

University of Mosul
College of Science



**Sedimentologic Study of Jeribe Formation
(Early Middle Miocene) in Bekhair Anticline,
Northern Iraq**

Nihayat Jarjees Ali Ahmed Mziri

M.Sc. Thesis

Geology/Sedimentology

Supervised by

Prof. Dr. Rafee Ibrahim Al-Hamidi

2025 A.D.

1446 A.H.

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(Early Middle Miocene) in Bekhair Anticline,
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M.Sc. Thesis Submitted by
Nihayat Jarjees Ali Ahmed Mziri

To

The Council of the College of Science at the University of Mosul, in
partial fulfillment of the requirements for the degree of Master's

In

Geology/Sedimentology

Supervised by

Prof. Dr. Rafee Ibrahim Al-Hamidi

2025 A.D.

1446 A.H.

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We certify that we, the members of the Evaluation and Discussion Committee, have reviewed this thesis and discussed the student (**Nihayat Jarjees Ali Ahmed Mziri**) regarding its contents and related matters on 2 / 2 / 2025 , and she is worthy of obtaining a Master's degree in Geology/ Sedimentology.



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And Allah is the Grantor of Success.

Nihayat Mziri 

Dedication

The success of this thesis is lovingly dedicated:

To the good of mankind who conveyed his message in the most perfect way, the illiterate Messenger, the seal of prophets and messengers, the truthful and trustworthy, Mohammad peace be upon him.

To my dearest father, the martyr who left us while we needed him the most, his departure remains my greatest defeat. He was a strong pillar and a light in my life. Despite life's difficulties and concerns, he is always in my heart, never leaving my thoughts and prayers. His pure soul inspires me to move forward despite the difficulties. May Allah have mercy on his pure body, forgive him, and reunite us with him in his paradise.

To the light of my path and to the apple of my eye and the secret of my success, my beloved mother. I thank Allah every day for her presence in my life and pray that He protects her and rewards her with all goodness. May He bless her with health and well-being.

To my dear brothers and sisters, they are a strong pillar in my life, continually providing me with positivity. I appreciate every moment they have spent beside me, and for all the support, understanding, and love they always show. I love you.

To all those who guided, helped, and supported me, even with a word, in completing this thesis, I present to you my humble thesis.

Nihayat Mziri ✍️

Abstract

The microfacies analysis and depositional environment of the Jeribe Formation (early Middle Miocene) were studied for the first time in the two outcrops, Gali Zakho and Gali Duhok sections. within the Bekhair anticline in the High Folded Zone, located in the Duhok Governorate of the northwestern part of the Kurdistan region in northern Iraq. This research emphasises the formation's new lateral extension in the two study sections.

The formation in the Gali Zakho section consists of (77.7 m) of massive dolomitic limestone, chalky limestone, and limestone, while in the Gali Duhok section, it includes (16.05 m) of medium to thick beds of limestone, marly limestone, dolomitic limestone, and chalky limestone with very thin marl layers with dolomite specially in the lower part of section. In the Gali Zakho section, the Jeribe Formation unconformably overlies the Dhiban Anhydrate Formation and is unconformably underlain by the Fat'ha Formation, due to the presence of Fat'ha Basal Conglomerate (FBC). In the Gali Duhok section, the lower contact is unconformable with the PilaSpi Formation, with the underlying Hardground (lithified sea floors formed by the cementation of carbonate layers), while the upper contact is gradually conformable with the Fat'ha Formation.

The petrographic study of 60 thin sections of the two sections revealed the skeletal grains include benthic foraminifera (*Quinquiloculina* sp., *Triloculina* sp., *Pyrgo* sp., *evolute Peneroplis* sp., *Borelis* sp., *Rotalia* sp., *Textularia* sp., *Dendritina rangi d'Orbigny* sp., *Idalina* sp., and bioclasts of *Archaias kirkukensis* sp.), red algae (coralline red algae nodules called rhodoids, branching crustose coralline red algae of *Lithophyllum* sp., and red algae *Solenopora* sp.), green algae (*Halimeda*

sp.), mollusks (Pelecypod and Gastropoda), and bioclasts (bioclasts of benthic foraminifera and algae). The non-skeletal grains include peloids, coated grains (oncoids), and lithoclasts (intraclasts and extraclasts). The rocks of the study successions have been affected by various diagenetic processes, including neomorphism, cementation (granular, blocky, drusy, and bladed calcite cement), dolomitization, silicification, pyritization, oxidation, anhydritization, compaction, micritization, and dissolution.

Depending on detailed microfacies analysis of carbonate rocks, the groundmass consists of micrite and orthosparite, and seven main microfacies are recognized: Mudstone, Wackstone, Packstone, Grainstone, Boundstone, Floatstone, and Crystalline microfacies, these microfacies are divided to (17) sub microfacies. From the sum of facies analysis, the depositional environment of the Jeribe Formation was a shallow marine environment, deposited in restricted, open marine platform interior and marginal reef platform environments.

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Legend



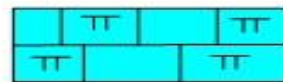
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Marl



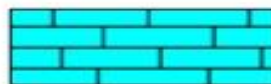
Dolomitic limestone



Chalky limestone



Cherty limestone



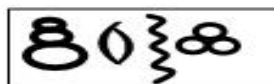
Limestone



Gypsum



Conglomerate



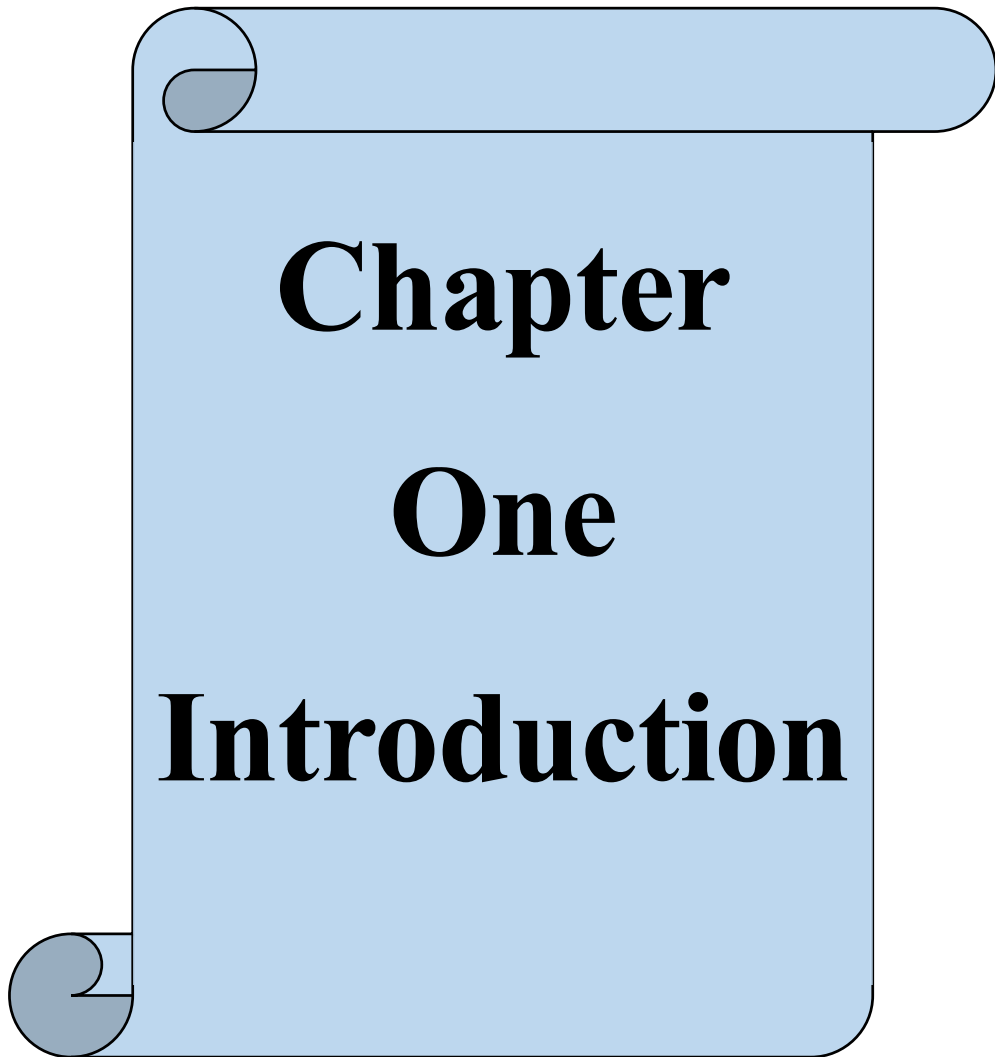
Fossiliferous



Unconformity



Gastropoda



Chapter One Introduction

1.1 Preface:

Jeribe Formation is one of the most important formations dating back to the early Middle Miocene sequences. The Jeribe Formation is important in the Kurdistan region due to its wide distribution in northern Iraq, especially in the northwestern areas, both as an outcrop and in the subsurface (Bellen *et al.* 1959), and it has industrial significance as cement production (Khudhur and Aqrabi, 2022) and it is considered one of the key productive reservoirs in northern Iraq, especially in the Kirkuk oil fields (Jassim and Goff, 2006). Recently, it has become the primary subject of research related to newly drilled oil fields in the Kurdistan Region of Iraq (Zaidky, 2021).

The current study includes a sedimentological study of the exposed Jeribe Formation within the Bekhair anticline. This study aims to shed light on the microfacies details of the formation and the nature of the depositional model that produced such microfacies in the Duhok region.

The significance of this study comes from the ongoing debate about the presence of the Jeribe Formation within the Bekhair anticline in Duhok city.

1.2 Study Area Location:

Geographically, the study area is located in the Duhok Governorate of the northwestern part of the Kurdistan region in northern Iraq (**Fig. 1.1**). It includes two outcrop sections, Gali Zakho and Gali Duhok. (**Table 1.1**) illustrates the geographic coordinates of the study sections and thickness of the formation.

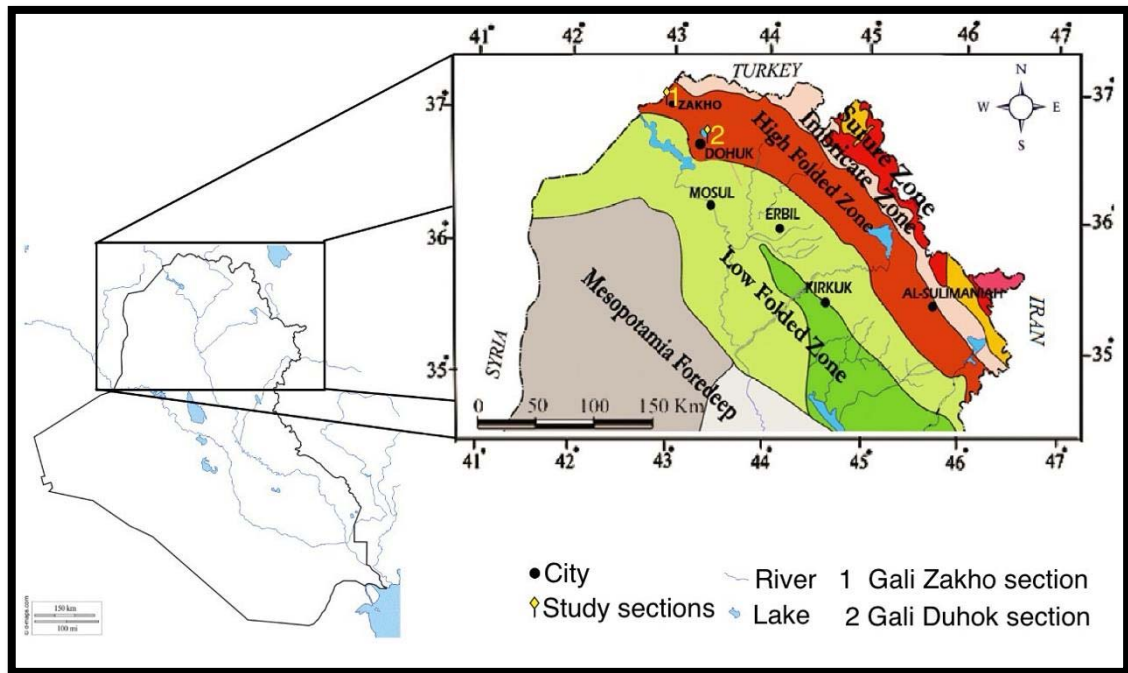


Figure 1.1: Tectonic Map (Fouad, 2015), illustrates the locations of the selected sections.

Table 1.1: Shows the geographic coordinates and thickness of the study sections.

Sections	Thickness (m)	Geographic Coordinates	
		Longitude (E)	Latitude (N)
Gali Zakho	77.7	42°38'40"	37°03'07"
Gali Duhok	16.05	43°00'07.42"	36°52'07.76"

1.2.1 Gali Zakho Section:

Gali Zakho section is located near the tunnel of Zakho city, Hasan Awa village, northwest of Duhok city and about 50 km away from Duhok dam (Gali Duhok section), and 12 km to the southwest of Zakho city (**Fig. 1.1**). This section is selected because the Jeribe Formation is very well exposed. The formations exposed within Bekhair anticline in this

section and that interest for this study from older to younger are: Dhiban, Jeribe and Fat'ha Formations.

1.2.2 Gali Duhok Section:

Gali Duhok section is located in Duhok city near Duhok dam (**Fig. 1.1**). This section is selected to study the stratigraphic succession of the Jeribe Formation and to confirm that it is indeed the Jeribe Formation and not the Fat'ha Formation. The formations exposed within Bekhair anticline in this section and that interest for this study from older to younger are : PilaSpi, Jeribe and Fat'ha Formations.

1.3 Geological Setting:

According to the tectonic divisions of Iraq (Fouad, 2015), the selected sections are located within the High Folded Zone (**Fig. 1.1**). Structurally, the study sections are exposed within Bekhair anticline on its southern limb. which is extend about 72 kilometers from the Zawita/Besari area (the southeastern plunge) to Derabun village near the Iraqi-Syrian-Turkish border (the northwest plunge) (Al-Azzawi and Al-Hubit, 2009) (**Fig. 1.2**).

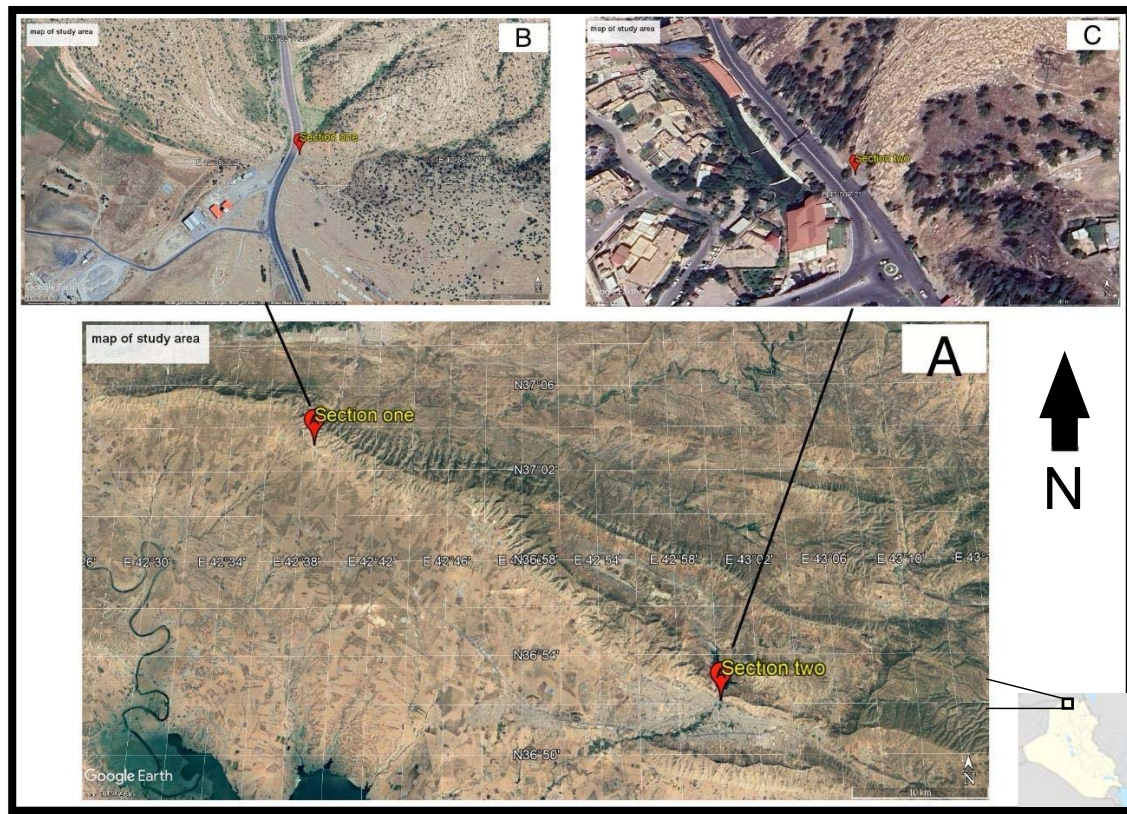


Figure 1.2: Satellite image of Study area (2024 Google Maps),
A: Bekhair anticline, **B:** Gali Zakho section, **C:** Gali Duhok section.

1.4 Previous Studies:

The Jeribe Formation was initially described by Damesin (1936) in Bellen *et al.* (1959). Later, Bellen (1957) in Bellen *et al.* (1959) defined it at the type locality near Jaddala Village in Jebel Sinjar anticline, within the Foothill Zone in northwestern Iraq. This formation comprises recrystallized and dolomitized, generally massive limestone beds, typically around 1-2 meters thick, and is considered to be of early Miocene age.

Al-Naqib (1959) described the Jeribe Formation in the Kirkuk area. He mentioned that it overlies the Dhiban Formation in the Jambur and Injana

field, while it overlies the Euphrates Formation in fields like Qaiyarah, Najmah, and Jwan. Additionally, it may overlie formations from the older Oligocene age in parts of the Bai Hassan field.

Aljadda (1988) studied the biostratigraphy and sedimentology of the Jeribe Formation in six selected wells within the areas of Balad and Tikrit. He determined that this formation was deposited in several secondary environments within the shallow marine environment, ranging from back reef to lagoonal and ending in a sabkha environment.

Lawa (1989) studied the depositional environment of (Oligocene - Miocene) deposits, showing that the depositional environment of the Jeribe Formation is a shallow, warm, and partially isolated lagoonal environment.

Al-Abbasi (1994) from his sedimentary study of the Jeribe Formation at Tell Masoud section, proposed that the lower and middle parts were deposited in back-reef and reef environments, while the upper part was deposited in reef and fore-reef environments.

Al-Banna *et al.* (2000) provided various sedimentary evidence to differentiate between the Euphrates and Jeribe Formations. They confirmed that the depositional environment of the Jeribe Formation includes tidal flat and coastal lake.

Al-Ayobe (2004) studied the microfacies and depositional model of the Jeribe Formation (early Middle Miocene) and determined that the facies of the Jeribe Formation were deposited in five sedimentary environments. These environments, starting from the bottom, are: Reef Front, Reef, Back Reef, Tidal Flats and Lacustrine.

Al-Dabbas *et al.* (2013) concludes that the microfacies of the Jeribe Formation include mudstone, wackestone, packstone, and grainstone. These were deposited in different platforms that represent the lagoonal environment. These platforms include the open platform, restricted

platform, and edge platform. Whereas the lower parts of the Jeribe Formation, particularly in well Hamrin-2, indicate a deeper fore slope environment.

Abdula *et al.*(2017) from Petrography study they proved that the Jeribe Formation contain a diversity of fauna such as large benthic foraminifera, *Austrotrillina sp.*, Miliolid in addition to *Borelis melo curdica*, which is indeed considered an index fossil for the Jeribe Formation. This formation also contains various types of mollusks. And suggest the Jeribe Formation was deposited in a ramp environment with varying energy levels.

Alatroshe *et al.* (2018) from petrographic analysis they showed a diverse range of foraminifera, Miliolids, Peneroplis, Nummulites, Rotalids and *Borelis melo curdica*, which is an index fossil for the Jeribe Formation. Other fauna such as gastropods, pelecypods, and echinodermata fragments were also present and there was presence of non-skeletal grains (intraclasts and pisoids). And revealed that the Jeribe Formation was deposited during the Middle Miocene age.

Al-khaykanee and Al-Dulaimi (2019) studied the Jeribe Formation in well No AJ-11, and found that It was consist of anhydritic marly limestone, limestone, marl bed, anhydritic limestone, and anhydric dolomitic limestone. The microfauna found in the Jeribe Formation are these foraminifera: *Austrotrillina*, *Borelis melo curdica*, *Peneroplis*, *pyrgo sp.* *Quinquiloculina sp.*, *Rotalia sp.* Other fossils are founded such as echinodemata, gastropoda, pelecypoda (bivalves), red alga, shell fragments.

Ameen *et al.* (2020) studied The microfacies types and deposition environment of the Jeribe Formation (Burdigalian) at the Wazyara and Xamsha sections. The deposition environment was an inner ramp environment.

Al-Sulaiman and Ahmed (2021) according that the Jeribe and Euphrates formations serving as the main reservoirs of the Tertiary reservoir in the Hamrin oil field , and the Dhiban Formation as a secondary reservoir, They studied the log interpretation of these formations showed that the Jeribe Formation is divided into two units, with the upper unit having better petrophysical properties than the lower unit. These units reflect the deposition environment of the formation, the Dhiban Formation and the lower part of the Jeribe Formation deposited in a brine basin , The upper part of the Jeribe Formation deposited in a stable shallow water platform system.

Qader and Ali (2022) studied characteristics of the Jeribe Formation in Kor Mor and found that the lithology of the Jeribe Formation is mostly dolostone and dolomitic limestone. And the estimated reservoir properties, such as clay content and clay types, revealed that the average porosity of the Jeribe reservoir is around 0.10 And the secondary porosity plays a significant role and impact on the reservoir characteristics.

Mahdi *et al.* (2022) conducted a study on the Jeribe Formation in the Khabaz Oilfield and found that the depositional environment of the formation was primarily restricted and semi-restricted.

Agrawi *et al.* (2023) studied that The petrographic components of the Jeribe Formation include skeletal grains, which are mostly shallow marine fossils such as benthonic foraminifera, rare planktonic foraminifera, gastropods, pelecypods, brachiopods, echinoderms, red algae, rare dacycladacean algae, and bioclasts , as well as non- skeletal grains such as peloids, ooids, intraclasts, and monocrystalline quartz. Also they interpreted that The lower part of the Jeribe Formation was deposited in a shallow marine environment within an intertidal setting, while to the upper part it changed to a semi-restricted lagoonal environment.

Ibraheem *et al.* (2023) studied the depositional environment of the Jeribe Formation in specific subsurface sections of Northern Iraq. They found that this formation features a variety of fauna, including benthonic foraminifera such as Miliolid, *Peneroplis sp.*, *Dendritina sp.*, and *Borelis melo curdica*, along with red algae and mollusks. Additionally, they identified the microfacies present in the formation, which include lime mudstone, wackestone, packstone, and Milioldal grainstone. Their study concluded that the Jeribe Formation was deposited in both restricted and open marine environments within an interior platform setting.

Al-Luhaibi (2023) Studied the basin development of Miocene-Pliocene age. His study concentrated on three sedimentary cycles: Burdigalian, Langhian, and Late Miocene-Pliocene. He identified that the Jeribe Formation falls within the second cycle, the Langhian. The grains within the Jeribe Formation included benthonic foraminifera such as Rotalia, Miliolid, and *Borelis melo curdica*, alongside red and green algae, coral, ostracods, bioclasts, peloids, ooids, intraclasts, and extraclasts. He concluded that the Jeribe Formation was deposited in reef, back reef, and lagoon environments, representing a range from relatively low to high energy environments.

Abdullah *et al.* (2024) investigated the microfacies and depositional environment of the Jeribe Formation. They identified four microfacies: mudstone, wackestone, packstone, and grainstone. They concluded that the Jeribe Formation was deposited in five distinct environments: open-marine (ranging from middle ramp to inner ramp), restricted, shoal, lagoon, and partial environments, with most microfacies being found within the inner ramp setting. Overall, the study concluded that the Jeribe Formation was formed in a shallow marine environment.

1.5 Methodology:

The study was done by three stages:

1.5.1 Preparatory Work:

The preparatory work includes selecting of the studied sections , collecting the information about the study area through reading reports, research, and studies related to the Gali Zakho and Gali Duhok or related to the same subject and benefit from it.

1.5.2 Field Work:

The Gali Zakho section have been selected as the typical stratigraphic section for this study because it is well exposed and easy to access. The Gali Duhok section was also chosen to complete the depositional images of the formation. The description and sampling of the two study sections have been conducted through three field trips.

In the field, seventy-four rock samples have been selected from two outcrop sections, with 41 samples from the Gali Zakho section and 33 samples from the Gali Duhok section. The selection process was carried out at varying intervals based on vertical distribution, lithological variations, color differences and bedding nature. Additionally, during the fieldwork, the thickness of each bed was measured, detailed descriptions of the beds and lithology were provided, field photographs were taken, and latitude and longitude coordinates were obtained.

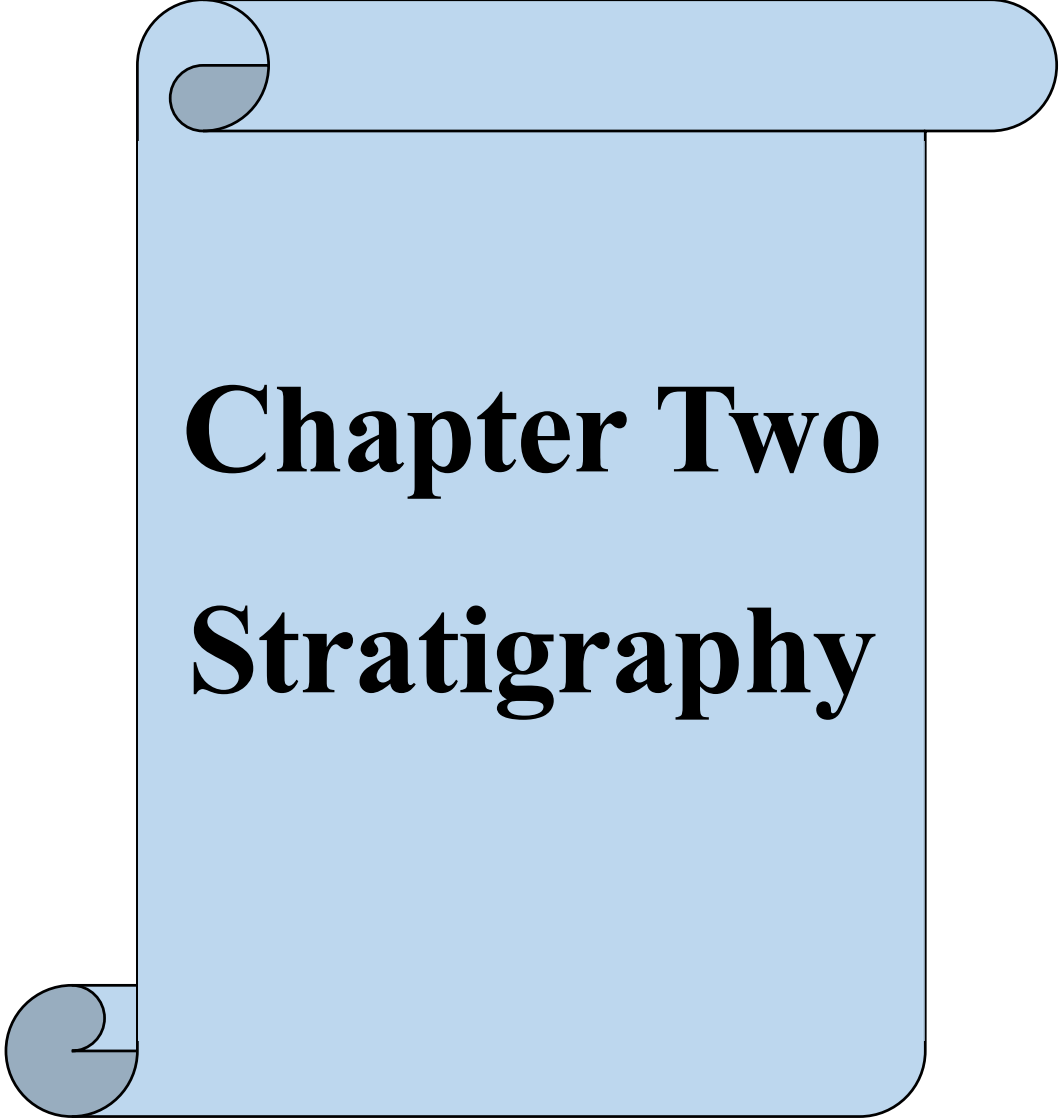
1.5.3 Laboratory Work:

The laboratory work included preparing sixty thin sections for a detailed petrographic study and examining the microfacies using a microscope. This process involved preparing of 31 thin sections from Gali Zakho samples and 29 from Gali Duhok samples.

1.6 Aims of Study:

The purpose of this study is to identify the following:

1. Studying the petrographic components to reach microfacies analysis of the Jeribe Formation.
2. Examining and classifying diagenetic processes, identifying their environments, and constructing a diagenesis model for the formation.
3. Conducting microfacies analysis to determine the depositional environment and construct the depositional model for the Jeribe Formation and understanding its connection to ancient geography.



Chapter Two

Stratigraphy

2.1 Preface:

To understand the stratigraphy of the Jeribe Formation it is important to provide a detailed record of formation's history. By studying the layers of rocks and their arrangement, boundaries, deposition environment, lithology, thickness, and equivalents, we can understand the sequence of events (tectonic activities, sea level changes, and climate variations) that have contributed to the deposition of this formation.

2.2 Paleogeography of Iraq During Early Middle Miocene:

The development of the paleogeography in the platform during the Early-Middle Miocene is represented by the development of wide shallow basin, Where the Savian geological movement affected the Zagros Suture during the Oligocene-Early Miocene caused the Balambo-Tanjero Trough to rise. Some areas of the region could have been underwater in the Early Miocene, contributing to the creation of a broad shallow basin (Jassim and Goff, 2006).

Jassim and Goff (2006) divided early-middle Miocene sequence into two 2nd order sequences, Early Miocene sequence and Middle Miocene sequence, each transitioning from shallow water carbonates to evaporates. The current study deals with the Middle Miocene sequence (Langhian age). During the Early Middle Miocene, widespread shallow water lagoonal and reefal carbonates (Jeribe Formation) were deposited on a wide carbonate platform (**Fig 2.1**).

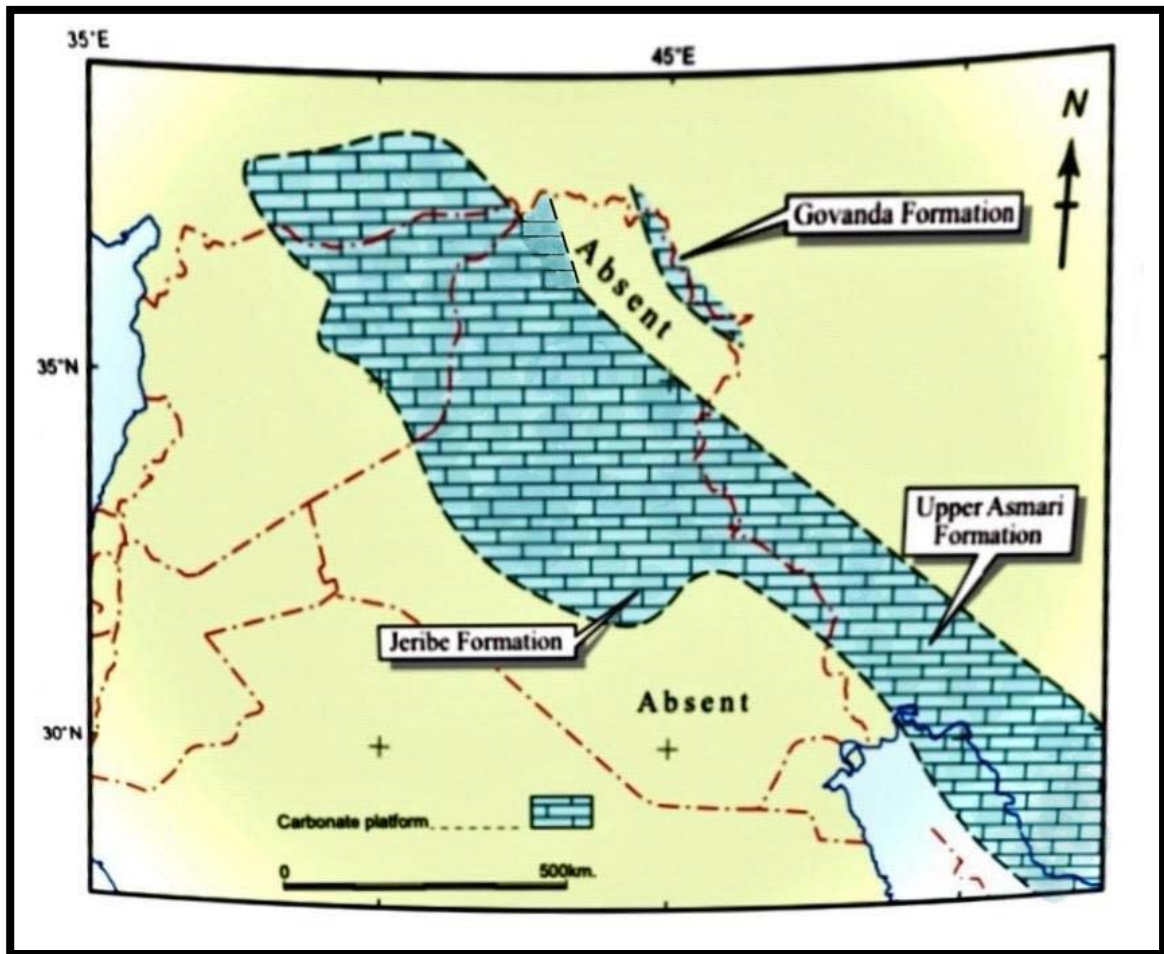


Figure 2.1: Palaeogeographic of the Jeribe Formation modified from Aqrawi *et al.*(2010).

