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

*IBGM (**2025**, Vol 21; Issue 2)* *275-304*

SEQUENCE STRATIGRAPHY AND RESERVOIR PROPERTIES OF THE EARLY MIOCENE SUCCESSIONS FROM KURDISTAN FORELAND BASIN, (N-IRAQ)

Shanga N. Abdalla[1] and Fadhil A. Ameen Lawa[1*]

[1] University of Sulaimani, College of Science. Department of Earth Sciences and Petroleum.
* Corresponding author. Fadhil A. Lawa (fadhil.ameen@univsul.edu.iq).

Type of the Paper (Article)
Received: 12/06/2025
Accepted: 18/08/2025
Available online: 27/12/2025

Abstract

The Cenozoic lithostratigraphic units are the most prolific throughout the surface and in subsurface sections, acting as hydrocarbon reservoirs, aquifers, or raw material resources in the Kurdistan region and Iraq. Recent substantial finds of hydrocarbon resources have been confirmed in the Kurdistan area of the Oligocene-Miocene succession as a carbonate reservoir target. The facies types of the Kurdistan foreland basin during the Oligocene and Miocene can be classified into two notable chronostratigraphic successions. The first prevalent facies are reefal and open marine carbonate, mainly deposited during the Rupelian and Chattian times, that extends into the Aquitanian. In contrast, the second predominant facies, deposited during the Aquitanian, Burdigalian, and Langhian ages, is distinguished by a succession of carbonates and evaporites, encompassing several formations: Hamrin, Serikagni, Euphrates, Dhiban, Jeribe, and Fatha. This study is based on core and rock bit samples, in addition to log data from four wells drilled in three blocks: Taza, Shakal, and Kor Mor. The lithofacies and microfacies have been complemented by biostratigraphic data (foraminifera) to develop the chronostratigraphic and sequence stratigraphic framework of the investigated successions. This study revealed three third-order depositional sequences. The first third-order sequence is represented by the late Chattian-lowermost Aquitanian succession, particularly the Ibrahim and/or Azkand-Anah formations. The second third-order sequence is identified by the deposits of the Euphrates Formation, marked by the absence of the Serikagni and Hamrin formations. The third (or final) third-order sequence is illustrated by the Dhiban and Jeribe formations. In the reservoirs, porosity is closely correlated with the main parasequence types, stacking patterns, and depositional system tracts of each third-order sequence. The transgressive system tracts parasequences are mostly well developed to be good reservoirs, while the High stands system tracts are less developed, with remarkable variations at the sequence boundaries.

Keywords: Biozonation; Carbonate-Evaporite Sequence Stratigraphy; Carbonate Reservoirs; Hydrocarbon Reservoir; Low Folded Thrust Zone.

ISSN 1811-4539, EISSN 3005-3714
https://doi.org/10.59150/ibgm2102a14
IBGM: http://ibgm-iq.org/
Academic Scientific Journals: www.iasj.net

1. Introduction

The study area is located in the Low-Folded Thrust Zone, specifically in Taza, Shakal, and Kor Mor (Figure 1). Understanding the properties of sequences and sedimentary facies significantly aids in the development of carbonate platforms and the distribution of reservoirs (Al-Awwad & Collins, 2013). The Miocene chronostratigraphic framework (23.03 – 5.33 Ma) in the Kurdistan region and Iraq shows high diversity in lithofacies, facies association, biofacies, depositional environments, tectonic setting, and geographical distribution. They are well known by about 15 formations, and they are Anah, Azkand, Ibrahim, Hamrin (Informal), Serikagni, Euphrates, Ghar, Dhiban, Jeribe, Fatha, Nfayil, Injana, Mukdadiya, Govanda, and part of the Suwais Group. (Koshnaw *et al.*, 2024) noted that following the Oligocene continental collision, the foreland basin on the Arabian plate changed from being underfilled with marine deposits (the proto-Zagros, which were caused by ophiolite obduction) to being filled and overfilled with mostly nonmarine clastic deposits (the Neogene Zagros, which were caused by the collision). The Miocene successions are well exposed to the surface in the Low-Folded Thrust Zone and Mesopotamian Zone, while they are less developed or mostly disappear in the High-Folded and Imbricated Zones. That is mainly controlled by the generation and evolution of the Kurdistan Foreland Basin, which was formed in the late Cretaceous as a result of the collision between the Arabian plate and Eurasia. Some of the ridges that are now part of the Imbricated zone, Balambo-Tanjero High Zagros Reverse Fault, Zagros Mountain Front Fault, and the thrust faults in the Low Folded Thrust Zone may represent the fault propagations on the surface that were there when the basin was formed in the Early Miocene (Berberian, 1995; Ibrahim, 2009; Lawa *et al.*, 2013; Fouad, 2015; Omar *et al.*, 2015; Le Garzic *et al.*, 2019). Iraq boasts three of the most significant Cenozoic reservoir groups: the reefal facies of the Kirkuk Group, the Euphrates Formation, and the Dhiban and Jeribe formations. The Early Carbonate part of the Fatha (hence it is called the Lower Fars Formation). It may also act as a reservoir occasionally (Al Naqib, 1967). The Euphrates and Jeribe formations are important oil and gas reserves; they are recorded from more than 30 structures in Iraq (Al-Ameri *et al.*, 2011; Baban & Hussein, 2016; Bamerni *et al.*, 2025; Qader & Ali, 2022). Hence, most of the oil and gas in Iraq comes from the Euphrates and Jeribe formations in most of the areas, especially those in northern Iraq (Jassim et al., 2006). (Mackertich & Samarrai, 2015) mentioned that the majority of the surface anticlinal features in Kurdistan have been drilled, but remain to be fully evaluated.

2. Materials and methods

This study is based on 24 selected core samples from the Taza blocks, including Taza wells 2 and 3, as well as approximately 120 rock bit samples from Kor Mor wells, and well log data from Shakal wells. The sample interval is mostly between 2 and 3 meters and is also controlled by the availability of the samples from the related authorities (Table 1). The inferred data have been calibrated with (Haq & Ogg, 2024), Retraversing the Highs and Lows of Cenozoic Sea Levels, in addition to updated sequence stratigraphic concepts by(Catuneanu, 2022). Some of the data have been derived from M.Sc. and Ph.D. Theiss and published articles, as well as published data by the companies.Obtaining well logs from the related authorities and from M.Sc. and Ph.D. Thesis and published articles including (Master log, Gamma Ray (GR), Spontaneous Potential (SP), Caliper (CALI), Shallow Resistivity (LLS and ILD), Deep Resistivity (LLD and ILD), Density (RHOB), Neutron Porosity (NPHI), Sonic (DT), Photoelectric (PEF). The lab work includes preparations of thin section preparation for microfacies and biostratigraphy, Routine Core Analysis, and KS Analysis for the determination of the total porosity and effective porosity.

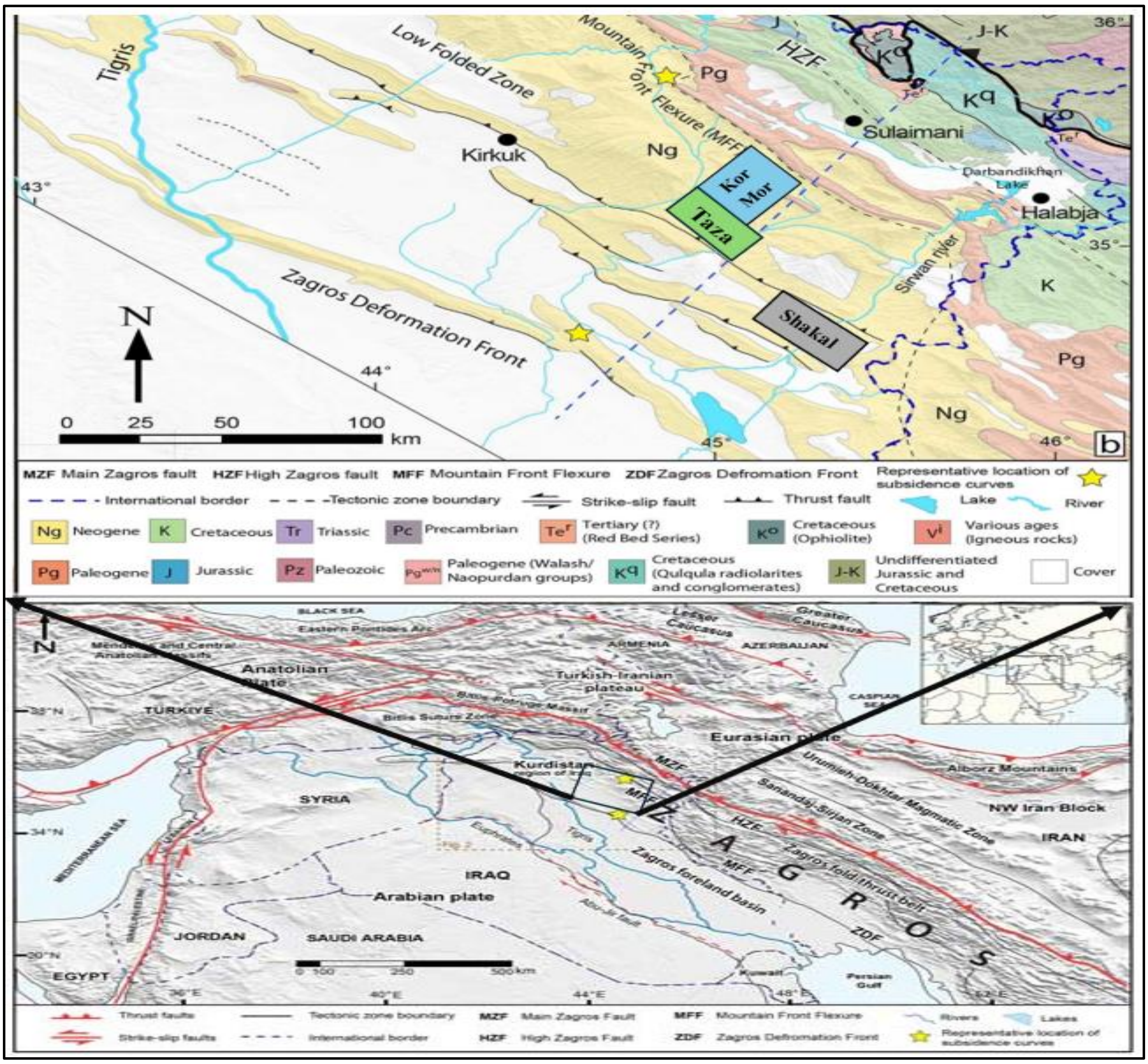

Figure 1. a. Tectonic Map of the Middle East, including Iraq, showing the main Structural Features of Tectonic Plates. b. The Study Area in the Northwestern Segment of the Zagros Fold-Thrust Belt and Foreland Basin. The Colored Boxes represent the study blocks and wells. Modified after (Alavi, 1991, Ma'ala, 2007, Kober, 2009, Lawa *et al.*, 2013, Fouad, 2015, Koshnaw *et al.*, 2017, Koshnaw *et al.*, 2024).

Table 1. Shows the recorded lithostratigraphic units in each studied well.

Studied wells	Formation	Top (m)	Bottom (m)	Thickness (m)
Well A	Jeribe	1320	1374	54
	Dhiban	1374	1388	14
	Euphrates	1388	1416	28
	Azkand	1416	1502	86
	Ibrahim	1502	1555	53
Tz-2	Jeribe	3216	3260	44
	Euphrates	3425	3453	28
Tz-3	Ibrahim	3706.3	3722.9	16.6
Well B	Jeribe	2325.6	2377.4	51.8
	Dhiban	2377.4	2505.4	128
	Euphrates	2505	2523.7	18.7

2.1. Geological setting

The studied area is characterized by subdued relief and low topography within the Low Fold Thrust Zone of the Western Zagros Fold Thrust Belt (Lawa *et al.*, 2013), which is also referred to as the Low Folded Zone (Fouad, 2015). The vast, exposed Neogene Evaporites and clastic sediment column (many exceed 4000 meters) covered and sealed the Miocene and Oligocene Prolific reservoirs. This zone reflects the propagation history of the collision between the Arabian and Eurasian plates, which reached its culmination during the Miocene and Pliocene collision (Ibrahim, 2009; Koshnaw *et al.*, 2017) (Figure 2). The major anticlines series are of an echelon pattern and separated by very wide synclinal structures and mostly represent fault-propagated folds, which act as an important Hydrocarbon trap *(Ameen et al., 2020; Farouk et al.*, 2023; Lawa *et al.*, 2013; Zebari, 2013). The new exploration phase during the last 20 years has improved the enrichment of this zone with good gas and oil potential. The research area is considered a part of the Hemrin-Makhul subzone, which is part of the Low fold thrust zone (Buday, 1980). Due the fact that each block has its specific geological setting, therefore below short description of each block.

2.1.1. Taza block

This block is situated west of the Qadir Karam sub-district in the Garmian region, spanning part of the Nawjul district. It covers 700 square kilometers and boasts a sizable gas concentration along with an estimated 3 billion barrels of oil reserves. Oil Search (Australia). The Kor Mor Block forms its northern boundary, while the Topkhana Block forms its southern one. The selection of this block is based on a structural tendency whereby the giant creates the Sarqala Field to the southeast and the Jambur Field to the northwest. Drilled back in 2013, the first well (Tz-1) was managed by PNG Oil Search business from which the business revealed a proven discovery of 38°API oil, together with associated gas in Jeribe/ Dhiban and Euphrates formation and / Kirkuk Group. Located 10 km north-west of the discovery well Tz-1, Tz-2 was drilled in 2014 to evaluate the hydrocarbon-bearing zones identified by Tz-1. The well penetrates additional Cenozoic and Cretaceous layers, with the Shiranish Formation being among the Cretaceous formations examined. Taza 2 is 10 km northwest of Taza 1 and has achieved a total depth of 4,200m in the Oil search website (Mackertich & Samarrai, 2015).

