), e) planktic foraminiferal lime packstone microfacies with *H. globulosa*, Gulneri Formation (40X), f) Planktic foraminiferal lime packstonemicrofacies with *A. cretacea*, *D. primitive* and *M. holmdelensis*, Gulneri Formation (40X), g & h) Planktic foraminiferal lime packstone microfacies with *A. blowi*, *G. arca*, *R. rugosa* and *M. holmdelensis*, Kometan Formation (40-100X), i) Lime-mudstone microfacies belong to the Dokan Formation (40X).

4.4.2. Planktic foraminiferal lime-wackestone microfacies

This microfacies is dominated by many planktic foraminiferal species such as *A. cretacea, M. holmdelensis,* and *D. primitiva* (Figures 7b and c). The grains and the dark grey micritic groundmass are both impacted by several diagenetic processes such as recrystallization, dissolution, and micritization. The lower and middle parts of the Gulneri Formation belong to this microfacies.

4.4.3. Planktic Foraminiferal lime-packstone microfacies

This microfacies is characterized by the occurrence of a large number of the planktic foraminiferal species including *A. cretacea, A. bosquensis, A. blowi, M. holmdelensis, D. primitiva, Hx. globulosa, Hx. reussi, H. Helvetica* and *M. planispira* (Figures 7d, e and f). Few rounded dark brown organic materials are present. The lower part of the Kometan Formation belongs to this microfacies and is enriched with glauconite grains (Figures 7g and h). The micritization and recrystallization strongly affected the grains in the Kometan Formation.

5. Discussion

The current study investigates the Gulneri Formation from a new section (Qallat section) exposed in the Dokan area (Figure 3). The age of the OAE2 locally represented by the Gulneri Formation has been well constrained by planktic foraminiferal stratigraphy (*Whiteinella archaeocretacea* Partial-Range Zone, *Helvetoglobotruncana helvetica* Taxon-Range Zone, and *Dicarinella primitiva-Marginotruncana sigali* Interval Zone). These biozones range from the latest Cenomanian to the late Turonian (~ 93.9 – 89.8 Ma) according to Gradstein et al., (2012).

The *Whiteinella archaeocretacea* Partial-Range Zone was introduced by Bolli (1966). This zone is equivalent to the same zone recorded by Abawi et al., (2006) from the type section of the Gulneri Formation in the Dokan dam site in the Sulaimani area. They estimated a Late Cenomanian – Early Turonian age for this zone. It is also correlated to the same zone of Lawa et al., (2023) based on a detailed stratigraphic investigation of Tethyan Cenomanian/ Turonian succession and OAE2 in the Dokan area. This zone shows abundant *M. holmdelensis* (Olsson), and *M. planispira* (Tappan), as well as common occurrence of the biserial *Hx. globulosa* (Ehrenberg), *Hx. reussi* (Cushman), and triserial *G. cenomana* (Killer) in addition to the existence of the zonal marker taxon *Whiteinella archaeocretacea* Pessagno. This study matches well the biostratigraphic investigation of Abawi et al., (2006), where both studies have not recorded specimens of *R. cushmani* (Morrow) from the Gulneri Formation even from the underlies Cenomanian Dokan Formation.

The *Helvetoglobotruncana helvetica* Taxon-Range Zone was introduced by Sigal (1955). This zone of the Gulneri Formation is well recorded in the Qallat section and is characterized by the lowest number of planktic foraminiferal species compared with underlies and overlies zones of this study. It includes the total range of the zonal taxon *H. helvetica* (Bolli) and rare occurrences of *Hx. reussi* (Cushman), *M. holmdelensis* (Olsson), and *M. planispira* (Tappan). Although the *H. helvetica* zone is stratigraphically represented by a very short interval, some peculiar biostratigraphic characteristics have been recorded through this zone. It contains the LO of *Dicarinella primitiva* (Dalbiez) in the lower part. On the other hand, the upper part of this zone is, in this study, recognized with the last occurrences of *G. cenomana* (Keller). The current study is unique in recording the *Helvetoglobotruncana helvetica* Taxon-Range Zone from the Gulneri Formation The previous studies didn't record the exact extension of this zone, Abawi et al., (2006) mentioned that the occurrence of the *Helvetoglobotruncana helvetica* (Bolli) is first recorded immediately above the Gulneri/ Kometan contact within the lowermost part of

the Kometan Formation Also, Lawa et al., (2023) recorded this zone from the lower part of the Turonian Kometan Formation to be early to middle Turonian. While the *Helvetoglobotruncana helvetica* Taxon-Range Zone was recorded as defined by the international definition introduced by Sigal (1955). Additionally, some bioevents recorded from this zone such as LO of *M. planispira* (Tappan) and HO of *G. cenomana* (Keller) have been worldwide recorded from the *H. helvetica* zone constructed from various sections of the Tethyan realm (Petrizzo and Premoli-sliva, 2011; Peryt et al., 2022).