The deposition of the Jeribe Formation marks the beginning of the second depositional cycle of Miocene cycles. It appears to have initiated depositing with the early marine transgression that affected the Foreland basin in the early Middle miocene. However, these marine conditions regressed as the basin separation increased, forming lagoonal basins semi-connected to open marine waters. This led to the repetition of evaporite cycles composing the sequences of the Fat'ha Formation during the Middle Miocene (Mustafa, 1980). According to Numan (1997), The second deposition cycle ended with the Late Miocene, deposition of the Injana Formation in the Foreland basin, indicating the end of marine

conditions in the region (Iraq) and the start of molasse conditions (the sediments deposited following the orogenic movements stabilization).

Jeribe Formation is related to Latest Eocene-Recent Arabian Plate Megasequence AP11(Sharland *et al.*, 2001) which is subdivided into 3 sequences of Latest Eocene-Oligocene, Early-Middle Miocene and Late Miocene-Recent Age (Jassim and Goff ,2006) (**Fig. 2.2**).

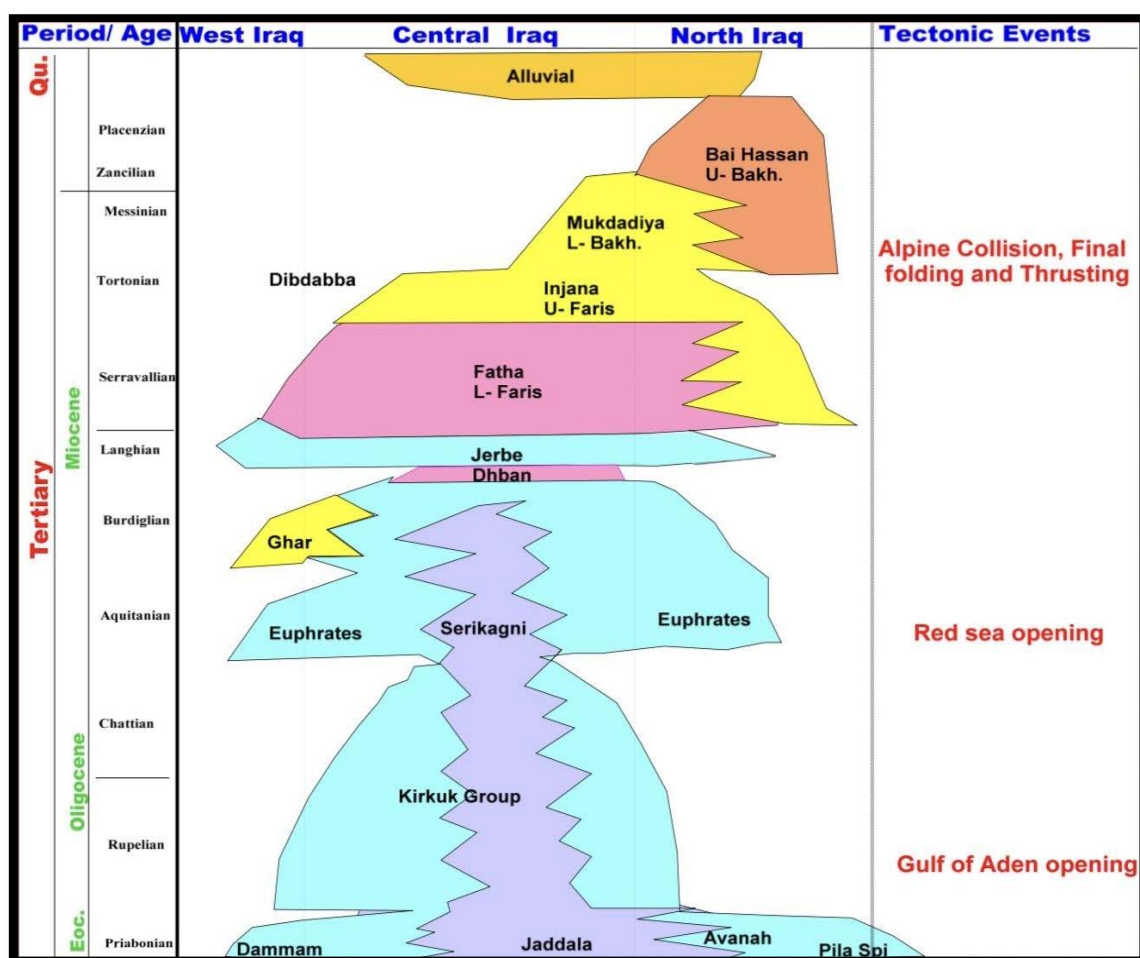


Figure 2.2: Formations of the Arabian Plate megasequences AP11 modified from Alfaris (2022).

2.3 Age of the Jeribe Formation:

There are many different opinions in determining the age of the Jeribe Formation. The age of the formation was first determined as early Miocene by Bellen *et al.* (1959). However, they mentioned the difficulty in accurately determining the age of the Jeribe Formation because it contains the index fossil *Borelis melo curdica*, which is also found in the Govanda Formation with Early Miocene age and in Lebanon with middle Miocene fossils. This creates doubt in determining the exact age of the formation. As a result, they did not definitively conclude the age of the formation and suggested more research and investigation.

Al-Juwaini (2001) studied the sedimentary sequences of the Jeribe Formation in selected wells from the fields of the Hamrin area. He identified that the age of the formation is early Middle Miocene based on the presence of basal conglomerate and benthic foraminifera (*Orbulina*) and the presence of the *Borelis melo curdica*.

Based on the studies by Ibrahim and Al-Dulaimi (2023) as latest study related to determining the age of the formation, they confirmed that the age of the Jeribe Formation is Early-Middle Miocene based on the presence of two specific biozones, the *Austrotrillina asmariensis-Dendritina rangi* Concurrent Zone and the *Borelis melo curdica* range zone.

2.4 Jeribe Formation Boundaries:

2.4.1 Lower Contact:

The lower contact of the Jeribe Formation is unconformable with all the formations below it. The nature of the lower contact of the Jeribe Formation varies from area to another, in some locations, it sharply overlies the Serikagni Formation, as seen in the type locality section (Bellen *et al.*, 1959), and in other localities, it overlies the Euphrates Formation, as in the Timar and Pungala sections (Hussein *et al.*, 2017). The Jeribe Formation can directly rest on Oligocene formations as in the Kirkuk area (Bellen *et al.*, 1959) and in the derzila village section (Abdula *et al.*, 2017).

In the current study, the lower contact of the Jeribe Formation in the Gali Zakho section is unconformable with the Dhiban Anhydrate Formation (**Fig. 2.3**). While, in the Gali Duhok section, the lower contact of the Jeribe Formation is unconformable with the PilaSpi Formation , characterized by layers of cherty limestone and dolomitic limestone with a brownish-gray in weather colour and gray in fresh colour, irregular, very tough, and highly bioturbated (**Fig. 2.4**). Between the PilaSpi and Jeribe Formations lies a 1.13 m thick of hardground surface composed of marly limestone and dolomitic limestone, rich in macrofossils (such as Gastropoda) and trace fossils (**Fig. 2.5**), representing the boundary between the formations (**Fig. 2.4**).

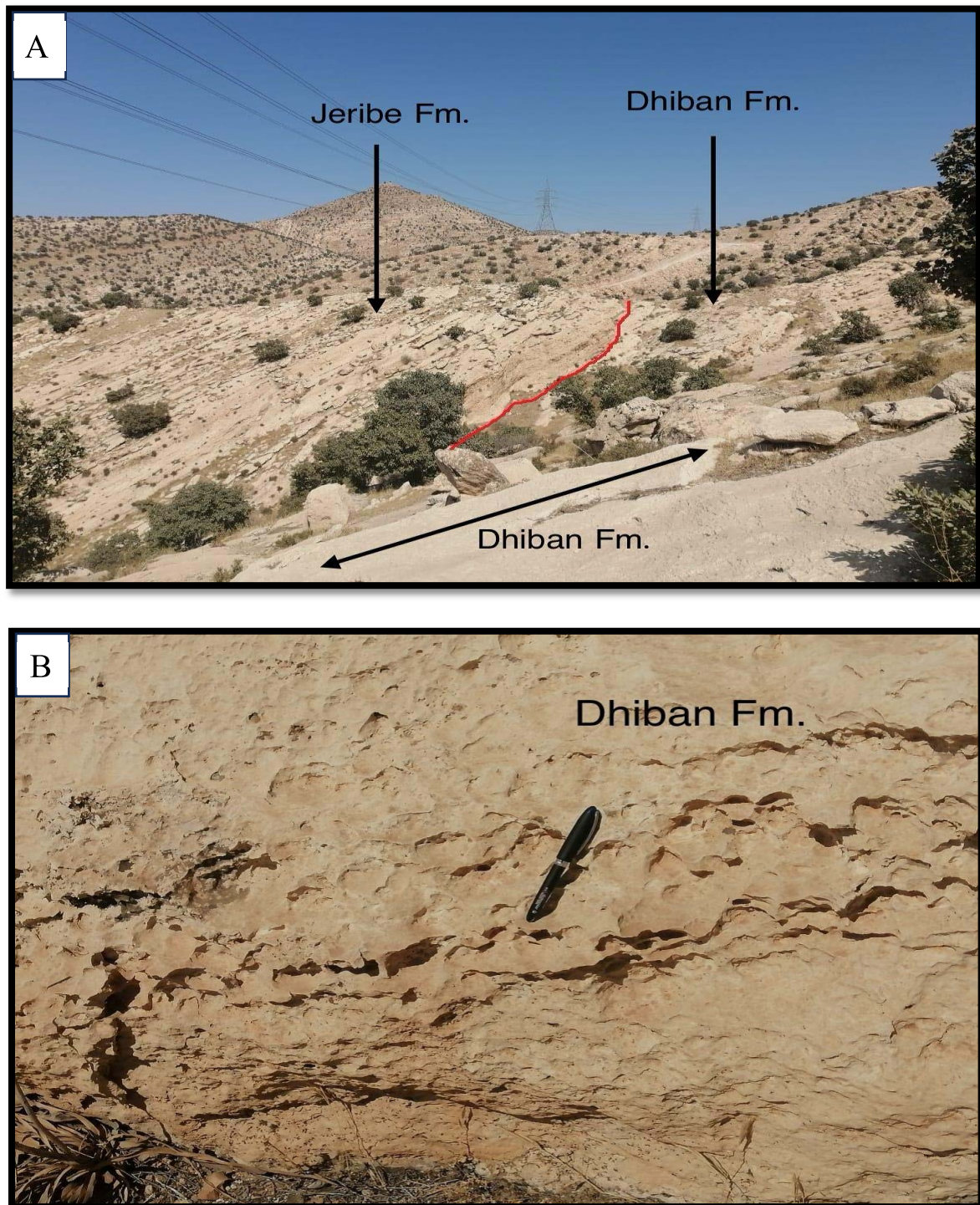


Figure 2.3: Field photograph showing, **A.** The lower contact of the Jeribe Formation which is with the Dhiban Anhydride Formation. Gali Zakho section. **B.** Gypsum of the Dhiban Anhydride Formation. Gali Zakho section.

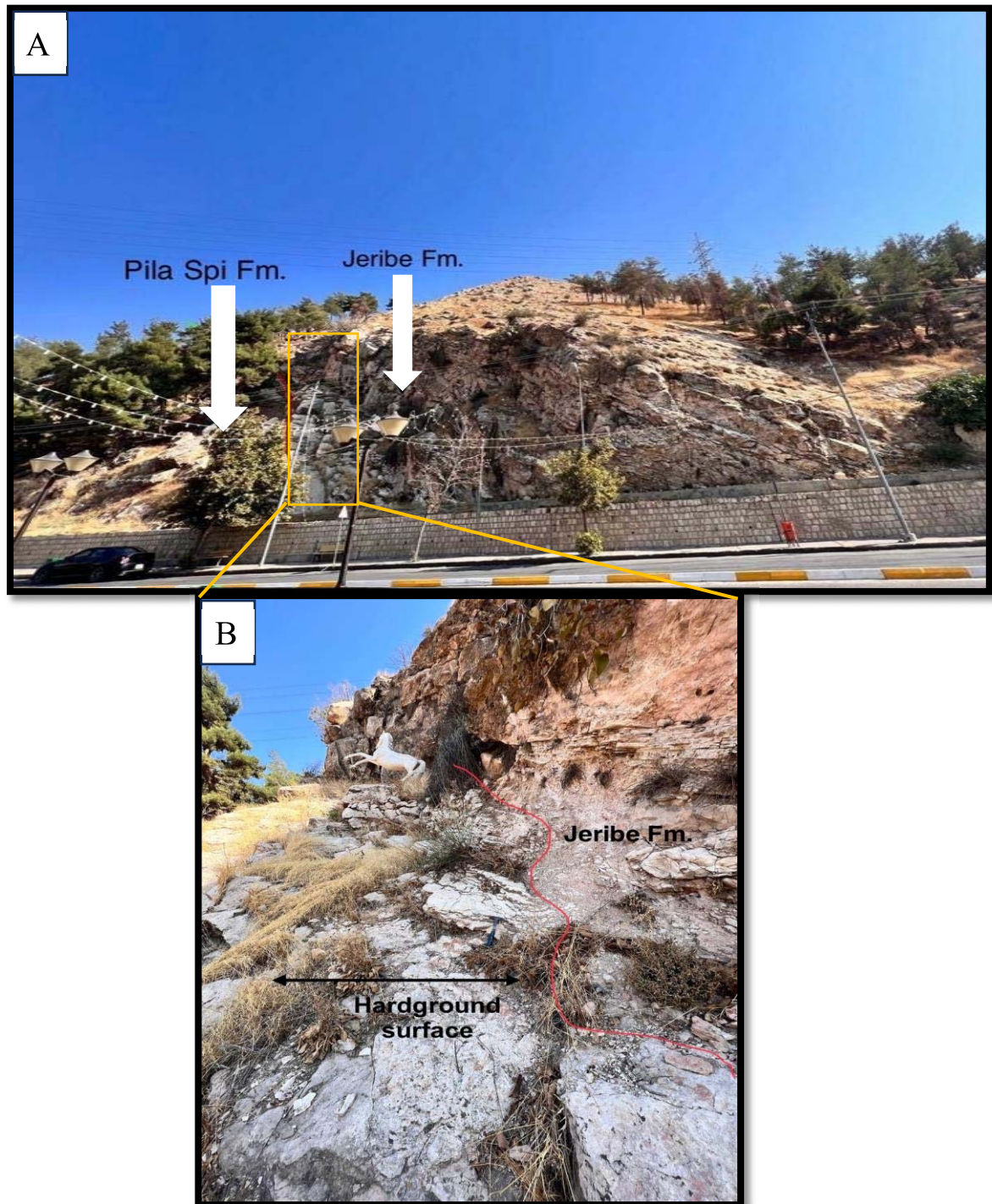


Figure 2.4: Field photograph showing, **A.** The lower contact of the Jeribe Formation which is with the PilaSpi Formation. Gali Duhok section. **B.** The hardground surface representing the boundary between the Jeribe Formation and PilaSpi Formation. Gali Duhok section.

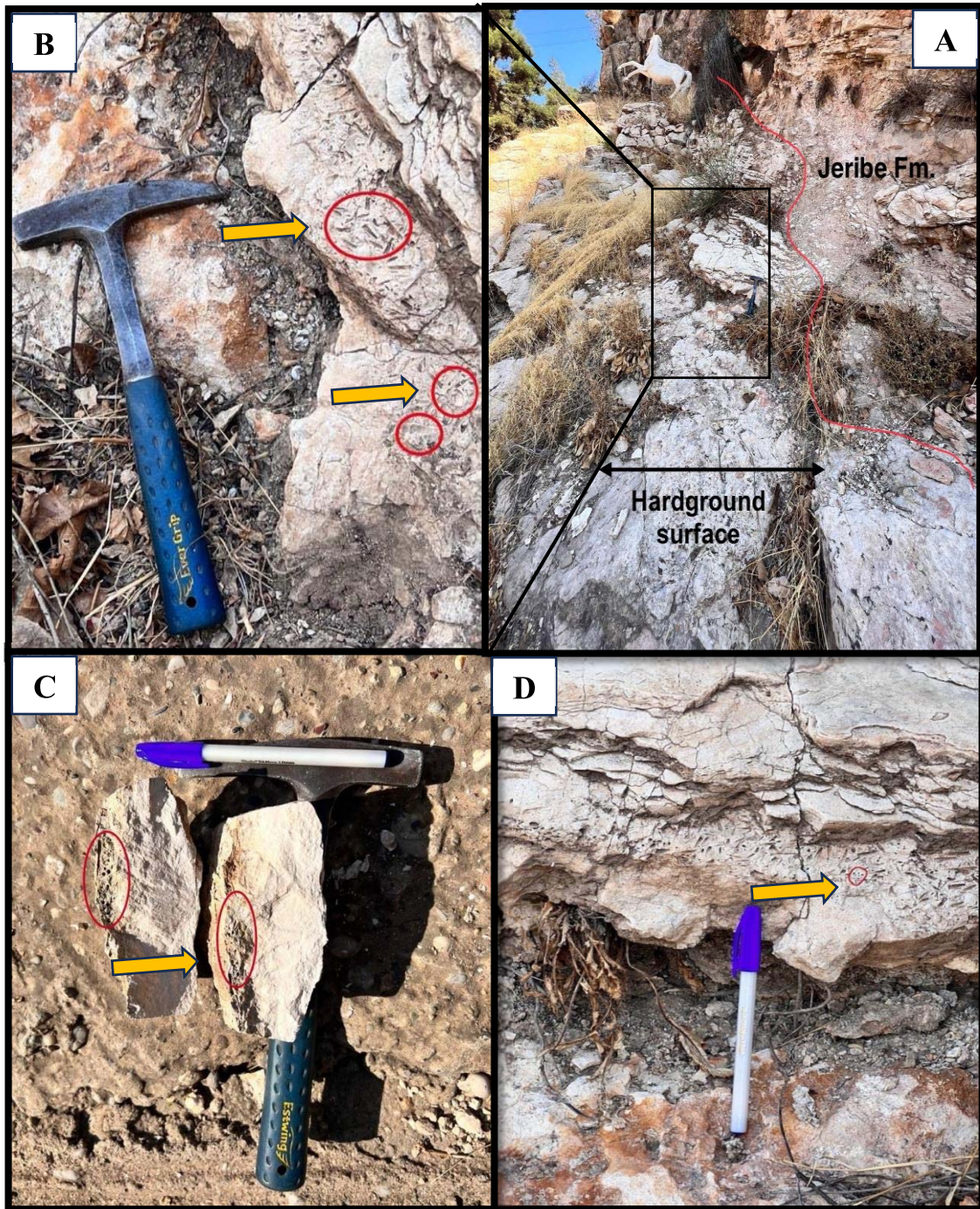


Figure 2.5: Field photograph showing, **A.** the hardground surface **B.** Gastropoda shell indicated by red circle and yellow arrow **C. and D.** boring indicated by red circle and yellow arrow. Gali Duhok section.

The different nature of the lower contact is due to the progressive deposition of the Jeribe Formation over all those old formations. Before the Jeribe Formation was deposited, the region experienced the deposition of the Lagoonal Euphrates Formation in the shallow areas of the basin and the Baisnal Serikagni Formation in the deeper parts. As the sea regressed , small lagoonal basins formed in the region, leading to the deposition of evaporites of Dhiban Anhydride Formation, marking the end of the sedimentary cycle that preceding the deposition of the Jeribe Formation (Jassim and Goff , 2006).

2.4.2 Upper Contact:

In Gali Zakho section, the upper contact of the Jeribe Formation is characterized by a sharp unconformable surface. it is overlain by the basal conglomerate unit of 8.5 meter thick, consisting of rounded pebbles of siliciclastic, igneous and metamorphic , and the groundmass is mostly composed of sandstone and may contain carbonate, but in very low percentages (**Fig. 2.6**). The conglomerate layer represents the boundary between the Jeribe and Fat'ha Formations (consisted of chalky limestone and dolomitic limestone, massive , highly fractured, rich in pores) and upper part of the Jeribe Formation (**Fig 2.6**). In contrast, in the Gali Duhok section, it is directly overlain by the Fat'ha Formation with gradational and conformable boundary (**Fig. 2.7**).

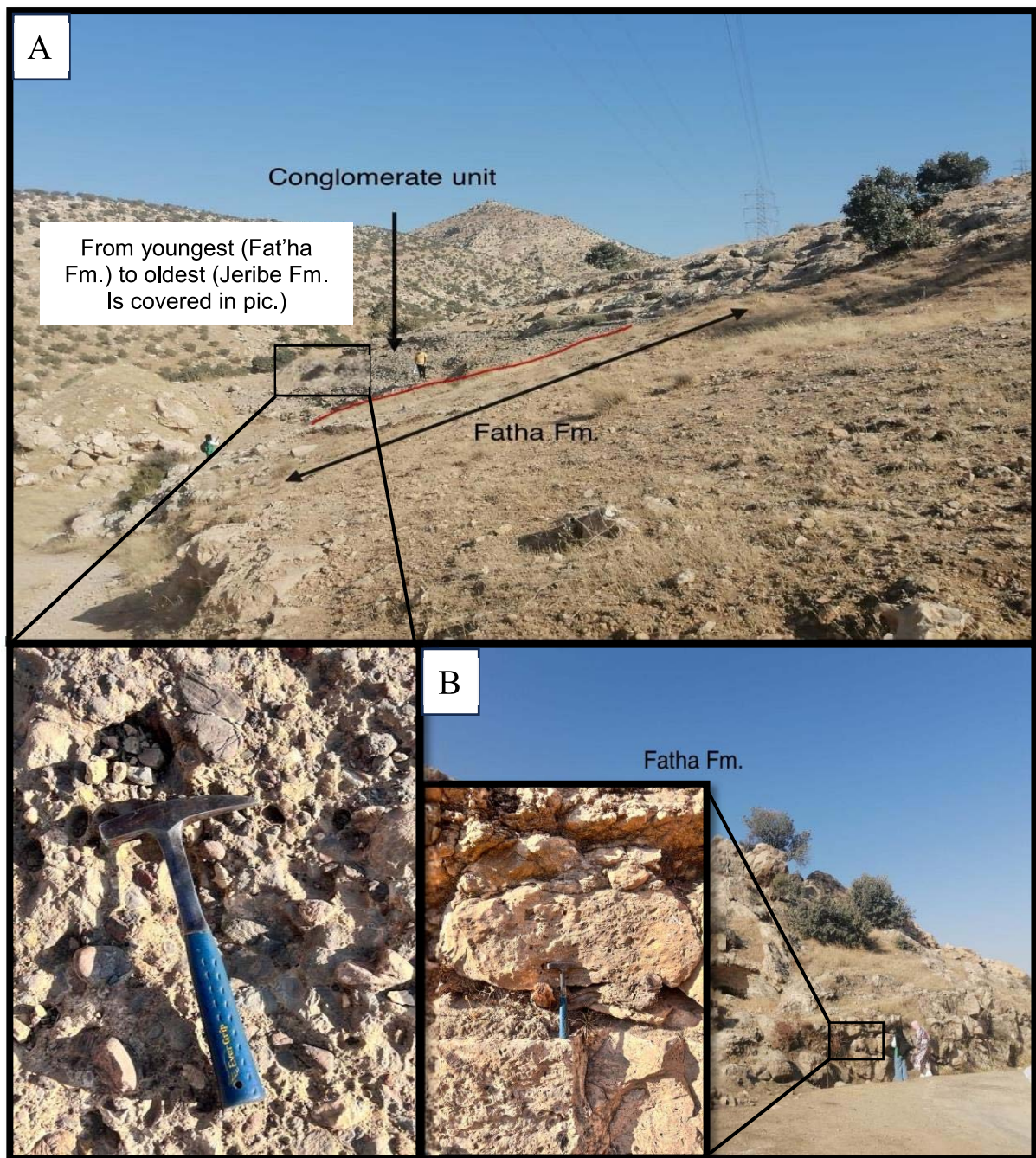


Figure 2.6: Field photograph showing: **A.** Conglomerate layer represents boundary between Jeribe Formation and Fat'ha Formation. **B.** The upper contact of the Jeribe Formation. Gali Zakho section.



Figure 2.7: Field photograph showing the upper contact of the Jeribe Formation. Gali Duhok section.

2.5 Thickness and Extent of the Jeribe Formation:

As known, the thickness of any formation can vary from location to another. It depends on factors such as tectonic activity, sediment supply, and local depositional environment (location within the basin). The Jeribe Formation is widely distributed in northern Iraq, especially in the northwestern parts, both at the surface and in wells (**Fig. 2.8**). Regionally, it extends into northern and northeastern Syria and also eastward into Iran, where it is known as the Asmari Formation. (Bellen *et al.*, 1959; Metwalli *et al.*, 1974) (**Fig. 2.1**).

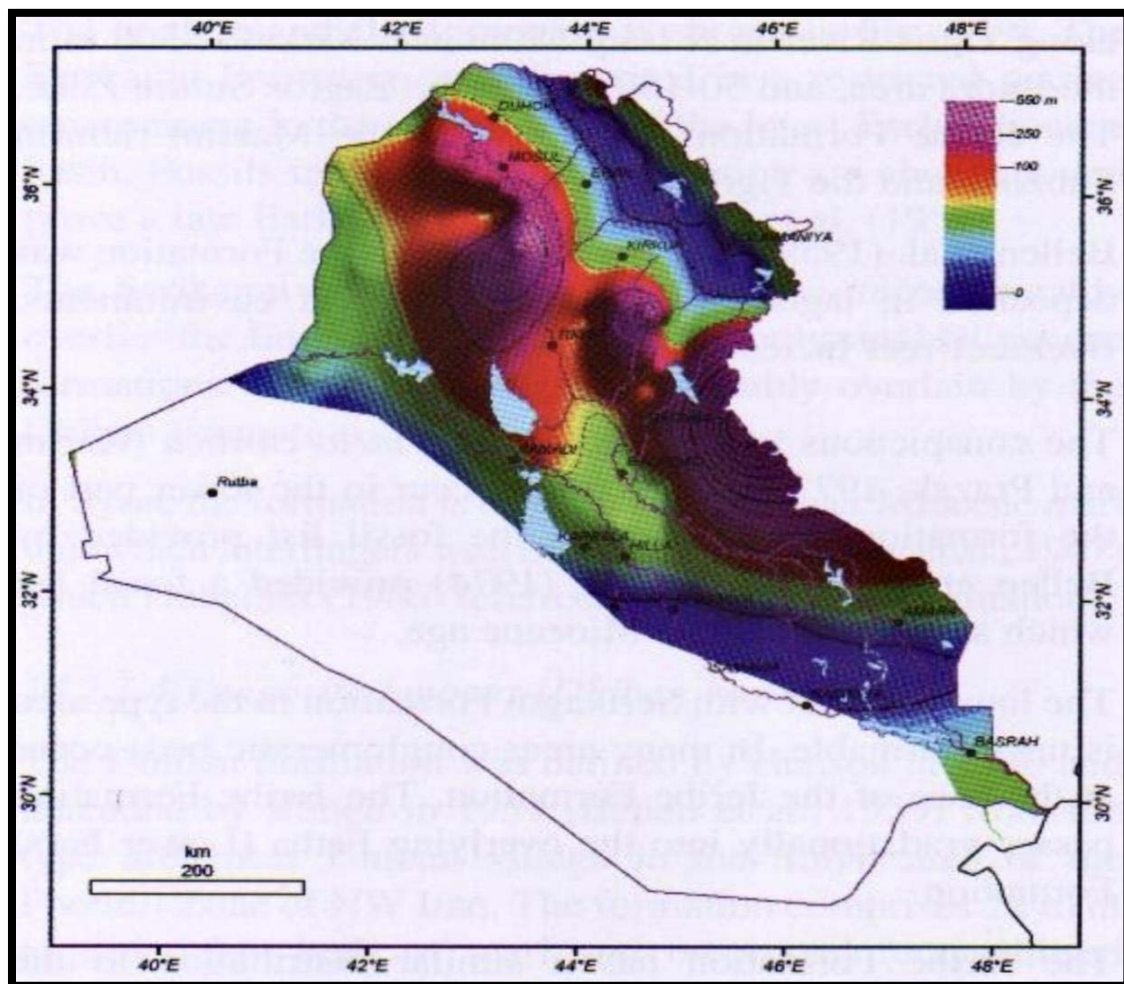


Figure 2.8: Thickness of the Jeribe and Govanda Formations (Jassim and Goff, 2006).

The current study indicates variations in the thickness distribution of the Jeribe Formation and its extensions in the Bekhair anticline, where the thickness of the formation is about 77.7 m in the Gali Zakho section and about 16.05 m in the Gali Duhok section.

2.6 Equivalents of the Jeribe Formation:

The equivalent formations represent sedimentary deposits that were formed during the same geological time period. These equivalent formations in different regions provide valuable insights into the geology and paleoenvironment of that time and help establish connections between different areas.

The Jeribe Formation is equivalent in age to the Govanda Formation in northeast Iraq (Jassim and Goff, 2006) (**Fig. 2.1**) and to the upper part of the Ghar Formation (Early- early Middle Miocene) in western and southern Iraq (Gayara and Ajar, 2015).

The Jeribe Formation shows regional equivalence to various formations in different countries. According to Beydoun (1990), it is equivalent to the Asmari Formation in Iran, the Firat Formation in Turkey in terms of lithology and age. In Kuwait, Saudi Arabia, and Turkey, it equivalents in age with the Ghar, Dam, and (Silvan and Lice) Formations respectively.

According to Jassim and Goff (2006), in the SW Iran, It is equivalent in age to the Kaihur Limestones and upper part of Asmari Formation.

2.7 Lithological Description of the Jeribe Formation:

2.7.1 Gali Zakho Section:

The Jeribe Formation in Gali Zakho section is approximately 77.7 meters thick and the bedding nature is generally horizontal. Based on field observations regarding the bedding nature, distinct lithological characteristics of each layer, fossil content, as well as colour , The Jeribe Formation in the Gali Zakho section has been divided into three distinct units: lower, middle, and upper unit as described in the following (Fig. 2.9):

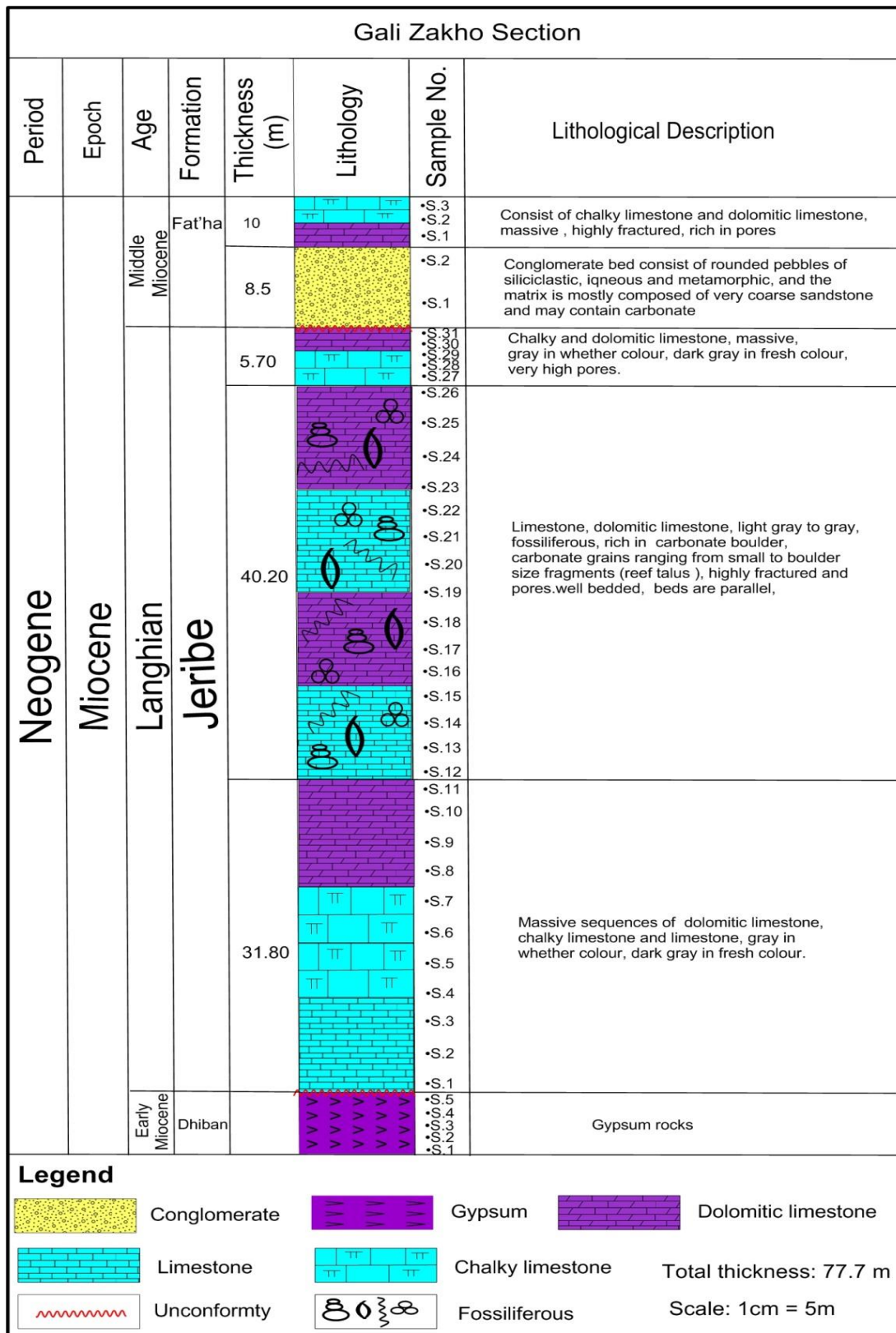


Figure 2.9: Illustrates the lithological section of the Jeribe Formation in Gali Zakho section.

- **Lower Unit:**

Thickness of this unit is about 31.80 meters of massive sequences of dolomitic limestone, chalky limestone and limestone, parallel, gray in weather colour , dark gray in fresh colour.(**Fig. 2.10**).



Figure 2.10: Field photograph showing a massive bed of dolomitic limestone, chalky limestone and limestone of the lower unit of the Jeribe Formation. Gali Zakho section.