2.1.2. Shakal Block

covers the areas of Kalar, Rizgari district, and Kefri district in the Garmian area; it has 832 square kilometers and almost 2 billion barrels of oil. It sits on the southeast fairway of the large Zagros Fold Belt in Kurdistan, approximately southeast of the Pulkhana field, which has proven and probable oil reserves. Research suggests that the Pulkhana construction might reach the Shakal Block (Mackertich & Samarrai, 2015; Yakymchuk *et al.*, 2023; Figure 2).

2.1.3. Kor Mor block

It is in northeastern Iraq and is the southeast extension of the Kirkuk Field, separated by a saddle about 20 kilometers long. The field is located 35 kilometers southeast of Kirkuk City and about 8 kilometers southwest of Qadir-Karam Township. The gas presence in the Jeribe Formation, traditionally called the Main Limestone, was confirmed by the well (Mackertich & Samarrai, 2015).

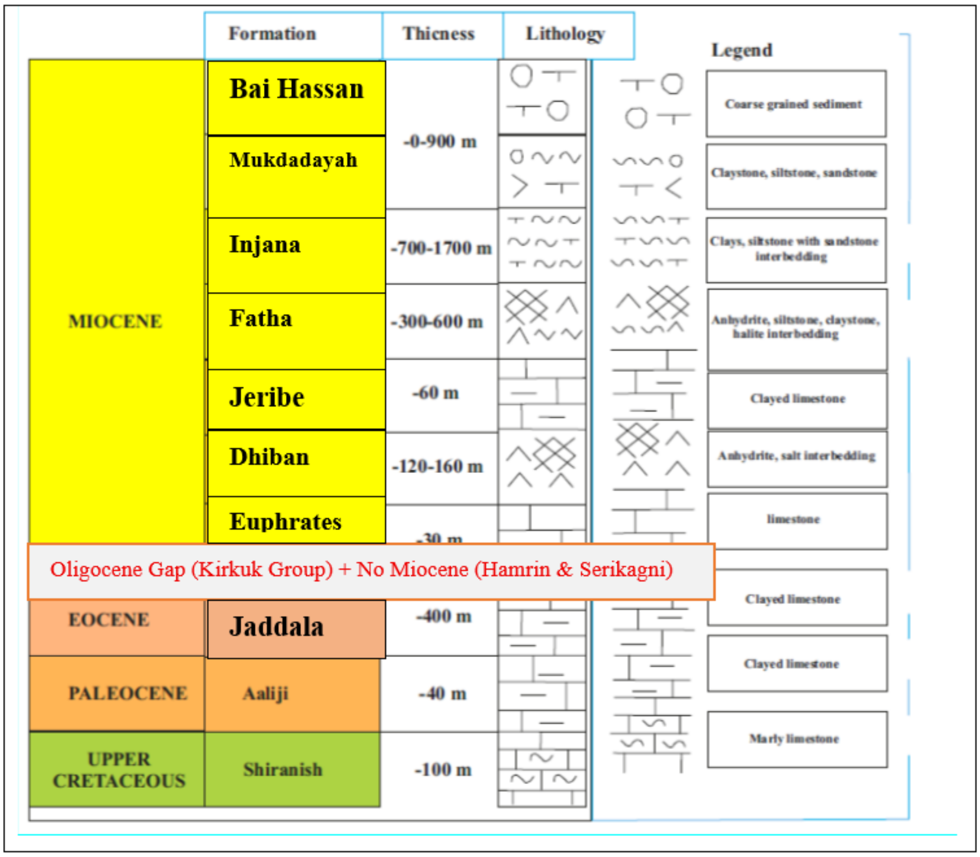

Figure 2. Lithology and stratigraphy of Shakal block modified after (Yakymchuk *et al.*, 2023).

3. Lithostratigraphy

The Cenozoic lithostratigraphic column shows variations in facies types, thickness, and depositional environments from the High Folded -Thrust zone and Low Folded Thrust zone, including the study area (Ameen *et al.*, 2020; Aqrawi *et al.*, 2010; Farouk *et al.*, 2023; Stevanovitic *et al.*, 2003; Van Bellen *et al.*, 1959). Recently, the Late Oligocene- Early Miocene sequences have been proven to be an important carbonate reservoir in the Kurdistan region (English *et al.*, 2015; Mackertich & Samarrai, 2015) (Figure 3). The obvious turnover from a predominated reef-related carbonate factory (represent by Kirkuk Group) to a lagoonal carbonate and evaporite Factory (Euphrates – Dhiban and Jeribe formations) started at the Early Miocene, and more precisely at the Early Aquitanian. It marks an important segment in the geological history of the Low folded-thrust zone. To understand such variations, we must recognize the basin type paleogeography, the sea level changes, accommodation space, tectonic unrest, and sediment supply (Farouk *et al.*, 2022; Lotfy *et al.*, 2025).

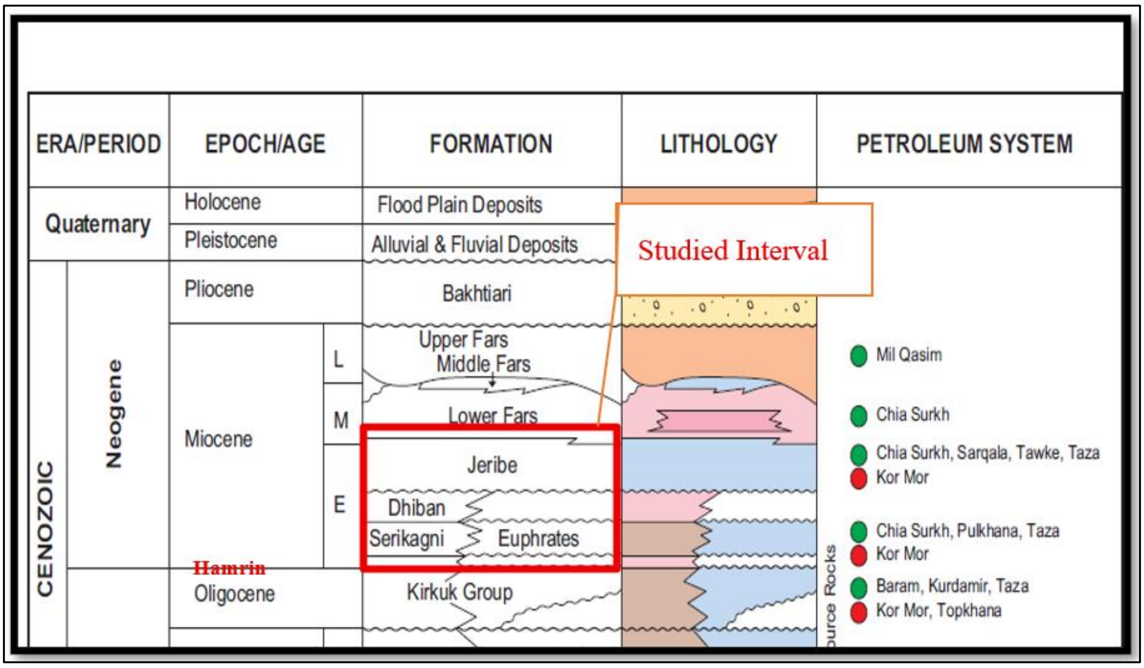

Figure 3. Show the generalized stratigraphic column of the Oligocene – Neogene and hydrocarbon (English *et al*., 2015).

The basin type is considered to be a foreland basin (Numan, 2000), named as Kurdistan Foreland Basin (Lawa, 2018), and shows progressive evolution since the Late Cretaceous up to recent times (Farouk *et al.*, 2023; Al-Qayim, 2024). Recently, Haq & Ogg. (2024) postulated a new sea level curve that also takes into consideration those variations in the Kurdistan region, including the studied area. The tectonic unrest has been clarified by (Koshnaw *et al.*, 2017; Al-Qayim, 2012; Zebari, 2013; Le Garzic *et al.*, 2019), and manifested that the Miocene successions in Kurdistan are mostly affected by the Zagros Mountain uplifting and tectonic unrest. In this work, the facies types of the Kurdistan foreland basin, during the Oligocene and

Miocene, are categorized into two important chronostratigraphic frameworks. The first group is well known as the predominant Reef carbonate facies of the Kirkuk Group, which extends in age from Early Oligocene (Abid, 1983; Muhammed, 1983; Al-Banna, 2008; Al-Hashimi & Amer, 1985; Al-Qayim, 2006; Van Bellen *et al.*, 1959). The second stratigraphic succession is the Early Miocene predominated lagoonal Facies and well known by (Serikagni, Euphrates, Dhiban, Jeribe and Fatha formations. (Liu *et al.*, 2017) proposed Euphrates Group (informal nomenclature), to cover the above mentioned Early Miocene lithostratigraphic units. The Oligocene/ Miocene boundary is of high stratigraphic and sequences stratigraphic importance, therefore, its worthy to place that chronostratigraphic boundary in the lithostratigraphic recorded precisely taking in consideration all recent studies using large benthic foraminifera and isotopic studies like (Ameen Lawa & Ghafur, 2015; Kharajiany, 2014; Ameen *et al.*, 2020; Ghafor & Ahmad, 2021; Ameen, 2022; Al-Qayim, 2024; Al-Hussiny & Al-Dulaimi, 2024). The basin was shaped by the "Savian" Tectonic activity during the Early-Middle Miocene, according to lithostratigraphic viewpoints. The recorded lithostratigraphic units in the studied wells are clarified below from the oldest to the youngest, (Figure 9) shows the lithostratigraphic correlation of the Lower Miocene successions in the studied wells (Well-A, Tz-2, Tz-3, Well-B). The reactivation of the blind thrust fault, leads to the segmentation of Miocene foreland and controls the paleogeography of the basin as well s the nature of the facies distributions (Farouk *et al.*, 2023). A erosional unconformity connects the Late Oligocene and Early Miocene borders (Karim *et al.*, 2014), (Sissakian *et al.*, 2016). Such gaps and discontinuities with facies changes, almost considered as diagnostic features, and marked the lithostratigraphy of the studied wells (Figure 4). Below description of the recorded lithostratigraphic units from oldest to youngest:

3.1. Ibrahim Formation

The thickness of this section was approximately 18 meters. It was researched in the (Well-A, Tz-3) formation and was mostly composed of argillaceous and fossiliferous limestone, with a high concentration of planktic foraminifera. They consist mainly of globigerina marly limestone, occasionally with glauconite green grains and pyrite concretions. They mostly indicate a basinal to offshore environment (Al-Banna & Al-Mutwali, 2002; Al-Hashimi & Amer, 1985; Jassim & Goff, 2006; Figure 3). The dominant microfacies are planktic mudstone and wackestone, which occasionally transition to packstone microfacies. Among the predominant planktic foraminifera are abundant (*Globorotaloides*, *Globigerinoides, Paragloborotalia* sp, *Globorotalia,* and *Globigerina* sp.). The age is estimated to be late Oligocene Rupelian to Lower Aquitanian. Based on the planktic foraminifera, the fossil data *Globorotalia kugleri* and *Globigerina binaiensis* indicate the Late Oligocene – Miocene age. This unit is well known in Iraq as a basinal facies of the last cycle in the Kirkuk group (Abdulrahman & Awadh, 2021).

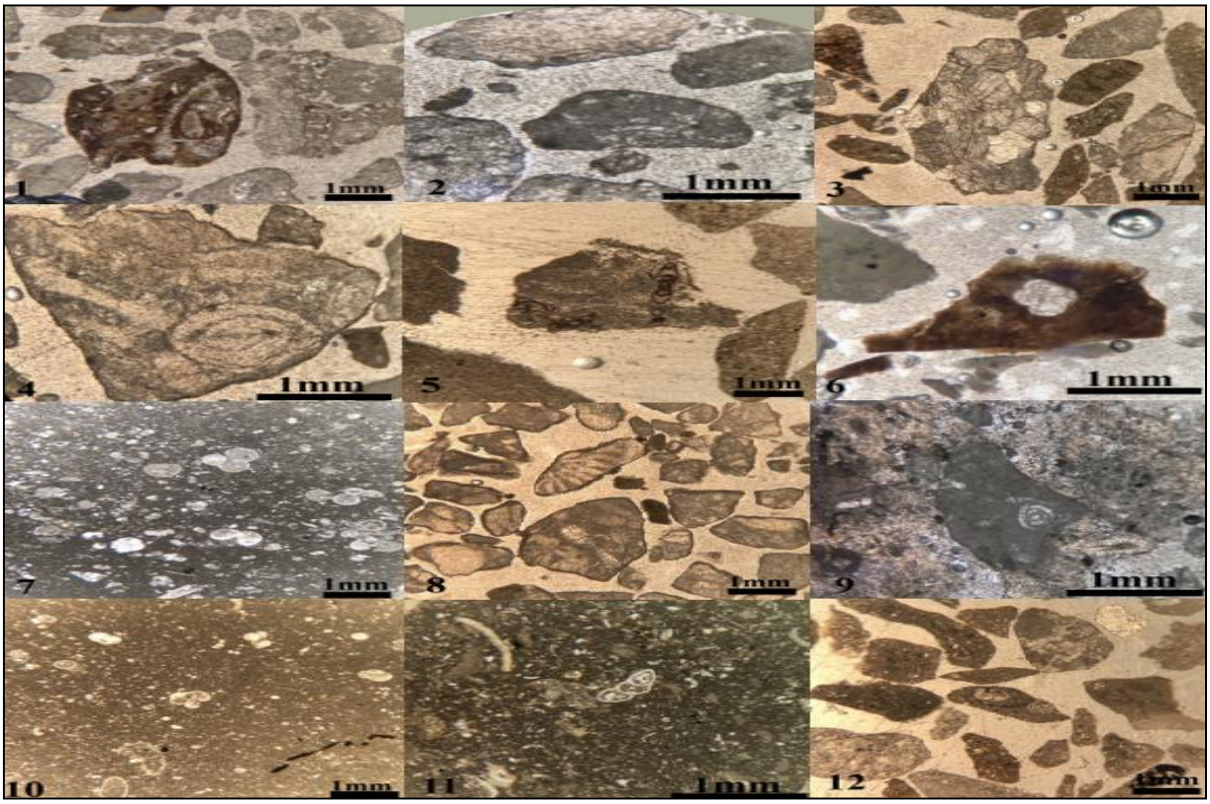

Figure 4. (1) Extraclasts rudstone submicrofacies. (2) *Miliolids*, packstone microfacies. (3) *Gastropoda* affected by the partial recrystallization process. (4) *Lepidocyclina-Nummulitids* packstone- grainstone submicrofacies. (5) packstone to Grainstone microfacies bearing *Dendritina rangi*, *Miliolid* sp. (6) *Globigerina ciperoensis*. (7) Bioclast *foraminifera* wackestone to packstone. (8) *Nummulitids* packstone- grainstone submicrofacies. (9) *Triloculina trigonula*. (10) *Planktic foraminifera* wackestone to packstone. (11) Bioclast *foraminifera* wackestone to packstone. (12) *Planktic foraminifera* packstone to Grainstone microfacies.

