Scientific Journal for faculty of Science - Sirte University

ISSN: 2789-858X

Volume1 Issue No.1 October 2021

Bi-annual Peer-review Journal

Legal Deposit Number: 990/2021

sjsfsu@su.edu.ly
journal.su.edu.ly/index.php/JSFSU

Scientific Journal for the Faculty of Science-Sirte University Vol. 1, No. 1 October (2021) 24-31

Scientific Journal for the Faculty of Science-Sirte University
(SJFSSU)
Journal home page: http://journal.su.edu.ly/index.php/JSFSU/index

Microfacies Analysis, Diagenetic Aspects and Depositional Environments of the Oligocene-Miocene Rock Units Exposed at Al Bardia Coastal Area, North East Tobruk City, Libya

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ARTICLE INFO

Article history:

Received 16 August 2021

Received in revised form 30 sptemper 2021

Accepted 6 October 2021

Keywords:

Microfacies,

Wadi Shamas,

Wadi Rizk,

Al Khowaymat Formation ,

Al Faidiyah Formation,

Al Jaghbub Formation.

ABSTRACT

The Oligocene-Miocene carbonate succession exposed at Wadi Shamas and Wadi Rizk in the coastal area of Al Bardia was investigated to determine their depositional environments. This succession includes from base to top; Al Khowaymat, Al Faidiyah and Al Jaghbub Formation s. It was found that Al Khowaymat Formation is characterized by three microfacies associations (foraminiferal bioclastic(packstone, Wackestone and floatstone) rich with foraminifera and bivalves pointing to deposition within intertidal to lagoonal conditions related to regressed sea level with relatively high agitation due to the presence of bivalves and shell banks. Al Faidiyah Formation has three microfacies associations (packstone, floatstone and grainstone) rich in algae, bivalves, bryozoans and foraminifera indicating deposition in prograding advanced sea with deeper sub-environments from shallow energetic. Al Jaghbub Formation have four microfacies associations (packstone, floatstone, dolomitic wackestone and rudstone) rich with bryozoa, algae, bivalves and foraminifera, indicating deposition in tidal flats to mid ramp conditions. Micritization, dissolution and replacement are the main diagenetic processes affected the studied carbonate rocks.

1 Introduction

The study area lies within Al Bardia area, northeast Libya. It is the first sheet from east Libya contiguous to the Libyan Egyptian border (Fig, 1), lying between longitudes 24˚ 00′ and the Egyptian border nearly at 25˚ 00′ E and between latitudes 31˚ 00′ and the Mediterranean Sea nearly at 32˚ 00′ N. The area covers approximately 10,450 km2 (El-Deftar and Issawi, 1977).

As the authors aware, few authors study Oligocene-Miocene carbonate rocks at Al Bardia area (Annoscia 1968, Bellini 1969, Pietersz 1968, Imam 1999, El Safory and Muftah 2007, and Muftah et al., 2017).

This work aims to determine facies development, besides diagenetic and depositional environments of Al Khowaymat, Al Faidiyah, and Al Jaghbub formations. The study area located at the eastern border of the Al Bardia area encompassing two Wadis; Rizk and Shamas (Fig,2). The area was affected by post Miocene faulting. The two Wadis are located about 150 km from Tobruk city. The two Wadis are 3 Km apart. Based upon the detailed field study and facies characteristics, the different successions exposed are stratigraphically consisting from the base to top of the Al Khowaymat Formation, Al Faidiyah Formation and Al Jaghbub Formation ranging in age from Early Oligocene to Middle Miocene.

1 Materials and Methods

During field trips to the study area, two sections (Wadi Rizk and Wadi Shamas) were sampled and described bed by bed for each lithological changes and sedimentary structures. Thirty-five rock samples were collected according to their variations in color, texture, lithology, sedimentary structures and faunal content.