- **Middle Unit:**

Thickness of this unit is about 40.20 meters thick, composed of limestone, dolomitic limestone, light gray to gray, well bedded, thickened towards NE, beds are parallel, fossiliferous, rich in limestone boulder, carbonate grains ranging from small to boulder size fragments (reef talus), highly fractured, and pores (**Fig. 2.11**).



Figure 2.11: Field photograph showing Fossiliferous bed that is rich in limestone boulder, carbonate grains ranging from small to boulder size fragments (reef talus) of the middle unit of the Jeribe Formation. Gali Zakho section.

- **Upper Unit:**

Upper unit is about 5.70 meters thick of chalky and dolomitic limestone, massive, parallel, gray in weather colour , dark gray in fresh colour very high pores, thickness of this unit become thinner towards NE (**Fig 2.12**).

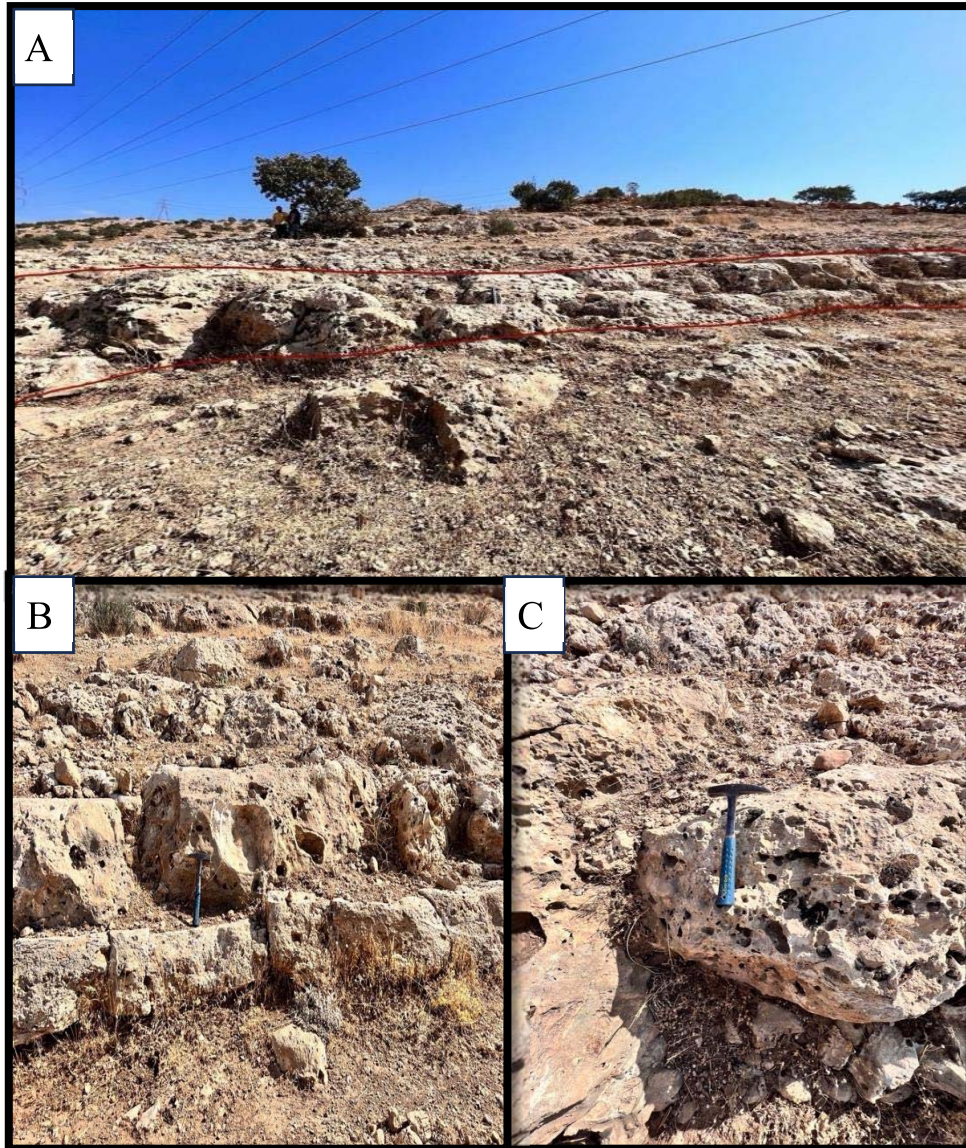


Figure 2.12: Field photograph showing, **A.** Beds that become thinner towards NE of the upper unit of the Jeribe Formation. Gali Zakho section.

B and C. Beds of the highly pores of the upper unit of the Jeribe Formation. Gali Zakho section.

2.7.2 Gali Duhok Section:

The Jeribe Formation in Gali Duhok section is about 16.05 meters thick and the nature of bedding is inclined. It exhibits an alternation between bedded and massive layers. Based on field observations regarding the bedding nature, distinct lithological characteristics of each layer, fossil content, as well as colour, The Jeribe Formation in Gali Duhok section has been divided into four distinct units: lower, middle part A, middle part B and upper unit as described in the following **(Fig. 2.13)**:

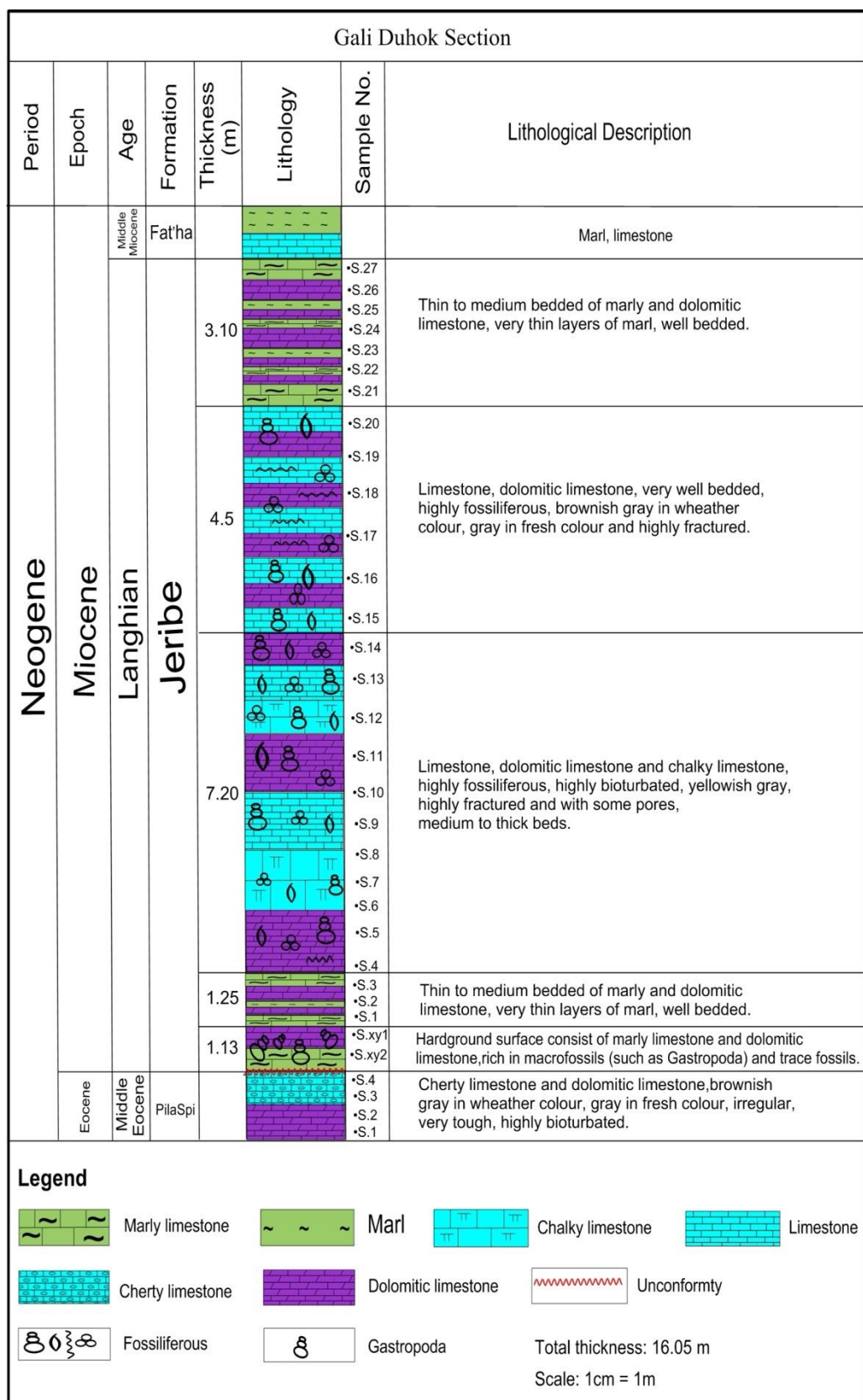


Figure 2.13: Illustrates the lithological section of Gali Duhok section.

- **Lower Unit:**

Thickness of this unit is about 1.25 meters, thin to medium bedded of marly and dolomitic limestone, very thin layers of marl, well bedded, continuous and tabular. (Fig 2.14).



Figure 2.14: Field photograph showing well bedded of the lower unit of the Jeribe Formation. Gali Duhok section.

- **Middle Unit Part-A:**

Thickness of this unit is about 7.20 meters thick of limestone, dolomitic limestone and chalky limestone, medium to thick beds, thickened towards southwest, highly fossiliferous, highly bioturbated, yellowish gray, highly fractured and with some pores (Fig 2.15).



Figure 2.15: Field photograph showing the pores of the middle unit part-A of the Jeribe Formation. Gali Duhok section.

- **Middle Unit Part-B:**

Thickness of this unit is about 4.5 meters thick of limestone, dolomitic limestone, very well bedded, thickened towards southwest, highly fossiliferous, brownish gray in weather colour, gray in fresh colour and highly fractured (**Fig 2.16**).



Figure 2.16:Field photograph showing the highly fossiliferous of the middle unit part-B of the Jeribe Formation. Gali Duhok section.

- **Upper Unit:**

Thickness of this unit is about 3.10 meters thick of thin to medium bedded of marly and dolomitic limestone, very thin layers of marl, well bedded and tabular (**Fig. 2.17**).



Figure 2.17:Field photograph showing the well bedded of the upper part of the Jeribe Formation. Gali Duhok section.

**Chapter
Three
Petrography
and
Diagenesis**

3.1 Preface:

Petrography involves describing thin sections of rock samples under a microscope to identify grains and groundmass, enabling the determination of microfacies. This process leads to the interpretation of depositional environments and sea level variations. Additionally, it aids in determining the complex history of post-depositional changes (diagenesis), including the timing of diagenetic events like cementation or secondary porosity development.

This chapter includes the petrographic analysis of the study sections and the diagenetic processes that affected on it.

3.2 Petrographic Analysis:

When examining carbonate rocks under a microscope or collecting samples, depositional components and diagenetic features will be distinguished. Depositional components originated from the initial deposition, while diagenetic features result from post-depositional processes. The depositional components consist of carbonate particles (grains) and groundmass (micrite and sparite) (Flügel, 2004). The diagenetic features would be cementation, dissolution, dolomitization, micritization and others.

By describing thin sections of carbonate samples under a microscope, the petrographic components , mainly grains and groundmass can be identified. Additionally, diagenetic features can be observed. Below is a detailed description of the petrographic components in the carbonate rocks from the study sections (**Fig. 3.1**).

3.2.1 Ground Mass (Orthochems, Matrix):

The term orthochems introduced by Folk (1959) for groundmass. Groundmass known as the primary matrix, refers to the fine-grained

materials between different grain components that bind them together, acting as cement. These materials, classified by size into Micrite and Sparite, provide insights into water current intensity and depositional environment characteristics (Folk, 1959). In the study of thin sections of the formation successions, it was observed that the groundmass consists of micrite and sparite.

3.2.1.1 Micrite (Lime Mud):

Folk (1959) was the first to use the term micrite to describe the fine crystalline calcite (Microcrystalline calcite) with grain size generally less than 4 microns. In field descriptions, the terms lime mudstone, mudstone, calcium and Calcilutite are used to describe it. Under the microscope, they display a grayish to brownish with a sub-translucent appearance, easily distinguishable from carbonate grains and sparry calcite crystals due to their extremely tiny crystal size (Folk, 1959). Micrite can be deposited in low-energy marine environments unaffected by strong currents and high waves (Friedman, 1985 ; Flügel ,2004 ; Boggs, 2006). Micrite provides indications of deep-sea and lagoon settings according (Selley, 1976).

Micrites are susceptible to diagenetic changes and transform into microspar, typically sized between 4-10 microns, as a result of recrystallized during early carbonate diagenesis (Tucker, 1985). The microspar crystals are characterized by uniform and homogeneous sizes and shapes. The rocks of the current study in the lower part of Gali Zakho section and in all parts of Gali Duhok section are composed originally of micrites, but now it has been partially or completely recrystallized (**Pl.A-1**) or dolomitized (**Pl.A-2**). Hence, there are no original micrites in the study rocks except in the lowermost part of Gali Duhok section (**Pl.A-3**). Flügel (1982, 2010), pointed to various origins and mechanisms for micrite formation as illustrated in (**Table 3.1**):

Table 3.1: Terminology and Processes of micrite origin modified from Flügel (2010).

Origin of micrite			Processes
Primary (orthomicrite)	Automicrite (autochthonous)	Abiogenic (inorganic)	physicochemical processes leading to precipitation due to changes in salinity and water temperature.
		Biologic	organic materials facilitate carbonate precipitation by binding Ca-binding organic molecules, resulting in organo mineralization and the creation of organomicrite. Metabolic processes of Bacteria like heterotrophs, chemolithotrophs, and phototrophic cyanobacteria and algae causing microenvironmental changes, leading to carbonate precipitation.
	Allomicrite (allochthonous)		It is formed from broken-down skeletal material and fine eroded debris like the disintegration of benthic calcareous algae, epibionts on seagrass, invertebrate skeletons, bioerosion, microborings, accumulation of calcareous plankton, and mechanical erosion of limestones, especially along coastlines.
Secondary pseudomicrite (diagenetic micrite)			formed by micro- and crypto- crystalline carbonate cements, along with processes like recrystallization and reduce in grain size, where former larger crystals are replaced by tiny crystals. These secondary processes modify the original micritic structure and give rise to pseudomicrite

3.2.1.2 Sparite (Sparry cement):

The term Sparite is used to describe coarse crystalline calcite cement which represent Sparry calcite cement with sizes >10 microns of calcite crystals (Flügel, 2010). It appears clear or white when seen through a hand lens or under a polarizing microscope in plane light. It is differentiated from micrite by its big size and clarity, and from carbonate grains by its crystal shapes and absence of internal texture. According to Flügel (2004), these calcite crystals are found either inside the grains or within the cavities, voids and channels as a result of diagenesis processes (cementation) (Pl.A- 4).

It can be classified into two types: Orthosparite and Pseudosparite. The Orthosparite forms as cement between and/or within the grains (Flügel, 1982). It is observed in middle and upper parts of Gali Zakho section (Pl.A-5), while The Pseudosparite consists of large, shapeless crystals resulting from continuous recrystallization processes of micrite or sparite (Flügel, 1982) It is found in Jeribe Formation in the lower part of Gali Duhok section (Pl.A- 6).

3.2.2 Grains (Allochems):

Folk (1959), introduced the term allochems to describe carbonate grains that are formed through chemical or biochemical precipitation. According to Folk (1962), carbonate grains are skeletal and non-skeletal grains. Grains are essential in carbonate rocks as they provide the important information about the transportation method of these grains, and the environment in which they were deposited (Flügel, 2010).

During the current study, some of the grains are undistinguishable or obscured due to the effects of diagenesis. The grains identified in this study are:

3.2.2.1 Skeletal grains:

The skeletal grains are either be found preserved in their entirety as complete fossil shells (Biomorpha) or exist as differently shaped and sized fragments, known as fossil debris (Bioclasts). They are composed of calcite, aragonite, low / high Mg - calcite or silica (Flügel, 2010). The common skeletal grains determined in the study successions are:-

3.2.2.1.1 Benthonic Foraminifera:

Benthonic foraminifera are the most common skeletal grains in the current study of the two sections, except for the lower part of the Gali Duhok section. These foraminifera serving as significant indicators of paleo environment. And they include the following:

- From the Miliolina Suborder, following families have been identified:
 - Miliolidae Family is highly abundant in the upper, and middle parts of Gali Zakho section and in middle part of Gali Duhok section. They are *Quinquiloculina sp.*, *Triloculina sp.* and *Pyrgo sp.*, (Pl, A-2), (Pl.A-7), (Plat, A- 8).
 - Soritidae Family is identified in the upper and middle part of Gali Zakho section. They are *evolute peneroplis sp.*, *Peneroplis sp.* (Pl.B-1), (Pl.B-2).
 - Alveolinidae Family is identified in the lower part of the formation in the Gali Zakho section. Represented by *Borelis sp.*, we can not confidently identify it as *Borelis melo curdica*, which is considered the index fossil of the Jeribe Formation because it is greatly affected by diagenesis. It characterized by thick walls and large chambers (Pl.B-3).

- From the Rotaliina Suborder, the *Rotalia sp.* has been identified among the benthonic foraminifera in the middle and upper part of the Gali Zakho section **(Pl.B- 4)**.

- From Textularina Suborder, the *Textularia sp.* has been identified in the upper parts of the Gali Duhok section **(Pl.B-5)**.

In addition to the presence of *Dendritina rangi d'Orbigny sp.* **(Pl.B-6)**, *Idalina sp.* **(Pl.B-7)**, bioclast of *Archaias kirkukensis sp.* **(Pl.B- 8)** and uniserial benthonic foraminifera in the middle part of Gali Zakho section **(Pl.C- 1), (Pl.C- 2)**.

3.2.2.1.2 Calcareous Algae:

In the current study two types of calcareous algae have been identified, red algae and green algae as following:

3.2.2.1.2.1 Red Algae (Rhodophyta):

Tucker and Wright (2001), mentioned that algae are essential in building organic reefs and deposits. Red algae are commonly found in reef environments. Red algae are identified in the middle part B in the Gali Duhok section and in the middle and upper parts the Gali Zakho section. In the Gali Zakho section represented by the the coralline red algae nodule Called a rhodoid **(Pl.C- 3)** and a branching crustose coralline red algae of *Lithophyllum sp.* **(Pl.C- 4)** and red algae *Solenopora sp.* **(Pl.C- 5)**.

3.2.2.1.2.2 Green Algae (Chlorophyta):

In this study the green algae have been identified in the middle and upper part of Gali Zakho section represented by *Halimeda sp.* **(Pl.C- 6)**. green algae indicates a reef and near-back reef environment. It is commonly found at depths ranging from 2 to 30 meters and exhibits a wide range of salinity tolerance, from strongly hypersaline to brackish conditions (Scholle and Ulmer-Scholle, 2003).

3.2.2.1.3 Mollusks:

The mollusk phylum is a significant group of invertebrate animals with a wide variety of distribution and forms found all around the world (Al-Omari and Al-Nasser, 2002). Their shells tend to be thicker in warm water compared to cold water (Scholle and Ulmer-Scholle, 2003). Two classes of mollusk has been identified in both sections, Pelecypod in the middle part of Gali zakho section and in the middle of Gali Duhok section (**Pl.C- 7**), and Gastropoda in the (**Pl.C- 8**), (**Pl.D- 1**), all parts of the Gali Zakho section and Gali Duhok section (except lower part).

3.2.2.1.4 Bioclasts:

Bioclasts are broken skeletal grains that could have been broken by water currents or through mechanical compression and deposited in the sedimentary basin (Abawi *et al.*, 2000). Also, the shearing, cutting, and polishing operations during thin section preparation in the workshop can lead to the fragmentation of skeletal grains. The major bioclasts identified in this study include benthonic foraminifera and algae. Bioclasts are identified in the middle and upper part of Gali Zakho section (**Pl.D- 2**) and (**Pl.C- 4**).

3.2.2.2 Non- Skeletal Grains:

These grains are inorganic origin, they are not derived from the skeletons of organisms. These can include Peloids , Lithoclasts and other materials that are not of biological origin. In this study, Peloids, coated grains (oncoids) and Lithoclasts have been identified as following:

3.2.2.2.1 Peloids:

Peloid is a term refer to grains made of micritic material without specifying a particular origin (Scholle and Ulmer-Scholle,2003). They tend to have rounded or subrounded shapes and lack internal structure and typically range in size from 0.1 to 0.5 mm in diameter. The majority

of peloids are of fecal origin , hence they are often called pellets (Tucker, 1982). Soja *et al.* (2000) mentioned that the high abundance of peloids reflects the impact of crustal organisms and micro borers that alter the skeletal grains. The peloids have been identified in the two study sections, the middle and upper parts of the Gali Zakho section, and the lower and middle parts of the Gali Duhok section (**Pl.D- 3**).

3.2.2.2.2 Coated Grains:

A coated grains is a common term that is often used to refer to ooids and pisoids, and it encompasses oncoids, which are grains covered with a microbial coating (Tucker and Wright, 2001).

3.2.2.2.2.1 Oncoids:

Oncoids are coated grains, typically originate from a biological or lithoclastic nucleus with an enclosing micritic, laminated cortex (Flügel, 2004). They forms in environments that are agitated by currents and waves. They are identified in the lowermost of the middle part of Gali Zakho section. (**Pl.D- 4**).

3.2.2.2.3 Lithoclasts:

Lithoclasts are rock fragments that have been re-deposited in the sedimentary basin. The lithoclasts include intraclasts and extraclasts (Folk, 1959).

3.2.2.2.3.1 Intraclasts:

Intraclasts are rock fragments of carbonate sediments that have been eroded and then re-deposited within the same depositional basin (Tucker and Wright, 1990). These fragments exhibit similar composition and texture to the basin floor (Folk, 1959). They are identified in this study in the middle and upper part of Gali Zakho section (**Pl.D- 5**).

3.2.2.2.3.2 Extraclasts:

Extraclasts are rock fragments (calcareous or non- calcareous components) that come from outside the depositional basin (Folk, 1959). and they are different lithologically from the surrounding sediments. These are identified in the all parts of Gali Zakho section (**Pl.D- 6**), (**Pl.D- 7**).

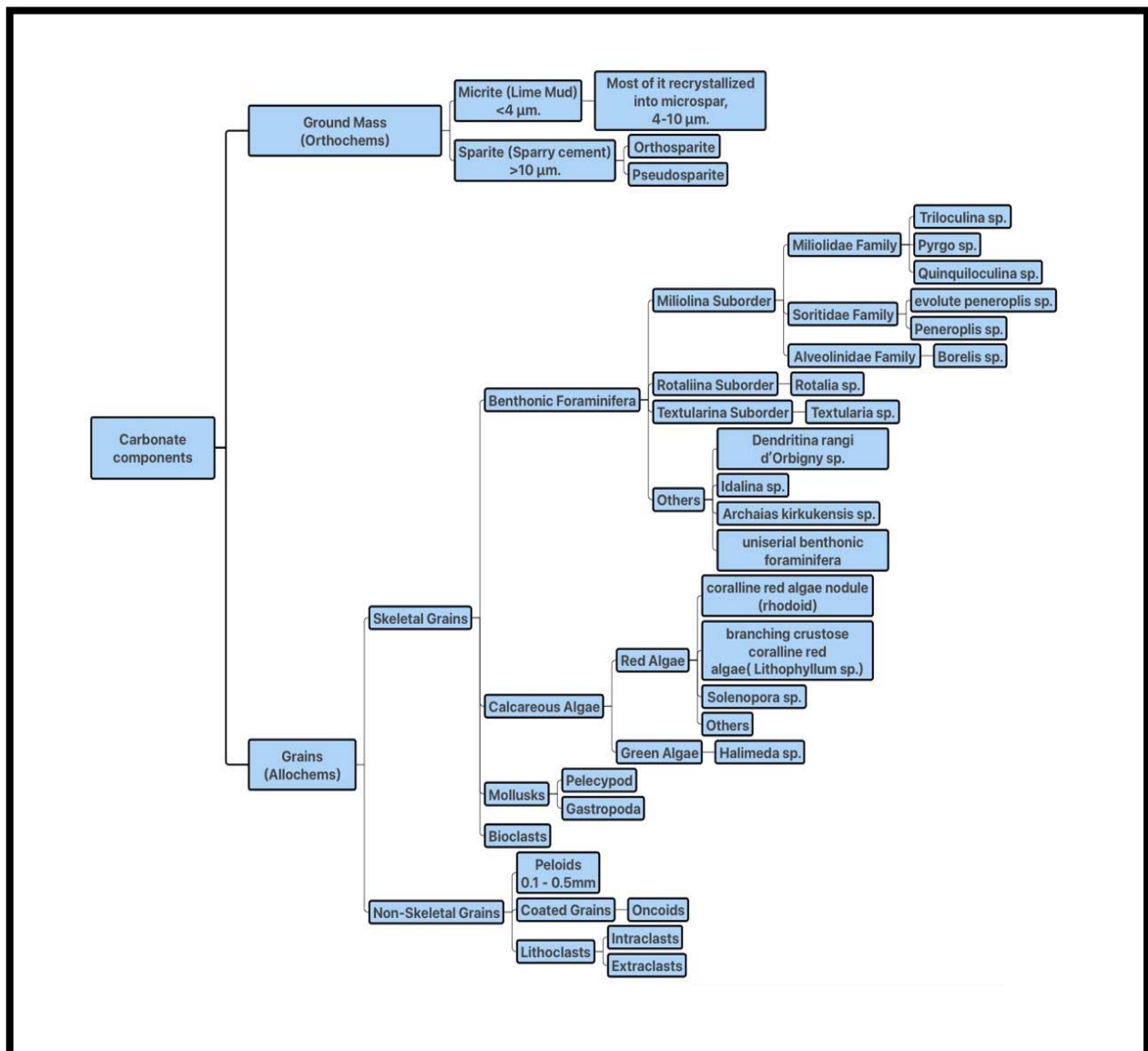


Figure 3.1: A diagram illustrating the main components of carbonate rocks that have been identified in the current study.

3.3 Diagenetic Processes:

Diagenetic processes encompass all the chemical, physical, and biological processes that occur in sediments from the time of deposition before their metamorphism (Blatt *et al.*, 1972 ; Flügel, 1982). These processes leading to alternation the texture, mineralogy, and characteristics of the original sediments, as well as in the hardening of fragile deposits through lithification (Pettijohn, 1975 ; Boggs, 2006).

Two main stages of diagenesis are early diagenesis, which includes processes from deposition to shallow burial, and late diagenesis, which involves processes affecting sediments at deeper levels and during uplift. diagenetic processes that are greatly impacted by the depth of burial is compaction (Flügel ,2010). Various factors control diagenetic processes, such as burial rate, temperature, pressure, and tectonic activities (Reeckmann and Friedman, 1982, Boggs,2006). Blatt (1982) mentioned that the diagenetic processes in carbonate rocks are influenced by factors, such as changes in sea level related to tectonic events and climatic variations. These two factors are significant in determining the sequence of diagenetic stages.

Knowing diagenetic processes is economically important as they affect the properties of carbonate rocks, impacting their value as reservoir rocks and for industrial use (Flügel ,2010).

3.4 Classification of Diagenetic Processes

According to Milliman (1974) and Flügel (1982, 2004), the diagenetic processes are typically classified in to two categories (**Table 3.2**):

Table 3.2: Classification of diagenetic processes according to Milliman (1974) and Flügel (1982, 2004).

Diagenetic Processes		
Constructive Diagenetic Processes	Isochemichal constructive diagenesis processes These processes do not involve any changes in chemical or mineral composition	Neomorphism (Recrystallization and Inversion)
		Cementation
	Allochemical constructive diagenetic processes These processes involve changes in chemical and mineral composition	Dolomitization
		Authigenic minerals (Silicification, Pyritization, Oxidation and Anhydritization)
		Dedolomitization
Destructive diagenetic processes	These processes involve biological, mechanical, and chemical activities	Compaction (Mechanical and Chemical)
		Micritization
		Dissolution
		Bioturbation

3.4.1 Constructive Diagenetic Processes:

These processes are divided into two groups of processe:-

3.4.1.1 Isochemichal Constructive Diegenesis Processes:

Isochemical processes do not involve any changes in chemical or mineral composition. including neomorphism and cementation (Engelhardat, 1977). Below are the identified Isochemical constructive processes in this study:

3.4.1.1.1 Neomorphism:

The term neomorphism refers to the processes of recrystallization and inversion. The recrystallization process involves a change in the size or shape of crystals without a chemical change in the mineral such as increase or decrease in the size of calcite crystals. The Inversion process is the alternation of one mineral to its polymorph such as aragonite to calcite (Folk, 1965). Inversion process involves converting unstable minerals to stable minerals, such as aragonite to calcite without changing the chemical composition (Geary, 2007).

Neomorphism occurs in various diagenetic environments, particularly in meteoric phreatic, vadose and shallow burial environments (Boggs, 2006). This process occurs in the late stage of diagenetic Processes within subsurface environments (Flügel, 1982). Through the identification of thin sections, The neomorphism process was identified In the Jeribe Formation involving the recrystallization of the micrite into microspar (Pl.A-1).

3.4.1.1.2 Cementation:

Cementation is the process of chemical deposition of calcium carbonates from saturated solutions in the intergranular or within the intragranular (Bathurst, 1958). Cementation occurs in all depositional environments, with each type of cement reflect the specific diagenetic environment (Longman, 1980). According to Tucker and Wright (2001), several factors control the cementation process, including the chemical composition of solutions, temperature, carbon dioxide (CO₂), pressure, acidity (pH), the duration of cementation, and the presence of CaCO₃. Four types of cement have been identified in the current study as following:

1. Granular Cement:

Granular cement is characterized by calcite crystals of equal sizes and mostly non- to sub-equant in shape (Flügel, 2004). It is found between and within grains, including some foraminifera, due to dissolution processes. It also forms in channels and voids. This cement is classified as a late-stage diagenesis (Flügel, 1982; Bathurst, 1975). It precipitates in the meteoric phreatic and vadose environment in addition to burial environment (Scholle and Ulmer-Scholle and, 2003; Flügel, 2004). This type of cement is identified in the lower part of Gali Zakho sections (**Pl.D- 8**).

2. Blocky Calcite Cement:

Blocky cement composed of crystals that are medium to coarse-grained, occupying the voids between grains in a blocky manner without any size gradation of the crystals, ranging in size from tens of microns to several millimeters (Longman, 1980). blocky cement can also be formed from the recrystallization of previous cements. It is formed during the late stages of diagenetic processes (Longman, 1980). And precipitates in the vadose and burial environments (Scholle and Ulmer-Scholle, 2003; Flügel, 2004). It is identified in lower and middle parts of Gali Zakho sections (**Pl.E- 1**).

3. Drusy Calcite Cement:

Drusy cement fills voids and lining of pores in intergranular and intraskeletal pores, molds, and fractures. It is identified by non-ferroan calcite crystals that are equant to elongated, anhedral to subhedral in shape, and its concentration increases towards the center of the void. It is considered late diagenetic cement (Flügel, 1982). It occurs in meteoric phreatic and vadose environments

(Flügel, 1982; Scholle and Ulmer-Scholle, 2003; Barthurst, 1975). Drusy cement is prevalent in the upper part of Gali Zakho section in lower part of Gali Duhok section. (Pl.E- 2).

4. Bladed Calcite Cement:

Bladed cement consists of tabular crystals of calcite resembling blades with vertical axes deposited mostly in voids present in the matrix. Bladed cements usually form isopachous rinds and are the first marine cements (Flügel, 2010). This type of cement has been identified in the upper part of Gali Duhok section and middle part of Gali Zakho section. (Pl.E- 3).

3.4.1.2 Allochemical Constructive Diagenetic Processes:

Allochemical processes involve changes in chemical and mineral composition. including dolomitization, the formation of authigenic minerals and dedolomitization (Flügel, 1982). Below are the identified Allochemical constructive processes in this study:

3.4.1.2.1 Dolomitization:

The process of dolomitization refers to the alteration of limestone into dolomite when limestone interacts with magnesium-rich water. In this alteration, the mineral dolomite, composed of calcium and magnesium carbonate ($\text{CaMg}(\text{CO}_3)_2$), replaces the calcite (calcium carbonate, CaCO_3) in the rock (Nichols, 2009). The most important environments where dolomitization occurs is in settings with varying salinity levels and Mg^{2+} content that is supersaturated. These environments include mixing zones between seawater and freshwater, moderately to highly saline subtidal environments, evaporitic environment, isolated coastal lagoons, sabkhas, and playa lakes (Atabey, 1995). Warren (2000) and Qing *et al.* (2001), mentioned that important environments for the formation of diagenetic dolomite are located in

shallow marine environments, shallow burial marine zone, as well as in mixing zones and brine reflux waters, in addition to deep burial zone. According to Flügel (1982), dolomitization can be divided into two types:

- 1. Early Diagenetic Dolomitization:** occurs in lime mudstone for non-lithified carbonate deposits, typically resulting in non-porous dolomite (Flügel, 2004). Early diagenetic dolomitization was identified in the current study in the Gali Duhok section, identified by the presence of very fine dolomite crystals ($<0.02\text{mm}$) (**Pl.E- 4**).
- 2. Late Diagenetic Dolomitization:** occurs post-lithification stage of carbonate sediments (Sibley, 1982). This process is crucial for producing coarsely crystalline dolomite and increasing in porosity (Boggs, 2006). Late diagenetic dolomitization was identified in the current study in the upper and middle of Gali zakho section, identified by the presence of coarse dolomite crystals and intercrystalline porosity (**Pl.E- 5**).

3.4.1.2.1.1 Classification of Dolomite Textures:

The current study based on the classification of dolomite texture proposed by (Randazzo and Zachoz, 1984) (**Fig. 3.2**) This classification is based on crystal size, shape, crystal distribution, structural content, and the origin of dolomitized rock.