Despite the limited thickness of the Gulneri Formation, the close sampling interval and the high-resolution biostratigraphic investigation enabled us to recognize a third biozone and compare with nearby sections (Abawi et al., 2006; Lawa et al., 2023 for details) that have not recorded three zones from the Gulneri Formation. This study considers the first local stratigraphic attempt that records a part of the *Dicarinella primitiva-Marginotruncana sigali* Interval-Range Zone.

The bio-events recorded in this zone are the LO of the genus *Archaeoglobigerina* (*A. bosquensis* Pessagno, *A. blowi* Pessagno), beside the rare occurrences of the very low trochospiral coiling *Loeblichella hessi* (Pessagno), which matching the same bioevents that recorded by Petrizzo and Premoli-silva (2011) and Coccioni and Premoli-silva (2015).

The Late Middle – Late Turonian age has been inferred from the correlation with the same zone in the aforementioned studies.

According to the identified planktic foraminifera and the recorded biozones, the geological age of the Gulneri Formation represents the OAE2 (BL) and is supposed to be Latest Cenomanian to late Turonian. The sediments of the Gulneri Formation in this study show in general similar characteristics of microfacies including lime mudstone, wackestone, and packstone microfacies. According to the MFS zones, these microfacies are mostly related to the deep, stagnant waters with high a diversity of planktic foraminifers. The deeper basin of the Gulneri Formation in the studied section is indicated by lime mudstone and packstone microfacies bearing dwarf planktic foraminifera which show euxinic conditions including the organic matter. The lime mudstone microfacies are recorded in the lower and upper parts of the formation. The presence of planktic foraminifera with micrite indicates that the facies are possibly deposited in a deep basinal environment. Similar to this facies. Wilson (1975) described it as a deep and open maritime environment. Kenter et al., (2004) noted that the dominant lithofacies in the deep basinal environment are foraminifera and small skeletal grains. This facies resembles Wilson's (1975) SMF type (1) and represents deposition in a calm deep marine environment. The wackestone microfacies are recorded along the vertical extension of the Gulneri Formation and are comparable to Wilson's (1975) SMF type (8), which represents deposition in medium-energy deep marine neritic or open sea shelf environments. On the other hand, the lime packstone microfacies are recorded in the lower and middle parts of the formation. This facies is possibly deposited in a deep shelf margin or a somewhat shallow open marine resembling Wilson's (1975) SMF type (3).

Schlanger and Jenkyns (1976) claimed that the reduced oxygenation of the bottom water is led to preserve organic-carbon black shale, and the extensive and enlarged oxygen minimum zones associated with transgression sea-level pulses. The OAE2 at the boundary between Cenomanian – Turonian around 93-94 Ma is one of the best-known anoxic events in the geological history of the Earth. This time is marked by global climate warming and high eustatic sea level rise. The evidence of the OAE2 event from the Gulneri Formation is the occurrence of black, laminated, organic-rich shales along with the identification of pyrite nodules and low diversity of foraminiferal species. The age of the formation in the studied section well corresponds with the GSSP of the Turonian in the Bridge Creek Limestone Member of the Greenhorn Fm. (Colorado, USA).

According to the microfacies analyses and the recognized environmental index fossils, the Gulneri Formation was deposited in a middle shelf, semi-basinal, pelagic, open marine environment with quiet subsiding and reducing conditions (Figure 8). The abundance of the planktic foraminifera with glauconite grains and black papery shales represents the anoxic and pelagic conditions of the marine water. The Gulneri Formation basin may represent a low-lying area in the Dokan – Sulaimani – Kirkuk areas that separated this basin from the surrounding carbonate-dominated basins.