3.2. Azkand Formation

Consists of massive limestone rocks, dolomitized and recrystallized limestones, and is known for its high porosity. The Formation is a key component of the reef-fore reef sequence and shows variation in thickness from the depocenter to the paleoshoreline (Buday, 1980). Respectively, the lower contact stratigraphically conforms with the Ibrahim Formation and is Unconformable with the Anah Formation. The following Large benthic foraminifera assemblage has been recorded by Van Bellen *et al.* (1959). In these assemblages: Miogypsinoides complanatus (Schlumberger), *M. dehaartii* (Van der Vlerk), *M. grandipustulus* Cole, *Heterostegina antillea* Cushman, *Lepidocyclina* (*Nephrolepidina*) *morgani* Lemoine, *Nummulites vascus* Joly & Leymerie, *Rotalia viennoti* Greig, *Austrotrillina howchini* (Schlumberger), *A. Paucialveolata* Grimsdale, *Miliolids*, Algae. The abundance of the large benthic foraminifera, including *Lepidocyclina eulepidina*, *nephrolepidina* with packstone textures and bioclastic textures, almost points to outer ramp depositional environments.

3.3. Euphrates Formation

This unit comprises dolomitic limestone, vuggy dolostone, and dolostone with anhydrite. The common larger benthic foraminifera are: (*Miliolids and Peneroplids*, *Austrotrillina* sp., *Austrotrillina paucialveolata*). From the depth of (1400 – 1430) m in Well-A, diagenesis is very effective and destroys most of the fossils, and it appears just like a ghost, as well as with the indication of bitumen in the upper parts. The Formation is underlain unconformably by the Azkand Formation, while its upper boundary is sharp and shows an irregular surface with the Evaporites of the overlying Dhiban Formation. This unit shows variation in thickness in the Kor Mor Field, which ranges between 30 and 60 m in wells KM-2, 3, 7 (Qader & Ali, 2022). The sub-conglomeritic units in the lower part, as in the type of section, are not recognized in this study, while a few Evaporite nodules are recorded in the upper parts**.** Previous studies of (Alkhaykanee & Al-Dulaimi, 2019) considered a Lagoonal depositional environment for this unit.

3.4. Jeribe Formation

It's about (54) meters thick, extending between depths of (1320 – 1374) meters in well-A. Its successions consist of limestone, Vuggy dolomitic limestone, and vuggy dolostone, with a few anhydrites. The carbonate unit is occasionally fossiliferous and characterized by porcelaneous wall foraminifera, mainly *Miliolids* and *Peneroplis* represented by *foraminifera* like *Austrotrillina* sp., *Austrotrillina howchini*, *Miliolids*, *Pyrgo*, *Quinqueloculina* sp, *Dendritina rangi*, *Spiroloculina* sp., *Peneroplis* sp., *Peneroplis evolutus*, *Peneroplis thomasi*, *Ammonia* spp., *Rotalids, Triloculina, Borelis melo curdica.*

4. Biozonation

This work is only based on the important biozones (Figures 5, 6, 7, and 8), and they are from the oldest to youngest (Figures 5 and 8):

4.1. Globigerinoides primordius Partial – Range Zone (GP).
4.2. Catapsydrax dissimilis Partial -Range Zone (CD).
4.3. Miogypsinoides complanatus Total Taxon -Range Zone (MC).
4.4. Miogypsina globulina Total – Range Zone (MG). (Figure. 6)
4.5. Borelis melo melo biozone (BMM).
4.6. Borelis melo curdica biozone (BMC).

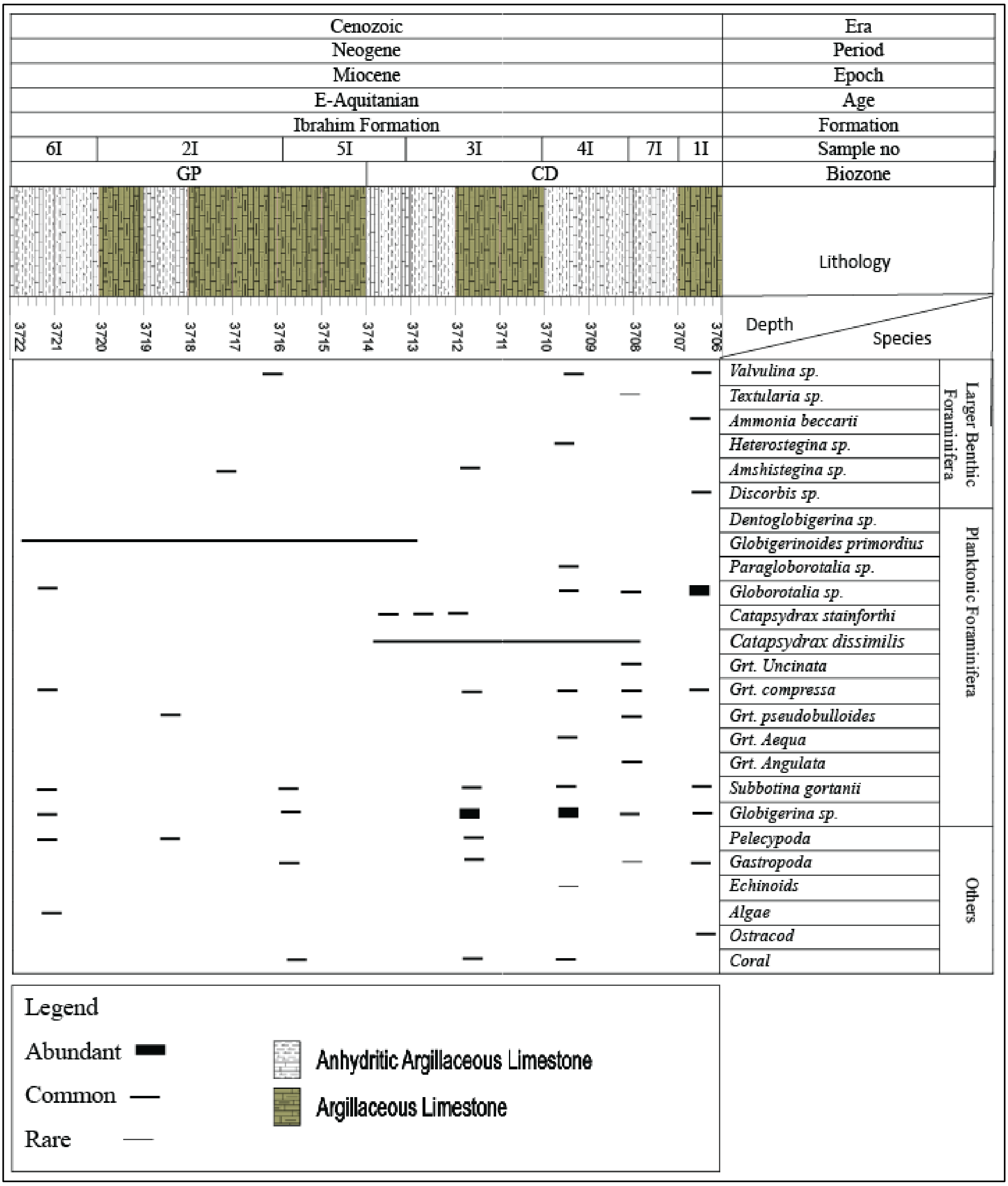

Figure 5. Biostratigraphic distribution chart of the E- Aquitanian of Ibrahim Formation in the Tz-3 Well.

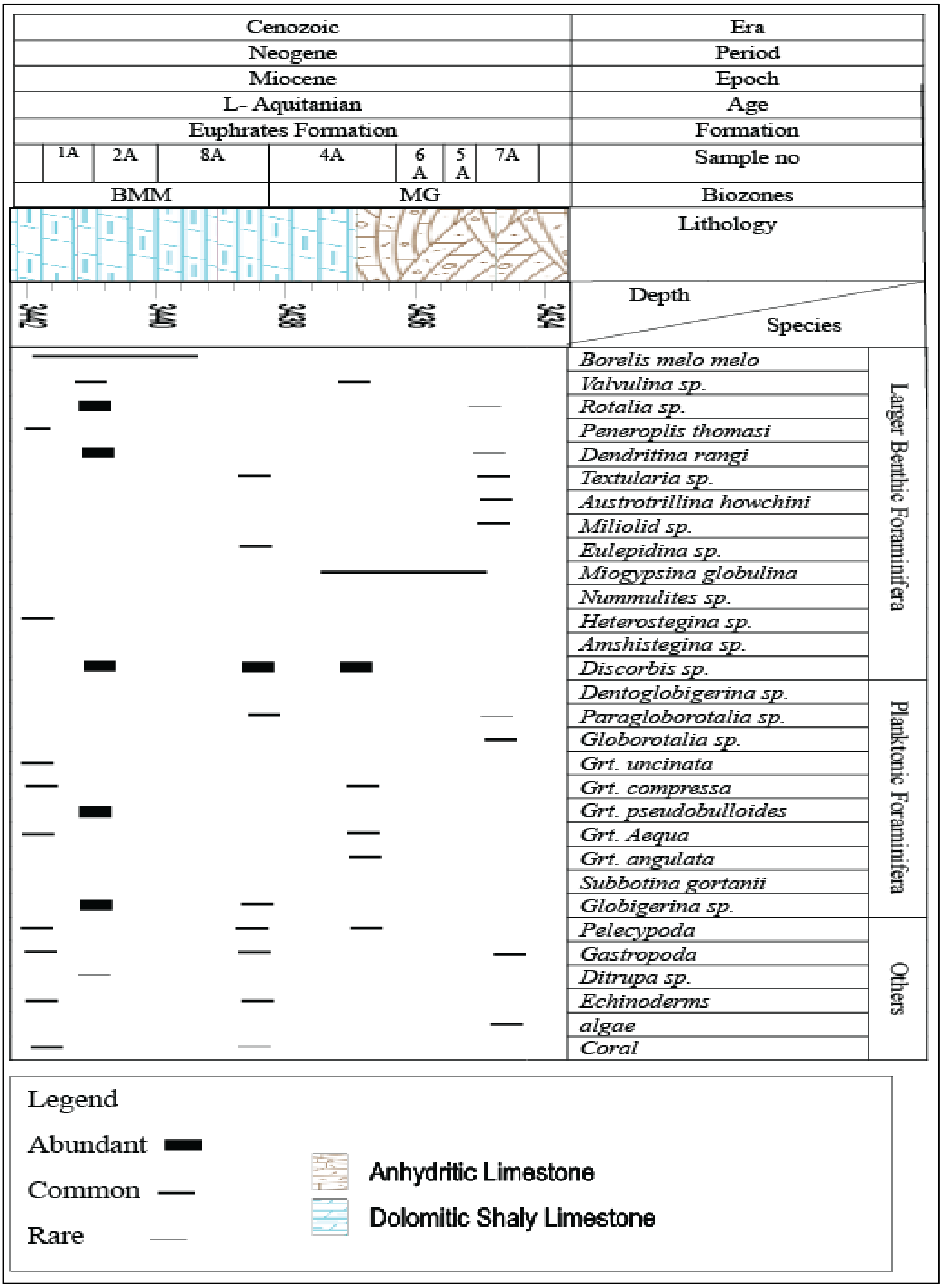

Figure 6. Biostratigraphic Distribution chart of the L- Aquitanian Euphrates Formation in the Tz-2 Well.