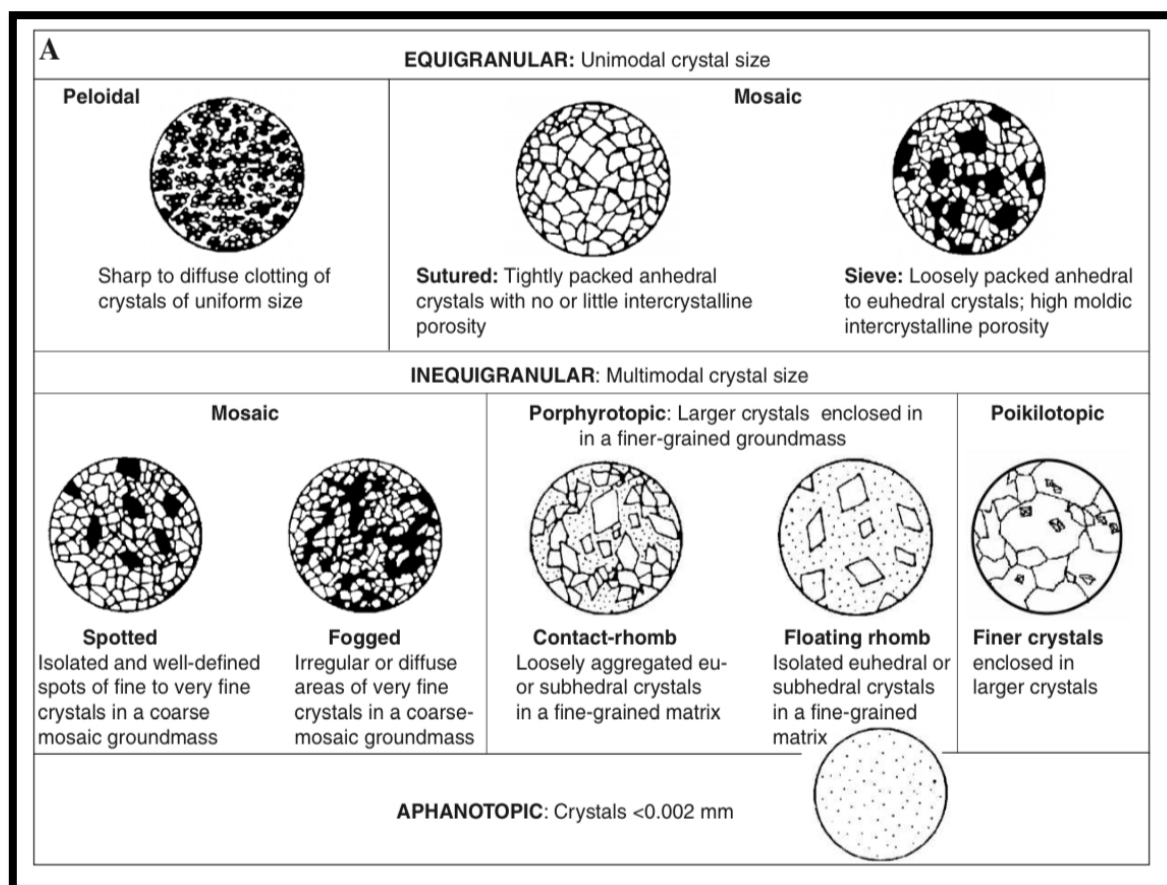


Figure 3.2: Classification of dolomite texture by (Randazzo and Zachos, 1984).

Five types of dolomite textures have been identified in this study as following:

1. Sieve Mosaic Texture:

It consists of anhedral to euhedral crystals ranging between (0.25–0.3mm) with low packing and high porosity. It alter the original texture of the rock (Sibley, 1982). Typically associated with the dissolution of skeletal components in the lime wackstone and lime packstone . This indicates a deep burial origin during a late diagenetic process (Randazzo and Zachos, 1984) . It is found in the lower part and upper of the Jeribe Formation in the Gali Zakho section (PI.E- 5).

2. Suture Mosaic Texture:

It is identified by tightly packed anhedral crystals, resulting in minimal to no intercrystalline porosity (Randazzo and Zachos, 1984). It arises from the later stage of homogeneous dolomitization in the lime mudstone microfacies. It is observed in the lower part, lowermost of middle part and lowermost of upper part of Gali Zakho section (**Pl.E- 6**), (**Pl.E- 7**).

3. Fogged Mosaic Texture:-

It is represented by dolomite crystals featuring a cloudy center and clear edges, a result of inclusions clustering around the crystal of dolomite center, these inclusions are remnants of calcite indicating a late burial origin (Sibley, 1982). The crystal shape typically ranges from euhedral to anhedral. This texture resulted from the packstone facies, indicating increased porosity due to the growth of dolomite crystal rims through replacement and dissolution processes leading to increasing porosity. It is observed in the middle part of the Gali Zakho section (**Pl.E- 8**).

4. Aphanotopic Texture:

It is a fine-grained fabrics, characterized by crystals with sizes not exceeding 0.002 millimeters, a feature of early dolomitization where crystal boundaries can not be distinguished. This fabric type is formed by homogeneous dolomitization processes of lime mudstone(Randazzo and Zachos, 1984). It has been identified in the middle and upper parts of Gali Duhok section (**Pl.E- 4**).

3.4.1.2.2 Authigenic minerals:

Authigenic minerals are those that are formed in place after deposition when the physical and chemical conditions appropriate to form and maintain them. Within the current study, four types of authigenic minerals have been recognized and formed by the following processes:

3.4.1.2.2.1 Silicification:

Silicification involves the replacement of other minerals such as carbonate and evaporite minerals by silica, or it precipitates as void-filling cement (Flügel, 2004; Boggs, 2006; Blatt *et al.*, 1980). The process of silicification can occur during both the early and late stages of diagenetic processes (Hesse, 1989). In this study, the process of silicification was identified in all parts of the Gali Duhok section, but it is highly concentrated in the upper part of it and only in the lower part of the Gali Zakho section (**Pl.F-1**). One of the distinctive silicate minerals identified is Chert (**Pl. F- 2**).

3.4.1.2.2.2 Pyritization:

Pyritization process involves formation of pyrite mineral, The presence of fossils containing organic material undergo localized reduction processes, resulting in Pyrite formation (Chillingar *et al.*, 1967). pyrite being composed of iron sulfide (FeS_2) commonly found in sedimentary rocks, characterized by its dark brown color (Tucker, 2003). The cubic pyrite develops in the late diagenetic stage in reducing environments abundant in organic matter (Honjo *et al.*, 1965). It is identified in the middle and upper parts of Gali Zakho section (**Pl.F- 3**).

3.4.1.2.2.3 Oxidation:

Oxidation process lead to formation of iron minerals. According to Tucker (2003), most iron minerals form due to early diagenetic processes. Iron oxides were found in all parts of Gali Zakho section (**Pl.F- 4**).

3.4.1.2.2.4 Anhydritization:

Anhydritization process involves formation of anhydrite, a mineral composed of calcium sulfate (CaSO_4), forms from the dehydration of gypsum. Anhydrite is associated with late dissolving voids that indicate to the same environmental conditions where chemical diagenesis occurs, dissolving carbonate and depositing anhydrite (Saller and Yaremko, 1994). It is observed in all parts of the Gali Zakho section, while in the Gali Duhok section, observed in the lowerpart and middle part A (Pl.F-5).

3.4.2 Destructive Diagenetic Process:

These processes involve biological, mechanical, and chemical activities, including compaction, micritization, dissolution and bioturbation.

3.4.2.1 Compaction:

The compaction process leads to the reduction of porosity and total volume of the rock. As the overburden pressure increases, the sediments get compacted (Flügel, 1982 ;Tucker,2001). Compaction depends on the burial depth, the minerals stability , clay content, pressure of solutions, and cementation (Blatt,1982). According to Tucker and Wright (2001), the compaction process is divided into two categories: physical (mechanical) and chemical. The mechanical compaction occurs shortly after deposition, while chemical compaction develops post-burial (Friedman and Sanders, 1978). Both types of compaction are identified in the current study:

3.4.2.1.1 Mechanical (Physical) Compaction:

Mechanical compaction begins shortly after deposition and leads to a closer packing of the grains and rotate elongated bioclasts towards the bedding plane due to the reduction in the rock volume . When the

overburden pressure increases, bioclasts can fracture, and micritic grains may get compressed and distorted. Early cements surrounding grains can also be removed (Tucker and Wright, 2001). Scholle and Ulmer-Scholle (2003), mentioned that mechanical compaction leads to a reduction in the porosity.

The mechanical compaction can transform skeletal wackestones into skeletal packstones by packing grains more closely together. the impact of this compaction is noticeable through Shell fractures (Tucker and Wright, 2001).

One of the indicators and evidence of mechanical compaction is fractured shells, and approaching each other. Separation of shells, deformation, and shell convergence have been observed in small proportions in the middle part of Gali Duhok section (**Pl.F- 6**).

3.4.2.1.2 Chemical Compaction/ Pressure Solution and Stylolitization:

After undergoing mechanical compaction, various sediment types undergo chemical compaction through pressure solution, leading to the development of stylolites and solution seams commonly associated to fractured structures (Logan, 1984).

Stylolites are identified as irregular surfaces of discontinuity, along which two rock units (such as lithology and rock or mineral grains) seem to be intertwined or mutually penetrating. Stylolite occurs due to increasing solubility at grain contacts and sediment interfaces when subjected to stress. The overlying burden causes this, but tectonic stresses can also lead to increase in pressure-dissolution effects (Tucker,2001). Boggs (2006), indicated that the presence of stylolites indicates the presence of non-carbonate minerals with fine-grained sizes (insoluble residue) that accumulate as a solvent for carbonate minerals.

The classifications of Choquette and James (1987) (**Fig.3.3**) that modified from Logan and Semeniuk (1976) and Wanless (1979) have been used to distinguish the various types of pressure solutions and stylolites observed in this study.

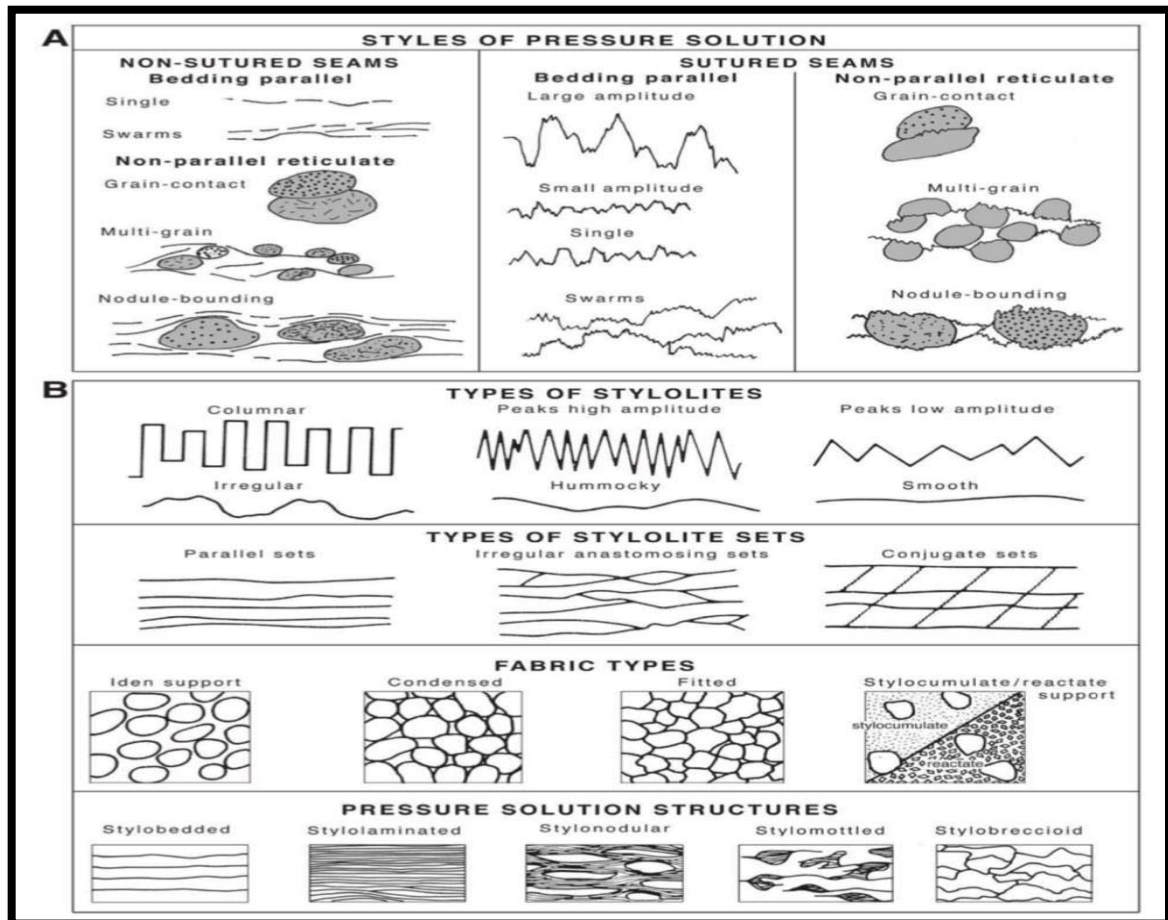


Figure 3.3: Classification of pressure solution and stylolites according to Logan and Semeniuk (1976) and Wanless (1979) modified by Choquette and James (1987).

3 types of pressure solutions and stylolites have been identified in the middle part of Gali Duhok section.

1. Stylolite of peaks low amplitude (**Pl.F- 7**).
2. Stylolite of peaks high amplitude (**Pl.F- 8**).
3. Stylolite of small amplitude (**Pl.G- 1**).

3.4.2.2 Micritization:

Micritization occurs as a result of biological activities. Organisms in carbonate depositional environments alter the skeletal grains and carbonate grains through boring, burrowing, and ingesting activities.

This process involves primarily the formation of micrite that envelope the skeletal grains and some intraclasts (**Pl.G- 2**). This occurs due to microbial actions that create bores or pits on the grain surfaces, which are then filled with micrite (Bathurst,1975) . Gischlor and Lomando (1997) indicated that this process occurs in the early stages of diagenetic processes in phreatic marine environment and form in the stagnant and calm water environments. According to (Flügel ,2004 ; Boggs 2006), the process of micritization is very intensive in shallow-water tropical environment. This process has been identified in the middle part A and upper part of Gali Duhok section and in intense in the middle and upper part of Gali Zakho section and (**Pl.G- 3**).

3.4.2.3 Dissolution:

Dissolution involves the complete or partial dissolution of grains, whether they are skeletal or non-skeletal, in unstable rock components or those with less mineralogical stability. This dissolution is selective, where only the grains, groundmass, or cement dissolve (Milliman, 1974). The most susceptible carbonate minerals to dissolution is high-magnesium calcite and aragonite (Longman, 1980). The dissolution process tends to be less intense in the deep burial due to the most aragonite and high-magnesian calcite may have already converted to more stable calcite (Boggs, 2006).

The dissolution process can occur in the early stages of diagenetic processes and sometimes even in the late stages when the solvent solutions are available (Boggs, 2006).

The dissolution process was observed in both sections, where it was noted in the Gali Duhok section in all parts of the formation, being particularly intense in the middle and upper parts. In the Gali Zakho section, it was also observed in the lower part of the formation, with the process being very intense in one layer of the middle part. Overall, its impact was minimal in the middle and upper parts compared to the Gali Duhok section. In this study various grains and groundmass components have dissolved, either partially or entirely, leading to the formation of different types of porosity such as vuggy, moldic, interparticle, channel, and others as illustrated below. Additionally, Some of these pores are filled by cements (Pl.G- 4) or have undergone silicification processes(Pl.F- 2).

3.5 Porosity:

porosity is the percentage of the pores volume to the total volume of the rock (Lucia,1995,2007). Porosity in carbonate rocks depends on several factors, including grain size, permeability, chemical composition of solutions, the manner in which solutions move, and compaction in the rock (Longman, 1980). According to the origin of pores, there are two main groups of porosity (Murray, 1960), which include:

A- Primary Porosity (Depositional):

Primary pores are formed simultaneously with the sedimentation process or immediately after it. Including: interparticle, intraparticle, growth framework, shelter and fenestral porosity.

B- Secondary Porosity(Diagenetic–Tectonic):

Secondary pores are formed during diagenesis at any time after deposition as a result of diagenetic processes. Including: intercrystal, moldic (with leached grains), fracture, channel. Cavern and vug porosity (caused by leaching between grains).

In this study, the classification of porosity by (Choquett and Pray ,1970) is used, which consist of 15 types of porosity and based on the fabric divided the porosity in to three groups(**Fig. 3.4**). Below are the main types of porosity found in the current study

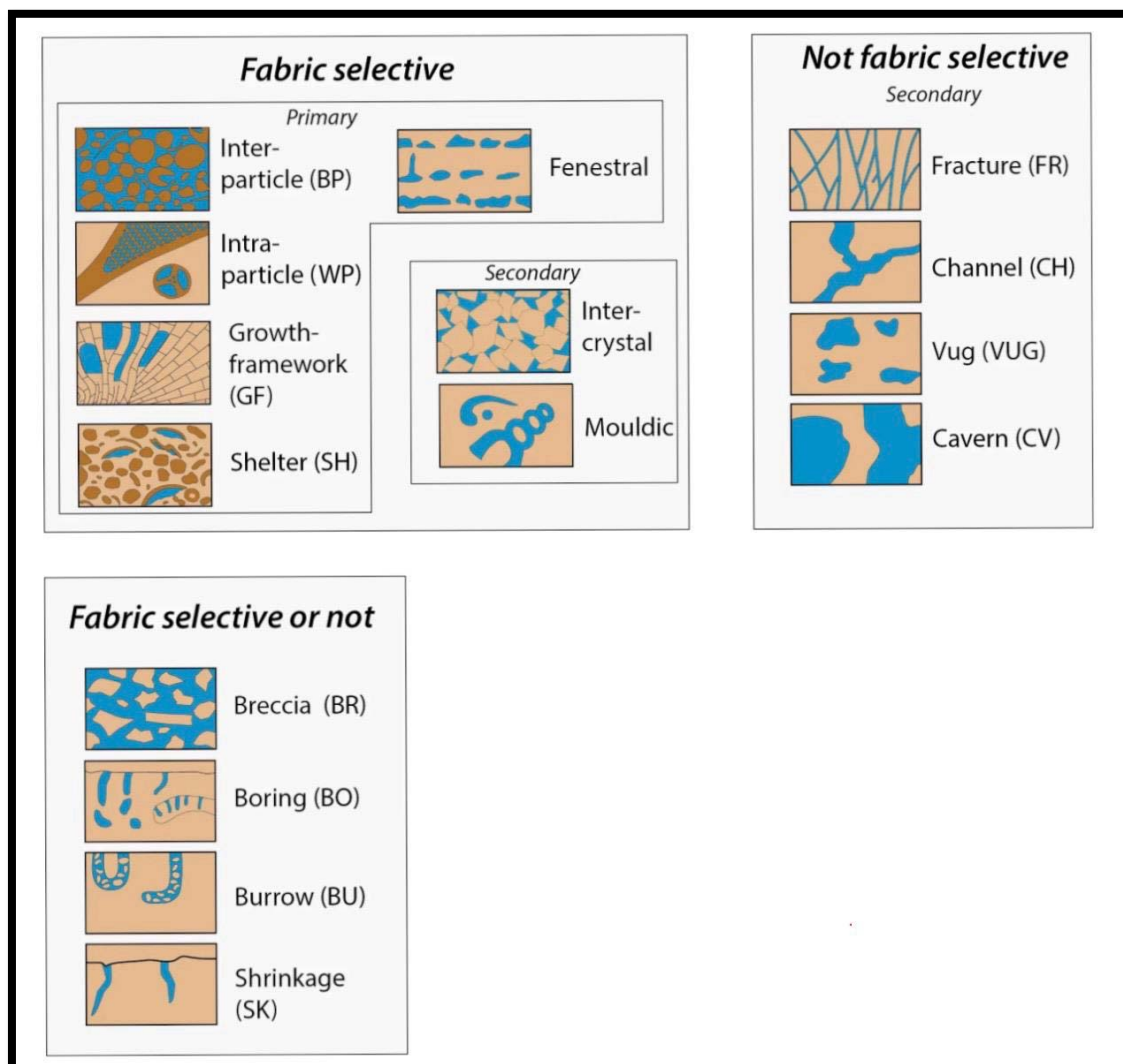


Figure 3.4: The classification of carbonate porosity by (Choquette and Pray , 1970).

A. Fabric Selective Group:

The solid depositional and diagenetic components of a sediment or rock are known as its fabric. These components include different types of primary grains like ooids, peloids, and bioclasts. When a correlation exists between porosity and fabric elements, the porosity is termed fabric-selective. Below are the types of fabric-selective porosity identified in this study:

1. Interparticle (Intergranular) Porosity:

Interparticle porosity formed between individual particles or grains of a sedimentary rock. This type is identified in the middle part of Gali Zakho section (**Pl.G- 5**).

2. Intraparticle (Intragranular) Porosity:

Intraparticle porosity formed due to the dissolution of soft parts of the fossil and found within specific parts of skeletons (intraskeletal like foraminifera chambers (Reeckmann and Friedman, 1982) or associated to voids formed by the elimination of less calcified internal components (such as the central part of Halimeda). It is influenced by the shape and internal structure of organisms tests and skeletons, as well as the ultrastructure of grains (for instance, ooids or aggregate grains). This type of porosity is identified in the middle part-A and highly in the middle part-B and upper part of the Gali Duhok section. It is minimally identified in the lower and middle part of the Gali Zakho section (**Pl.G- 6**).

3. Intercrystalline Porosity:-

Intercrystalline porosity found between individual Crystal and produced through dolomitization This porosity may exist between dolomite crystals (Tucker,2001). This type of porosity is

associated with the dolomitization and recrystallization processes and in the early and late stages of diagenesis (Tucker and Wright , 1990; AL-jwaini, 2015). It is identified in the lower and upper parts of Gali Zakho section (**Pl.G- 7**).

4. Moldic Porosity:-

Moldic porosity resulted from the selective removal, commonly by dissolution of skeletal and non skeletal grains such as Gastropoda and pelecypodea. Molds form in rocks of mixed mineralogies in meteoric-phreatic and burial settings. It is identified in the middle part of Gali Duhok section (**Pl.G- 8**),(**Pl.H-1**).

5. Shelter (Umbrella) Porosity:-

Shelter porosity formed by the protective influence of larger grains that shield the underlying pore space from sediment infill. This porosity is enhanced by the presence of significant flat fossils like larger foraminifera and platy algae. It is observed in the middle part-A of Gali Duhok section(**Pl.H- 2**).

B. Non Fabric Selective Group:

Not fabric-selective porosity identified by the lack of correlation between fabric and porosity. Below are the types of Non fabric-selective porosity identified in this study:

1. Vuggy Porosity:-

Vuggy porosity forms as semi-circular voids of various shapes and sizes due to the irregular distribution of dissolution processes during early or late diagenetic stages (Choquette and pray ,1970). It is very common and recognised throughout the both sections and specifically in a significant proportion of the Gali Duhok section (**Pl. G- 3**), (**Pl.H- 3**).

2. Cavern Porosity:

Cavern porosity appears in the form of large caves and the term cavern is used to describe large openings in the shape of channels or vugs that are mainly created by karstic solution processes. It was identified in the middle part-A of Gali Duhok section (PI.H- 4).

3. Channel Porosity:

Channel porosity appears as elongated gaps and branching channels, often filled with hydrocarbon materials or sparry calcite cement. It is observed in the upper part of Gali Zakho section (PI.H- 5).

4. Fracture Porosity:

Fracture porosity formed from various processes, it could be generated by tectonic activities, fault movements, or dissolution processes (Selley, 1998). It is identified in the lower and middle part-A and B of the Gali Duhok section, as well as in the middle part of the Gali Zakho section(PI.H- 6).

C. Group of Fabric Selective or Not

This study did not record the porosity types of this group.

3.6 Primary Sedimentary Structures:

Primary sedimentary structures refer to physical or biological features that develop during sediment deposition. Recognizing these structures enhances the understanding of depositional environments and aids in knowing patterns and timing of diagenetic processes (Scholle and Ulmer-Scholle, 2003). The main structures identified in this study include:

3.6.1 Geopetal Structures:

Geopetal structure refers to any pores filled with the spar at the top and micrite at the bottom (Tucker, 1982). It is indicating the original orientation such as top and bottom of strata (Scholle and Ulmer- Scholle, 2003). It is indicates a meteoric vadose environment (Longman, 1980). In this study a geopetal filling inside a gastropod chamber has identified in the middle part of the Gali Zakho section (**Fig. 3.5**), (**Pl.C- 8**) and (**Pl.D- 1**). where micrite occupies the lower part of the void, while sparry calcite fills the upper part, indicating a relatively level surface during deposition.

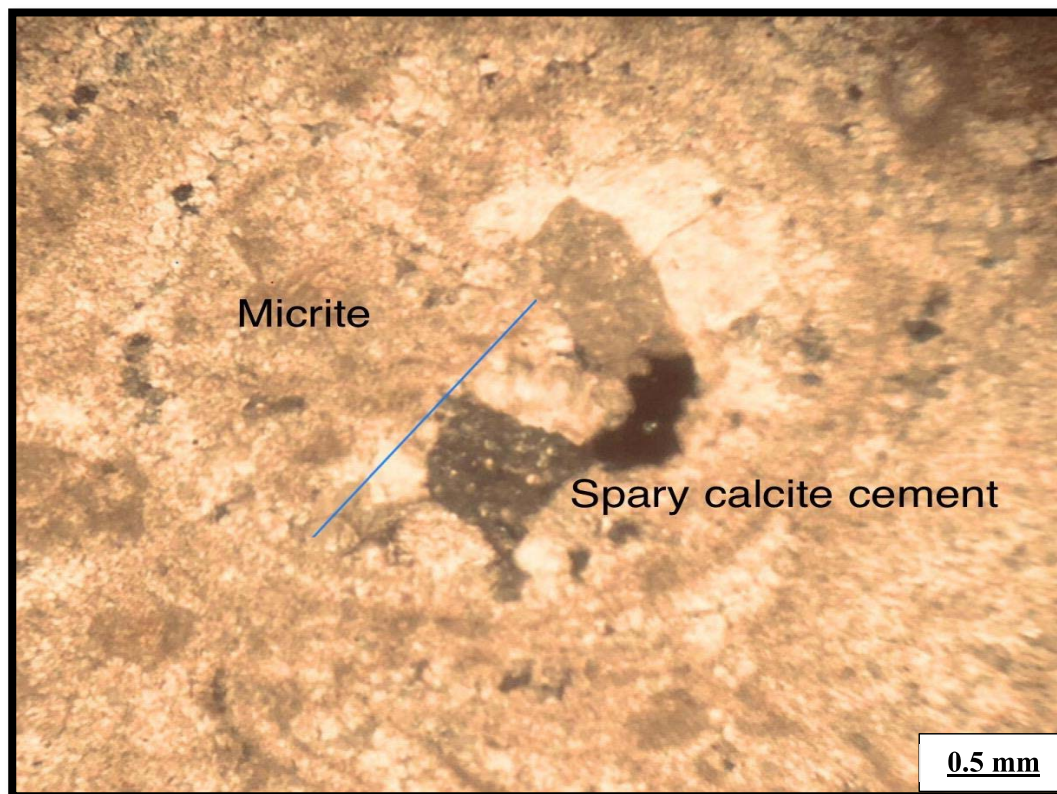


Figure 3.5: A Geopetal structure filling inside a gastropod chamber, where sparite calcite cement is related to the top of the bed, while micrite is related to the bottom of the bed, Gali Zahko section, sample No.15.

3.7 Carbonate Diagenetic Environments:

The diagenetic environments consist of environmental zones, each with distinctive diagenetic processes. Many carbonate rocks have transitioned between different diagenetic zones over time due to variations in sea levels, tectonic activities, and changes in burial depth (Flügel, 2004). According to (Longman ,1980 ; James and Choquett ,1983), diagenetic environments are classified into four main zones (**Fig.3.8**) based on water movement rate and the saturation level with calcium carbonate.

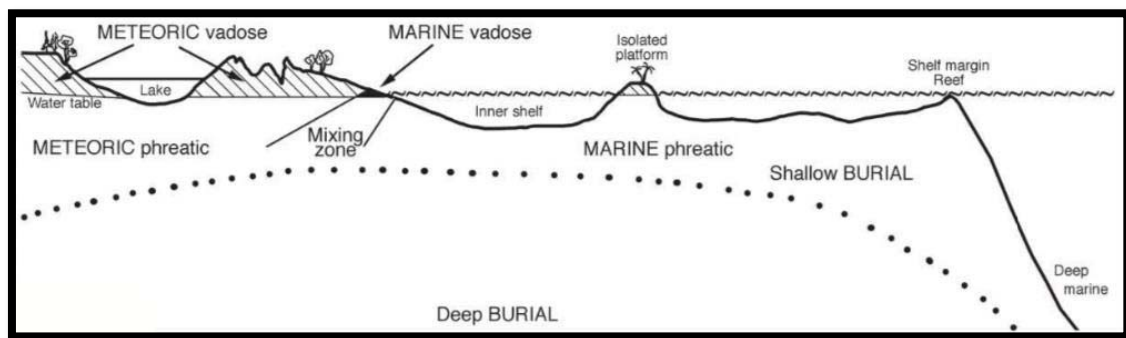


Figure 3.6: Major carbonate diagenesis zones and subzones (Flügel, 2004)

A. Meteoric (freshwater) Diagenetic Zone:

The meteoric zone includes all changes occurring on or near the surface that are primarily exposed to the effects of freshwater. This zone is divided into:

1. Meteoric Vadose Zone:

It is the zone between the Earth's surface and the groundwater level. In this zone, the rock pores are filled with both air and water due to the unsaturated of the deposits in water. the main diagenetic processes occur in this zone include cementation(blocky cement), dissolution, elimination of unstable

grains made up initially of aragonite and high Mg-calcite minerals, resulting in the creation of vuggy , shelter and moldic porosity.

2. Meteoric Phreatic Zone:

Meteoric phreatic zone is the zone between the meteoric Water Vadose zone and the Mixing Zone. known for having its pores filled with freshwater saturated in calcium carbonate. The main diagenetic processes occur in this zone are neomorphism, dissolution (high leaching that led to the formation of the moldic and vuggy porosity) and cementation (drusy and granular cements).

B. Mixing Meteoric Marine Zone:

This zone is formed due to mixing of freshwater and more-saline water across the interface. solutions in this zone are undersaturated with calcium carbonate but supersaturated with magnesium ions. It is the potential site for dolomitization processes (Flügel, 2010).

C. Marine Phreatic Diagenetic Zone:

This zone encompasses all changes occurring near the contact surface between sediments and seawater, known as the depositional surface. The primary controlling factor in these processes is the seawater, which either comes into contact with the sediment surface or resides within the pores. It is divided into two subzones:

1. Active Zone:

The main diagenetic processes occur in this subzone is cementation (bladed, blocky, drusy and granular cements).

2. Stagnant Zone:

The main diagenetic processes occur in this subzone are dissolution and micritization.

D. Burial Diagenetic Zone:

Burial environments are typically categorized as shallow burial and deep burial (Flügel, 2004). This zone includes the changes occurring in the shallow and deep burial but above the metamorphism areas. One of the most important diagenetic processes that occur in this zone are compaction in both its physical and chemical.

The rock sequences of the Jeribe Formation are characterized by the presence of various diagenetic processes such as dolomitization, cementation, dissolution, neomorphism, compaction, and others. This indicates that the formation sequences in both sections, after deposition, have been subjected to most of the mentioned diagenetic environments (**Table 3.3**). The distribution of the diagenetic features of the Jeribe Formation in the two sections is illustrated in (**Fig.3.7**) and (**Fig.3.8**).

Table 3.3: Illustrating the main diagenetic environments that the formation sequences have been subjected to and the diagenetic fabrics that occurred in each part of the study sections.

Diagenetic Environments (Longman ,1980 ; James And Choquett ,1983)	Diagenetic Processes	Diagenetic Fabric	Sections						
			Gali Zakho Section			Gali Duhok Section			
			L	M	U	L	M. A	M. B	U
Vadose Zone	Dissolution	Vuggy Porosity	☐	☐	☐	☐	☐	☐	☐
		Shelter porosity					☐	☐	
		Moldic porosity					☐	☐	
	Cementation	Blocky cement	☐	☐					
		Geopetal Structure		☐					
Meteoric Phreatic Zone	Leaching	Cavern Porosity					☐		
		Moldic Porosity					☐	☐	
	Neomorphism	Microspar	☐	☐	☐		☐	☐	☐
	Cementation	Drusy Cement			☐	☐			
		Granular Cement	☐						
Mixing Zone	Dolomitization	Aphanotopic Texture of Dolomites					☐	☐	☐
Marine Phreatic Environment	Micritization	Micrite Envelop		☐	☐		☐		☐
	Cementation	Bladed Cement		☐					☐
Burial Environment	Mechanical Compaction	Packing And Deformation Of Grains				☐	☐		
	Stylolization	Stylolite					☐	☐	
	Silicification	Chert	☐			☐	☐	☐	☐
	Pyritization	Pyrite		☐	☐				
	Oxidation	Iron oxide	☐	☐	☐				
	Anhydritization	Anhydride	☐	☐	☐	☐	☐		
	Late Dolomitization	Large Crystal Of Dolomite. According To Identified Textures	☐	☐	☐				
☐ It Is Found, L: Lower Part, M: Middle Part, U: Upper Part, M.A: Middle Part A, M.B: Middle Part B									

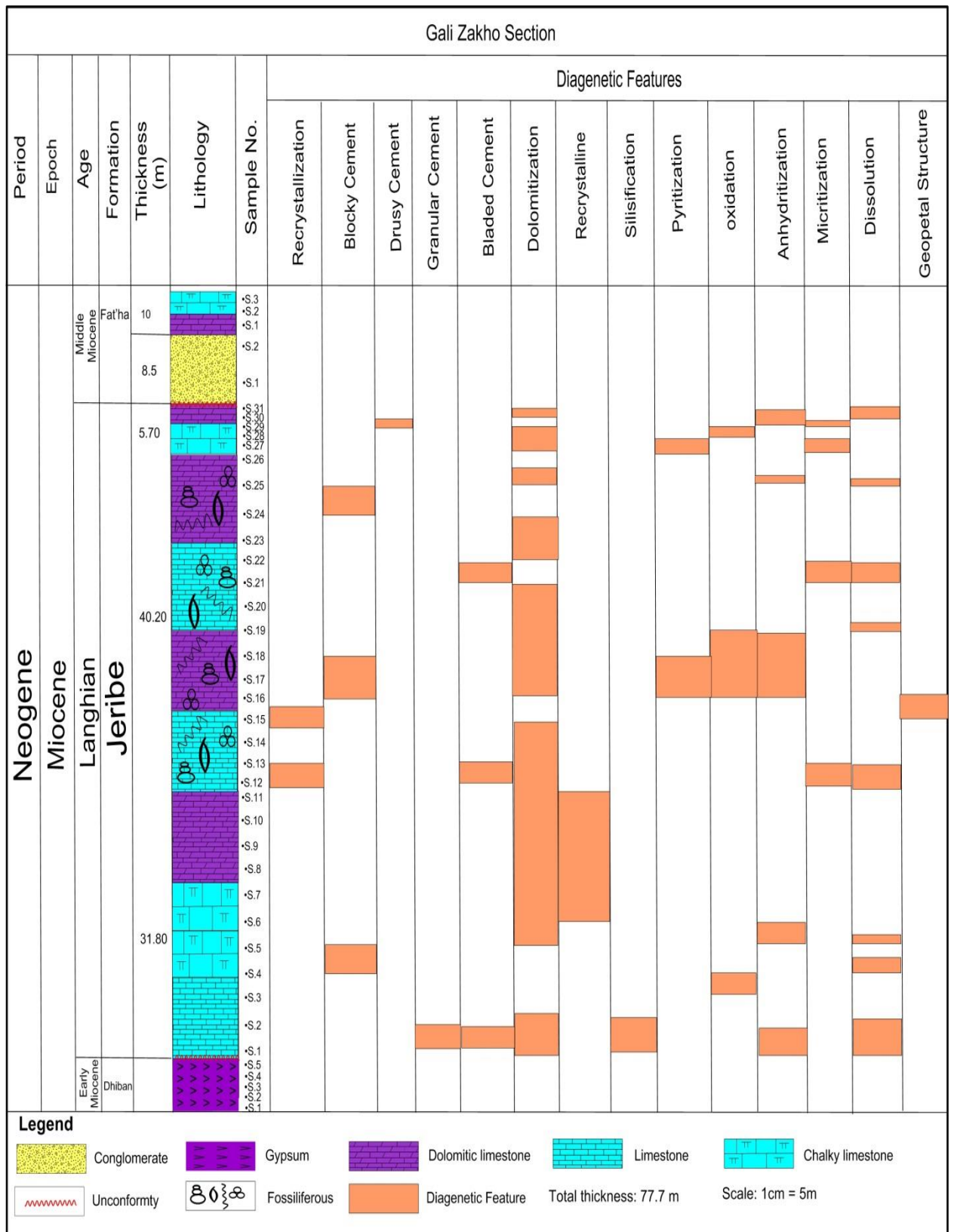


Figure 3.7: Stratigraphical column of diagenesis features for Gali Zakho section.