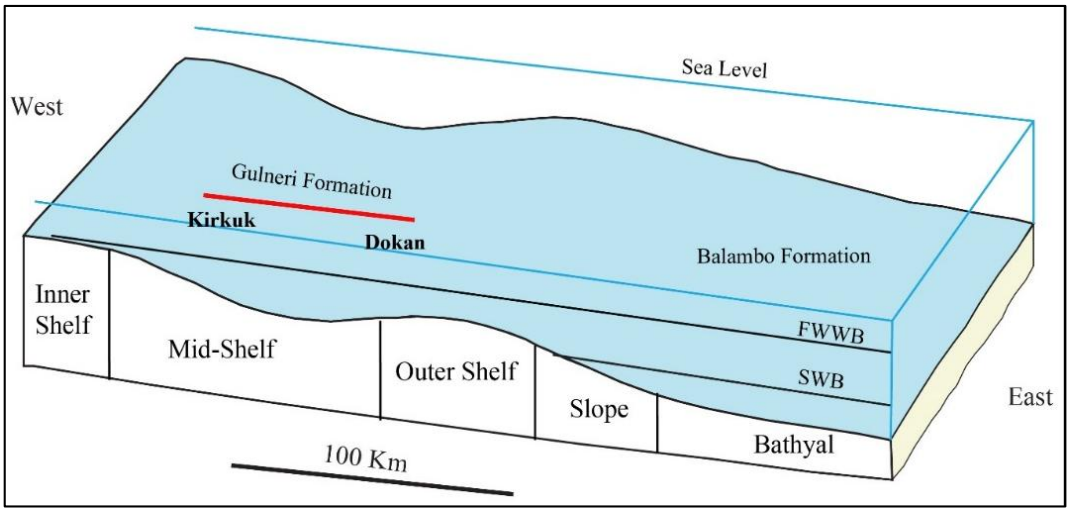

Figure 8. Depositional model of the Gulneri Formation.

6. Conclusions

Based on the results obtained from the study of the Gulneri Formation at the Qallat section (Sulaimani area of the Kurdistan Region, northeastern Iraq), we provide evidence that the Gulneri Formation lithologically consists of 1.5 m organic-rich calcareous black shale, bounded by double unconformity surfaces, with the underlies Cenomanian Dokan Formation, and with the overlies Turonian Kometan Formation. Moreover, three main biozones encompass this formation: the Whiteinella archaeocretacea Partial-Range Zone, the Helvetoglobotruncana helvetica Taxon-Range Zone, and the Dicarinella primitive-Marginotruncana sigali Interval

Zone. These identified biozones indicate the Latest Cenomanian – late Turonian age. In addition, three main microfacies are determined as lime mudstone, lime wackstone, and lime packstone that, overall, suggest deposition in the euxinic, stagnant, and open marine environment of the middle shelf. Finally, the low diversified and decreasing shell size (dwarfing) foraminiferal assemblage, the fish detritus, the dominant occurrence of the low oxygen tolerant *Heterohelix* genus, and the surface dweller *Muricohedbergella*, in addition to the occurrence of the disaster opportunist *Guembelitria cenomana* species are all good indicators that the 1.5 m thick of the Gulneri Formation is correlatable with the globally known OAE2.

Acknowledgments

The authors send their appreciation to Dr. Polla Khanaqa from the Kurdistan Institution for Strategic Studies and Scientific Research for his help with laboratory facilities.

Authors Contribution

Abdulrahman Bamerni conducted the planktic foraminiferal biostratigraphic analysis, interpreted the results, and prepared the initial draft of the manuscript. ***Arkan Sharazuri*** and ***Bzhar Delizy*** were responsible for sample collection, contributed to the petrographic data analysis, and participated in the manuscript preparation. ***Goran Hassan*** collected and compiled field data. ***Fabrizio Frontalini*** provided scientific and linguistic refinement to enhance the quality of the manuscript.

References

Abawi, T.S., Hammoudi, R.A., and Al-Khafaf, A. O. (2006). Stratigraphy of the Gulneri Formation (Upper Cretaceous) in the Type Section, Dokan Area, Northeastern Iraq. *Iraqi Journal of Earth Sciences*, *6*(2), 33–42.

AL-Lhaebi, S.F., AL-Badrani, O.A., AL-Juboury, A.I., and Mahanipour, A. (2020). Paleoclimatic Insights on the Cenomanian-Turonian Oceanic Anoxic Event (OAE2) from Northern Iraq based on Calcareous Nannofossil and Geochemical Data. *Iraqi Geological Journal*, *53*(2C), 68–86. https://doi.org/DOI: 10.46717/igj.53.2c.6Rs-2020-09/06.

AL-Salmani, S.A., and AL-Badrani, O. A. (2023). Calcareous Nannofossils Biostratigraphy of Gulneri Formation in Sulaimaniya, Northeastern Iraq. *Iraqi Geological Journal*, *56*(1E), 273–281. https://doi.org/10.46717/igj.56.1E.21ms-2023-5-31.