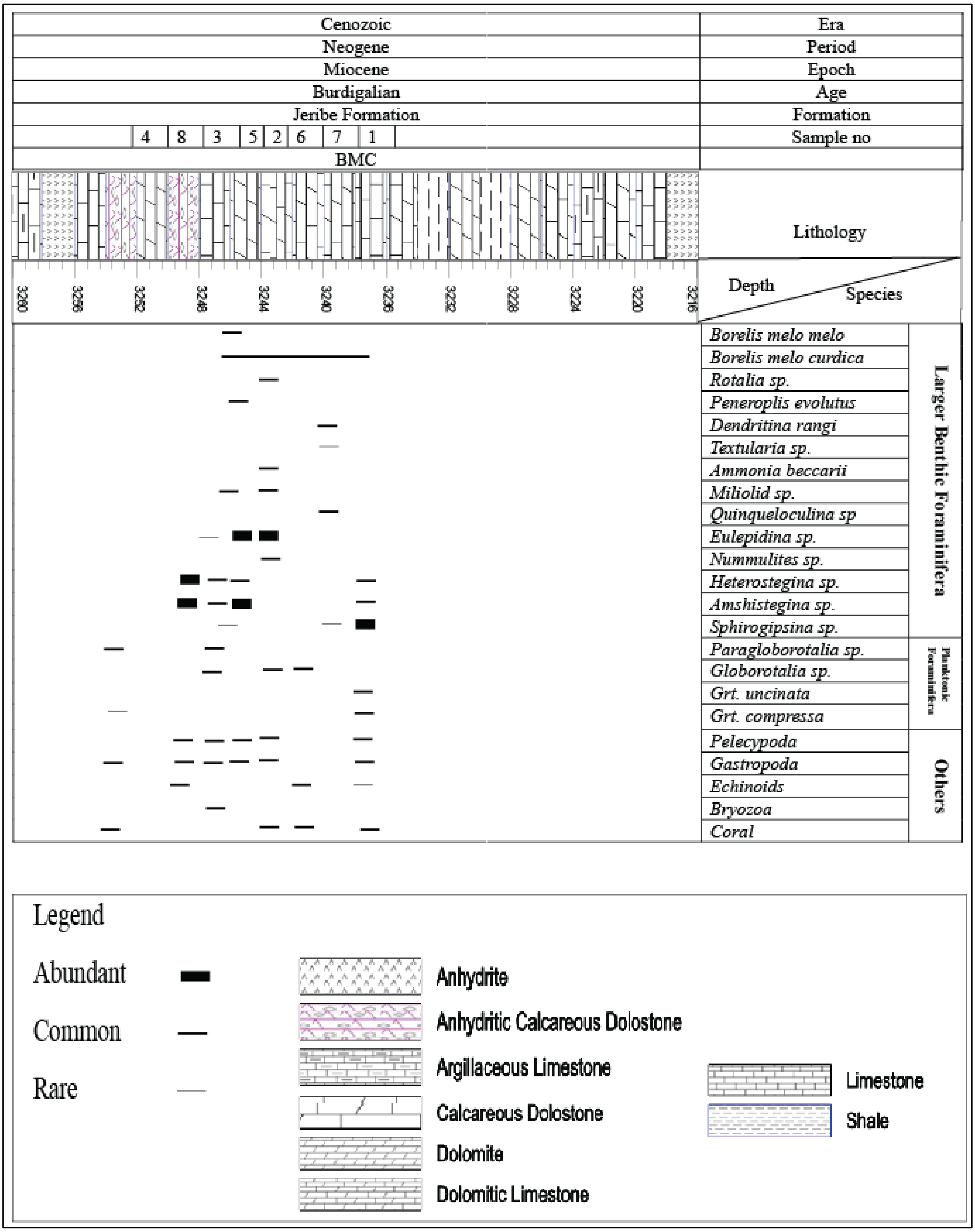

Figure 7. Biostratigraphic Distribution chart of the L- Aquitanian of Jeribe Formation in the Tz-2 Well.

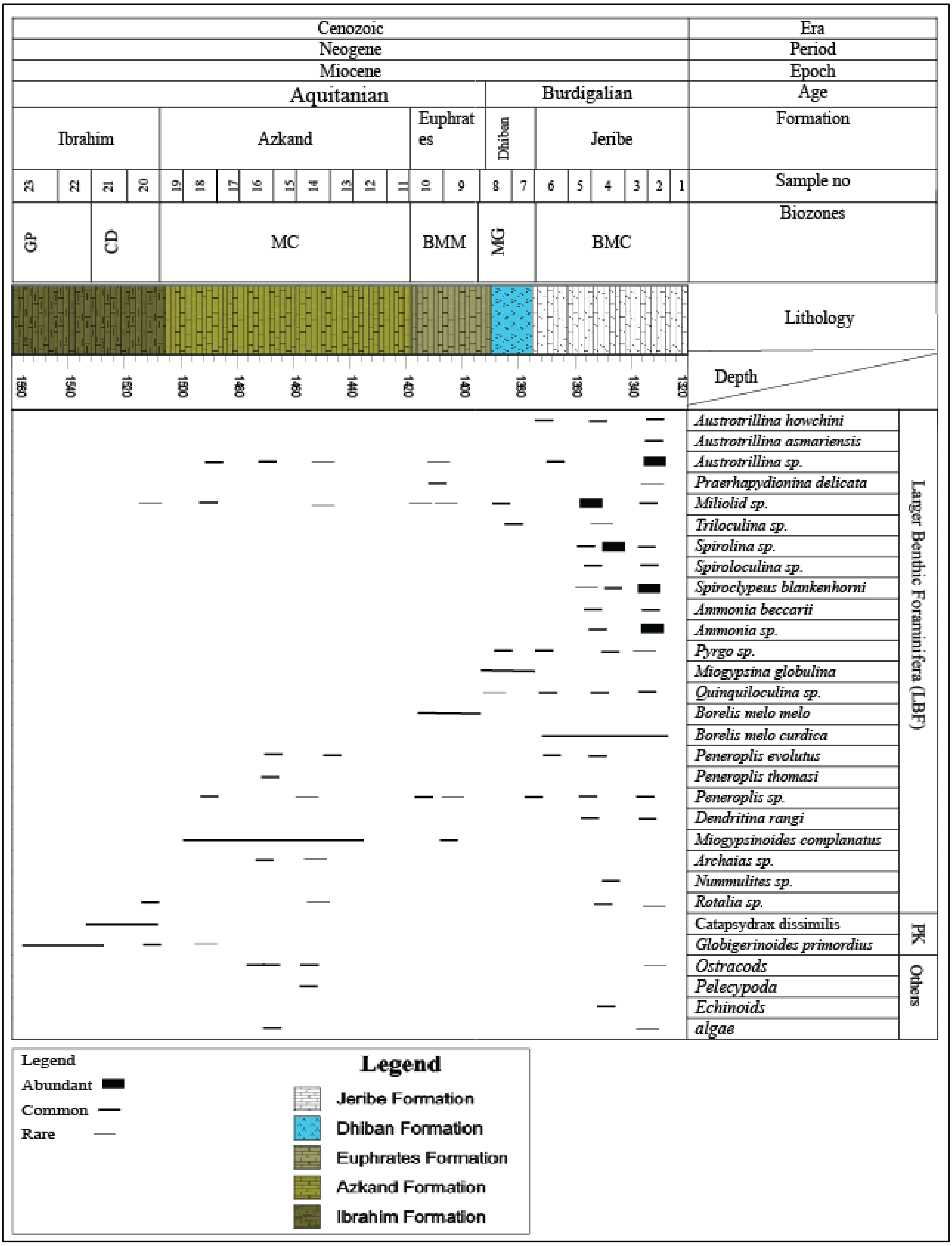

Figure 8. Distribution chart of the Lower Miocene foraminiferal species in the Well-A.

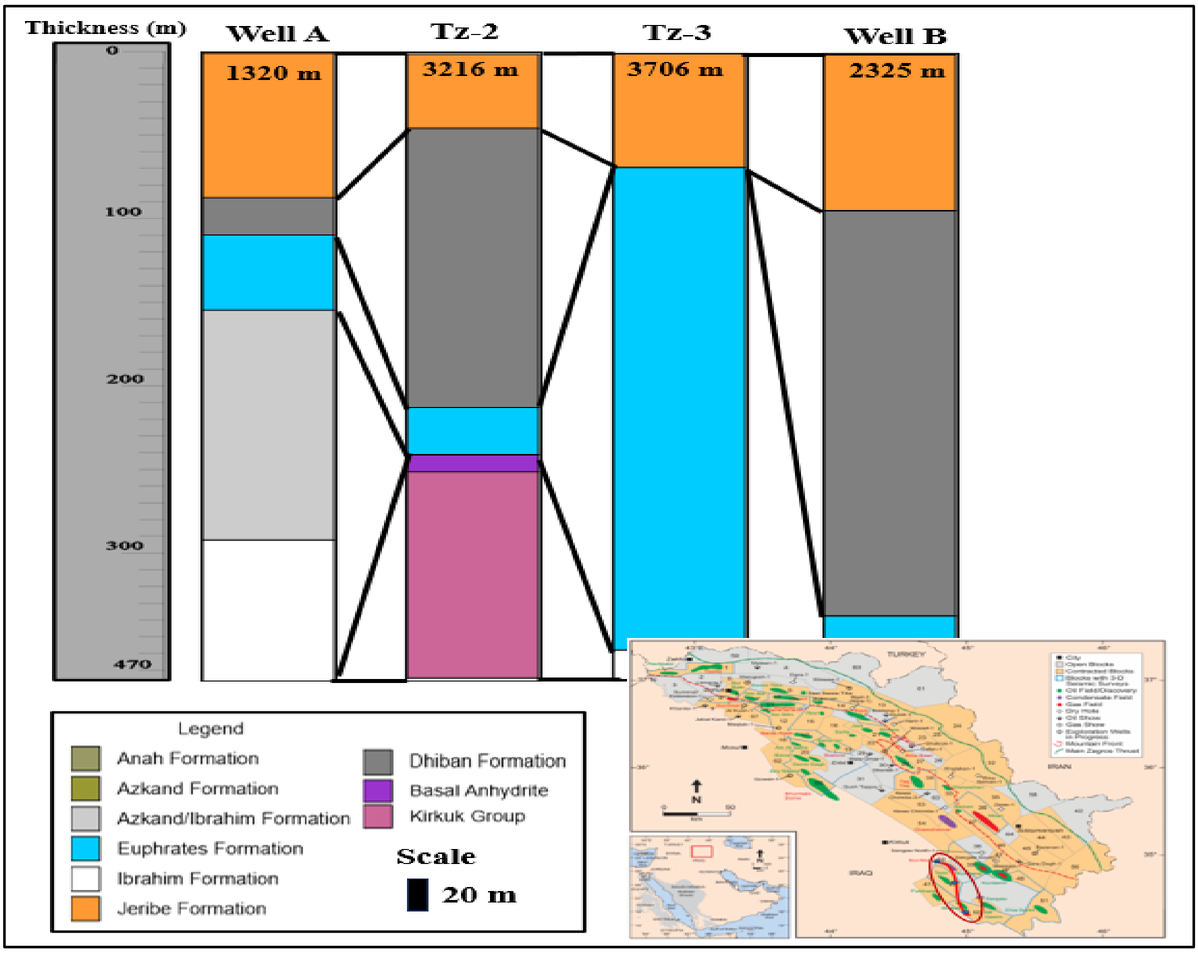

Figure 9. Lithostratigraphic correlation of the Lower Miocene successions in the studied wells (Well-A, Tz-2, Tz-3, Well-B).

5. Sequence Stratigraphy

A stratigraphic unit characterized by subaerial unconformities was initially proposed as a "sequence" in (Sloss *et al.*, 1949). Seismic stratigraphy began to take shape in the 1970s through the work of his student (Vail *et al.*, 1975) and was further developed alongside global sea-level cycles by (Vail, 1977). Over time, it has transformed into sequence stratigraphy, which links well logs, cores, and outcrops, and is seen as a groundbreaking approach in geosciences. Almost three schools have introduced the classical school or depositional system (Haq *et al.*, 1987; Mitchum, 1977; Posamentier *et al.*, 1988), the second is the genetic sequence stratigraphy (Frazier, 1974; Galloway, 1989), and the third is the transgressive regressive T-R Sequences (Embry, 1993). The conceptual packaging of strata into sequences, or the location of sequence borders in the rock record, is the fundamental point of disagreement among the different sequence stratigraphic theories (Catuneanu, 2019, 2022). All conventional units of sequence stratigraphy (depositional systems, systems tracts, and sequences) can be distinguished using stratal stacking patterns. Sedimentary deposits were formerly classified into six hierarchical orders based on temporal and spatial distribution (Zachos *et al.*, 2001). In Iraq and Syria, carbonate sedimentation in the Jeribe Formation was suppressed due to rapid deposition and plugging of accommodation space by anhydrite-dominated sabkha cycles with halite deposited locally in the center of the shallow, saucer-like basin (Sharland, 2001). In this study, the important recorded cyclicity between Evaporites and Non Evaporites succession in the Aquitanian– Langhian ages has been considered as important sequence generation, evolution, and termination with respect to sea level changes, restriction or opening of the basin, and the influence of the tectonic unrest, which segmented the basin into isolated or semi-isolated lagoons. The first evaporite succession represent by the Hamrin Formation (Ahmad & Al-Eisa, 2003). This evaporite is not recorded in this study. Nevertheless, they are usually underlain Serikagni Formation and overlain by the Kirkuk Group. The second important evaporite cycle represent by the Dhiban Formation (Henson, 1950 in Van Bellen *et al.* 1959), which is about 10 – 50 m thick and consists of evaporites, mostly anhydrites and alternated or staggered with dolostone and dolomitic limestone occasionally. This unit marks the Burdigalian boundary and indicates another sea level fall (Liu *et al.*, 2009; Liu *et al.*, 2010). The third and last evaporite cycle Represent by thick evaporites (Rock salt, anhydrite, and gypsum) that alternate with carbonates and siliciclastic, and is related to the Fatha Formation and overlying the Jeribe Formation unconformably. They represent the last marine facies in Iraq and the study block, which overfills the Kurdistan Foreland basin, and mostly acts as a seal for most of the hydrocarbon fields. Four major elements interact to determine the stratigraphic sequence and the depositional systems that comprise it: tectonic subsidence, eustacy, amount of deposited sediments, and climate. From the tectonic point of view the Miocene successions studied are mostly influenced by the tectonic unrest within the Kurdistan foreland basin. The reactivation of the blind faults (Lawa *et al.*, 2013) play important role in the segmentation of the foreland basin. The eustatic sea level change, as mentioned by that the relative magnitude of the sea-level falls at the SBs are as follows: Major >75 m; Medium 25 – 75 m; Minor < 25 m. The Aquitanian has two major sea-level fall events, interrupted by a minor one, which is also recorded in Kurdistan by (Ameen Lawa & Ghafur, 2015). During the Burdigalian time, two medium and two major seas fall. Have been recorded. It’s important to mention that within shallow Marin conditions, as in the study succession, the minor fall plays an important role in such facies variations too. The interplay between evaporite and non-evaporitic conditions may reflect also drier climatic conditions in addition to more restrictions of the lagoonal basin. Considering the above-mentioned factors, as well as the facies types and the nature of the Sequence boundaries, Transgressive and regressive surface, maximum flooding surfaces, staking patterns and depositional system types. The studied succussion can be categorized into one second order deposits that indicates the Neogene and Tectonic Megasequence Ap. 11 and can be classified into three third order 3 (3^{rd}) depositional sequences, that is based on core, well logging, and thin-section observation. Below are short notes about each of the three third orders:

5.1. First Third order deposition system (KG- DS.1)

This cycle for this work is represented in the Taza oil field, which consists of the Ibrahim and Azkand formations in Taza Well 3. The lower boundary of this cycle is not recognized in this study; therefore, it is considered as an incomplete third-order depositional sequence, where its Low stand system tract (LST) and lower Sequence boundary are not recognized. This depositional system starts with a new transgression by the end of Chattian and is characterized by the deposition of a deep open marine deposit consisting mainly of marl, marly limestone, and shale, rich in planktic foraminifera of the Ibrahim Formation. The alteration of marl and marly limestone manifests the parasequences of the lower part of this succession and almost indicates that deeper facies overlain the relatively shallower facies and pointing to the increase of the available accommodation space. The Planktic mudstone and wackestone microfacies almost refer to deep marine and quiet water sedimentation (Flügel & Munnecke, 2010). Accordingly, a retrogradational stacking pattern characterized the Transgressive system tract (TST), where progressively the planktic wackestone and Mudstone facies overlies the bioclastic packstone. The progressive deepening of these facies reaches its maximum depth when a condensed section of Planktic foraminifera, associated with Glauconites and pyritic concretion, is recognized in the upper parts of the Ibrahim Formation. Therefore, this surface can also be used as a good indication for the Maximum Flooding Surface MFS deposited as retrograditional (HST) parasequence (Figure 10). This maximum Flooding surface at 23.8 Ma (Haq & Ogg, 2024) and placed near the middle of the sequence of Chattian age as fine-tuned to be at the onset of the warmest (lowest $\delta^{18}O$) peaks in the curve of (Westerhold et al., 2020). This event has been recorded from Belgium, the Pannonian Basin, the New Jersey margin, and potentially also in Kurdistan (Haq & Ogg, 2024; Ameen Lawa & Ghafur, 2015). Hence, in this study, it is recognized in the upper parts of the Ibrahim Formation and within the Zone rich in planktic foraminifera and represent by several species of *Catapsydrax*, *Globigerinoides*, *Globorotalia*, *Globoquadrina*, and *Globigerina*. The fine micrite ground mass *is* embedded with skeletal grains of planktic foraminifera like *Globigerinids* and *Globorotalids* with deep benthic foraminifera. The high stand system tract HST of this third order represent by an Aggradational staking pattern of predominated Planktic foraminifera, especially *Paragloborotalia kugleri* and *Globigerina binaiensis,* within the marly limestone Aquitanian age. The sea level fall occurred, and the late High stand system is represented by the disappearance of the planktic foraminifera and appearance of Large benthic Foraminifera, such as *Miogypsionodes complanata*, within the Azkand Formation. The bioclastic packstone and grainstone microfacies predominated as our ramp facies association. Such microfacies predominated within a limestone-dominated succession and were characterized by a progradational stacking pattern, where shallow facies overlain deeper facies relatively. The upper boundary of the Third order is placed on the erosional surface between the Azkand and Euphrates formations. No indication for an incised valley for Sequence boundary type one, therefore it is considered as a sequence boundary of Type two.

5.2. Second third order (EUP-DS.2)

This depositional system is characterized by the disappearance of the Hamrin and Serikagni formations within the lower parts and by reduced thickness of the recorded lithostratigraphic unit of the Euphrates Formation (Figure 11). The lower sequence boundary can be considered as a gap in the depositional trend, when neither the Hamrin Formation nor the Serikagni Formation has been recorded in the Lower Sequence boundary of type one. Hence, no incised valley deposits have been recorded, but the Gap manifested by facial change and foraminiferal biozones. The erosional surface is recorded between the Azkand and Euphrates formations. The maximum folding surface can be recognized in this order within the lats deep marine facies of the Serikagni and Euphrates formations, and represent the maximum flooding surface Ng 10 MFS (Sharland, 2001; Sharland *et al.*, 2004). The deepest and last open marine facies in Kurdistan and Iraq have been recognized from this unit, which is only recognized from well log data in the Shakal well. Accordingly, the deeper facies of the Euphrates Formation in Kor Mor wells and in Taza wells, which can be considered as the equivalent of this MFS. Hence, this order of short depositional time with higher erosional rates. Therefore, the depositional parasequence and stacking patterns show remarkable variations from the NE part of the study area (Kor Mor) to the SW part of the Shakal block. The influence of the uplifting due to reactivations of the blind thrust faults controls, such as the Paleofacies distribution and gaps. However, the lower part of the Euphrates shows a retrogradational staking pattern when deep facies overlain Shallow facies, which indicates the Transgressive system tract. The maximum flourishing of the *Miogypsina globulina* and *Borelis melo melo* can be considered as the marker for the Ng 10 MFS (Sharland *et al*., 2004; Haq & Ogg, 2024). The high stand system tract is represented by the aggradational staking pattern, where the same facies overlain each other until the late HST part, where the shallower facies, like oolitic and gastropods bioclastic of intertidal conditions, overlain the previous sessions. The termination of this order is placed at the top of the fossiliferous limestone and dolomitic limestone of the Euphrates Formation and the base of the thick evaporites a of the Dhiban Formation.

5.3. Third-order Depositional system (DJ-DS.3)

The third-order DJ, DS started with a new Transgression during the Burdigalian, which is almost capped by a sequence boundary type one and is well known in Kirkuk Embayment as basal Fars Conglomerate & marks the sea level fall and Tectonic unrest (Koshnaw *et al.*, 2019; Koshnaw *et al.*, 2024) (Figure 12). The Second Miocene Evaporites are represented by the Dhiban anhydrites and dolostone can be considered as part of the Initial stage of the new transgression of this third order, and more points to the closure of the basin and reductions in the accommodation space associated with dry-warm climatic changes, where all previous Rotalids, Miliolids, and Soritoides of the lagoonal facies have been totally disappeared. The progressive transformation from the Dhiban Anhydrite to the lagoonal facies associations of the Jeribe Formation manifested the sea level rise during the Burdigalian. Therefore, relatively deeper lagoon facies, which superimposed the Shallow intertidal – Supratidal facies of the Dhiban Anhydrites. The transgression phase reaches its Maximum Flooding Surface with a remarkable increase in the benthic foraminifera, like *Borelis melo curdica*, *Dendritina* sp., *A*mphistegina sp., *Archaias* sp., *Peneroplis farsensis*, *Peneroplis* sp., *Triloculina* sp., *Spiroloculina* sp., and *Ammonia* sp. They are recognized within dolomitized lime mudstone and wackestone facies. Such a maximum abundance of those benthic foraminifera indicates the Burdigalian maximum flooding surface within the middle part of the Jeribe Formation, Burdigalian NBu-19-5 Ma. Based on the (Haq & Ogg, 2024) curve. Towards the top of this succussion is a notable sea level fall was indicated when intertidal facias are predominated and characterized by the predominance of Pelecypod, gastropod as bioclastic packstone and grain stone fcaies the upper part of the Jeribe Formation and point to the late stage of the High stands system trcat and capped by basal Fars conglomerate which is marked as sequence boundary of type one below the Fatha Formation.

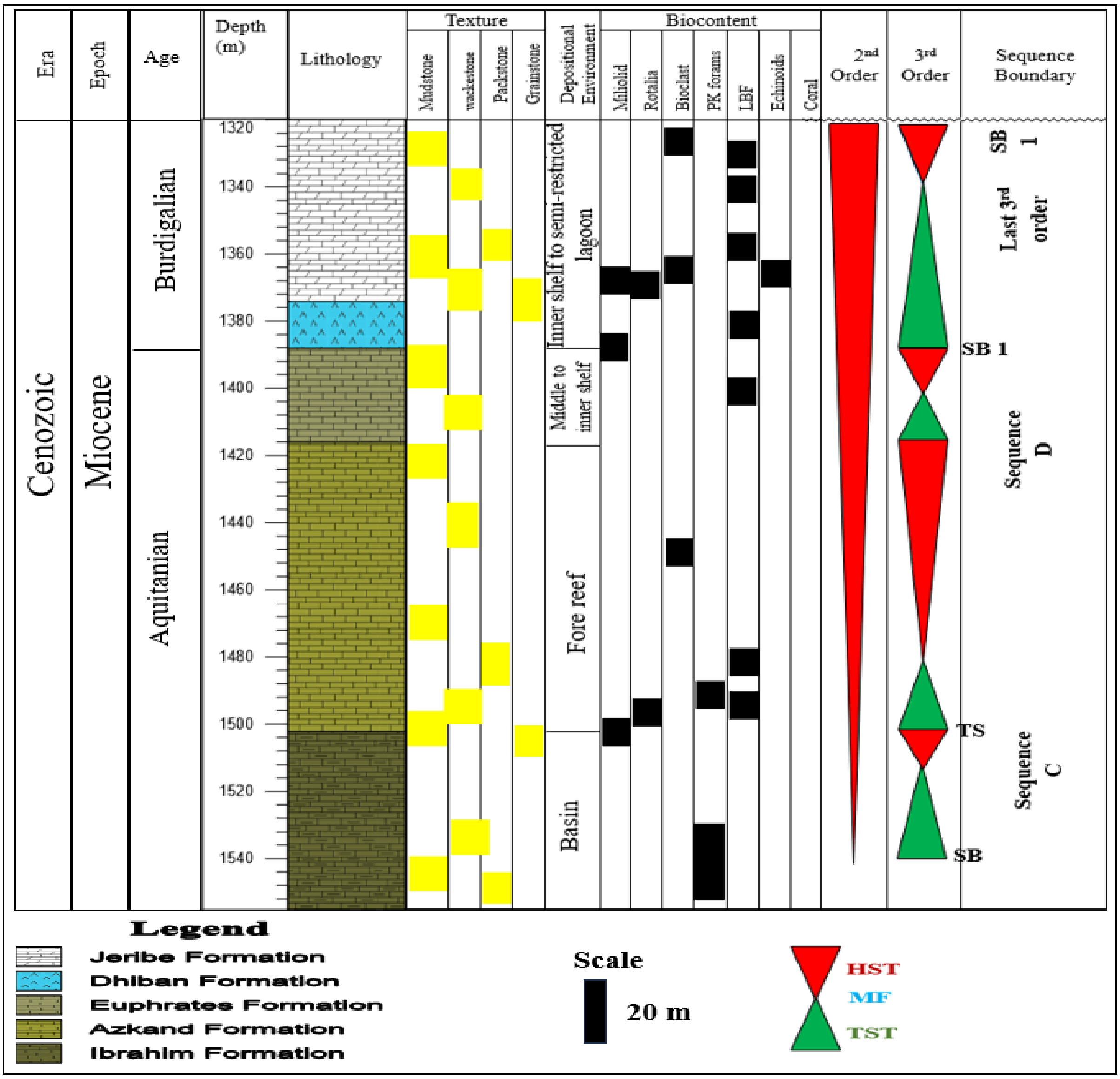

Figure 10. Sequence stratigraphic subdivision of the Lower Miocene successions in Well-A (Ibrahim, Azkand, Euphrates, Dhiban, Jeribe formations).

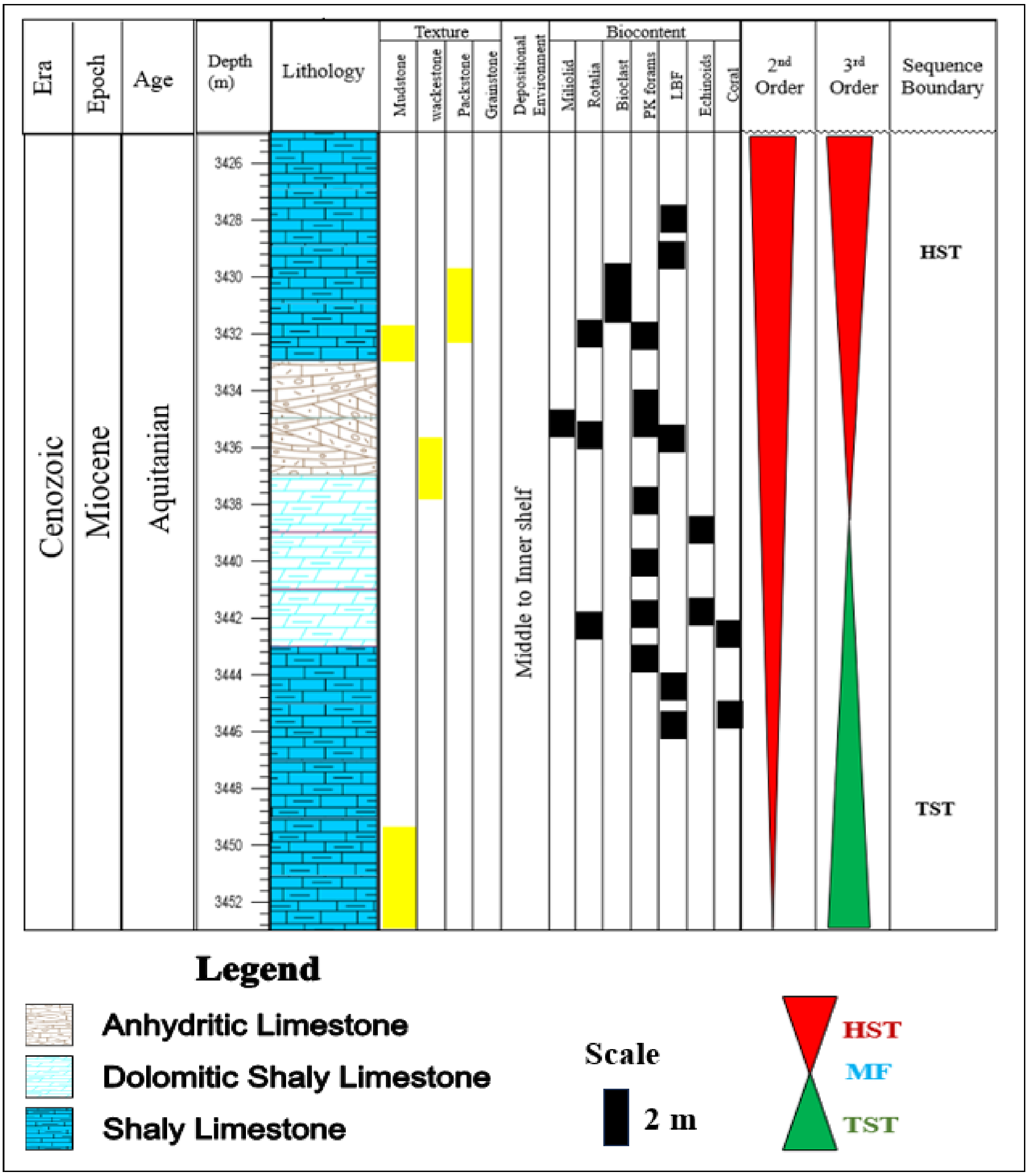

Figure 11. Sequence stratigraphic subdivision of the Late Lower Miocene succession in Tz-2 Well (Euphrates Formation).