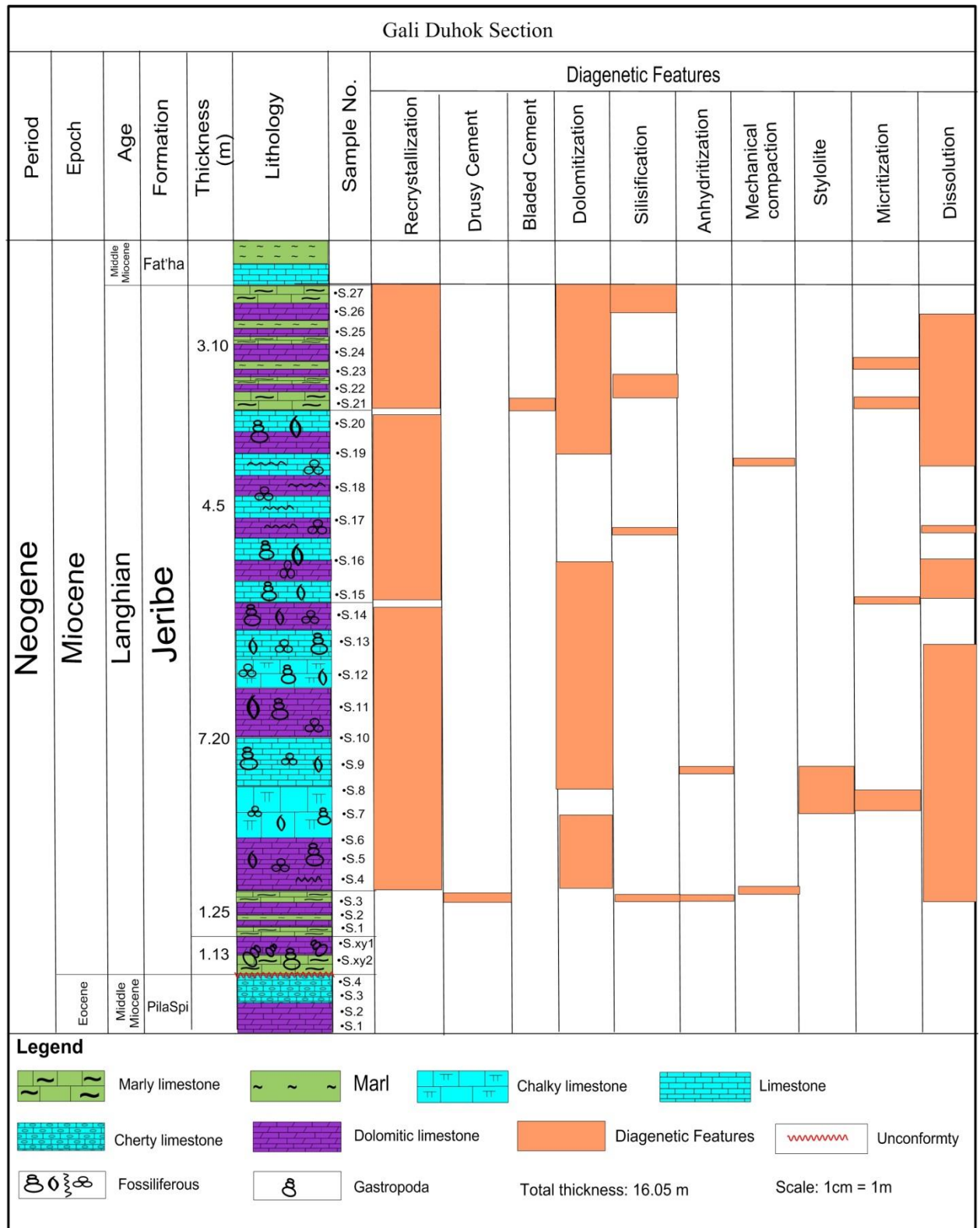


Figure 3.8: Stratigraphical column of diagenesis features for Gali Duhok section.

3.8 Sequences of Diagenetic Processes /Paragenetic sequence / Diagenetic History:

After deposition of the Jeribe Formation, it is exposed to various diagenetic environments, leading to intense exposure to diagenetic processes. This may be due to the shallow depositional environment of the formation. The diagenetic sequence of the current study starts in the marine phreatic diagenetic environment (**Table 3.4**). As mentioned by Friedman *et al.* (1971), The Phreatic marine environment characterized by micritization and cementation processes. The current study marked by both, micritization, where many mollusks and algae inhabited the shallow marine deposits and burrowed into them. Subsequently, these burrows were filled with lime mud (micrite) that created a micrite envelope. And Cementation, which is represented by bladed cement forming isopachous rinds, and according to Flügel (2010), this type of cement is the first marine cement (Flügel, 2010). The current study has exposed to mixing zone, as it observes the dolomitization process in Gali Duhok section with an aphanotopic texture, non-porous dolomite, indicating early dolomitization (Flügel, 2004). So, the diagenetic sequences then transitioned to the meteoric phreatic zone, indicating processes like neomorphism, cementation with drusy and granular cement, and Leaching. Leaching removes bioclastic tests, forming caverns, vuggy, and moldic porosity. Dissolution carries on in the vadose meteoric zone, showing vuggy and shelter porosity, and the vadose zone is marked by geopetal structure.

Then the successions exposed to burial environment indicated by processes like mechanical compaction (when the sediment load intensified, numerous grains were densely packed together, creating

grain-to-grain contact, leading to the deformation and fracturing of grains), stylolization (When the overlying pressure in the deep burial zone increased it resulted in the development of stylolites and fractured porosity), silicification pyritization, oxidation, Anhydritization, Late dolomitization process in (Gali Zakho section). Which all are indicators of late diagenesis.

Based on the multiple diagenetic processes and their different occurrence times and in different diagenetic environments, a table has been summarized to clarify the paragenetic sequence of these processes in the study sections (**Table 3.4**).

Table 3.4: Diagenetic parasequence of the Jeribe Formation, from petrographic study of both sections.

Diagenetic environments (Longman ,1980 ; James and Choquett ,1983)	Diagenetic processes	Diagenetic fabric	Diagenetic stages		
			Early	Middle	Late
Marine phreatic environment	Micritization	Micrite envelop	Affective	Slightly Affective	Affective
	Cementation	Bladed cement	Affective		
Mixing zone	Dolomitization	Aphanotopic dolomites texture		Affective	
Meteoric phreatic zone	Leaching	Moldic,cavern porosity		Affective	
	Neomorphism	Microspar	Affective	Affective	Affective
	Cementation	Drusy cement		Affective	Affective
		Granular cement		Affective	Affective
Vadose zone	Dissolution	Vuggy porosity		Slightly Affective	Affective
	Cementation	Blocky cement		Slightly Affective	Affective
		Geopetal structure	Affective		
Burial environment	mechanical compaction	Packing and deformation of grains	Slightly Affective		Affective
	stylolization	Stylolite		Affective	Affective
	silicification	Chert			Affective
	pyritization	Pyrite			Affective
	Oxidation	Iron oxide			Affective
	Anhydritization	Anhydride			Affective
	Late Dolomitization	Large crystal of Dolomite. According to identified textures			Affective

Chapter Four
Microfacies
Analysis and
Depositional
Environments

4.1 Preface:

The facies are defined as the smallest rock unit that can be distinguished from the other rocks within any sedimentary sequence by its lithological and biological characteristics, leading to conclude the depositional environment (Friedman and Sanders, 1978). The lithological diversity with the different facies variations laterally and vertically is a result of several factors, including the lateral and vertical differences in environmental systems and their physical and biological factors. These factors are the outcome of various variables such as changes in sea level, water depth, salinity, temperature, light penetration, and biological productivity (bioturbation) (Miall, 1985).

Microfacies are the characteristics observed under a microscope in thin sections of rocks and represent the combination of sedimentological and paleontological criteria that can be identified in these thin sections (Brown, 1943).

The different microfacies types of limestones from various ages can be categorized into broader types that indicate the depositional and ecological conditions present in specific sedimentary environments, utilizing sedimentological data (Flügel, 1982).

4.2 Microfacies Analysis:

The microfacies analysis of thin section revealed a wide range of submicrofacies within the Jeribe Formation. In the current study, the classification of Dunham (1962) modified by Embry and Klovan (1971), was used for the purpose of identifying the microfacies (Fig. 4.1). Then, the identified microfacies were compared with the standard microfacies set by Wilson (1975), Flügel (1982) and further modified by Flügel (2010). Each microfacies was then compared with the standard Facies Zone (FZ) (Fig. 4.2), to conclude the environmental deposition for each

identified microfacies. Below are the identified facies in the current study:

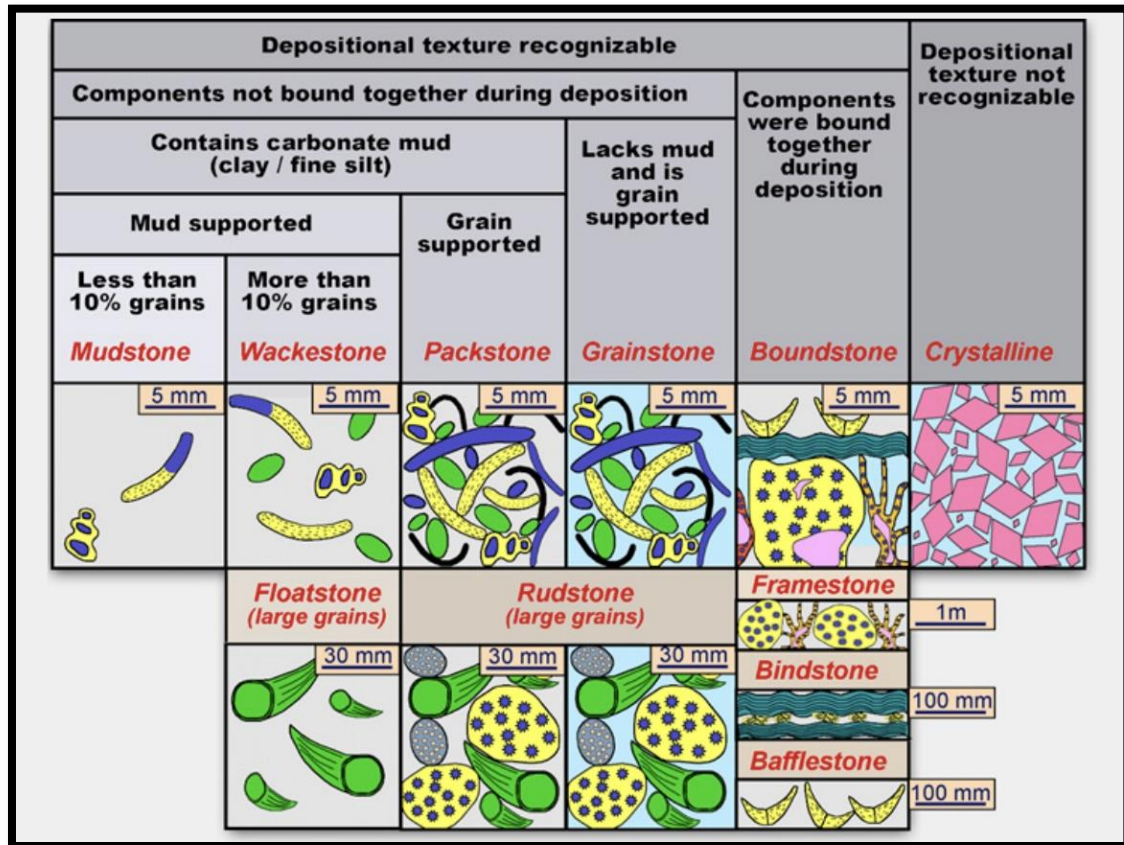


Figure 4.1: Dunham's carbonate rock texture classification (1962) with modified by Embry and Klovan (1971).

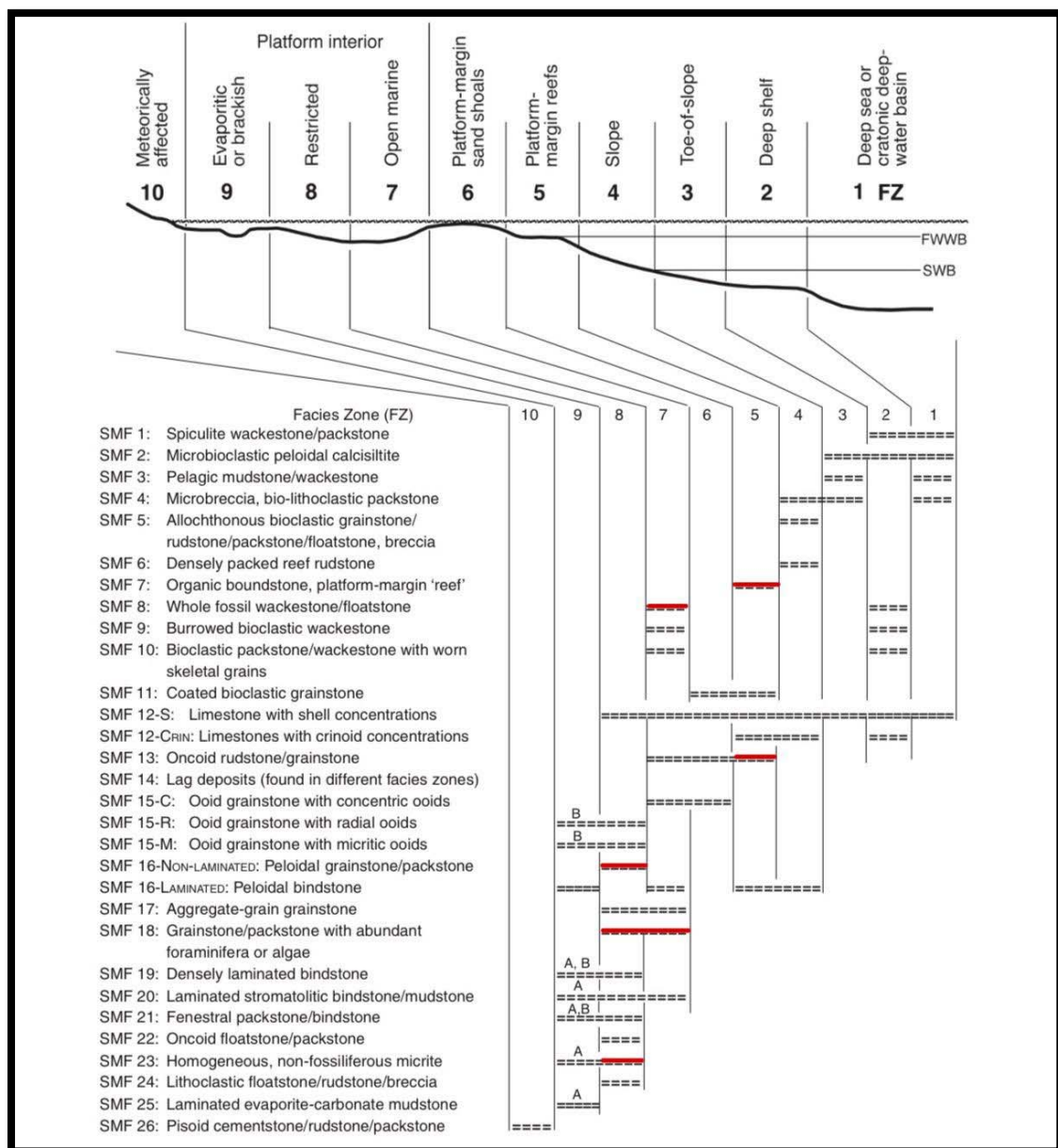


Figure 4.2: The distribution of standard microfacies (SMF) in the facies zones modified by Flügel (2010) from Wilson (1975) , Flügel (1982). The referenced red lines are SMF and FZ that were identified in the current study.

4.2.1 The Microfacies of the Jeribe Formation in the Study Sections:

In this study, and through Analysing thin sections, the following microfacies and submicrofacies were identified. (**Table 4.1**) illustrates the submicrofacie, the standard microfacies, the facies zones, and environmental zones of the Jeribe Formation in the two sections.

4.2.1.1 Lime Mudstone Microfacies (M):

In the current study, the lime mudstone microfacies is found in both sections of the Jeribe Formation. It is present in the all parts of Gali Duhok section, and in the lower part of Gali Zakho section. Lime mudstone microfacies is characterized as being mud-supported. The percentage of grains in this microfacies is less than 10%. Micrite is the primary component in this microfacies. This microfacies is mainly composed of highly recrystallized and dolomitized micrite. According to the identified grains, it has been divided into four submicrofacies as detailed below:

4.2.1.1.1 Miliolidal Lime Mudstone Submicrofacies (M1):

Miliolidal lime mudstone submicrofacies is found in the lower layer of middle part A in the Gali Duhok section. It is made up of Miliolidal skeletal grains of *Quinquiloculina sp.* and *Triloculina sp.* It sometimes associated with peloids. The groundmass is composed of micrite to microsparite. The dissolution, dolomitization and neomorphism affected this submicrofacies, with present of fracture, vuggy and intragranular porosity. By comparing this submicrofacies with the proposed model by Wilson (1975), Flügel (1982), it corresponds to the standard microfacies (SMF-8) that deposited within the facies zone (FZ-7), representing an open marine platform interior environment (**Pl.H- 7**).

4.2.1.1.2 Peloidal Lime Mudstone Submicrofacies (M2):

Peloidal lime mudstone submicrofacies is observed in the lower layers of lower part and in the lower and middle layers of middle part A in the Gali Duhok section. It is composed of peloids of non-skeletal grains. The groundmass is made up of micrite to microspar. The dissolution, physical compaction, micritization, neomorphism and chemical compaction processes have affected it. By comparing this submicrofacies with the proposed model by Wilson (1975), Flügel (1982), it corresponds to the (SMF-16) deposited within the (FZ-8), representing a restricted environment (Pl.H- 8).

4.2.1.1.3 Benthonic Formniferal Lime Mudstone Submicrofacies (M3):

Benthonic Lime Mudstone Submicrofacies is found in the upper part in Gali Duhok section. Represented generally by *Textularia sp.*, It associated in some parts with intraclast and evaporites. This submicrofacies has been influenced by various diagenesis processes such as dissolution, micritization, dolomitization, silisification, dissolution, and cementation with bladed cement type. This submicrofacies corresponds to (SMF-8) deposited within the (FZ- 7) according to Wilson (1975), Flügel (1982), representing an open marine platform interior environment (Pl.B- 5).

4.2.1.1.4 Mollusk Lime Mudstone Submicrofacies (M4):

Mollusk lime mudstone submicrofacies was found in the middle and upper layers of middle part A and in the lower and upper layers of middle part B in the Gali Duhok section. It is also identified in the lowermost layer of lower part of Gali Zakho section. It represents by pelecypods bivalve and gastropods and it is accompanied with peloids grains. The dissolution process is highly affected this submicrofacies

represents by moldic and vuggy porosity, dolomitization, silification, mechanical and chemical compaction also have been affected this submicrofacies. This submicrofacies corresponds to (SMF-8) deposited within the (FZ- 7) according to to Wilson (1975), Flügel (1982), representing an open marine platform interior environment (**Pl.I- 1**).

4.2.1.2 Lime Wackestone Microfacies (W):

Lime wackestone microfacies is characterized as being mud-supported. The grain components in it exceed 10% of the total microfacies content. These grains are immersed in a micritic groundmass that has undergone partial recrystallization to microspar. The skeletal components in this microfacies vary in type, size, and degree of diagenesis processes. Based on the type of skeletal and non skeletal grains, it is divided into two submicrofacies, as detailed below:

4.2.1.2.1 Miliolidal Peloidal Lime Wackestone Submicrofacies (W1):

Miliolidal lime wackestone submicrofacies is observed in the middle layers of middle part A in the Gali Duhok section and in the middle layers of lower part in the Gali Zakho section. It includes *Triquiloclina sp.*, *Borelis sp.* and peloids, these are the main components of this submicrofacies. Some parts of this submicrofacies exhibit micritization, while others remain unaffected. Micritization and dissolution are the main processes that influence the overall deposition of this submicrofacies in addition to dolomitization. This submicrofacies corresponds to (SMF-8) deposited within the (FZ-7) according to to Wilson (1975), Flügel (1982), indicating an open marine platform interior environment (**Pl.I- 2**),(**Pl.B- 3**).

4.2.1.2.2 Peloidal Lime Wackstone Submicrofacies (W2):

Peloidal lime wackstone submicrofacies is identified in the lowermost layer of middle part A and middle layer of middle part B in the Gali Duhok section. The dominant particles in this microfacies are peloids, which are non-skeletal particles. Sometimes, they are accompanied by skeletal particles of miliolids in the micritic groundmass. The dissolution, micritization, and recrystallization processes have influenced this submicrofacies. This submicrofacies corresponds to (SMF-16) deposited within the (FZ-8) according to Wilson (1975), Flügel (1982), representing a restricted environment (**PI.I- 3**).

4.2.1.3 Lime Packstone Microfacies (P):

Lime packstone microfacies is characterized by a high percentage of grains components, exceeding 50% of the total microfacies content. Therefore, it is considered a grain-supported microfacies. Its groundmass consists mainly of micrite, with interlocking fibers along with microspar. This microfacies is divided into two submicrofacies based on the identifying the grains as follows:

4.2.1.3.1 Miliolidal Lime Packstone Submicrofacies (P1):

Miliolidal lime packstone submicrofacies is identified in the middle layer of lower part in the Gali Zakho section and in the middle layer of middle part B in Gali Duhok section. It is mainly made up of Miliolids shell, peloids are also associated with this submicrofacies. This submicrofacies has been affected by dolomitization, micritization, physical compaction and dissolution, in addition to the presence of pyrite and Anhydrite. It corresponds to the standard microfacies (SMF-18) deposited within the (FZ-8 and FZ-7) according to Wilson (1975), Flügel (1982), representing a restricted environment (**PI.I- 4**), (**PI.I- 5**).

4.2.1.3.2 Fossiliferous Lime Packstone Submicrofacies (P2):

Fossiliferous lime packstone submicrofacies found in the middle layer of the middle part B in Gali Duhok section. It is characterized by presence of particles (over 60%) composed of peloids, shell of miliolids and algae. These particles exhibit a pack texture. It is mainly affected by physical compaction and dissolution processes. According to the proposed model by Wilson (1975), Flügel (1982), it corresponds to the (SMF-18), which is deposited within the (FZ-8 and FZ-7) according to Wilson (1975), Flügel (1982), representing a restricted environment (Pl.I- 6) (Pl.I- 7).

4.2.1.4 Lime Grainstone Microfacies (G):

Lime grainstone microfacies is characterized by a high percentage of grains components, which exceeds 60% of the total microfacies content, giving it the characteristic of being grain supported. Its groundmass consists mainly of orthosparite. It is generally limited in the Gali Zakho section. This microfacies has been divided into six submicrofacies based on the different types of grain components present in it:

4.2.1.4.1 Benthonic Foraminiferal Lime Grainstone Submicrofacies (G1):

Benthonic foraminiferal lime grainstone is found in the lowermost layer of the upper part of Gali Zakho section. The total volume of skeletal grains ranges from 70-80% of the submicrofacies, it is full of benthic foraminifera with abundant miliolids, consisting of Miliolids, *Rotalia sp.*, *Dendritina rangi d'Orbigny sp.*, *Peneroplis sp.*, *Peneroplis evolutus sp.*, Uniserial benthonic foraminifera and others. And also it associated with pyrites and extraclasts. They are found within a groundmass primarily composed of orthosparite. One of the important features of this

microfacies is the good sorting of its particles. The cementation process of blocky type affected this microfacies. Additionally, to the dolomitization process. It corresponds to the standard microfacies (SMF-18) deposited within the (FZ-8 and FZ-7) according to Wilson (1975), Flügel (1982), representing a restricted environment **(Pl.I- 8), (Pl.J- 1)**.

4.2.1.4.2 Oncolitic Lime Grainstone Submicrofacies (G2):

Oncolitee lime grainstone submicrofacies is present in the lowermost layer of the middle part in the Gali Zakho section. The oncoids formed by trapping and binding of sediment grains, the shape of the oncoids is influenced by the cores shape (Flügel, 2010). In this submicrofacies, the oncoids have the irregular knobby surface, it indicates the absence of oncoids reworking. The oncoids are all compacted and dissolved at the edges. This submicrofacies is associated with the peloids and red algae. The groundmass between the particles are filled with orthosparite cement. The dissolution process have been highly affected it. It corresponds to the standard microfacies (SMF-13) which is deposited within (FZ-5) according to Wilson (1975), Flügel (1982), representing reef marginal platform environment. **(Pl.J- 2), (Pl.J-3)**.

4.2.1.4.3 Fossiliferous Lime Grainstone Submicrofacies (G3):

Fossiliferous lime grainstone submicrofacies is identified in the lower layer of the middle part and in the middle layer of upper part of Gali Zakho section. It is full of various fossil, packed with each other and well sorted. They are all surrounded by an orthosparite groundmass. The skeletal grains make up about >75% of the submicrofacies content. Some times it associated with pyrgo , *Idalina sp.*, peneroplis, bioclast of *Archaias kirkukensis sp.* red algae (Branching crustose coralline red algae of *Lithophyllum sp.*), mollusks (Pelecypoda and Gastropoda), green algae (*Halimada sp.*), intraclasts and extraclasts. The dolomitization, oxidation

and micritization have affected this microfacies. It corresponds to the standard microfacies (SMF-18) deposited within the (FZ-8 and FZ-7) according to to Wilson (1975), Flügel (1982), representing a restricted environment **(Pl.J- 4), (Pl.J- 5) (Pl.J- 6)**.

4.2.1.4.4 Non Laminated Fine-Grained Peloidal Grainstone Submicrofacies (G4):

Non laminated fine-grained peloidal grainstone submicrofaies is found in the middle and upper layers of the middle part in the Gali Zakho section. The name of this submicrofacies is proposed by (Flügel, 2010) and mentioned that Some of the peloids are actually tiny rounded micrite clasts, representing the shallowest subtidal deposition on a relief formed by algal mounds. The *Solenopora* sp .of red algae is the main components of this submicrofacies. It is affected by dolomitization, micritization, dissolution. This submicrofacies corresponds to (SMF-16) deposited within the (FZ-8) according to to Wilson (1975), Flügel (1982), representing a restricted environment **(Pl.C- 5)**.

4.2.1.4.5 Green Algal Lime Grainstone Submicrofacies (G5):

Green algal lime grainstone submicrofacies is found in the middle layer of the middle part and in the upper layer of the upper part in the Gali Zakho section. This Microfacies is full of green algae represented by *Halimeda* sp. and it is associated with many others fossils such as Miliolids , red algae and mollusks. The process of dolomitiation, oxidation and cementation of drusy type have been affected this submicrofacies. This submicrofacies corresponds to (SMF-18) deposited within the (FZ-8 and FZ-7) according to to Wilson (1975), Flügel (1982), representing a restricted environment **(Pl.A- 5), (Pl.J- 7)**

4.2.1.4.6 Red Algal Lime Grainstone Submicrofacies (G6):

Red algal lime grainstone submicrofacies is found in the lower layer of the middle part in Gali Zakho section. The main grain in this submicrofacies is red algae. It is highly affected by dolomitization, micritization, dissolution and cementation. By comparing this submicrofacies with the proposed model by Wilson (1975), Flügel (1982), it corresponds to (SMF-18) deposited within the (FZ-8 and FZ-7), representing a restricted environment **(Pl.J- 8)**

4.2.1.5 Boundstone Microfacies:

When limestone deposits are interconnected with each other during the deposition process forming an organic rock mass, it is called lime boundstone. These facies are represented by benthic organisms such as corals and algae (all kinds) bryozoa, farther than benthic foraminifera and echinoderms. The Boundstone microfacies is identified in the Jeribe Formation in the two sections by red and green algae (green algae is not exist in Gali duhok) mixed with benthic foraminifera. Boundstones typically form in environments with higher energy levels, where the movement of currents can supply nutrients to the organisms responsible for their formation.

The proposed boundstone classification as described by Embry and Klovan (1971) as illustrated in (**Fig. 4.1**), is used to analyze the main boundstone submicrofacies. This classification is based on the nature of the spatially growing tissues, their interaction with other sediments, and and their role as frame builders, binders, or bafflers for the deposits. If these growing tissues are fragmented and subsequently re-deposited, they are described as rudstones or floatstones, depending on the dominance of grains and matrix. This classification also is based on whether the algae are bounded during deposition (Autochthonous) or transported and not

bounded (Allochthonous). In the current study , the boundstone microfacies is divided into the following submicrofacies based on the tissues nature:

4.2.1.5.1 Laminated Bindstone Submicrofacies (B1):

Laminated bindstone submicrofacies is identified in the middle layer of lower part in Gali Duhok section and in the lowermost layer of middle part of Gali Zakho section. This submicrofacies consists of laminated algae that act as binding materials for the sediments , forming mats with benthic foraminifera and peloids. This connection usually takes place between all components during deposition, and interference occurs during the movement of high waves. The micritization and dissolution process have been affected this submicrofacies. By comparing this submicrofacies with the proposed model by Wilson (1975), Flügel (1982), it corresponds to the standard microfacies (SMF- 7) deposited within the (FZ-5), representing the reef marginal platform environment (Pl.K- 1),(Pl.K- 2), (Pl.K- 3).

4.2.1.6 Floatstone Microfacies:

The Floatstone Microfacies is consist of the fragmented, re-deposited and allochthonous of grains larger than 2 mm. The particle content in this microfacies ranges from 10-20% of the total volume, and it is generally mud-supported (Embry and Klovan, 1971 in James and Choquett, 1983). According to the type of fragmented and re-deposited grains, this microfacies can be divided into one submicrofacies:

4.2.1.6.1 Red Algal Floatstone Submicrofacies (F1):

Red algal floatstone submicrofacies is identified in the upper layers of the middle part of Gali Zakho section. This submicrofacies represented by the coralline red algae, intraclast, extraclast and it is mud-supported which makes up about 80% of the microfacies volume. The

dolomitization, micritization and dissolution have affected this submicrofacies. According to the proposed model by Wilson (1975), Flügel (1982), it is correspond to the standard microfacies (SMF-8) deposited within the (FZ-7), representing the open marine platform interior environment (**Pl.C- 3**).

4.2.1.7 Crystalline Limestone Microfacies (C1):

Crystalline microfacies is found in a high percentage in the upper layers of lower part in the Gali Zakho sections. It is distinguished by its lack of grain components and original texture features. May be it contains grain but the intense recrystallization process seems to have destroyed all the grains and sedimentary and textural structures present in it (The process of dolomitization erased the original texture of these rocks). It is also affected by the dissolution process and channel porosity. According to the proposed model by Wilson (1975), Flügel (1982), this microfacies corresponds to the standard facies (SMF-23) deposited in the Facies Zone (FZ- 8), representing a restricted environment (**Pl.K- 4**).

Table 4.1: The main microfacies, submicrofacies, the standard microfacies, the facies zones, and environmental zones of the Jeribe Formation in two sections.