Barno, J. M. . (2017). *Structural Analysis of Kosrat Anticline and its Tectonic Implications, Northeastern Iraq.* Baghdad.

Bellen, R. C., Dunnington, H. V., Wetzel, R., and Morton, D. (1959). *Lexique Stratigraphique International: Asie. Iraq (Vol. 3C, Fasc. 10a).* Centre National de la Recherche Scientifique. http://paleopolis.rediris.es/LEXICON/IRAQ/

Bolli, H.M., Bechmann, J.P., and Saunders, J. B. (1994). Benthic Foraminiferal Biostratigraphy of the South Caribbean Region. In *Cambridge University Press*. Cambridge University Press.

Bolli, H. M. (1966). Zonation of Cretaceous to Pliocene marine sediments based on planktic foraminifera. *Boletin Informativo Asociacio'n Venezolana de Geologı'a. Mineraı'a y Petroleo*, *9*, 3–32.

Coccioni, R., and Premoli Silva, I. (2015). Revised Upper Albian – Maastrichtian planktic foraminiferal biostratigraphy and magnetostratigraphy of the classical Tethyan Gubbio section (Italy). *Newsletters on Stratigraphy.*, *48*(1), 47–90.

Dunham, R. J. (1962). Classification of Carbonate Rocks According to Depositional Texture. In: Ham, W.E., Ed., Classification of Carbonate Rocks. *AAPG*, 108–121.

Embry, A.F., and Klovan, J. . (1971). A Late Devonian Reef Tract on Northeastern Banks Island. *Canadian*

Petroleum Geology, *19*, 730–781.
Fouad, S. F. A. (2015). Tectonic Map of Iraq, Scale 1: 1000 000, 3rd edition, 2012. *Iraqi Bulletin of Geology and Mining.*, *11*(1), 1–7.
Gale, A.S., Kennedy, W.J., and Walasczcyk, I. (2019). Upper Albian, Cenomanian and Lower Turonian stratigraphy, ammonite and ino-ceramid bivalve faunas from the Cauvery Basin, Tamil Nadu, South India. *Acta Geologica Polonica*, *69*, 161–338.
Gradstein, F.M., Ogg. J.G., Schmitz, M.D., and Ogg, G. M. (2012). *The Geologic Time Scale 2012.* Elsevier. https://doi.org/10.1016/B978-0-444-59425-9.05001-0
Herrle, J.O., Kößler, P., Friedrich, O., Erlenkeuser, H., and Hemleben, C. (2004). High-resolution carbon isotope records of the Aptian to Lower Albian from SE France and the Mazagan Plateau (DSDP Site 545): A stratigraphic tool for paleoceanographic and paleobiologic reconstruction. *Earth and Planetary Science Letters*, *218*, 149–161.
Huber, B. T., MacLeod, K. G., Watkins, D. K., and Cof-fin, M. F. (2018). The rise and fall of the Cretaceous Hot Greenhouse climate. *Global Planet Change*, *167*, 1–23. https://doi.org/10.1016/j.gloplacha.2018.04.004
Jenkyns, H. C. (2010). Geochemistry of oceanic anoxic events. *Geochemistry, Geophysics, Geosystems*, *11*(3).
Keller. G, Madan L. Nagori, Chaudhary. M, A. Nallapa Reddy, B.C. Jaiprakash, Jorge E. Spangenberg, Mateo. P, and A. T. (2021). Cenomanian-Turonian sea-level transgression and OAE2 deposition in the Western Narmada Basin, India. *Gondwana Research*, *94*, 73–86.
Kenter, J.A.M., Harris, P.M., and Porta, G. D. (2004). Steep microbial boundstone dominated platform margin-examples and implications. *Sedimentary Geology*, *178*, 5–30.
Lawa, F. and Al-Khafaf, A. (2022). Biostratigraphy of Dokan and Gulneri formations from Kosrat Anticline, Sulaimani Area, Kurdistan Region-Iraq. *Iraqi Bulletin of Geology and Mining.*, *18*(IS-2), 25–42.
Lawa, F.A., Mohammed, I., Farouk, SH., Ahmed, F., Faris, M., Tanner, L., and Al-Kahtany, K. (2023). Stratigraphic architecture of the Tethyan Cenomanian-Turonian succession and OAE2 in Dokan Area, Kurdistan Region, northeast Iraq. *Journal of African Earth Sciences.*, *207*(105064), 1–17. https://doi.org/10.1016/j.jafrearsci.2023.105064
Leandro, C. G., Savian, J. F., Kochhann, M. V. L., Franco, D. R., Coccioni, R., and Frontalini, F. (2022). Astronomical tuning of the Aptian stage and its implications for age recalibrations and paleoclimatic events. *Nature Communications*, *13*(1), 29–41.
Leckie, R., Bralower, M., Timothy, J., Cashman, Katharine, V. (2002). Oceanic anoxic events and plankton evolution: Biotic response to tectonic forcing during the mid Cretaceous. *Paleoceanography*, *17*(3), 13–29.
Musavu-Moussavou, B., Danelian, T., Baudin, F., Coccioni, R., François, F. (2007). The Radiolarian biotic response during OAE2. A high-resolution study across the Bonarelli level at Bottaccione (Gubbio, Italy). *Revue de Micropaléontologie*, *50*(3), 253–287.
Peryt, D., Dubicka, Z., and Wierny, W. (2022). Planktic Foraminiferal Bioztratigraphy of the Upper Cretaceous of the Central European Basin. *Geosciences*, *12*(22), 1–24. https://doi.org/103390/geosciences12010022.
Petrizzo, M.R., and Premoli sliva, I. (2011). *Practical Manual of Cretaceous Planktic Foraminifera.* International School on Planktic Foraminifera 3rd Course. Cretaceous Planktic Foraminifera.
Robaszynski, F., and Caron, M. (1995). Foraminifères planctoniques du Crètacè: commentaire de la zonation Europe-Mèditerranèe. *Bulletin de La Sociètè Gèologique de France.*, *6*, 681–692.
Schlanger, S.O., and Jenkyns, H. C. (1976). Cretaceous Oceanic Anoxic Events: Causes and Consequences. *Geologie En Mijnbouw.*, *55*(3–4), 179–184.
Sigal, J. (1955). Notes micropaleontologiques nord-africaines. Du Cenomanien au Santonien. Zones et limites en facies pelagique. *Compte Rendu Sommaire Des Séances de La Société Géologique de France.*, *7*(8), 157–160.
Sliter, W. V. (1989). Biostratigraphic zonation for Cretaceous planktic foraminifera examined in thin section. *Journal of Foraminiferal Research.*, *19*(1), 1–19.
Wilson, J. L. (1975). *Carbonate Facies in Geologic History.* Springer Verlag.
Zarraq, G. A. (2021). Slope Stability Analysis of the Southwestern Limb of Kosrat Anticline in Dokan, Northeastern Iraq. *Iraqi Geological Journal*, *54*(2A), 34–48.