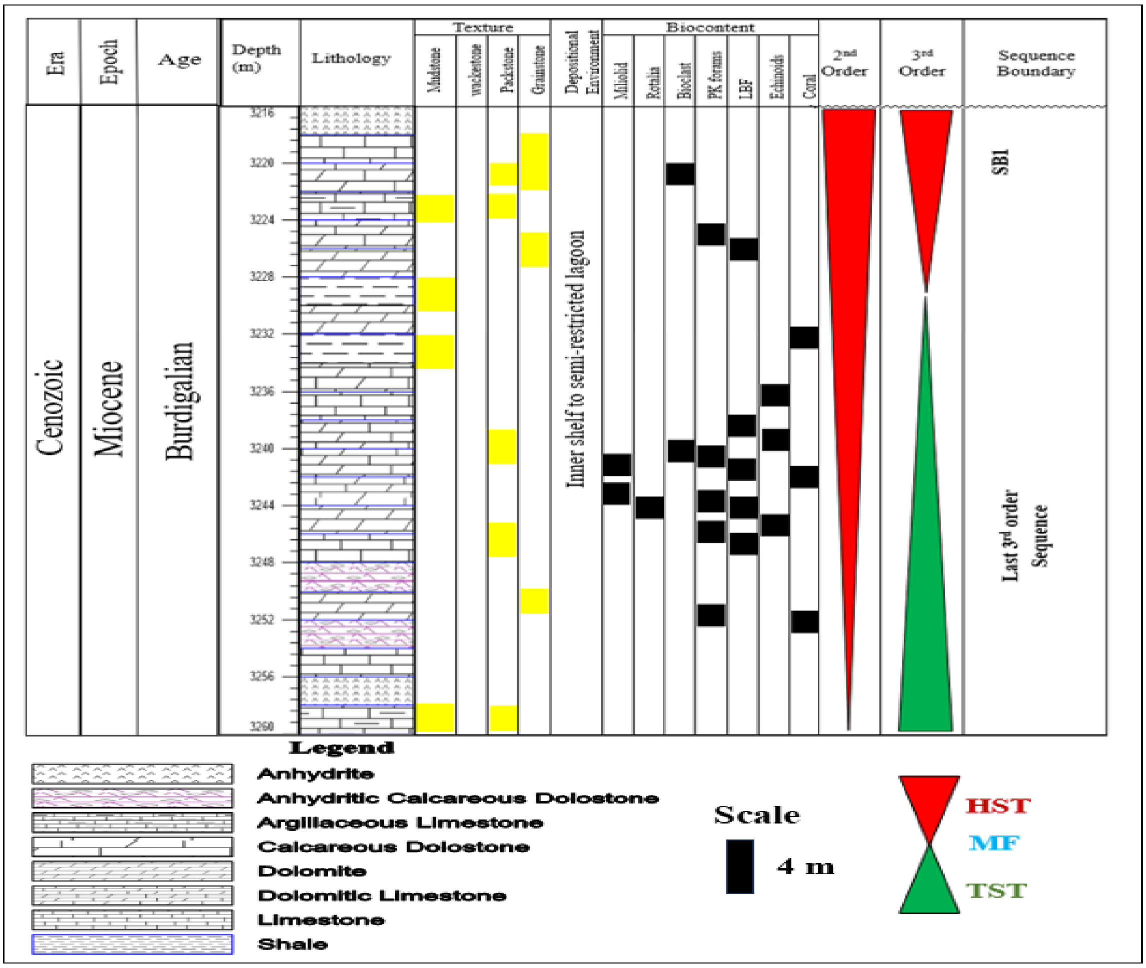

Figure 12. Sequence stratigraphic subdivision of the Late Lower Miocene succession in Tz-2 Well (Jeribe Formation).

6. Reservoir Properties

The most significant identified reservoir within the Miocene succession, represented by the Miocene Jeribe and Euphrates formations, is regarded as a major reservoir, containing oil and gas across more than 30 structures in Iraq (Al-Ameri *et al.*, 2011; Baban *et al.*, 2023; Barzanji *et al.*, 2023; Hussein *et al.*, 2017). Both formations are of inner shelf carbonates, which are characterized by having identifiable permeability, primary porosity, and improved secondary porosity due to different diagenetic processes. The majority of output originates from the Jeribe and Euphrates formations, particularly in the fields of Northern Iraq (Jassim *et al.*, 2006). Optimum reservoir quality occurs in mud-lean skeletal packstone with leached moldic and vuggy porosity, or oolitic pack-grain stones with primary intergranular porosity, and in coarsely crystalline dolomites. (Sun *et al.*, 1992) Suggested that dolomitization occurred when the Euphrates and Jeribe formations were exposed to saline brines following transgressions across the carbonate platforms.

6.1. Porosity measurements using core plugs

Core plugs of the Lower Miocene formations from wells Tz-2 and Tz-3 were analyzed, including measurements of porosity, by the Laboratories of the Kurdistan Institution for Strategic Studies and Scientific Research and the Department of Earth Sciences and Petroleum. These data were made available to the authors and used for correlation and calibration of log-derived porosity permeability data, and to calculate other petrophysical parameters. The average porosity of the Euphrates Formation is generally low and ranges between 1.41 and 7.51, and this is mainly controlled by the facies types, staking pattern, and depositional systems.

6.1.1. Jeribe Formation

The low stand system tract interval within the lower part of the Jeribe formation shows a low porosity value due to the predominance of cementation and compaction within the line mudstone, which predominated succussion, while the porosity increases in the Bioclastics. Packstone and grainstone microfacies of the middle and upper parts of the Jeribe Formation manifest almost the Transgressive system tract of the Depositional system. The maximum flooding surface was recorded at the top of the TST and recorded by the ordinances of relatively large benthic foraminifera like *Borelis melo melo*, which is the last large benthic foraminifera with intragranular porosity. In addition to other fossil assemblages, they are decreasing upwards in the High stand system tract microfacies; accordingly, they show a reduction in the porosity percent, relation between Depth and Measured Effective Porosity of Jeribe Formation in Tz-2 Well, illustrated (Table 2) and (Figure 13).

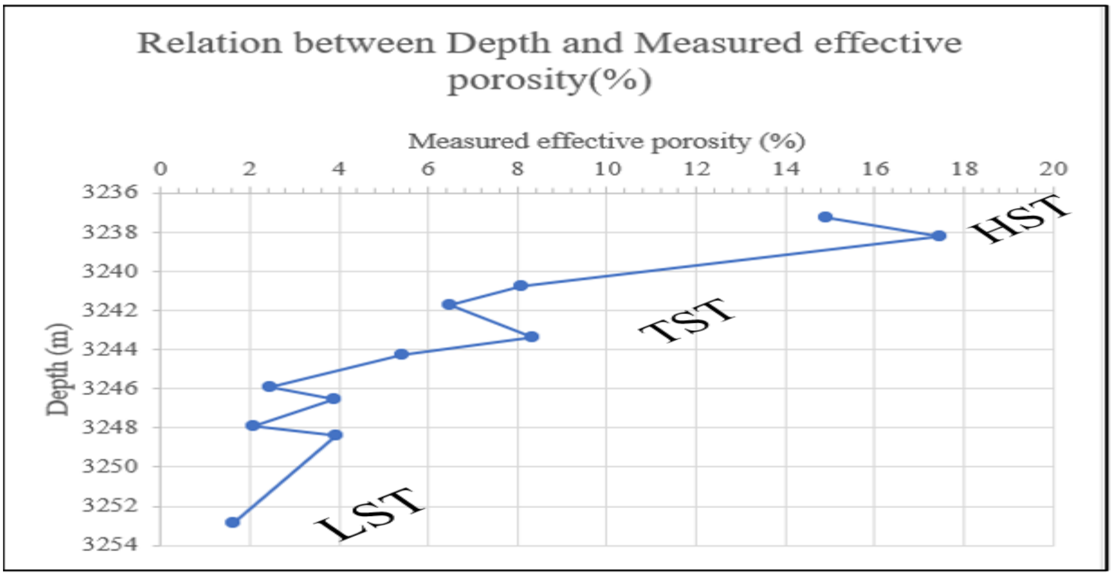

Figure 13. Shows the relationship between Depth and measured effective porosity (%) of the Jeribe Formation in Tz-2.

Table 2. The measured effective porosity from the Euphrates Formation. Taza -2 well.

Well	Formation	No.	Sample no.	Depth	Measured effective porosity (%)
Tz-2	Euphrates	1	7A	3434.6	1.45
		2	5A	3435.85	7.51
		3	6A	3436.6	1.41
		4	4A	3438.5	6.03
		5	8A	3440.5	3.11
		6	2A	3441.8	5.86
		7	1A	3442.5	2.64
	Jeribe	8	10B	3237.25	14.91
		9	18B	3238.25	17.47
		10	17B	3240.75	8.11
		11	11B	3241.75	6.47
		12	21B	3243.4	8.35
		13	16B	3244.3	5.41
		14	20B	3245.9	2.44
		15	14B	3246.5	3.91
		16	24B	3247.9	2.07
		17	25B	3248.4	3.95
		18	15B	3252.85	1.64
Tz-3	Ibrahim	1	1I	3706.7	5.04
		2	7I	3708.5	4.77
		3	4I	3710.9	2.95
		4	3I	3713.3	2.99
		5	2I	3720.10	2.37
		6	6I	3722.10	4.70

6.1.2. Euphrates Formation

Can say that the Low stand system tract facies is not recorded in the sequence stratigraphic framework of the studied intervals. Thais due to the fact that the new rapid transgression starts with a new sea level rise during the early Aquitanian. The new transgressive surface directly overlies the sequence boundary, with the underlaying Kirkuk Group represented by either the topmost part of the Ibrahim or Azkand formation. Therefore, the lower part of the Euphrates formation represents the retrogradational stacking pattern of the parasequences. Therefore, the TST part shows the porosity until it reaches the Maximum Flooding surface in the middle part of the Euphrates formation, as shown in Table 2 and Figure 14. On the other hand, the upper part of the Euphrates Formation after the Maximum flooding surface shows an aggradational stacking pattern and finally changes to a progradational stacking pattern of their parasequences sets. Hence, they are mostly of low porosity, which are characterized by line mudstone or wackestone microfacies. It's worth mentioning that close to the upper sequence boundary, the porosity value enhanced, which might be a result of the dissolution and diagenesis impacts.

6.1.3. Ibrahim Formation

The measured effective porosity of this unit almost points to an aggradational staking pattern that is always characterized by the predominance of the High stand system tract. The predominant planktic mudstone or deep Marnie benthic foraminifera are mostly with low effective porosity. Occasionally, in the upper parts when the successions show interaction with Azkand carbons, the effective porosity shows remarkable increases. Accordingly, the Ibrahim Formation has no remarkable effective porosity; it doesn't act as a potential hydrocarbon reservoir, as shown in Table 2 and Figure 15.

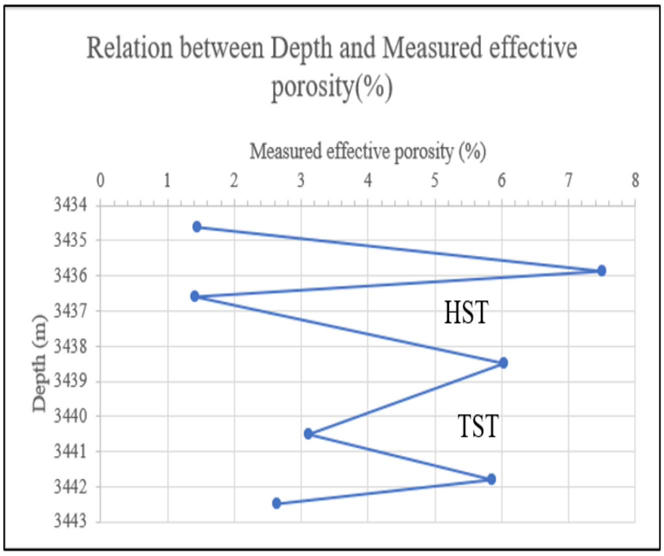

Figure 14. Shows the relationship between Depth and measured effective porosity (%) of Euphrates Formation in Tz-2.