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DOI: https://doi.org/10.37375/sjfssu.v1i1.78 **SJFSSU 2021**

In addition, some macrofossils (bivalves, echinoderms) were collected. Twenty thin sections have been prepared and examined using the polarizing microscope to knom their texture, mineralogical components and faunal content. The depositional environments and subsequent diagenetic changes have been determined. Microfacies of limestone were named following the classification of Dunham (1962) with the modifications of Embry and Klovan (1971).

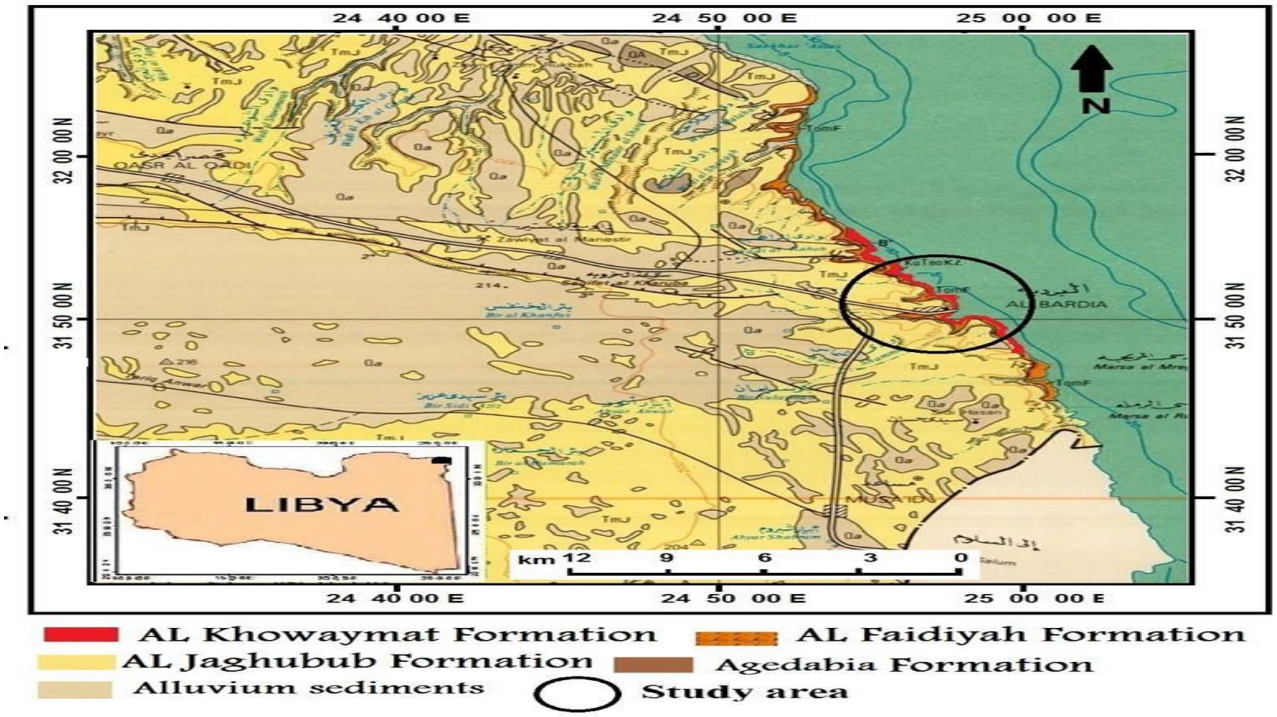

Fig. 1: Geological map of the Al Bardia area

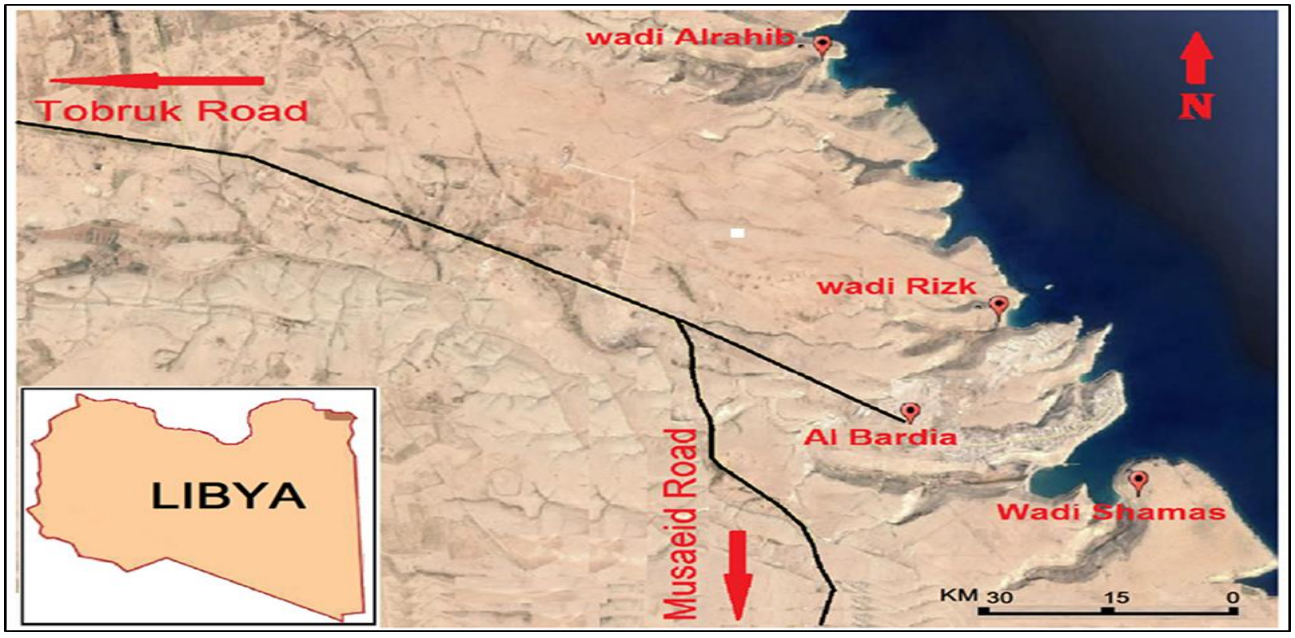

Fig.2. Landsat image showing the location of the studied Wadis Rizk and Shamas at the Al Bardia Area, northeast Libya.

2.1 Lithostratigraphy of the study area

The Al Khowymat Formation (Late Eocene-Early Oligocene) is the oldest rock unit in the study area and covers the northern part of it. It extended parallel to the Mediterranean Sea as a small strip west of the Al Bardia area (El Deftar and Issawi, 1977). This rock unit was originally described by Mazhar and lssawi (1977) in its type locality, Al Khowaymat village, a few kilometres southeast of Bir Habas. Its age was determined as Upper Eocene to Lower Oligocene with a thickness of 25 m.

The second Formation Al Faidiyah (Late Oligocene-Early Miocene) represents the oldest Miocene rock unit exposed in the study area. Pietersz (1968) is the first one who introduced the term Al Faidiyah Formation to describe calcareous rocks and shale that overlie the Shahat Formation in Al Jabal Al Akhdar area in its type section (Qaryat Al Faidiyah). Pietersz (1968) assigned this rock unit a Late Oligocene-Early Miocene age. The third Al Jaghbub Formation (Early-Middle Miocene) is represented by fossiliferous sandy to argillaceous limestone with subordinate calcareous shale. In the studied area, the Al Jaghbub Formation conformably overlies the Al Faidiyah Formation (Plate 1). The contact between the two formations occurs at the first appearance of carbonate or marl beds over the clay beds of the Al Faidiyah Formation (Fig.3,4)