About the author

Abdulrahman Bamerni works as a lecturer at the Department of Geology, University of Duhok. He is a Ph.D holder in Geology (Stratigraphy), with the main interest in foraminiferal biostratigraphy across the Cretaceous-Paleogene transition. By 2022 he managed to record the meteorite ejecta spherules of the K-Pg mass event for the first time in Iraq.

e-mail: abulrahman.qasim@uod.ac

Arkan O. Sharazuri is an assistant lecturer in the Petroleum Geosciences Department, at Soran University, Erbil. He got a B.Sc. in Petroleum Geosciences in 2015 at Soran University and an M.Sc. in paleontology and stratigraphy in 2022, from Soran University.

e-mail: arkan.osman@soran.edu.iq

Bzhar A. Delizy is an assistant lecturer in the Petroleum Geoscience Department, Faculty of Science, Soran University. He was awarded his B.Sc. in geology in 2014 at Salahaddin University, M.Sc. in sedimentology and stratigraphy in 2022, from the same university, and is now a Ph.D. student at Soran University.

e-mail: bzhar.kheder@soran.edu.iq

Goran F. Hasan is an assistant lecturer in the Petroleum Geosciences Department. Faculty of Science, Soran University. He was awarded his B.Sc. in Petroleum Geosciences 2016 from Soran University, and his M.Sc. in Paleontology and Stratigraphy 2021, from Urmia University, Iran.

e-mail: goran.hasan@soran.edu.iq

Fabrizio Frontalini is an associate professor at the Department of Pure and Applied Sciences (DiSPeA) of the Urbino University (Italy) where he earned his graduate and postgraduate degrees. His main research activity with more than 190 publications, mostly focuses on benthic foraminifera for environmental and paleo-environmental reconstructions. He was awarded the “Stanislaw Geroch Memorial Grant” (2008) of Grzybowski Foundation and the “Brian O’Neill Award” (2009), “Maria Umberta Corrado Delmonte Award” (2010) by the Italian Society of Protistologists and the prestigious “Debut in Research Prize Eni Award” (2011).

e-mail: fabrizio.frontalini@uniurb.it