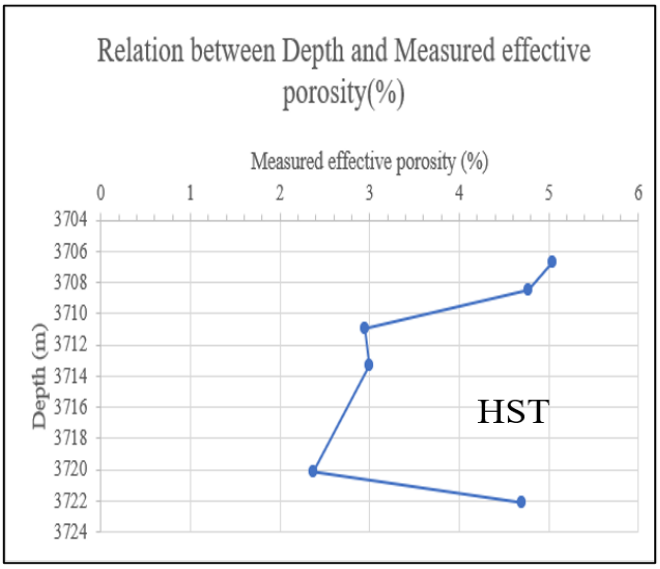

Figure 15. Relation between Depth and measured effective porosity (%) of Ibrahim Formation in Tz-3.

6.2. Reservoir Units

The sediments near the sequence boundaries are prone to leaching and forming dissolution pores; generally, the closer to the boundary, the stronger the dissolution effect. Furthermore, it increases the porosity of the reservoir, and diagenetic processes, such as dissolution, are distributed along the sequence boundary (Wenzhi *et al*., 2014). Vertical variation in a reservoir property is the result of the depositional environment and diagenetic processes. The Jeribe Formation studied in Well-A, Tz-2, and Well-B, and was divided into reservoir units from top to bottom, according to the log analysis, porosity, and shale content, without permeability.

6.2.1. Reservoir Unit 1(RU-1)

This unit is considered as an upper part of the Jeribe Formation at depth (1320 m) continuing to (1325 m), and it has a thickness of 5 m in well-A. The lithology of this unit succession mainly consists of limestone, Dolomite, dolomitic limestone rocks, and Dolomitic limestone fill with bitumen. As well as this succession includes a few anhydrite insertions, and it has negligible to fair porosity and high shale content.

6.2.2. Reservoir Unit 2 (RU-2)

This unit includes a part of the Jeribe Formation. The lithology of this unit is Limestone, (Vuggy) Dolomitic limestone, Vuggy dolostone, and a few crystals of Anhydrite with Argillaceous limestone. Well-A started from a depth of (1325 m) to (1350 m), and it has a thickness of (25 m). In Tz-2, this reservoir unit, located at the top of this formation at depth (3216 m continued to 3242m), (Figure 16). It consists of Bivalve-bearing Wackestone, Wackestone, Mudstone Microfacies, with Recrystallization, microvugs, and moldic Porosities. In Well-B, located at depth 2343 – 2352 m, it has the highest amount of shale content and porosity.

6.2.3. Reservoir Unit 3 (RU-3)

This unit includes the Jeribe Formation. The lithology of this unit is limestone, dolostone, dolomitic limestone, and vuggy dolostone (Anhydrite). In the Well-A located at depth (1350 – 1362 m). For Tz-2 of this formation at depth (3242m) continued to (3248m). It consists of Mudstone/ Wackestone Microfacies with Dolomitization, Cementation, poor visible matrix, and fracture Porosities. Well-B, which is from the depth of 2352 – 2355, has good to very good porosity.

6.2.4. Reservoir Unit 4 (RU-4)

The bottom portion of the Jeribe Formation is included in this unit. The lithology of this unit is Dolostone, Vuggy dolostone with (minor anhydrite content), with Argillaceous limestone. For Well-A, it is recorded at depth (1362 – 1374 m), and it is thick (25 m), with no visible matrix or fracture Porosities. Also, for Tz-2, it has (12) m thickness from the lower boundary at a depth of (3260 m), and it consists of Mudstone/Wackestone Microfacies. In Well-B, it has very low shale content. Not significant porosity (poor to poor-fair separately) exists in this unit. From the depth of (2355 –2368).

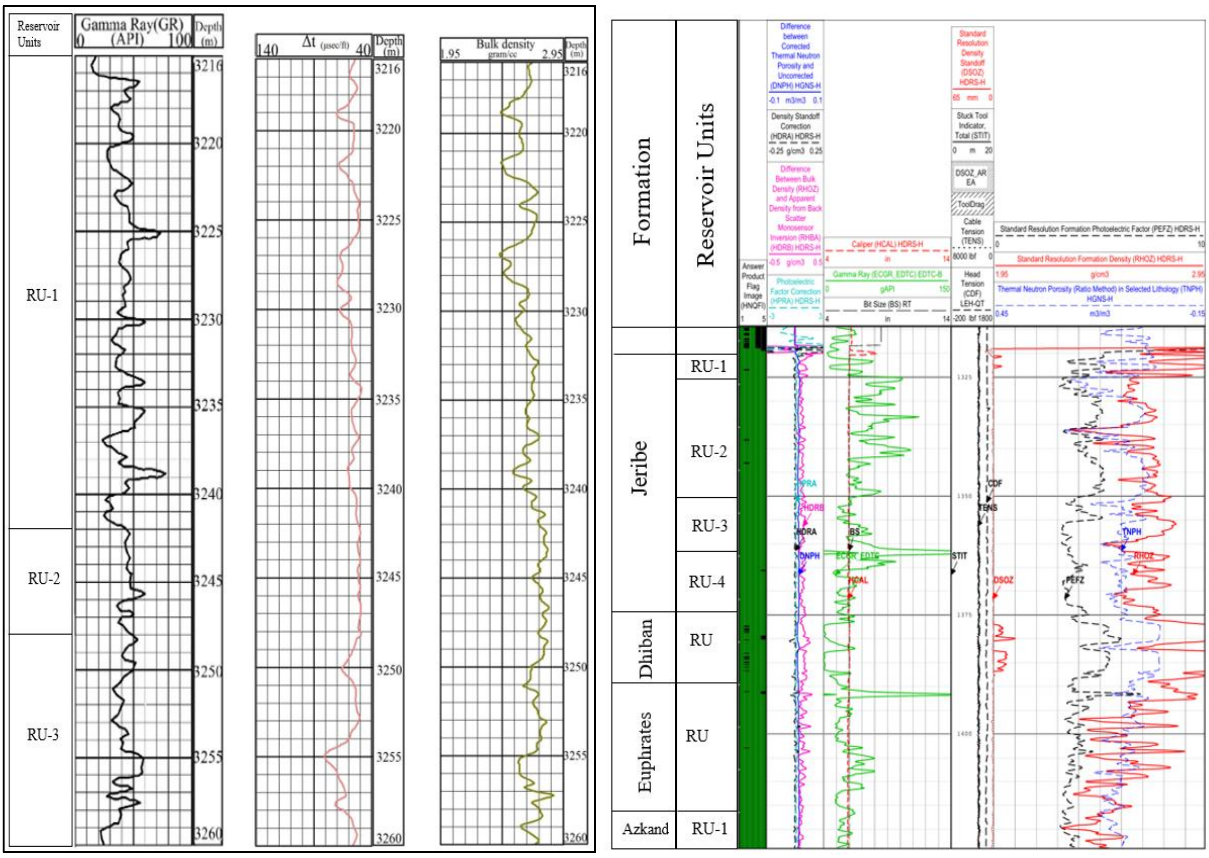

Figure 16. (a) Jeribe Formation in Tz-2 Well; Gamma Ray log**,** Sonic log record (Δt)(Msc/ft), and bulk density (ρb) (Abdolla, 2017). (b)Well logs of the Jeribe Formation in Well-A.

7. Conclusions

This study examines the Lower Miocene succession from the Kurdistan Foreland basin and reveals that the Late Oligocene to Middle Miocene succession in the studied wells and blocks is represented by the Ibrahin, Azkand, Euphrates, Dhiban, and Jeribe formations, with an annotated absence of the Serikagni and Hamrin formations. The studied wells have different types of facies associations, such as deep marine-offshore planktic marly limestones, reef limestones from the outer to mid-ramp, open marine limestones (Euphrates), restricted interior carbonate platforms with evaporitic areas (Dhiban), and slightly restricted interior platform carbonates (Jeribe). The sections were biostratigraphically dated as late Oligocene to Lower Miocene based on larger benthic foraminifera (LBF) and planktic foraminifera in the subsequent chronological order: Ibrahim Chattian-Aquitanian, Azkand. The Lower Aquitanian, Euphrates Aquitanian, Dhiban, and Jeribe formations of the Burdigalian epoch span roughly from 23.8 million to 15.99 million years ago. It requires around 7.9 million years. Major tectonic events influence depositional patterns at second-order depositional systems, while tectonic and eustatic sea level changes control the third-order depositional system during the

Aquitanian and Burdigalian. The presence of LBF and dasycladacean algae shows that the water is warm at the top of the Kirkuk group, represent by the reefal facies of Azkand Formation. The top cycle above the Kirkuk Group shows that the cyclic change between carbonates and evaporites throughout the Aquitanian and Burdigalian periods means that the climate was dry, hot, and at low latitudes. The information from core samples, rock bit data, microfacies, and biostratigraphic markers helps to create a timeline for three 3rd order depositional systems. The TST and HST cyclicity are present in each depositional order. The distinctive characteristics of the reservoirs evolved throughout time and place, with the most substantial reservoir type identified within the third depositional system, indicating a Transgressive Systems Tract (TST) with bioclastic facies, which are accentuated at the sequence boundaries. Three Maximum Flooding Surfaces (MFS) have been confirmed. The first one, correlated with the MFS (PCh2 - 24.8 Ma), occurred during the Ibrahim Formation. The second-highest flooding surface is in the open marine benthic wackestone facies of Euphrates Formation NAq1 - 23.03 Ma. While the third one of Burdigalian age, known as NBu-1, 19.5 Ma, and recorded within the Jeribe Formation. The facies association and sequence stratigraphic evolutions lead to a more well-developed Miocene reservoir towards SW, possibly in Qumar, Khasm al hammer, and Mansuria and blocks.

Further study is necessary to clarify the sources of the gaps noted in the analysed cycles comp ared to global models and to properly record the newly suggested factory for temperate carbo nate-evaporite platforms.

Acknowledgments

We are very grateful for the changes made by two anonymous reviewers. I want to thank Dr. Dler Hussein Baban in the Department of Earth Sciences and Petroleum from the University of Sulaimani for providing the Taza block samples.

References

Abdolla, A. S. (2017). *Reservoir Characterization of the Middle Miocene Jeribe Formation from Selected Oil Wells in Kurdistan Region/Northern Iraq* [M.Sc., University of Sulaimani].

Abdulrahman, A., & Awadh, S. M. (2021). Depositional environment of the Ibrahim Formation and determining the Oligocene-Early Miocene boundary in Eastern Iraq. *The Iraqi Geological Journal*, 85-97.

Abid, A. (1983). *Microfacies of Anah limestone formation*, M.Sc. Thesis, Unpublished, College of Science, University of Baghdad, Iraq.

Ahmad, M., & Al-Eisa, M. (2003). Hamrin Formation, a new lithostratigraphic unit from the Early Miocene in Northern Iraq. *Rafidain Journal of Science*, *14*(1), 68-78.

Al-Ameri, T. K., Jafar, M. S., & Pitman, J. (2011). Hydrocarbon generation modeling of the Basrah oil fields, Southern Iraq. AAPG Annual Convention and Exhibition, Houston, Texas, Search and Discovery Article,

Al-Awwad, S. F., & Collins, L. B. (2013). Carbonate-platform scale correlation of stacked high-frequency sequences in the Arab-D reservoir, Saudi Arabia. *Sedimentary Geology*, *294*, 205-218.

Al-Banna, N. Y. (2008). Oligocene/Miocene boundary in northern Iraq. *GeoArabia*, *13*(2), 187-190.

Al-Banna, N. Y., & Al-Mutwali, M. M. (2002). Microfacies Evidence for Eocene Sequences Stratigraphy of Jaddala/Avanah Formation, Sinjar Area, Northwest Iraq. *Iraqi Journal of Earth Science*, *2*(2), 48-58.

Al-Hashimi, H. A., & Amer, R. M. (1985). *Tertiary microfacies of Iraq*. Directorate general for Geological Survey and mineral investigation.

Al-Hussiny, M. D., & Al-Dulaimi, S. I. (2024). Biostratigraphy of the Late Oligocene-Early Miocene Anah and Bajwan Formations at Selected Sections of Northern Iraq. *The Iraqi Geological Journal*, 30-40.

Al-Qayim, B. (2006). Sag-interior Oligocene basin of north-central Iraq: sequence stratigraphy and basin overview. *GeoArabia*, *12*, 195.

Al-Qayim, B. (2012). Polyphase foreland basin of NE Arabia: basin differentiation and hydrocarbon potentiality. EAGE first workshop on Iraq, Istanbul, Turkey. Abstract with program,

Al-Qayim, B. A. (2024). The Paleogene Forebulge Carbonate Banks, Zagros Foreland Basin, Northern Iraq: Their Paleogeography, Basin Evolution, and Economic Implications. *The Iraqi Geological Journal*, 230-253.

Al Naqib, K. (1967). *Geology of the Arabian Peninsula; southwestern Iraq* (2330-7102).

Alkhaykanee, M. H., & Al-Dulaimi, S. I. (2019). Biostratigraphy of Euphrates, Dhiban, and Jeribe formations in Ajil oil field, Salah Al-deen governorate, central Iraq. *Iraqi Journal of Science*, 263-276.

Ameen, F. A. (2022). Sequence Stratigraphy of the Oligocene and Miocene Successions from Selected Wells in Garmian District, Kurdistan Region/Iraq. In A. Çiner, S. Grab, E. Jaillard, D. Doronzo, A. Michard, M. Rabineau, & H. I. Chaminé, *Recent Research on Geomorphology, Sedimentology, Marine Geosciences and Geochemistry* Cham.

Ameen, F. A., Fattah, A. I., & Qader, B. O. (2020). Microfacies and depositional environment of the Upper Oligocene and Lower Miocene successions from Iraqi Kurdistan Region. *Kuwait Journal of Science*, *47*(4).