Main Microfacies	Submicrofacies of Jeribe Formation	Standard Microfacies (SMF) and Facies Zones (FZ) (Flügel, 2010)			Zone of Environment According to Flügel (2010)
		Standard Microfacies SMF	Facies Zones FZ	Environment of Microfacies	
Mudstone	Miliolidal Lime Mudstone (M1)	SMF-8	FZ-7	Open Marine	Interior Platform
	Peloidal Lime Mudstone (M2)	SMF-16	FZ-8	Restricted	
	Benthonic Foraminiferal Lime Mudstone (M3)	SMF-8	FZ-7	Open Marine	
	Mollusk Lime Mudstone (M4)	SMF-8	FZ-7	Open Marine	
Wackstone	Miliolidal Peloidal Lime Wackstone (W1)	SMF-8	FZ-7	Open Marine	
	Peloidal Lime Wackstone (W2)	SMF-16	FZ-8	Restricted	
Packstone	Miliolidal Lime Packstone (P1)	SMF-18	FZ-8	Restricted	
	Fossiliferous Lime Packstone (P2)	SMF-18	FZ-8	Restricted	
Grainstone	Benthonic Foraminiferal Lime Grainstone (G1)	SMF-18	FZ-8	Restricted	Marginal Platform
	Oncolitic Lime Grainstone (G2)	SMF-13	FZ-5	Reef	
	Fossiliferous Lime Grainstone (G3)	SMF-18	FZ-8	Restricted	Interior Platform
	Non Laminated Fine-Grained Peloidal Grainstone (G4)	SMF-16	FZ-8	Restricted	
	Green Algal Lime Grainstone (G5)	SMF-18	FZ-8	Restricted	
	Red Algal Lime Grainstone (G6)	SMF-18	FZ-8	Restricted	
Bindstone	Laminated Bindstone (B1)	SMF-7	FZ-5	Reef	Marginal Platform
Floatstone	Red Algal Floatstone (F1)	SMF-8	FZ-7	Open Marine	Interior Platform
Crystalline	Crystalline (C1)	SMF-23	FZ-8	Restricted	

4.3 Depositional Environments:

Inferring the depositional environment is one of the main aims in most sedimentary studies. It is done through detailed petrographic and microfacies analysis, reflecting a variety of physical, chemical, and biological factors that prevailed within the depositional environment of the rock sequences (Flügel, 2010). Scholle and Ulmer- Scholle (2003) and Boggs (2006), demonstrated that various factors influenced the depositional environment including temperature, salinity, water currents, water depth, turbidity, and light penetration, all of which are dependent on changes in sea level. Differences in these factors indicate variations in the depositional environment, leading to differences in sedimentary facies and distinguishing each environment from the others. The impact of these factors on sediment deposition is reflected in the form of environmental evidences, resulting in distinct sedimentation patterns within various facies zones (Miall, 1985). Below are the environmental evidences:

4.3.1 Environmental Evidences:

The depositional environment can be inferred by identifying the environmental evidence, which includes sedimentary and biological evidences obtained from petrography and detailed microfacies analysis, and by correlating these findings to identify the specific environmental conditions during deposition. Below are the detailed description of sedimentary and biological evidences:

A. Sedimentary Evidence:

The current study of the Jeribe Formation showed many sedimentary evidences indicating the nature of the depositional environment, among the most distinguished .

- The prevalence of micrites in most samples of the current study explains the occurrence of most depositional processes in low-

energy environments below the wave base level. As mentioned by Selley (1976) that micrite provides indications of deep-sea and lagoon settings.

- The presence of multiple intraclast and extraclast rock fragments from various sources and sizes indicates proximity to the continent. And The presence of intraclasts indicates marine hiatus surfaces, reefs, fore-reef slopes, and carbonate beaches. Additionally, the presence of intraclasts indicates an environment with fluctuating energy currents that erode unconsolidated sediments to produce intraclast (Williams and Picard, 1974).
- The presence of pyrite authigenic minerals indicates the depth of the depositional environment and also the oxygen deficiency and the slowing down of depositional processes (Nichols, 1999).
- The distribution of peloids indicates shallow, low-energy, restricted marine environments. (Tucker and Wright ,1990; Al-Mowla and Al- Hameedy, 2024).
- The presence of orthosparite groundmass indicates a high energy (Flügel, 1982).

B. Biological Evidences:

The current study mentioned a set of biological evidence that provides clues about the depositional environment of the Jeribe Formation, with some of the prominent ones being:

- The distribution of benthic foraminiferal tests, represented by large and small benthic foraminifera suggest sedimentation occurred in normal marine to transitional restricted marine environment in hard to firm substrate and warm water conditions (Flügel, 2010).
- The distribution of Miliolidae genera shells compared to other benthic foraminifera shells in specific layers of the studied

formation reflects sedimentation in a lagoon environment (Flügel, 2004). This is because Miliolidae genera thrive in warm, shallow depositional environments at depths not exceeding 50 meters. Typically, Miliolidae group (*Quinquiloculina sp.*, *Triloculina sp.*, and *Pyrgo sp.*) is found in coastal lagoons and back reef environments (Murray, 2006; Brasier, 1980; Henson, 1950)

- The distribution of the *Peneroplis sp.* indicates a warm, shallow tropical environment (Qader, 2020).
- The presence of the *Rotalia sp.* Indicate a deposition in shallow carbonate environments with normal salinity (Hallock, 2000). Additionally, (Qader ,2020) indicated that Rotaliids are found in the restricted platform environment with high salinity within the inner platform with a depth of water not exceeding 50 meters (Murray, 2006).
- Presence of the *Borelis sp.* which is regarded as index fossil of the Jeribe Formation, indicating shallow tropical waters (Abawi *et al.*, 2000) and a depth not exceeding 60 meters (Murray, 1973).
- The distribution of the *Textularia sp.* Indicates a salinity and the shallowness of the depositional basin (Abawi *et al.*, 2000).
- The presence of Coralline Algae indicates open marine platform interior environmental conditions, with high energy, shallow, normal salinity, represented by a reef environment, similar to what is found in the Shelf Margin in southwest America during the Pennsylvanian- L. Permian era. (Wary, 1968). Additionally, the presence of An association dominated by *Lithophyllum* suggests shallow water and high-energy environments (Hamad *et al.*, 2015).
- The presence of *Halimeda sp.* that belong to calcareous green algae, these green algae indicates a reef and near-back reef

environment. It is commonly found at depths ranging from 2 to 30 meters and exhibits a wide range of salinity tolerance, from strongly hypersaline to brackish conditions (Scholle and Ulmer-Scholle, 2003). Leeder (2011) mentioned that the presence of green algae indicates deposition in lagoon environments and from brackish to marine waters.

- The Presence of mollusks indicate a warm shallow marine environments with low water movement (Scholle and Ulmer-Scholle, 2003; Moore *et al.*, 1952; Milliman, 1974). Pelecypod can inhabit deep and shallow marine environments (Al-Badrani, 2019), Gastropoda can be found in marine, transitional, and freshwater environments.
- The presence of bioclasts indicates a very shallow marine environment (Ghafur, 2012). And high energy of the depositional environments (Flügel ,2004). Their existence indicates that the skeletal particles have been subjected to fragmentation and breakage due to transport processes and deposition in high-energy environments, which may provide evidence of a change in energy level from high to low energy.

4.4 Depositional Environments of the Jeribe Formation:

Based on the nature of the identified submicrofacies and their correlation with accurate standard microfacies (**Table 4.1**), sedimentary evidence and biological evidence, the current study has indicated that the successions of the Jeribe Formation were deposited within three depositional environments. The changes in these depositional environments are due to sea level fluctuations. These environments include :the back reef environment, the open marine platform interior

environment and the reef environment (**Fig. 4.3** and **Fig. 4.4**). Below is a detailed description of these depositional environments:

4.4.1 Back Reef / Restricted / Lagoon Environment:

The Back reef environment of the Jeribe Formation in the Gali Zakho and Gali Duhok sections is equivalent to standard microfacies (SMF) 16 and 18, that represented by facies zone (FZ-8) according to Wilson (1975), Flügel (1982). It has been identified through the presence of the following submicrofacies: Peloidal Lime Mudstone (M2), Peloidal Lime Wackstone (W2), Miliolidal Lime Packstone(P1), Fossiliferous Lime Packstone(P2), Benthonic Foraminiferal Lime Grainstone(G1), Fossiliferous Lime Grainstone(G3), Non Laminated Fine-Grained Peloidal Grainstone (G4), Green Algal Lime Grainstone(G5), Red Algal Lime Grainstone(G6) and Crystalline (C1) (**Table 4.1**) and as illustrated in the stratigraphic column of submicrofacies distribution (**Fig. 4.3**) and (**Fig. 4.4**).

Green Algae, Red Algae, peloids, Miliolids and Benthonic foraminifera (*Borelis sp.*, *Rotalia sp.*, *Peneroplis sp.*, *Quinqueloculina sp.*, *Triloculina sp.*, and *Pyrgo sp.*) are among the most important grain components of the deposited submicrofacies within this environment. It should be mentioned that these grain components collectively act as evidences of a lagoonal environment as mentioned in the paragraph of sedimentary evidences. Leeder (2011) mentioned that the presence of green algae indicates deposition in lagoon environments and from brackish to marine waters. The presence of peloids indicates shallow, low-energy, restricted marine environments. (Tucker and Wright ,1990). The presence of Miliolidae genera shells compared to other benthic foraminifera shells in specific layers of the studied formation reflects sedimentation in a lagoon environment (Flügel, 2004). The presence of benthic foraminiferal tests, suggest sedimentation occurred in normal

marine to transitional restricted marine environment in hard to firm substrate and warm water conditions (Flügel, 2010)

Generally, it is a relatively shallow environment with a depth not exceeding 50 meters and moderate water energy and protected by a barrier like a central reef, with changing, sometimes restricted water circulation. It is also typically of normal marine salinity, despite occasional indications to the contrary. (Flügel, 2010; Henson, 1950).

4.4.2 Open Marine Platform Interior Environment:

The open marine platform interior environment of the Jeribe Formation in the Gali Zakho and Gali Duhok sections is equivalent to standard microfacies (SMF-8) , that represented by facies zone (FZ-7) according to to Wilson (1975), Flügel (1982). It has been identified through the presence of the following submicrofacies: Miliolidal Lime Mudstone (M1), Benthonic Formniferal Lime Mudstone (M3), Mollusk Lime Moudstone (M4), Miliolidal Peloidal Lime Wackstone (W1) and Red Algal Floatstone (F1) (**Table 4.1**) and as illustrated in the stratigraphic column of submicrofacies distribution (**Fig. 4.3**) and (**Fig. 4.4**).

Miliolids, *Textularia* sp., coralline red algae, Pelecypods, Gastropoda and red algal are among the most important grain components of the deposited submicrofacies within this environment. According to percentage the grain components and the groundmass it is evidences of open marine platform interior environment (Wilson, 1975; Flügel, 1982).

The presence of Coralline Algae indicates open marine platform interior environmental conditions, with high energy, shallow, normal salinity, represented by a reef environment, similar to what is found in the Shelf Margin in southwest America during the Pennsylvanian-L. Permain era. (Wary, 1968). The Presence of mollusks indicate a warm shallow

marine environments with low water movement (Scholle and Ulmer-Scholle, 2003; Moore *et al.*, 1952; Milliman, 1974). The presence of benthic foraminiferal tests, suggest sedimentation occurred in normal marine to transitional restricted marine environment in hard to firm substrate and warm water conditions (Flügel, 2010)

Open marine platform interior environment refers to a flat platform top within the euphotic zone, typically above the fair-weather wave base. When shielded by sand shoals, islands, or reefs at the platform's edge, it is known as a lagoon. This environment consists of organisms found in shallow waters, including algae, foraminifera, bivalves, and gastropods, which are abundant. These environments also contain marine grasses and patch reefs. The common microfacies of it are wackestone, floatstone, packstone and grainstone. (Flügel, 2010).

4.4.3 Reef Environment:

The reef environment of the Jeribe Formation in the Gali Zakho section is equivalent to standard microfacies (SMF) , that represented by facies zone (FZ-5) according to to Wilson (1975), Flügel (1982). This environment has been identified within the formation sequences of the current study through the presence of laminated bindstone and oncoids lime grainstone microfacies (**Fig.4.3**). They form the middle sequences of the formation in the Gali Zakho section. This can be attributed to the tectonic uplift of the basin floors in the region. Accordingly, it seems that the necessary environmental conditions for algae growth and flourishing, such as shallow water, good light penetration, nutrient availability, and oxygen, have been well provided. The red algal coralline algae are considered the main component of this submicrofacies of reef environment in the Jeribe Formation where they are found. Despite the fact that coralline red algae inhabit relatively deep marine environments exceeding 400 meters (Flügel,2010). the presence peloids within the

bindstone submicrofacies composing the structure of the reef in the Jeribe Formation indicates the shallowness of its depositional environment. Reading (1978) emphasized the importance of red algae in the bounding and formation of rigid structures (Ridge Frame) in modern reef accumulations. Red algae encrusters serve as the main binding organisms in the majority of reefs from the Cenozoic era to the present day (Asaad *et al.*, 2022).

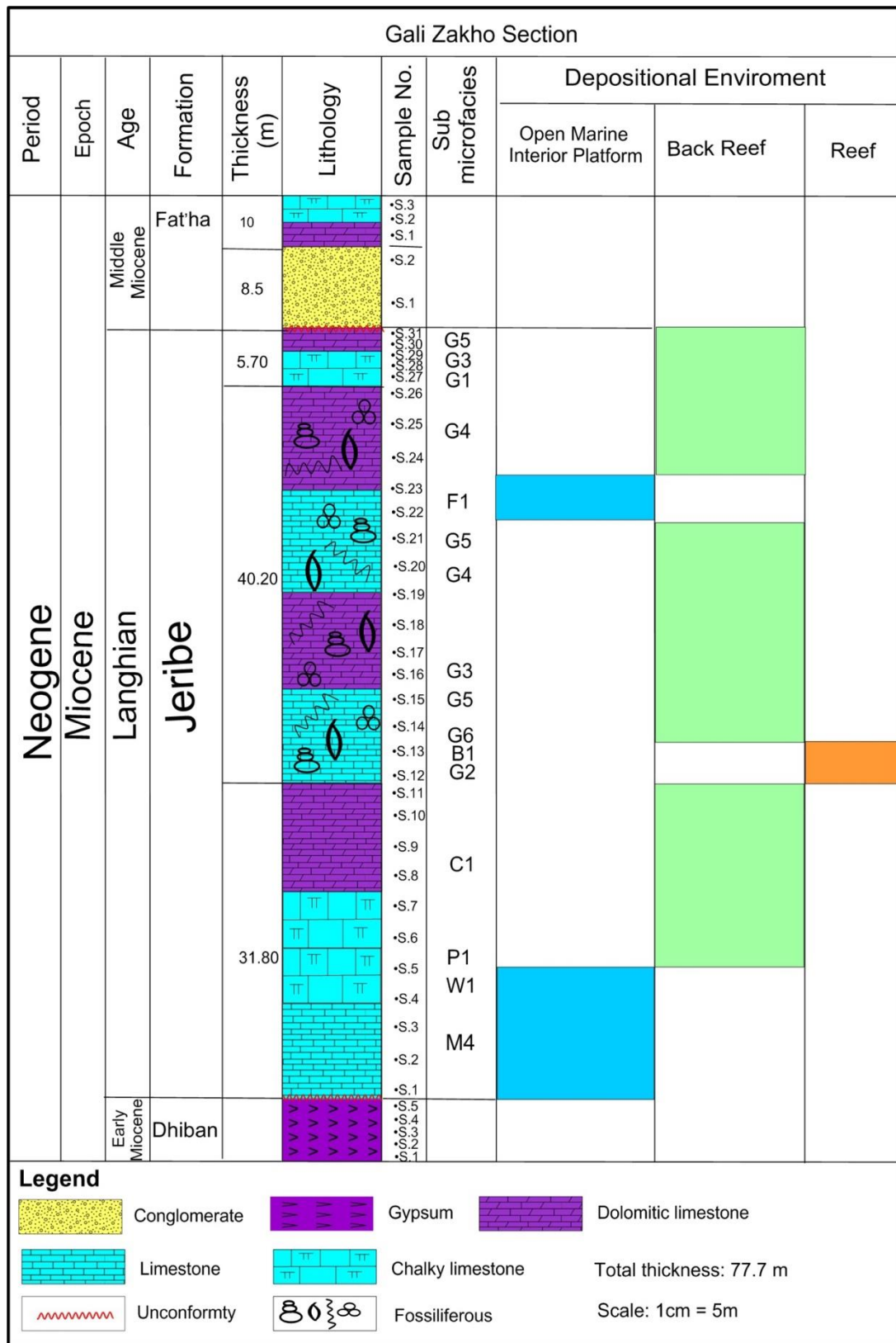


Figure 4.3: A stratigraphic column illustrates the distribution of submicrofacies and their depositional environments in the Gali zakho section.

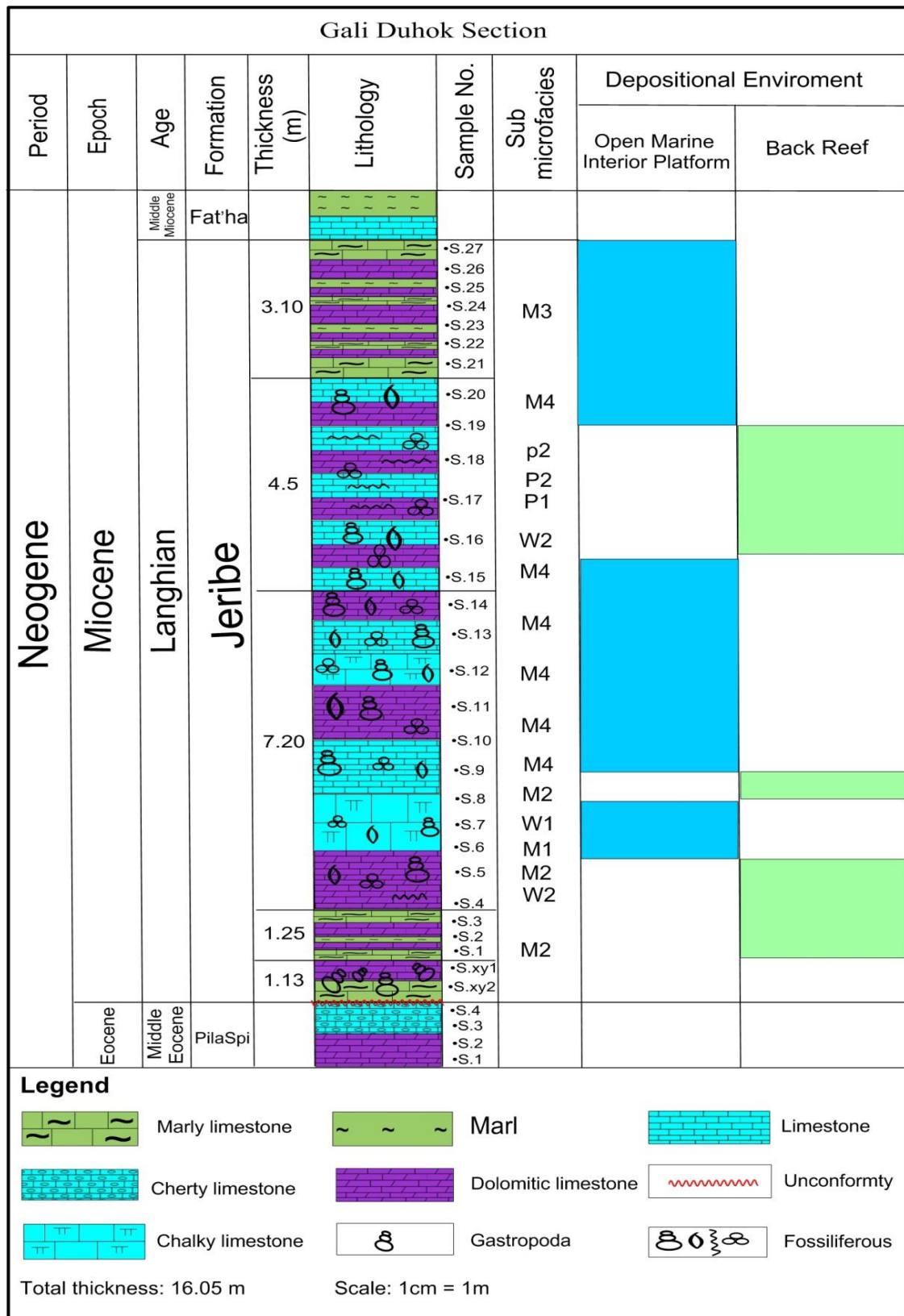


Figure 4.4: A stratigraphic column illustrates the distribution of submicrofacies and their depositional environments in the Gali Duhok section.

4.5 Depositional Model:

Several researchers have discussed proposed models for describing and distinguishing shallow marine lime depositional environments (Wilson, 1975; Read, 1985; Tucker and Wright, 1990; Moore 2001). These models are primarily based on the microfacies distribution pattern and their response to tectonic changes and sea level fluctuations. According to the microfacies analysis, their distribution, sea level fluctuations, the sedimentary and biological evidences of the current study, a sedimentary model for the Jeribe Formation have been constructed (**Fig. 4.5**). This model illustrates the scenario that led to the deposition of the microfacies of the Jeribe Formation in the current sections as shown below:

A. Gali Zakho Section:

The lower part of the Jeribe Formation sequence in the Gali Zakho section begins with lime mudstone and lime wackestone microfacies containing miliolid and mollusk fossils, belongs to (FZ-7). These were deposited in an open marine platform interior environment. These microfacies indicate shallowing in the depositional basin, followed by a significant presence of crystalline microfacies belongs to (FZ-8), suggesting a restricted environment. Gradually, red algae fossils appear in the lowermost layers of the middle part, represented by laminated bindstone (containing red algae fossils) and oncoids lime grainstone submicrofacies, deposited in (FZ-5) within the marginal platform reef zone. This indicates an increase in the depth of the sedimentary basin due to either sea level rise or tectonic subsidence of the region. Moreover, the appearance of benthic foraminifera, mollusks, and both green and red algae in the middle layers of middle part, represented by

lime grainstone facies within FZ-8, indicating a change in sea level, leading to deposition in a restricted environment. The continued shallowing extends to the uppermost layers of the middle part with the appearance of coralline red algae, representing the floatstone microfacies, which lies within FZ-7 and indicates an open marine platform interior environment, this signifies a shallowing in the depth of the sedimentary basin due to either sea level fall or tectonic uplift, indicating the shallowness of the environment in the upper layers of the middle part. The shallowing continues from the upper layers of middle part to the upper part of formation, marked by the reappearance of benthic foraminifera, fossiliferous, green and red algae fossils, represented by lime grainstone, corresponding to FZ-8, indicating deposition in restricted environments. The persistence of sea level decrease indicates that shallowing in the depositional environment of the Jeribe Formation is occurring.

B. Gali Duhok Section:

The lower part of the Jeribe Formation in the Gali Duhok section begins with peloidal lime mudstone, indicating a back reef environment (FZ-8). Despite the presence of laminated bindstone submicrofacies in this part, the lower part was deposited in a back reef environment, due to according to field observations that showed the lower part is well-bedded with no evidence of a reef body in this part. The non-skeletal peloids continue in the middle part A , represented by lime wackestone and lime mudstone microfacies, deposited in a restricted back reef environment, suggesting further shallowing of the depositional basin.

Subsequently, the deposition environment became more shallower due to the presence of benthic foraminifera fossils in

the lime mudstone and wackestone microfacies indicates a deposition in the open marine platform interior environment and a decrease in sea level.

The peloidal lime wackestone of a restricted environment reappears, followed by lime mudstone microfacies in the uppermost layers of middle part A and continuing into the lowermost layers of middle part B (**Fig 4.4**), which contain Gastropoda and Pelecypoda fossils, deposited within an open marine platform interior environment, suggesting a shallowing of the depositional basin and sea level fluctuations.

In middle layers of middle part B, a third appearance of submicrofacies in a restricted environment is represented by lime wackestone and packstone containing algae, miliolid, and peloid grains. The shallowing continues from the upper layers of Middle part B into the upper part of the formation, characterized by lime mudstone submicrofacies with mollusk and benthic foraminifera fossils, dominated by the *Textularia* sp. These are situated in an open marine platform interior environment, indicating a very shallow setting due to a decrease in sea level.

Evidence derived from the microfacies analysis indicates that the Jeribe Formation sequences were deposited in an open marine platform interior environment, as well as in restricted and marginal reef platform. Based on this evidence and the identified microfacies in the two study sections, which show shallowing in the upper part of the formation, a depositional model for the Jeribe Formation sequences in the study sections has been proposed (**Fig. 4.5**). These interpretations align with numerous previous studies on the Jeribe Formation.

Generally, the Jeribe Formation was deposited during the early Middle Miocene subcycle (Langhian) due to a marine transgression that occurred during this cycle, resulting in the deposition of the Jeribe Formation in marginal basins. Over time, the marine conditions became more isolated, leading to the formation of various lagoons that were intermittently replenished with seawater. This process resulted in the cyclic deposition of evaporites, forming the Fat'ha Formation in the Middle Miocene (Numan, 1997).

The nature of the formation successions of the Jeribe Formation clearly reflects significant influences from changes in sea levels, temperature and salinity. Overall, all components of the formation deposits indicate a shallow marine environment characterized by moderate salinity and temperature. However, the presence of specific and limited fossil types, such as Miliolids, in certain layers suggests that the Jeribe deposits were exposed to elevated temperature and salinity. Several researchers (Hallock and Glenn, 1986; Flügel, 2010), have pointed out that the low biodiversity in specific layers, which are limited to high-temperature and high-salinity-resistant organisms like Miliolids, serves as evidence of increased temperature and salinity of the water in those facies.

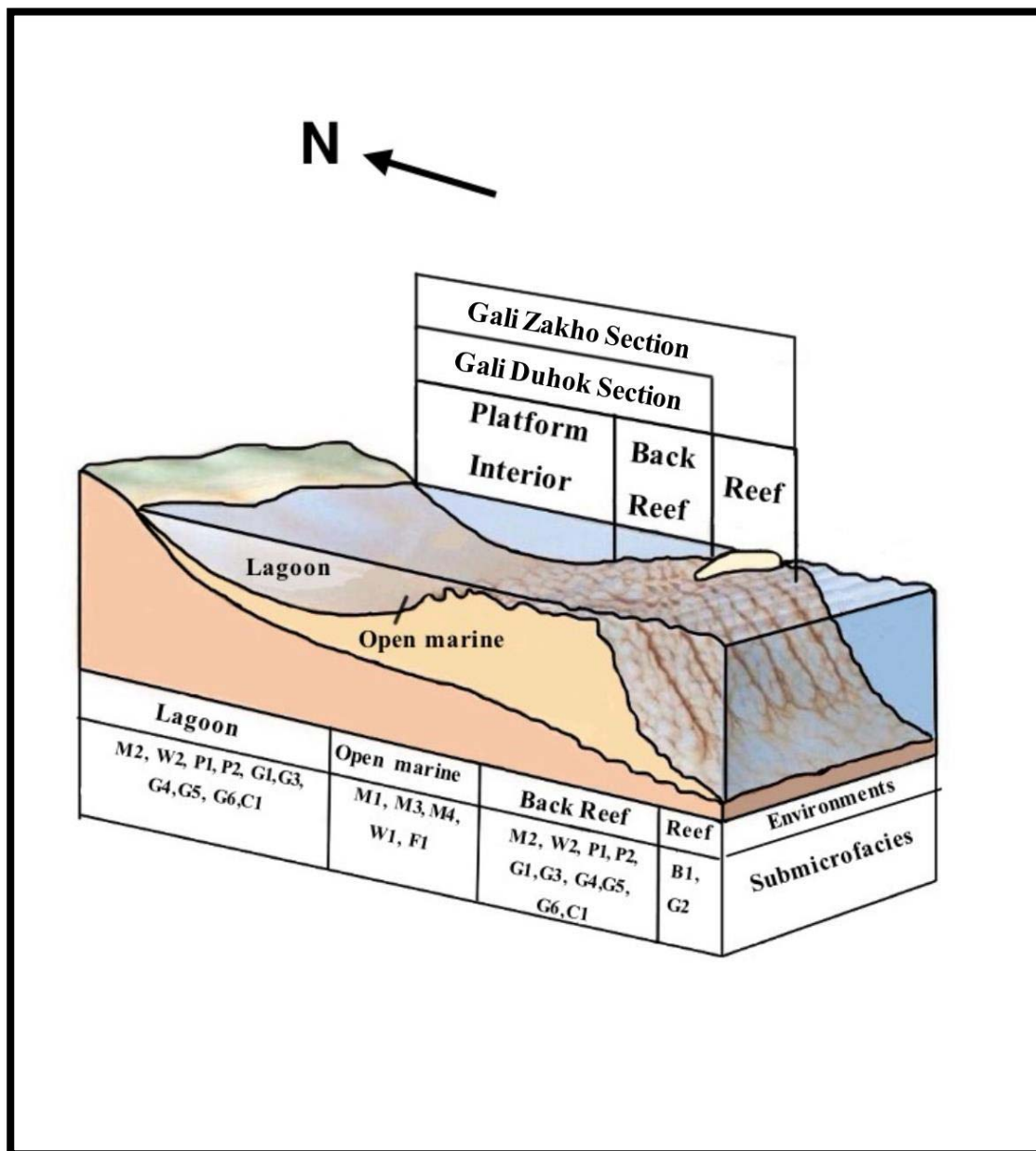


Figure 4.5: The proposed depositional model for the Jeribe Formation sequences of the study sections.

**Chapter
Five
Conclusions
and
Recommendations**

5.1 Conclusions:

Sedimentology of the Jeribe Formation were studied in the two sections, Gali Zakho and Gali Duhok sections. Depending on field observations and petrographic studies from these two sections the followings are concluded:

1. In the Gali Duhok section, based on the field evidences and microfacies analysis, there is highly fossiliferous surface between Jeribe Formation and underlying PilaSpi Formation. In the current study, this surface is interpreted as hardground (lithified sea floors formed by the cementation of carbonate layers). This could indicate a period of no deposition (unconformity). From previous evidences, it can be concluded that the boundary between the Jeribe Formation (early Middle Miocene) and the PilaSpi Formation (Middle Eocene) is unconformable.
2. Likewise, in the Gali Zakho section, the upper boundary of the Jeribe Formation is with Fat'ha Formation, with the presence of the conglomerate layer in between. The nature of the upper contact of the Jeribe Formation with overlying Fat'ha Formation in the Gali Zakho section is unconformable, as well.
3. The current study indicates variations in the thickness distribution of the Jeribe Formation and its extensions in the Bekhair anticline, where the thickness of the formation is about 77.7 m in the Gali Zakho section and about 16.05 m in the Gali Duhok section. The differences in the thickness of the Jeribe Formation from one section to another reflect its location within the basin (a thin bed thickness indicates deposition at the basin

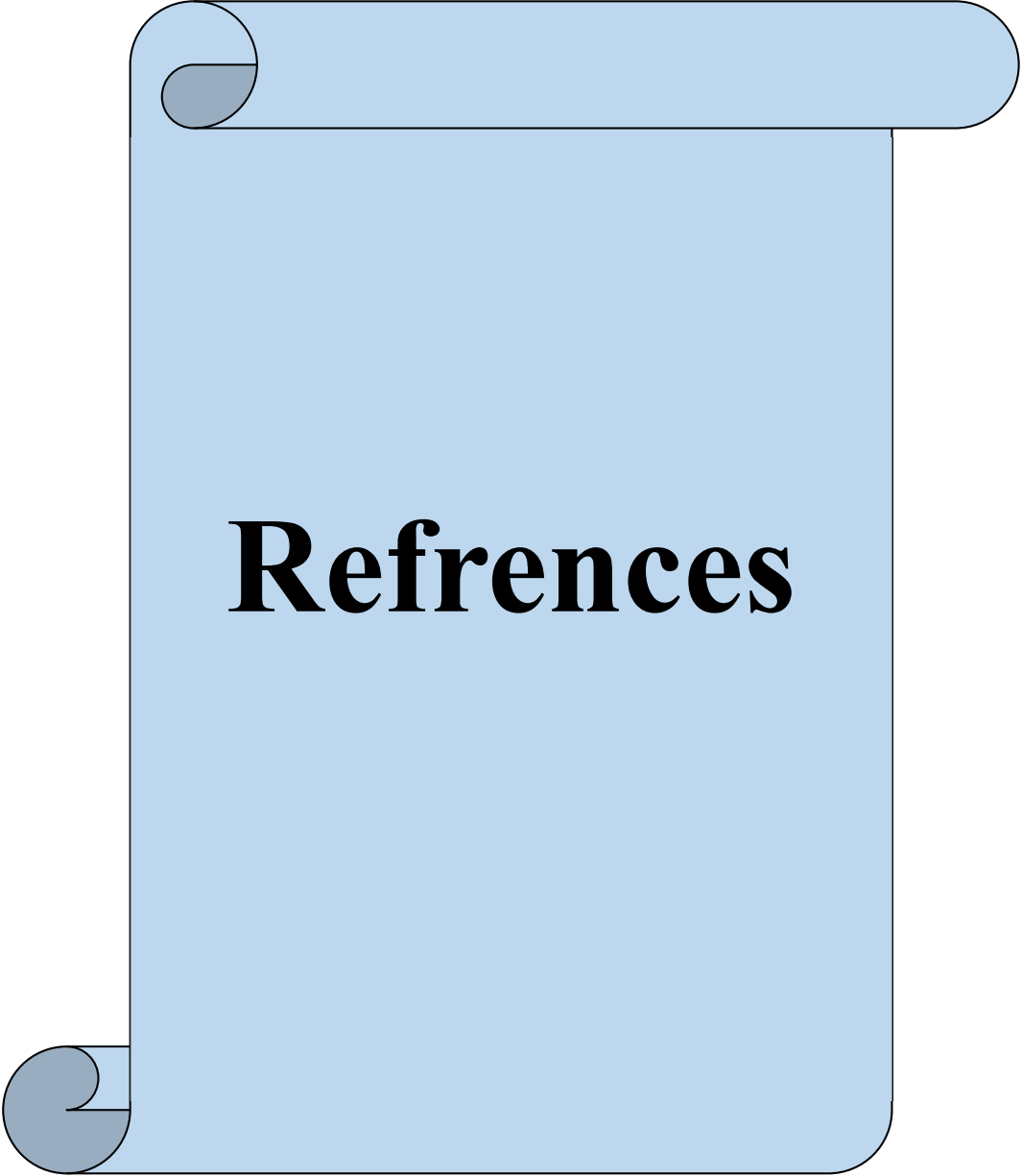
edge, while a thick bed thickness means it was deposited in the center or deeper part of the basin).

4. From petrographic investigations and microfacies studies, deposits of the Jeribe Formations have a great diversity (vertically and laterally) of components, and they are highly affected by the diagenetic processes in the whole studied areas. This means during the period of the Jeribe sediments deposition, the basin was highly affected by either sea level fluctuation and or tectonic activities (uplift and subsidence).
5. Depending on detailed microfacies analysis, seven main microfacies and seventeen submicrofacies are recognized in the study of thin sections of the Jeribe Formation as follows: Mudstone microfacies (Miliolidal Lime Mudstone, Peloidal Lime Mudstone, Benthonic Foraminiferal Lime Mudstone, Mollusk Lime Mudstone), Wackstone microfacies (Miliolidal Peloidal Lime Wackestone, Peloidal Lime Wackestone), Packstone microfacies (Miliolidal Lime Packstone, Fossiliferous Lime Packstone), Grainstone microfacies (Benthonic Foraminiferal Lime Grainstone, Oncolitic Lime Grainstone, Fossiliferous Lime Grainstone, Non-Laminated Fine-Grained Peloidal Grainstone, Green Algal Lime Grainstone, Red Algal Lime Grainstone), Boundstone microfacies (Laminated Bindstone), Floatstone microfacies (Red Algal Floatstone), and Crystalline microfacies.
6. Based on the submicrofacies divisions and their environmental interpretation, The vertical and lateral transitions concluded that the Jeribe Formation was deposited in restricted, open marine platform interior and marginal reef platform environments.

5.2 Recommendations for Future Work:

This project has aimed to create a comprehensive geological model for the Jeribe Formation through textural and petrology analysis, as well as facies analysis, in order to support further exploration and exploitation of these sediments. The results of this research suggest that additional work is necessary in the future along the following lines:

- More detailed study of the biostratigraphic and palaeontology database in order to improve the regional biostratigraphy and correlation for the entire basin; particularly, the identification and quantification of additional genera and/or species of benthic foraminifera, could give more precise indications on their palaeoecology.
- Extend the work outside the boundary of this study to try and establish sequence stratigraphic and lithofacies relationships (proximal, distal and marine facies equivalents).
- Combined well log correlation and seismic interpretation (particularly 3D) along regional key lines with outcrop data in the area, could help to establish a more complete picture of the Jeribe Formation regarding hydrocarbon reservoir characteristics.
- Sedimentology and biostratigraphy study of the hardground surface that lies between the Jeribe and Pilaspi Formations in the Gali Duhok Section.



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**The
Plates**

Plate A

1. **Microspar**, the effect of micrite recrystallisation, Jeribe Formation, early middle Miocene, middle part-A Gali Duhok section, Sample No.5.
2. ***Quinquiloculina sp.*** affected by dissolution referred by blue arrow. Within the groundmass affected by dolomitization referred by green arrow, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.5.
3. **micrite groundmass**, Jeribe Formation, early middle Miocene, lower part of Gali Duhok section, sample No.1.
4. **Cemented channel** showed the effect of cementation process, Jeribe Formation, early middle Miocene, Gali Zakho section, Sample No.4.
5. **Green algal lime grainstone**, green algae referred by green arrow within the groundmass of orthosparite referred by blue arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
6. **pseudosparite** (large, shapeless crystals) resulting from continuous recrystallization processes of micrite or sparite, Jeribe Formation, early middle Miocene, lower of Gali Duhok section, sample No.3.
7. ***Triloculina sp.*** have been affected by the micratization process Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.7.
8. ***Pyrgo sp.*** enveloped by micrite within the orthosparite groundmass, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section, Sample No. 15.

Plate A

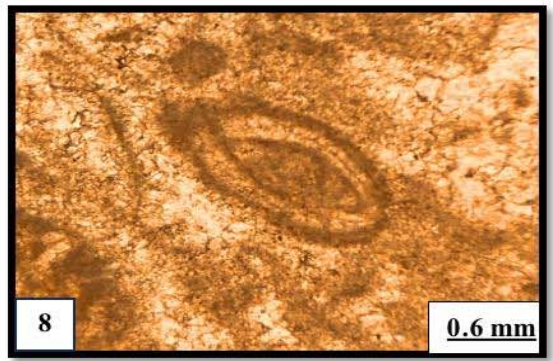
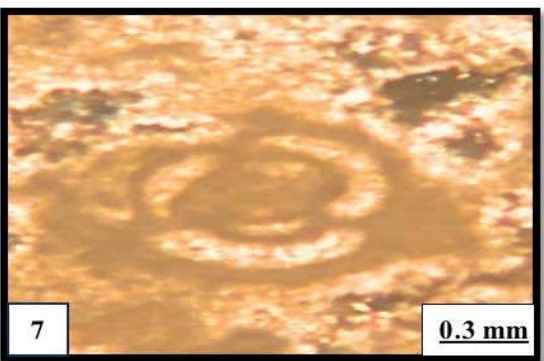
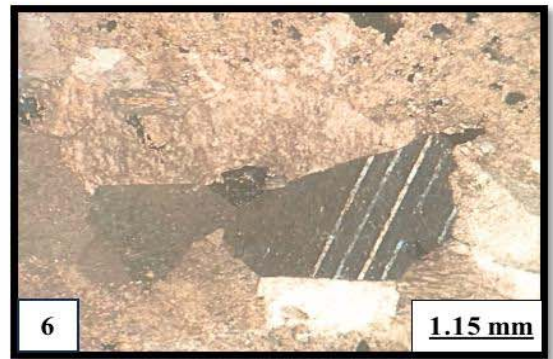
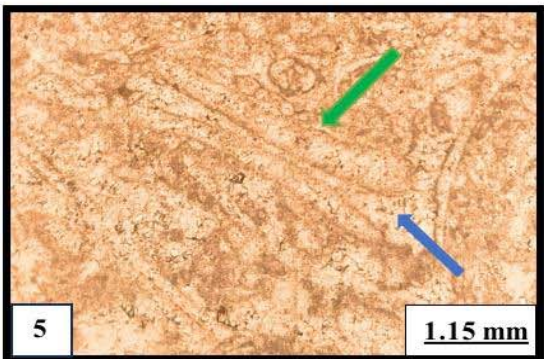
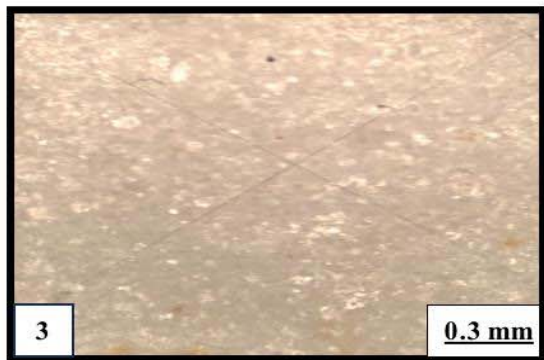
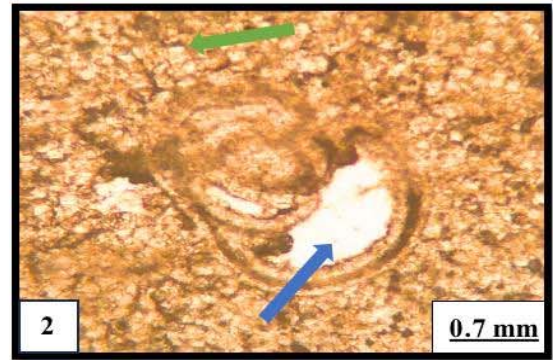
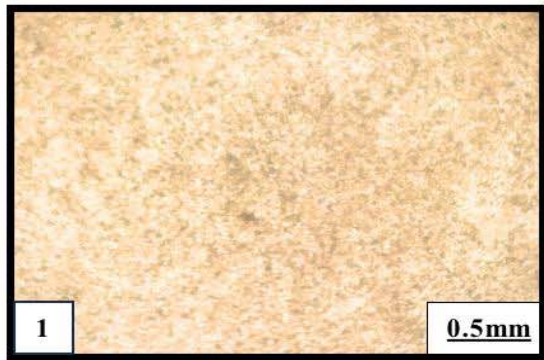


Plate B

1. *Peneroplis evolutus sp.* referred by blue arrow, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section. Sample No.27.
2. *Peneroplis sp.* indicated by green arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
3. *Borelis sp.* affected by micritization and dolomitization, **Miliolidal Peloidal lime Wackstone**, Jeribe Formation, early middle Miocene, Gali Zakho section, Gali Zakho, sample No.5.
4. *Rotalia sp.* Referred by blue arrow showing micrite envelop feature, within the groundmass of orthosparite referred by orange arrow, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section, sample No. 27.
5. *Texturalia sp.*, affected by dissolution process showing the intragranular porosity, **Benthonic Foraminiferal lime mudstone**, Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No.22.
6. *Dendritina rangi d'Orbigny sp.* referred by blue arrow, Jeribe Formation, early middle Miocene, upper part o Gali Zakho section, sample No.27.
7. *Idalina sp.*, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section, Sample No. 15.
8. **Bioclast of *Archaias kirkukensis sp.***, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.

Plate B

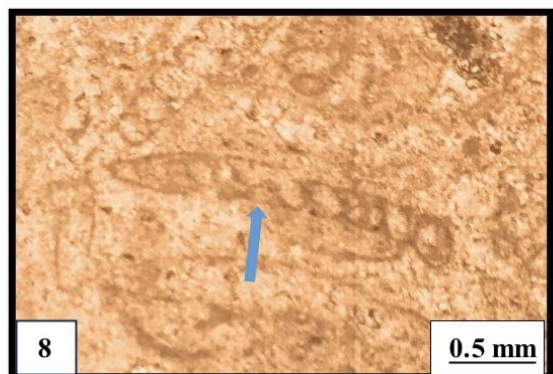
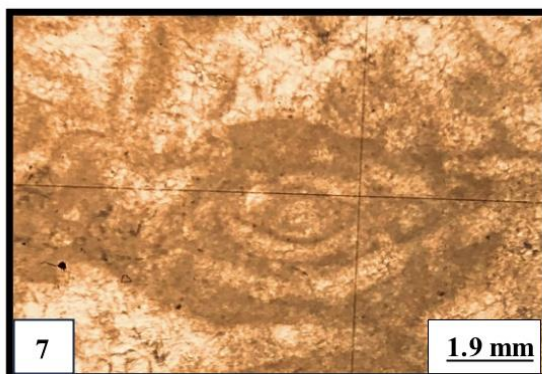
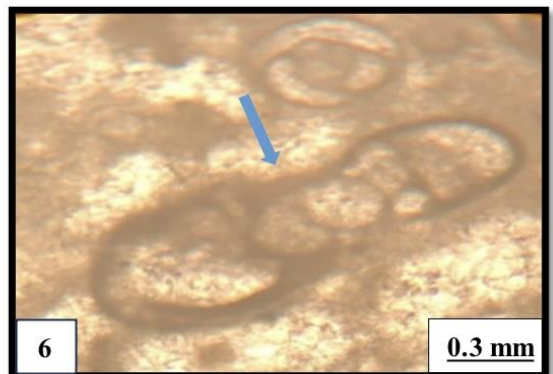
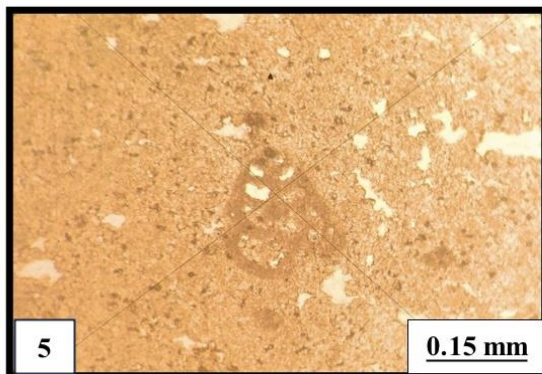
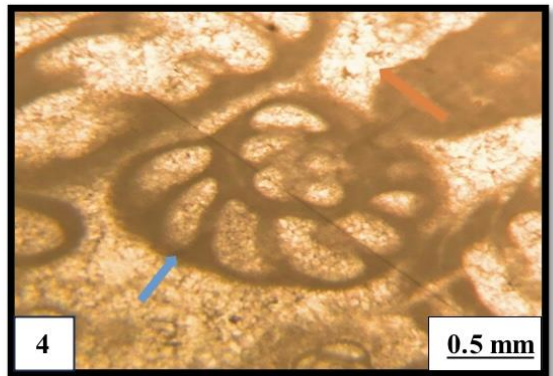
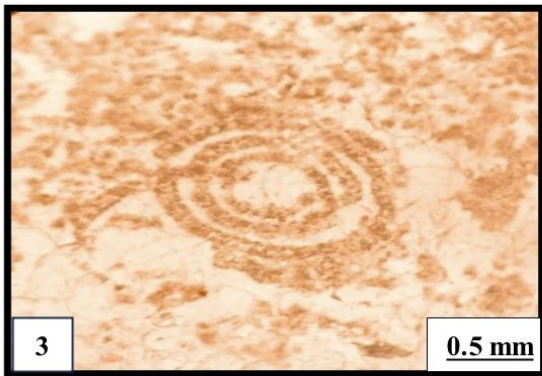
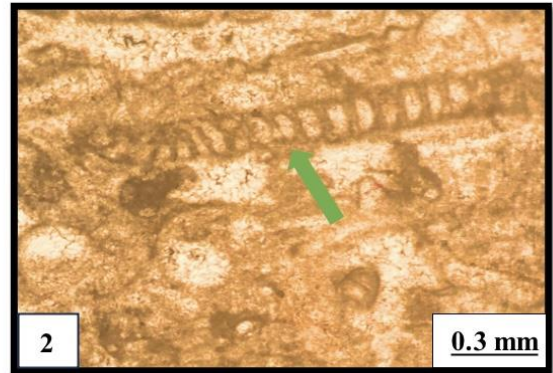
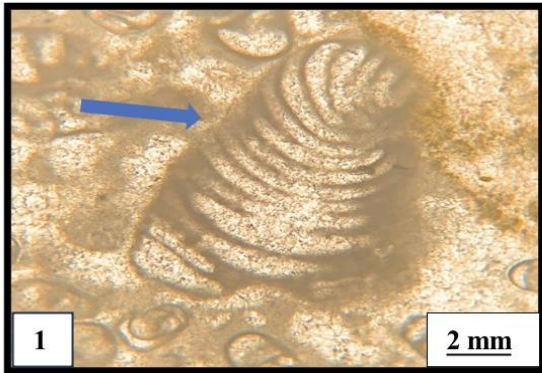


Plate C

1. **Uniserial benthonic foraminifera** showing micrite envelope feature referred by green arrow with miliolid shell referred by blue arrow within orthosparite groundmass, upper part of Gali Zakho section, sample No.27.
2. **Benthonic foraminifera referred by green arrow**, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section, sample No.27.
3. **Rhodoid coralline red algal nodule** showing a fine-scale cellular structure with distinct, lighter-coloured rows, **Red Algal Floatstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.22.
4. **Branching crustose coralline red algae of *Lithophyllum* sp.** referred by blue arrow and Bioclast of *Archaias kirkukensis* sp. (green arrow) and algae (orange arrow), Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
5. ***Solenopora* sp.** of red algae ,showing the characteristic of (undifferentiated) elongate cellular or tubular fabric, **Non Laminated Fine-Grained Peloid Grainstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.19.
6. ***Halimeda* sp.** of green algae referred by blue arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
7. **Pelecypod shell** have been subjected to cementation, Jeribe Formation, early middle Miocene, middle part-B of Gali Duhok section. Sample No.16.

8. **Gastropoda shell** showing Geopetal structure half of it has been filled with cement and is referred to by the blue arrow, while the other half has been filled with micrite and is referred to by the green arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15, Under regular light.

Plate C

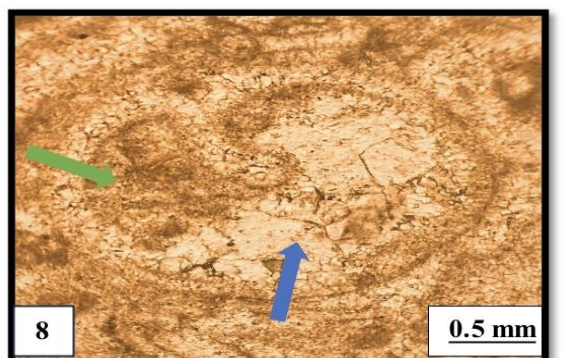
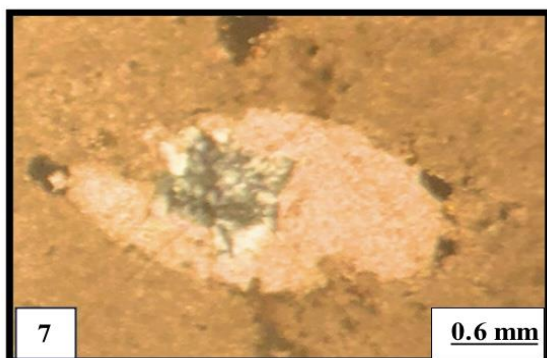
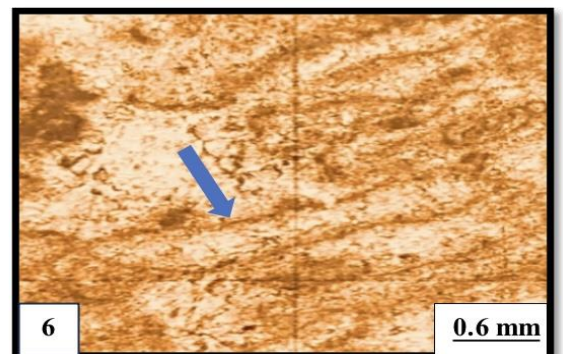
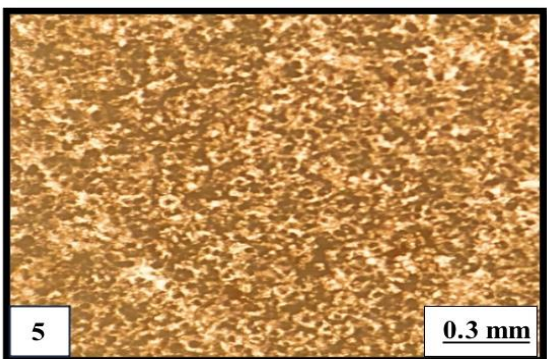
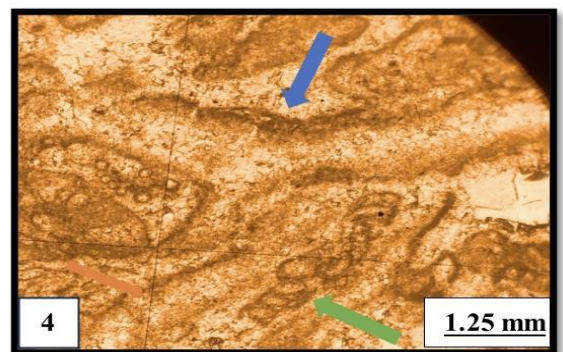
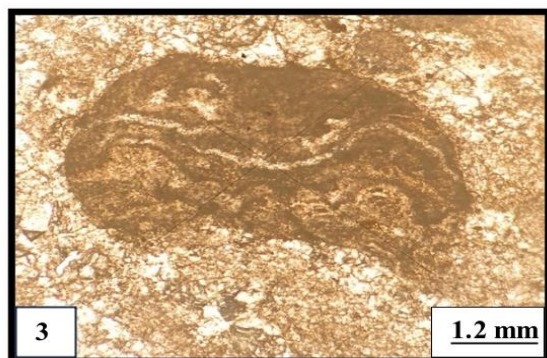
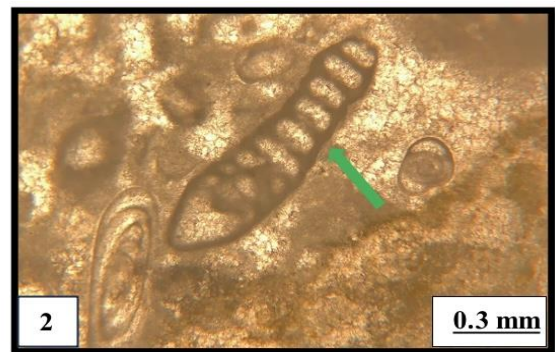
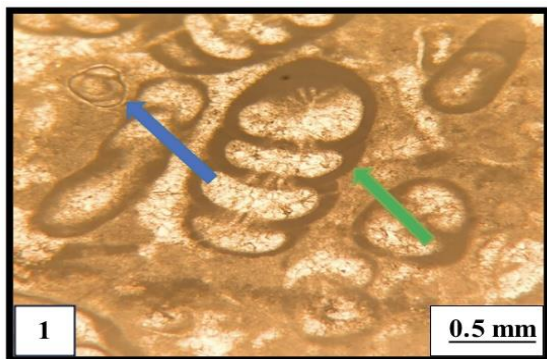


Plate D

1. **Gastropoda shell** showing Geopetal structure half of it has been filled with cement (blocky cement) and is referred to by the blue arrow, while the other half has been filled with micrite and is referred to by the green arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15, Under polarised light.
2. **Bioclasts**, the referred blue arrow is bioclast of *Archaias kirkukensis sp.*, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
3. **Peloids**, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No. 18.
4. **Oncoids** referred y blue arrow within orthosparite groundmass referred by green arrow, Gali Zakho section, sample No.12.
5. **Intraclast**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section, sample No.16.
6. **Extraclast**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.22.
7. **Extraclast**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.16.
8. **Granular cement**, Jeribe Formation, early middle Miocene, Gali Zakho section, sample No.1.

Plate D

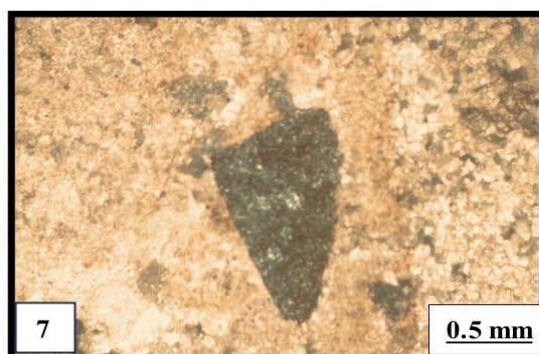
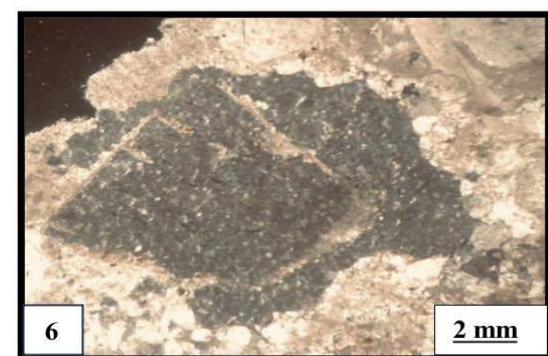
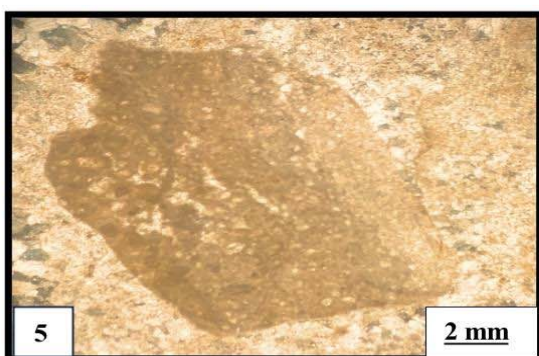
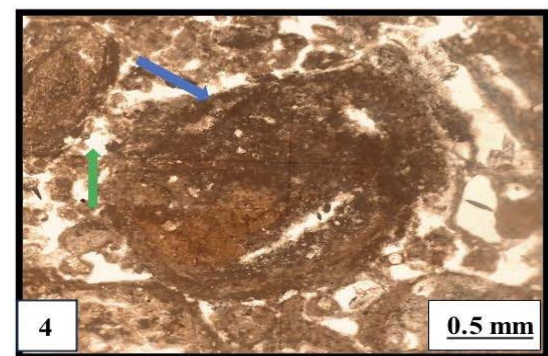
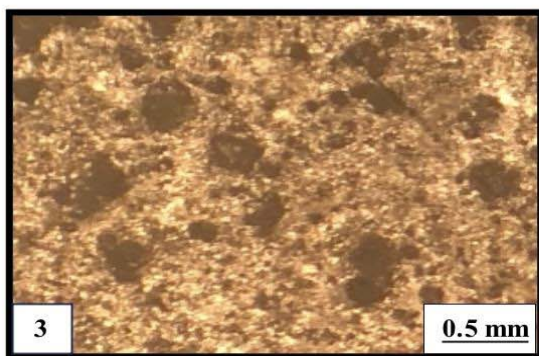
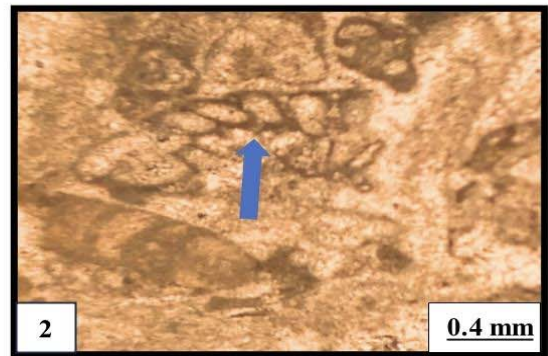
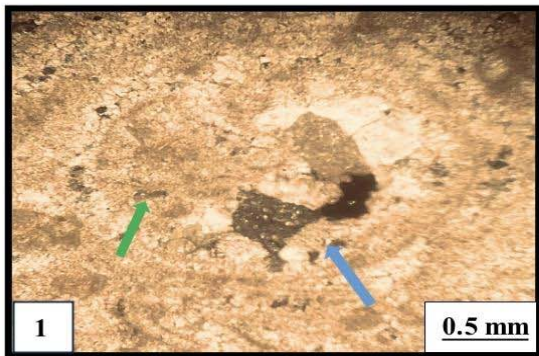


Plate E

- 1. Blocky cement**, Jeribe Formation, early middle Miocene, lower part of Gali Zakho section, Sample No.4.
- 2. Drusy cement**, Jeribe Formation, early middle Miocene, Gali Duhok section, sample No.3.
- 3. Bladed cement**, Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No.21.
- 4. Aphanotopic Texture**, Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No. 23.
- 5. Seive mosaic texture with Intercrystalline porosity** referred by orange arrow, Jeribe Formation, early middle Miocene, Gali Zakho section. Sampl No. 5.
- 6. Suture mosaic texture**, Jeribe Formation, early middle Miocene, Gali Zakho section, sample No.12.
- 7. Suture mosaic texture**, Jeribe Formation, early middle Miocene, Gali Zakho section,sample No.27.
- 8. Fogged mosaic texture**, Jeribe Formation, early middle Miocene, Gali Zakho section Sample. No. 16.

Plate E

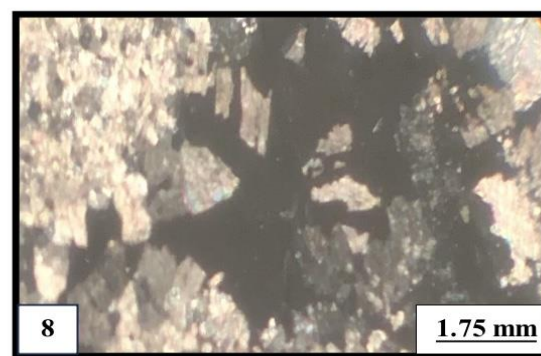
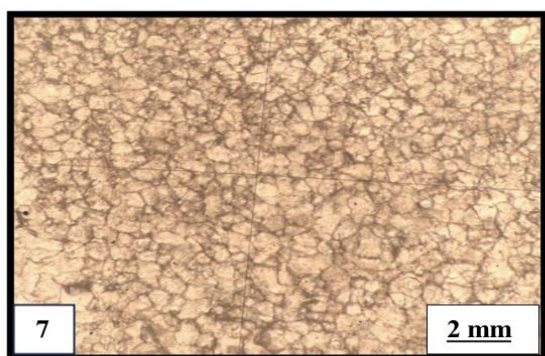
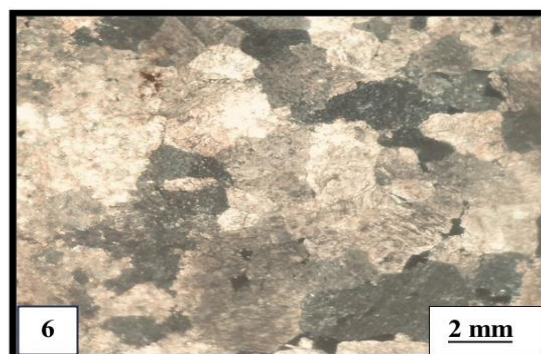
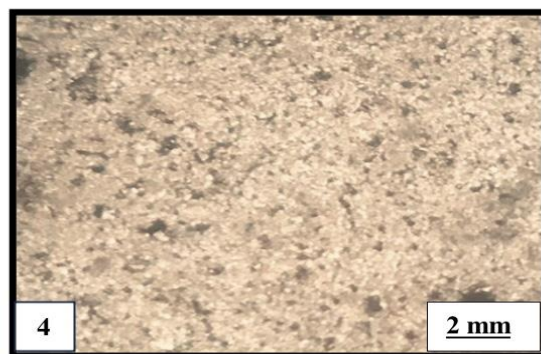
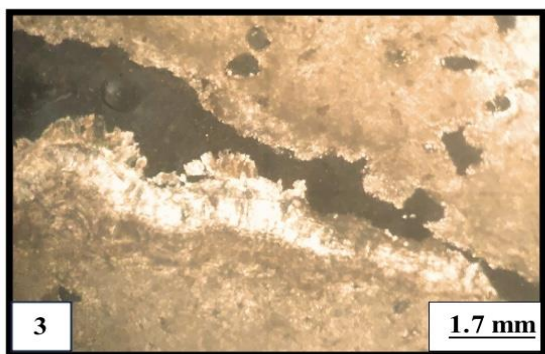
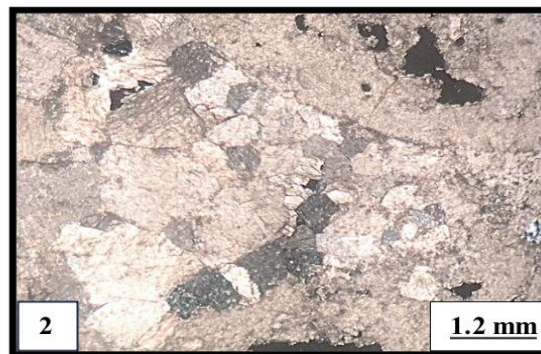
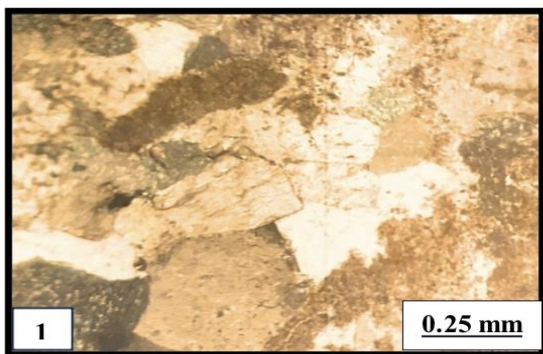


Plate F

- 1. Voids** have been filled through the process of silisification, Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No.27.
- 2. Void** has been filled with chert mineral through the process of silisification, Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No.22.
- 3. Pyrite minerals** characterized by its dark brown color, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section. Sample No.27.
- 4. Iron oxide**, Jeribe Formation, early middle Miocene, middle part-B of Gali Zakho section. Sample No.28.
- 5. Anhydrite mineral**, Jeribe Formation, early middle Miocene, lower part of Gali Zakho section, Sample No.5.
- 6. distortion of a triloculina shell** is caused by the physical compaction effect and also this shell have been affected by dissolution process, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.18.
- 7. Stylolite of peaks low amplitude**, middle part-A of Gali Duhok section, sample No.7.
- 8. Stylolite of peaks high amplitude**, Jeribe Formation, early middle Miocene, middle part of Gali Duhok section, sample No.8.

Plate F

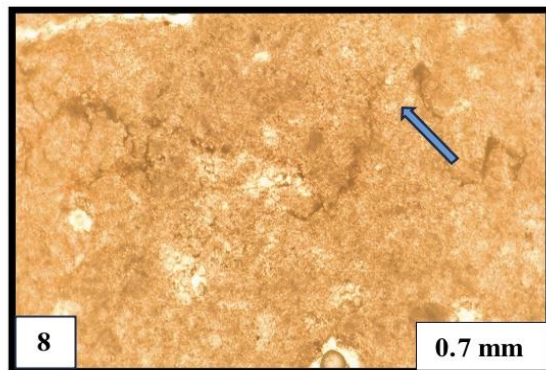
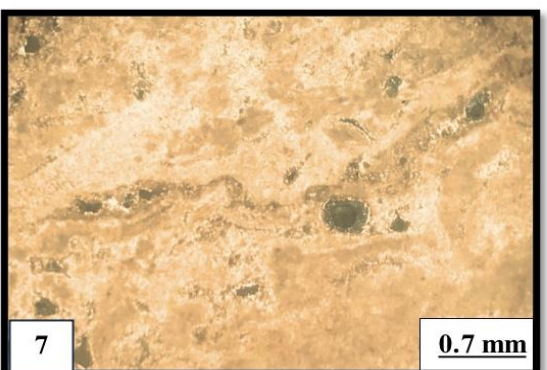
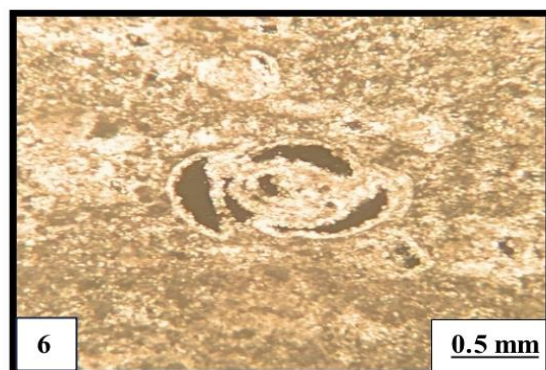
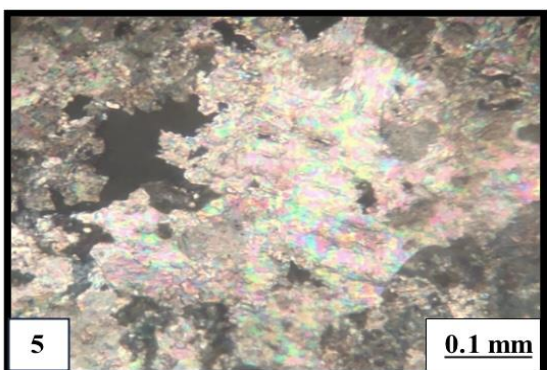
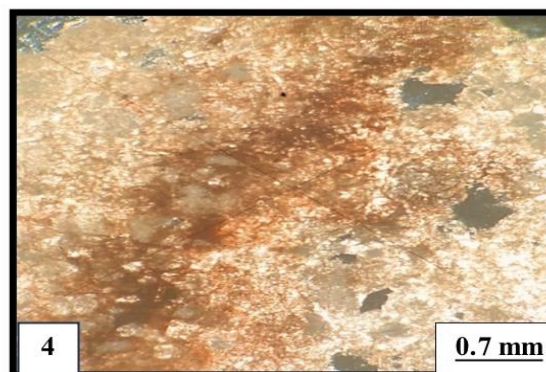
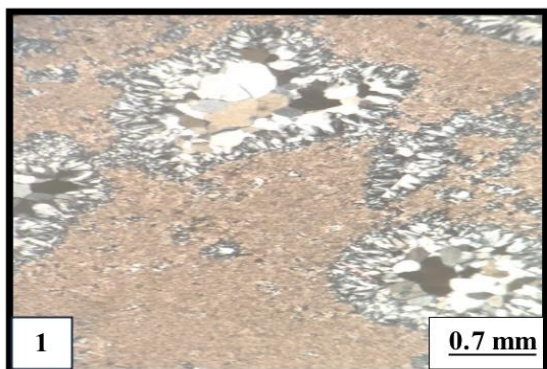


Plate G

1. **Stylolite of small amplitude**, Jeribe Formation, early middle Miocene, middle part of Gali Duhok section, sample No.8.
2. **Micrite envelope** (blue arrow) around the skeletal grain resulting from the micritization, peloid (green arrow), Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.4.
3. **Vuggy porosity** and intense micritization, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section, sample No.21.
4. **Green algae**, half of it has been cemented while the other half has been dissolved, within the groundmass affected highly by micritization, Jeribe Formation, early middle Miocene, middle of Gali Zakho section, sample No.21.
5. **Red algae** (referred by green arrow) within orthosparite groundmass (referred by blue arrow), intergranular porosity referred by orange arrow, Jeribe Formation, early middle Miocene, Gali Zakho section, sample No.12.
6. **Intraparticle porosity** in the *Textularia sp.* , Jeribe Formation, early middle Miocene, upper part of Gali Duhok section, sample No.24.
7. **Intercrystalline porosity** referred by blue arrow, Jeribe Formation, early middle Miocene, Gali Zakho section Sample. No. 16.
8. **Moldic porosity**, Jeribe Formation, early middle Miocene, middle part-A, sample No.13.