Ameen Lawa, F. A., & Ghafur, A. A. (2015). Sequence stratigraphy and biostratigraphy of the prolific late Eocene, Oligocene and early Miocene carbonates from Zagros fold-thrust belt in Kurdistan region. *Arabian Journal of Geosciences*, *8*, 8143-8174.

Aqrawi, A. A., Goff, J. C., Horbury, A. D., & Sadooni, F. N. (2010). *The petroleum geology of Iraq* (Vol. 424). Scientific Press, Beaconsfield, UK.

Baban, D., & Hussein, H. S. (2016). Characterization of the Tertiary reservoir in Khabbaz Oil Field, Kirkuk area, Northern Iraq. *Arabian Journal of Geosciences*, *9*, 1-19.

Baban, D. H., Barzanji, S. S. S., & Ahmed, M. M. (2023). Evaluation of the shale impact on reservoir characterization, the Jeribe carbonate reservoir in an Oilfield Northern Iraq as a Case Study. *The Iraqi Geological Journal*, 185-207.

Bamerni, A., Barzani, A., & Sharazwri, A. (2025). Stratigraphy and Microfacies Analysis of the Euphrates Formation: Insights from the Duhok Area, Northern Iraq. *The Iraqi Geological Journal*, 140-154.

Barzanji, S. S., Baban, D. H., & Ahmed, M. M. (2023). Moveability and Nature of the Reservoir Hydrocarbons in the Lower Miocene Jeribe Formation in X-Oilfield, Northern Iraq. *The Iraqi Geological Journal*, 80-92.

Berberian, M. (1995). Master "blind" thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics. *Tectonophysics*, *241*(3-4), 193-224.

Buday, T. (1980). *The regional geology of Iraq: stratigraphy and paleogeography* (Vol. 1). State Organization for Minerals, Directorate General for Geological Survey.

Catuneanu, O. (2019). Model-independent sequence stratigraphy. *Earth-Science Reviews*, *188*, 312-388.

Catuneanu, O. (2022). Sequence stratigraphy of deepwater systems. In *Deepwater Sedimentary Systems* (pp. 443-470). Elsevier.

Embry, A. (1993). Triassic TR sequence analysis. Sverdrup basin, Canadia Arctic archipelago: Canadian Society of Petroleum Geologists, Carboniferous to Jurassic Pangea, Program and Abstracts, Calgary, Alberta, 89.

English, J. M., Lunn, G. A., Ferreira, L., & Yacu, G. (2015). Geologic evolution of the Iraqi Zagros, and its influence on the distribution of hydrocarbons in the Kurdistan region. *AAPG Bulletin*, *99*(2), 231-272.

Farouk, S., Lawa, F. A., Abdeldaim, A., Mohammed, I. Q., & Al-Khatany, K. (2023). Astronomical time scale of the lower Miocene depositional sequences (Aquitanian-Burdigalian) in the Jambour Field, northern Iraq. *Marine and Petroleum Geology*, *151*, 106182.

Farouk, S., Ren, C., Abdeldaim, A., Salama, A., Wu, H., El-Kahtany, K., & Zaky, A. S. (2022). An astronomical time scale of early Pliocene from the Mediterranean Sea, Egypt. *Global and Planetary Change*, *215*, 103869.

Flügel, E., & Munnecke, A. (2010). *Microfacies of carbonate rocks: analysis, interpretation and application* (Vol. 976). Springer.

Fouad, S. F. (2015). Tectonic map of Iraq, scale 1: 1000 000, 2012. *Iraqi Bulletin of Geology and Mining*, *11*(1), 1-7.

Frazier, D. E. (1974). Depositional-episodes: their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf basin.

Galloway, W. E. (1989). Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units. *AAPG Bulletin*, *73*(2), 125-142.

Ghafor, I. M., & Ahmad, P. M. (2021). Stratigraphy of the Oligocene-early Miocene successions, Sangaw area, Kurdistan region, NE-Iraq. *Arabian Journal of Geosciences*, *14*(6), 454.

Haq, B. U., Hardenbol, J., & Vail, P. R. (1987). Chronology of fluctuating sea levels since the Triassic. *Science*, *235*(4793), 1156-1167.

Haq, B. U., & Ogg., J. (2024). Retraversing the Highs and Lows of Cenozoic Sea Levels. *GSA Today, 34,* 4-11.

Henson, F. (1950). The stratigraphy of the Main Producing Limestone of the Kirkuk oilfield. *Int. Geol. Congr. 1948, 6*.

Hussein, D., Collier, R., Lawrence, J., Rashid, F., Glover, P., Lorinczi, P., & Baban, D. (2017). Stratigraphic correlation and paleoenvironmental analysis of the hydrocarbon-bearing Early Miocene Euphrates and Jeribe formations in the Zagros folded-thrust belt. *Arabian Journal of Geosciences*, *10*, 1-15.

Ibrahim, A. (2009). Tectonic style and evolution of the NW segment of the Zagros fold-thrust belt, Sulaimani Governorate, Kurdistan Region, NE Iraq. *Unpublished Ph. D. Thesis, University of Sulaimani, College of Science, 187pp*.

Jassim, S. Z., Al-Gailani, M., & Goff, J. (2006). Hydrocarbons. *Geology of Iraq*, 232-250.

Jassim, S. Z., & Goff, J. C. (2006). *Geology of Iraq*. DOLIN, sro, distributed by the Geological Society of London.

Karim, S. A., Sissakian, V. K., & Al-Kubays, K. (2014). Stratigraphy of the Oligocene-Early Miocene exposed formations in Sinjar area, NW Iraq. *Iraqi Bull Geol Min*, *10*(3), 1-28.

Kharajiany, S. (2014). The Occurrence of Early and Middle Miocene Rocks (Euphrates, Dhiban and Jeribe Formations) In Ashdagh Mountain, Sangaw Area, Sulaimaniyah Vicinity, NE Iraq. *Iraqi Bull. Geol. Min*, *10*(1), 21-39.

Koshnaw, R., Kley, J., & Schlunegger, F. (2024). Miocene evolution of the NW Zagros foreland basin reflects SE-ward propagating tear of the Neotethys slab. *Egusphere, 2024*, 1-25.

Koshnaw, R. I., Horton, B. K., Stockli, D. F., Barber, D. E., Tamar-Agha, M. Y., & Kendall, J. J. (2017). Neogene shortening and exhumation of the Zagros fold-thrust belt and foreland basin in the Kurdistan region of northern Iraq. *Tectonophysics*, *694*, 332-355.

Koshnaw, R. I., Stockli, D. F., & Schlunegger, F. (2019). Timing of the Arabia-Eurasia continental collision—Evidence from detrital zircon U-Pb geochronology of the Red Bed Series strata of the northwest Zagros hinterland, Kurdistan region of Iraq. *Geology*, *47*(1), 47-50.

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

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

Le Garzic, E., Vergés, J., Sapin, F., Saura, E., Meresse, F., & Ringenbach, J. (2019). Evolution of the NW Zagros Fold-and-Thrust Belt in Kurdistan Region of Iraq from balanced and restored crustal-scale sections and forward modeling. *Journal of Structural Geology*, *124*, 51-69.

Liu, C., Alway, R., Moreton, D. J., Samarrai, A., & Hmasalih, F. (2017). Recommendation for A Practical Log-based Stratigraphic Framework for the Kurdistan Region of Iraq. *AAPG Search and Discovery Article*, *30487*, 39p.

Liu, C., Zhao, H., Zhang, C., & Wang, J. (2009). The important turning period of evolution in the Tibet-Himalayan tectonic domain. *Earth Science Frontiers*, *16*(4), 1-12.

Liu, J., Zhang, P., Zheng, D., Wan, J., Wang, W., Du, P., & Lei, Q. (2010). Pattern and timing of late Cenozoic rapid exhumation and uplift of the Helan Mountain, China. *Science China Earth Sciences*, *53*, 345-355.

Lotfy, N. M., Farouk, S., & ElBehery, A. K. (2025). Organic Geochemical Characteristics of Pre and Syn-rift source rocks in the Geisum concession, South Gulf of Suez, Egypt. *Egyptian Journal of Chemistry*, *68*(5), 431-443.

Mackertich, D. S., & Samarrai, A. I. (2015). History of hydrocarbon exploration in the Kurdistan Region of Iraq. *GeoArabia*, *20*(2), 181-220.

Mitchum, R. (1977). Seismic stratigraphy and global changes of sea level, part 11: glossary of terms used in seismic stratigraphy.

Muhammed, Q. A. (1983). Biostratigraphy of kirkuk group in Kirkuk and Bai-Hassan areas. Baghdad University, M.Sc. Thesis, College of Science, and University of Baghdad, 187p.

Numan, N. (2000). Major Cretaceous tectonic events in Iraq. *Rafidain Journal of Science*, *11*(3), 32-52.

Omar, A. A., Lawa, F. A., & Sulaiman, S. (2015). Tectonostratigraphic and structural imprints from balanced sections across the north-western Zagros fold-thrust belt, Kurdistan region, NE Iraq. *Arabian Journal of Geosciences*, *8*, 8107-8129.

Posamentier, H., Jervey, M. T., & Vail, P. (1988). Eustatic controls on clastic deposition I—conceptual framework.

Qader, F. M., & Ali, S. M. (2022). Reservoir Characteristics of the Lower Miocene Carbonate Formations in Kor Mor Gasfield, Kirkuk Area, NE Iraq. *Tikrit Journal of Pure Science*, *27*(3), 43-52.

Sharland, A. (2001). The negotiation process as a predictor of relationship outcomes in international buyer–supplier arrangements. *Industrial Marketing Management*, *30*(7), 551-559.

Sharland, P. R., Casey, D. M., Davies, R. B., Simmons, M. D., & Sutcliffe, O. E. (2004). Arabian plate sequence stratigraphy–revisions to SP2. *GeoArabia*, *9*(1), 199-214.

Sissakian, V. K., Karim, S. A., Al-Kubaisyi, K. N., Al-Ansari, N., & Knutsson, S. (2016). The Miocene sequence in Iraq, a review and discussion on the stratigraphy, paleogeography and economic potential. *Journal of Earth Sciences and Geotechnical Engineering*, *6*(3), 271-317.

Sloss, L. L., Krumbein, W. C., & Dapples, E. C. (1949). Integrated facies analysis.

Stevanovitic, Z., Markovitic, M., & Adrian, M. (2003). Geology and hydrogeology of Sulaimani and Kirkuk area. *FAO (UN) report. Sulaimani office*, *52*.

Sun, Y., Spellmeyer, D., Pearlman, D. A., & Kollman, P. (1992). Simulation of the solvation free energies for methane, ethane, and propane and corresponding amino acid dipeptides: a critical test of the bond-PMF correction, a new set of hydrocarbon parameters, and the gas phase-water hydrophobicity scale. *Journal of the American Chemical Society*, *114*(17), 6798-6801.

Vail, P. R. (1977). Seismic stratigraphy and global changes of sea level. *Memoir of the American Association of Petroleum Geologists*, *26*, 49-50.

Vail, P. R., Mitchell Jr, R., Sangree, J., & Thompson III, S. (1975). Eustatic cycles from seismic data for global stratigraphic analysis.

Van Bellen, R., Dunnington, H., Wetzel, R., & Morton, D. (1959). Lexique stratigraphique international, Iraq. *Internat. Geol. Cong. Comm. Stratig*, *3*.

Westerhold, T., Marwan, N., Drury, A. J., Liebrand, D., Agnini, C., Anagnostou, E., ... & Zachos, J. C. (2020). An astronomically dated record of Earth's climate and its predictability over the last 66 million years. *science*, *369*(6509), 1383-1387.

Wenzhi, Z., Anjiang, S., Jingao, Z., Xiaofang, W., & Junming, L. (2014). Types, characteristics, origin and exploration significance of reef-shoal reservoirs: A case study of Tarim Basin, NW China and Sichuan Basin, SW China. *Petroleum Exploration and Development*, *41*(3), 283-293.

Yakymchuk, M., Javadova, A., & Korchagin, I. (2023). Results of the Application of Direct-search Mobile Technology in the Exploration Blocks of Shakal and Halabja (Kurdistan). *Earth and Planetary Science*, *2*(2), 74-84.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., & Billups, K. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, *292*(5517), 686-693.

Zebari, M. (2013). Geometry and evolution of fold structures within the high folded zone: Zagros fold-thrust belt, Kurdistan Region, Iraq.

About the author

Professor Dr. Fadhil Ahmed Ameen Lawa received his Ph.D. degree in stratigraphy and paleontology, sequence stratigraphy from the University of Sulaimani in 2004. He was employed as a lecturer at the University of Salahaddin in 1983. In 1985 transferred to the Iraq Geological Survey and participated in several explorations in Iraq and the Kurdistan region, like pb-zn in Zakho and copper of Mawat Ophiolites. In 1991, he acted as a director of geological surveys. In 1992, he participated in the re-establishment of the University of Sulaimani and the College of Sciences, and is now a retired professor. He worked as a consultant (part-time) for FAO-UN and several oil companies in Kurdistan. He published more than 65 research papers and more than 80 multipurpose reports. His joint venture research with universities abroad (Cardiff, Leeds, Uppsala, Gubkin, Gottingen, and Bergen). Prof. Fadhil also participated in more than 78 local and international conferences and acted as a peer reviewer for several journals published by Springer, Elsevier, etc. Members of EAGE, AAPG, EGU, and GSA email.

e-mail: Fadhil.ameen@univsul.edu.iq

Shanga N. Abdalla graduated from the University of Sulaimani in 2020. with a B.Sc. degree in Geology and standing in the 2^{nd} rank. She has one year of academic experience with the Department of Earth Sciences and Petroleum, University of Sulaimani. Currently studying M.Sc. in Stratigraphy at the University of Sulaimani, College of Science, Department of Earth Sciences and Petroleum.

e-mail: shanganawzad3@gmail.com