Plate G

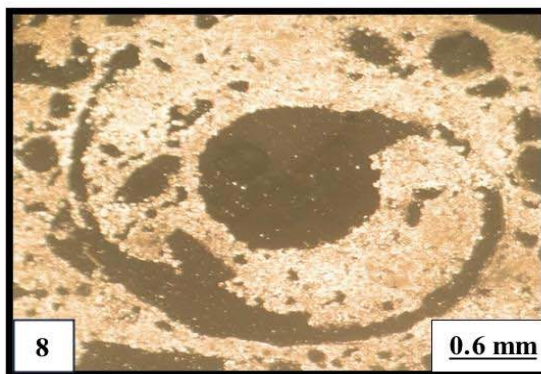
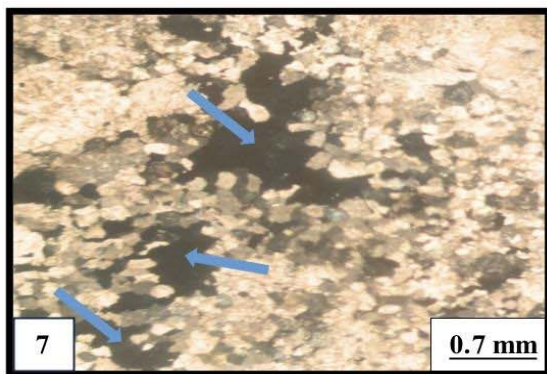
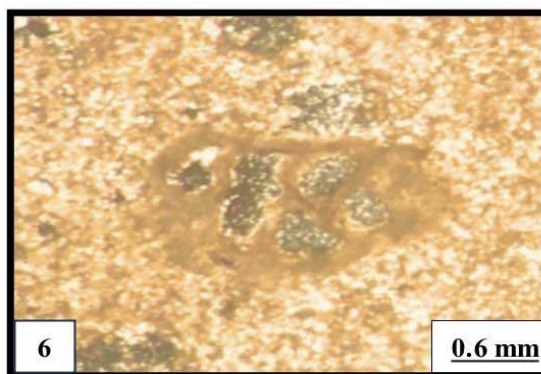
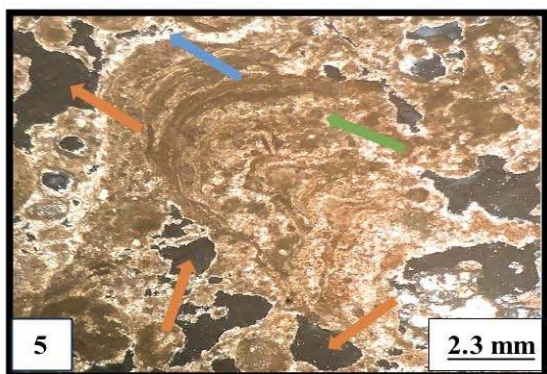
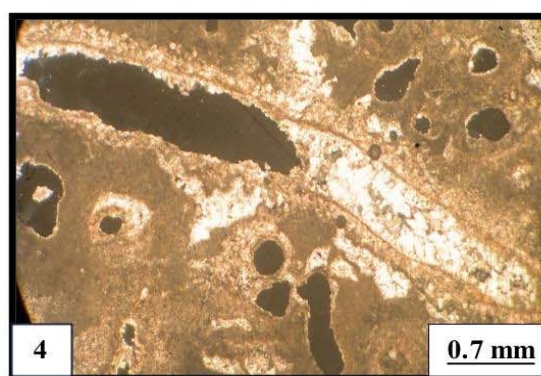
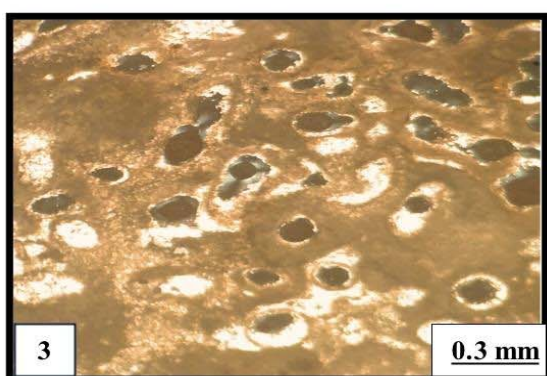
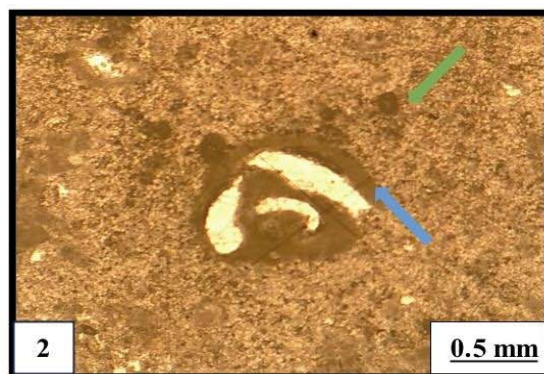
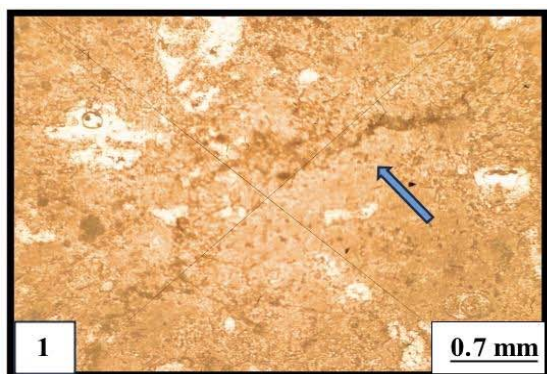


Plate H

- 1. Moldic porosity** (green arrow), Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.13.
- 2. Shelter porosity**(blue arrow) and vuggy porosity (green arrow), Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.11.
- 3. Vuggy porosity**, Jeribe Formation, early middle Miocene, middle part-B of Gali Zakho section, sample No. 15.
- 4. Cavern porosity**, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section, sample No.7.
- 5. channel porosity**, Jeribe Formation, early middle Miocene, lower part of Gali Zakho section. Sample No.1.
- 6. Fracture porosity**, Jeribe Formation, early middle Miocene, middle part-B of Gali Duhok section, sample.No18.
- 7. Miliolidal lime mudstone**, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section. Sample No.4.
- 8. Peloidal lime mudstone** showing fracture porosity (blue arrow), Jeribe Formation, early middle Miocene, Middle part-A of Gali Duhok section. Sample No.4.

Plate H

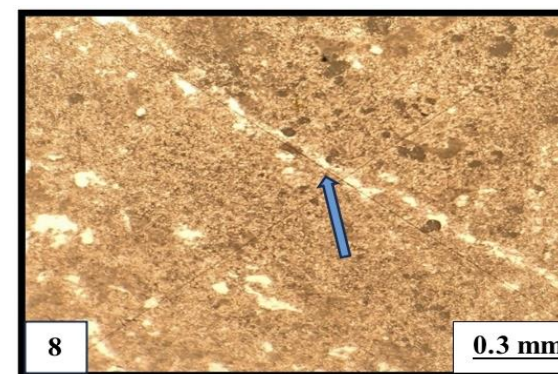
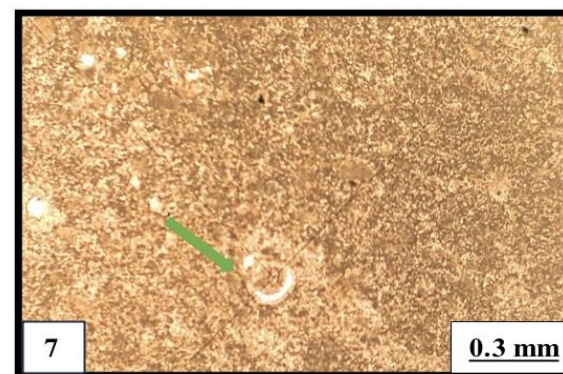
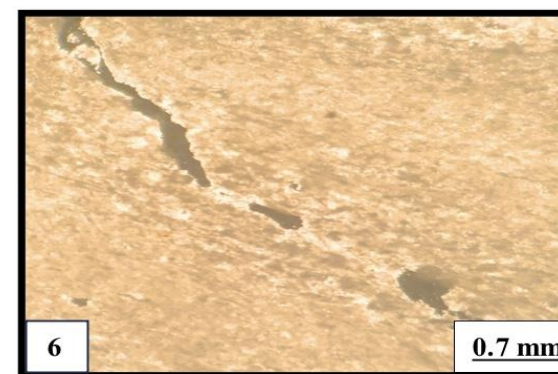
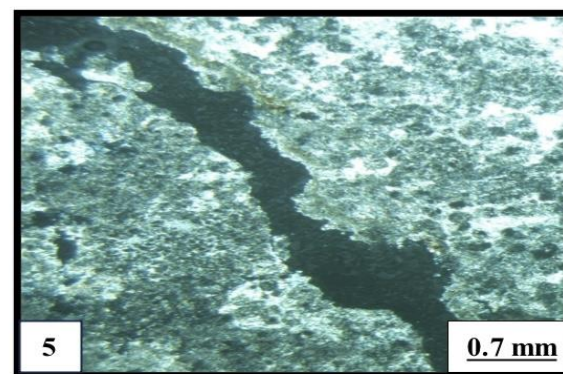
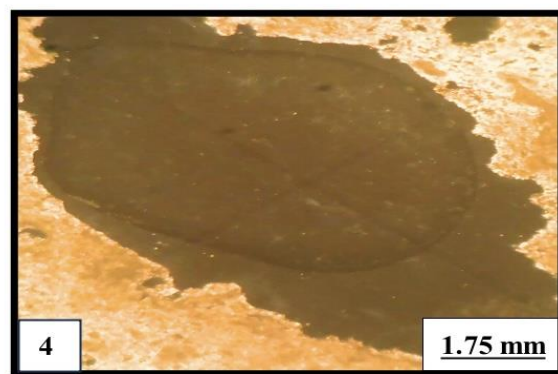
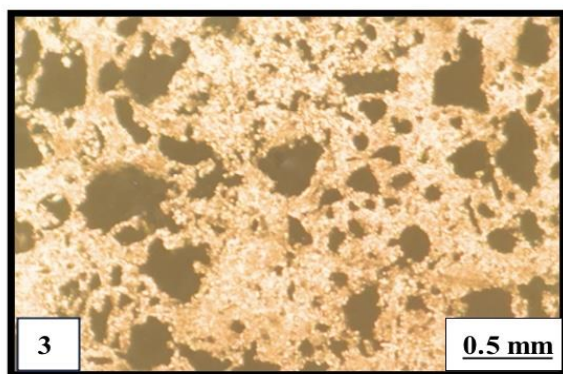
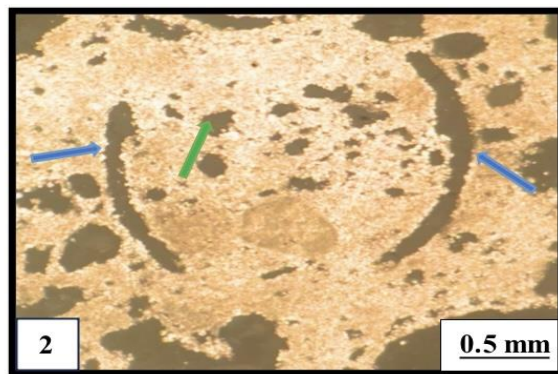
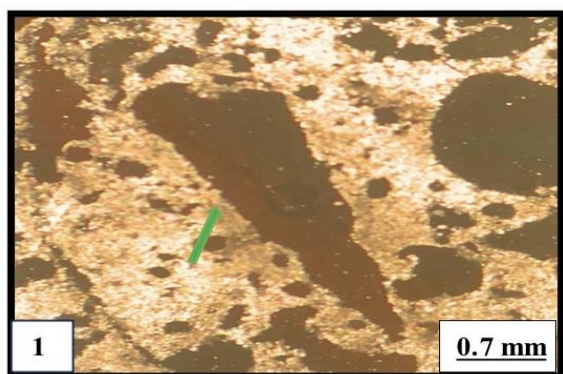


Plate I

1. **Mollusk lime mudstone**, cemented Pelecypoda shell indicated by blue arrow, Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section. Sample No.8.
2. **Miliolidal Peloidal lime wackstone**, it shows the effect of micritization and dissolution (vuggy porosity referred by blue arrow), Jeribe Formation, early middle Miocene, middle part-A of Gali Duhok section. Sample No.7.
3. **Peloidal lime wackstone**, Jeribe Formation, early middle Miocene, Middle part-A of Gali Duhok section. Sample No.4.
4. **Miliolidal lime packstone**, Jeribe Formation, early middle Miocene, Jeribe Formation, early middle Miocene, middle part-B of Gali Duhok section. Sample No.18.
5. **Miliolidal lime packstone**, which is highly affected by dolomitization and micritization processes, Jeribe Formation, early middle Miocene, lower part of Gali Zakho section. Sample No.5.
6. **Fossiliferous lime packstone**, Jeribe Formation, early middle Miocene, middle part-B of Gali Duhok section. Sample No.18.
7. **Fossiliferous lime packstone**, Jeribe Formation, early middle Miocene, middle part-B of Gali Duhok section. Sample No.18.
8. **Benthonic Foraminiferal lime grainstone**, grains are packed within orthosparite groundmass. The grains showing micrite envelop feature, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section. Sample No.27.

Plate I

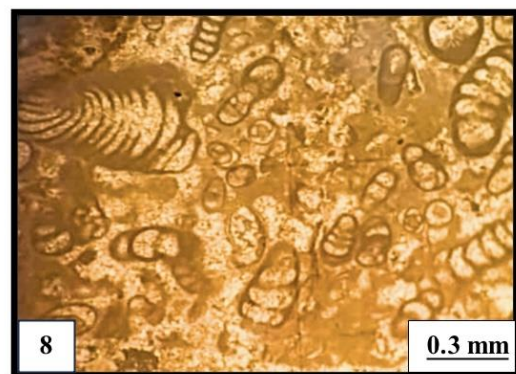
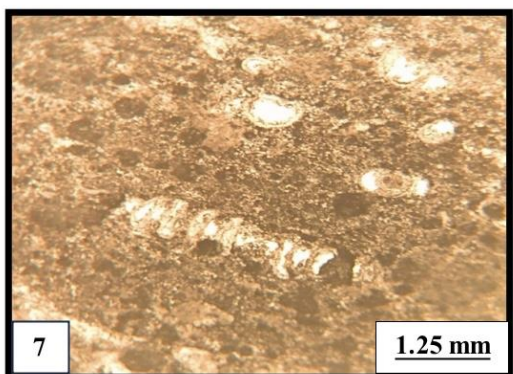
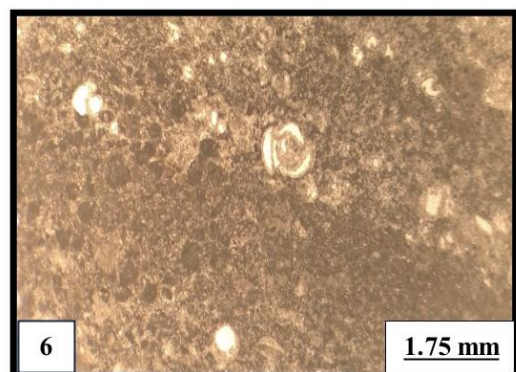
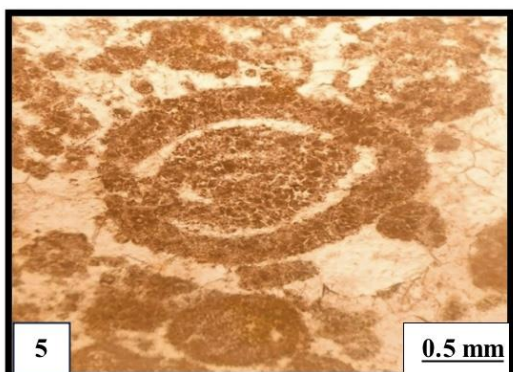
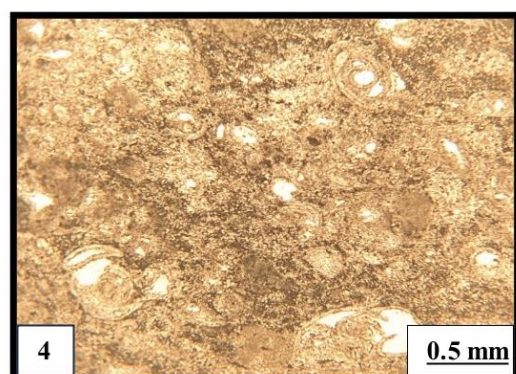
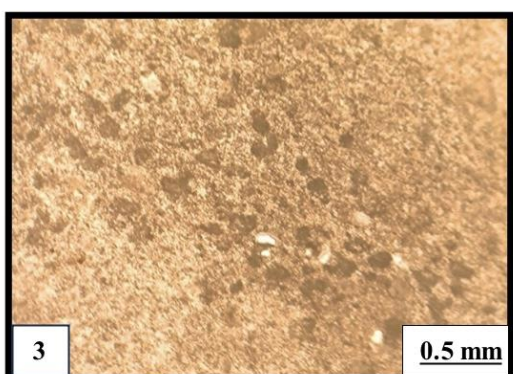
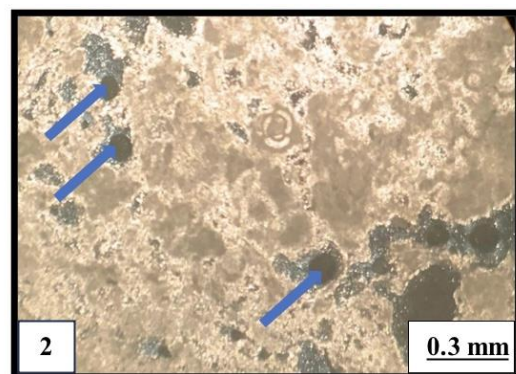
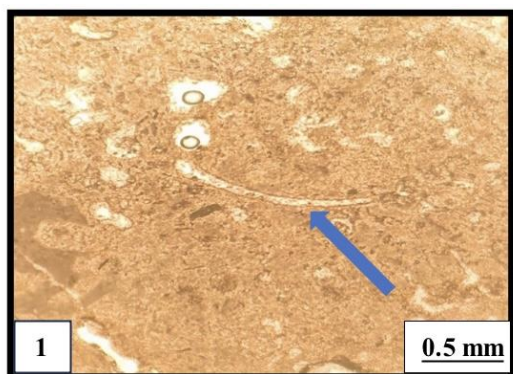


Plate J

1. **Benthonic Foraminiferal lime grainstone**, grains are packed within orthosparite groundmass, Jeribe Formation, early middle Miocene, upper part of Gali Zakho section. Sample No.27.
2. **Oncolitic lime grainstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.12. Under regular light.
3. **Oncolitic lime grainstone**, intergranular porosity referred by orange arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.12. Under polarised light.
4. **Fossiliferous lime grainstone** includes Pelecypod shell (indicated by blue arrow), miliolid shell (indicated by green arrow) and others within the groundmass of orthosparite referred by orange arrow . Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
5. **Fossiliferous lime grainstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section, Sample No. 30.
6. **Fossiliferous lime grainstone**, bioclast of *Archaias kirkukensis* sp., *Halimeda* sp. and Gastropoda referred by blue, green and orange arrow respectively. Grains are packed within orthosparite groundmass, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
7. **Green algal lime grainstone**, green algae referred by green arrow, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.15.
8. **Red algal lime grainstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.13.

Plate J

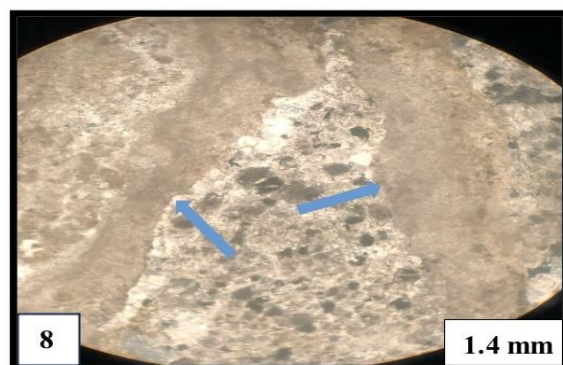
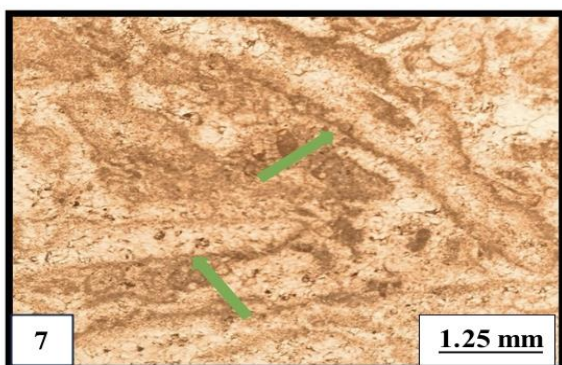
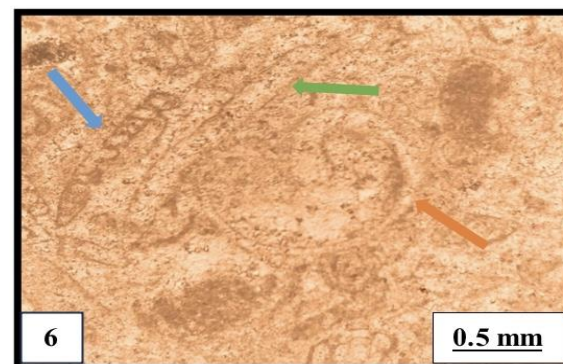
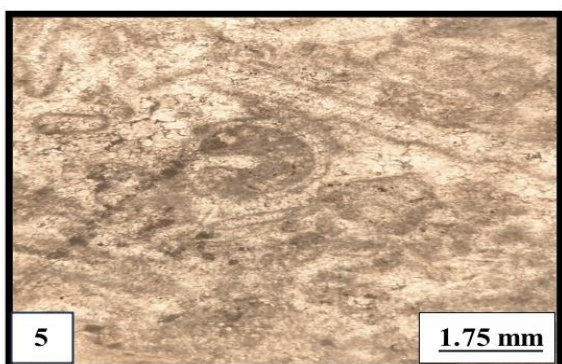
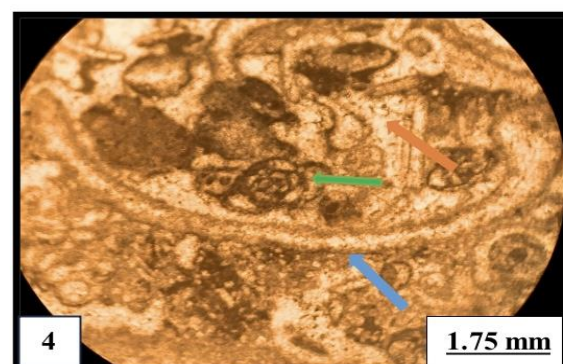
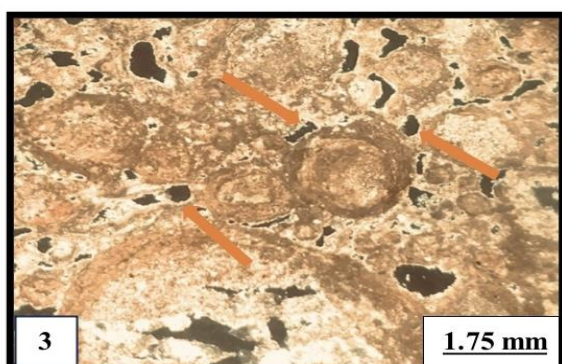
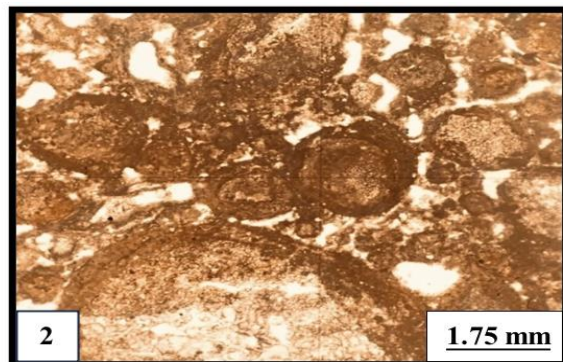
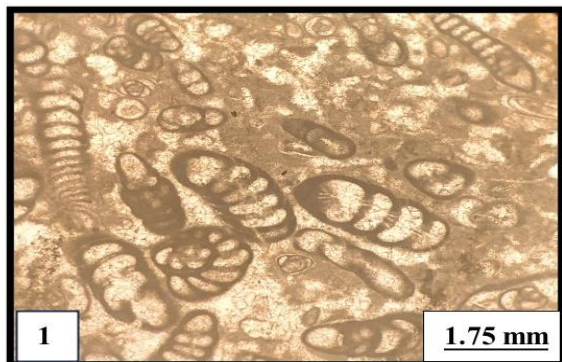
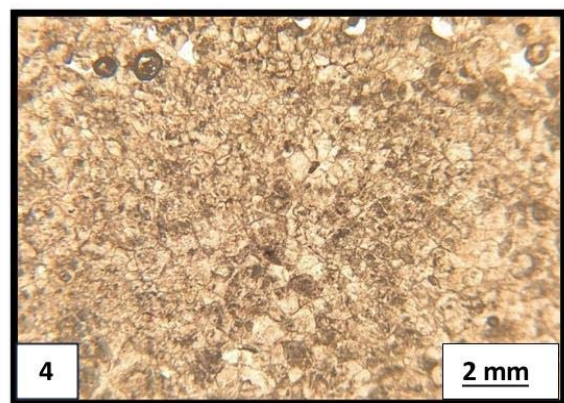
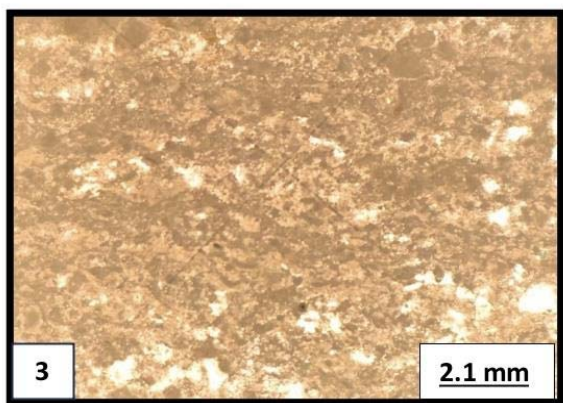
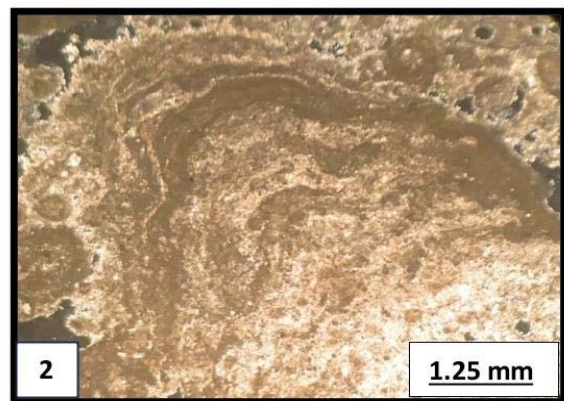
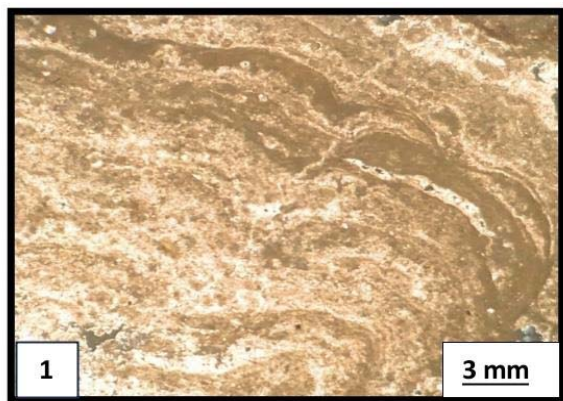


Plate K

- 1. Laminated Bindstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.12.
- 2. Laminated Bindstone**, Jeribe Formation, early middle Miocene, lower part of Gali Duhok section. Sample No.2.
- 3. Laminated Bindstone**, Jeribe Formation, early middle Miocene, middle part of Gali Zakho section. Sample No.12.
- 4. Crystalline, Jeribe Formation**, early middle Miocene, lower part of Gali Zakho section. Sample No.2.

Plate K



بالإضافة إلى ذلك، توجد الطحالب الخضراء من جنس (*Halimeda sp.*)، والرخويات الممثلة بـ (Pelecypod و Gastropoda)، والفتاتات العضوية التي تعود إلى الفورامينيفرا القاعية والطحالب. وأظهرت صخور التكوين تأثيراً بالعديد من العمليات التحويرية متمثلة بالاذابة والدلمة والسمنتة والمكرتة والتشكل الجديد.

سحناً، تميزت سحنات تكوين الجريبي بشيوع الدعم المكرايتي غالباً، وأحياناً السباري الحقيقي. تم تشخيص سبع سحنات رئيسة، وهي: سحنة الحجر الجيري الطيني، سحنة الحجر الجيري الواكي، سحنة الحجر الجيري المرصوص، سحنة الحجر الجيري الحبيبي، سحنة الحجر الجيري المترابط، سحنة الحجر الجيري الطافي، وسحنة الحجر الجيري المتبلور. وقد قسمت هذه السحنات بدورها إلى سبعة عشر سحنة ثانوية دقيقة. و أوضحت نتائج التحليل السحني أن التكوين ترسب في بيئة بحرية ضحلة متذبذبة مابين المحصورة الخلف حاجزية الى شعابية خصوصاً في مقطع گلي زاخو.

المُستخلص

دُرِسَتْ تتابعات تكوين الجريبي (المايوسين الأوسط المبكر) في مقطعين سطحين في محافظة دهوك شمال العراق. يقع المقطع الأول في غلي زاخو، بينما يقع المقطع الثاني في غلي دهوك. يتألف التكوين في مقطع غلي زاخو من (٧٧.٧م) من الحجر الجيري الدولومايتي، والحجر الجيري الطباشيري، والحجر الجيري. إمّا في مقطع غلي دهوك، فيتألف من (١٦٠.٥م) من الحجر الجيري، والحجر الجيري المارلي، والحجر الجيري الدولومايتي، والحجر الجيري الطباشيري، بالإضافة إلى طبقات رقيقة من الدولوميت متبادلة مع طبقات رقيقة من المارل، خصوصاً في أجزاءه السفلى. يحد التكوين من الأسفل في مقطع غلي زاخو تكوين ذبان الأنهايدرايتي بصورة غير متوافقة، بينما يحده من الأسفل في مقطع غلي دهوك تكوين پيلاسپي بصورة غير متوافقة أيضاً بوجود طبقة الأرض الصلبة المميزة بين التكوينين. أما الحد العلوي للتكوين في كلا المقطعين يكون مع تكوين فتحة ، إذ يكون متوافق تدريجياً في مقطع غلي دهوك، بينما يكون غير متوافق في مقطع غلي زاخو، حيث يفصل بينهما طبقة من الحصى العائدة لتكوين فتحة.

بتروغرافياً، تحوي صخور التكوين على أصداف متحجرات الفورامنيفرا القاعية، المتمثلة بأجناس المليوليد والروتاليد، مثل (*Quinquiloculina sp.*, *Triloculina sp.*, *Pyrgo sp.*, *evolute Peneroplis sp.*, *Borelis sp.*, *Rotalia sp.*, *Textularia sp.*, *Dendritina rangi d'Orbigns sp.*, *Idalina sp.* و الفتاتات العضوية العائدة ل *Archaia kirkukensis sp.*). كما تحتوي على الطحالب الحمراء، والتي تشمل نوع (branching crustose, coralline red algae nodules called rhodoids) و coralline red algae of *Lithophyllum sp.* و *Solenopora sp.* (red algae).



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نهايت جرجيس علي أحمد مزيري

إلى

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من متطلبات درجة الماجستير في اختصاص

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بإشراف

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