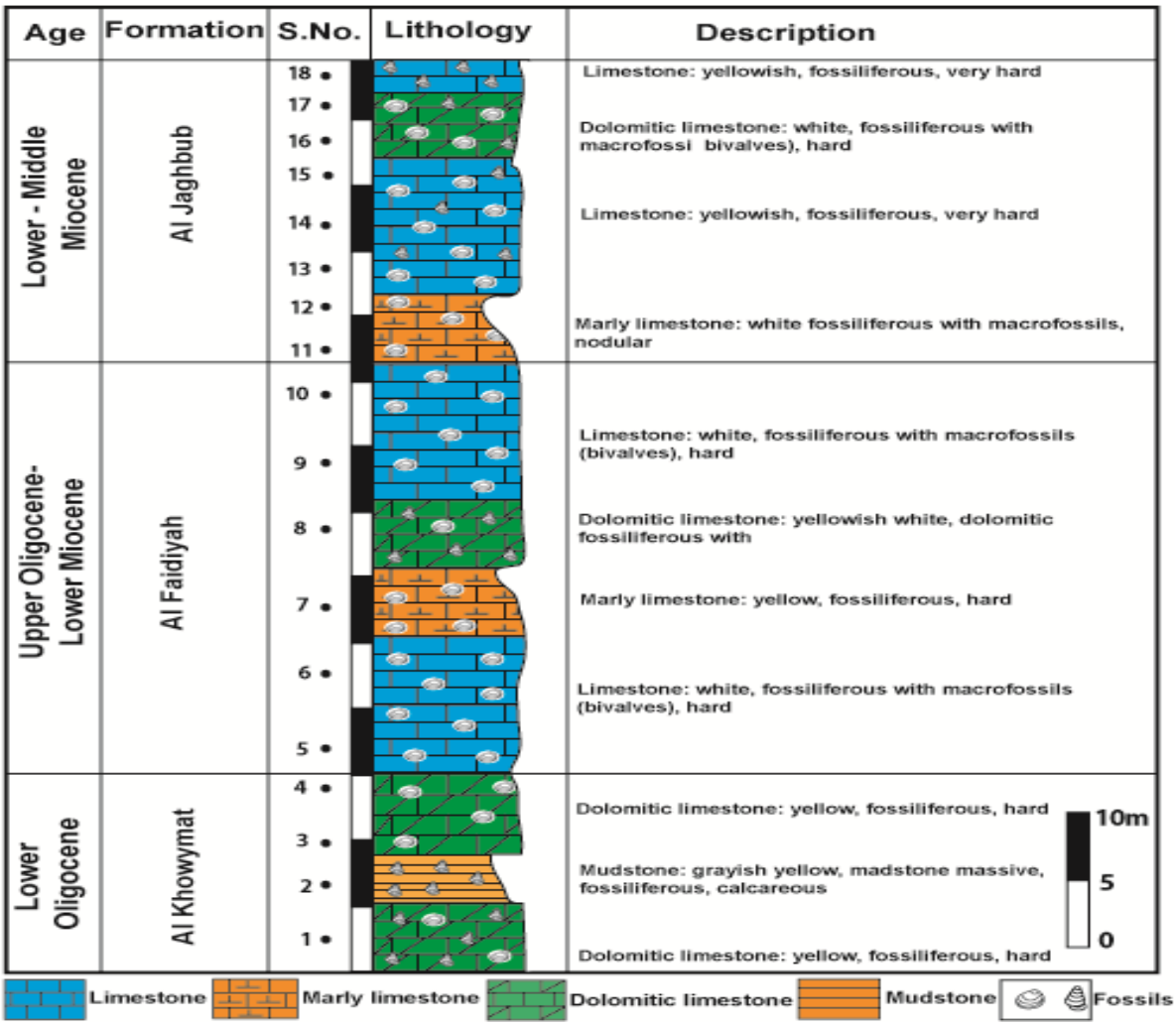

Fig.3: Lithostratighraphic column of the studied rock units at Wadi Rizk.

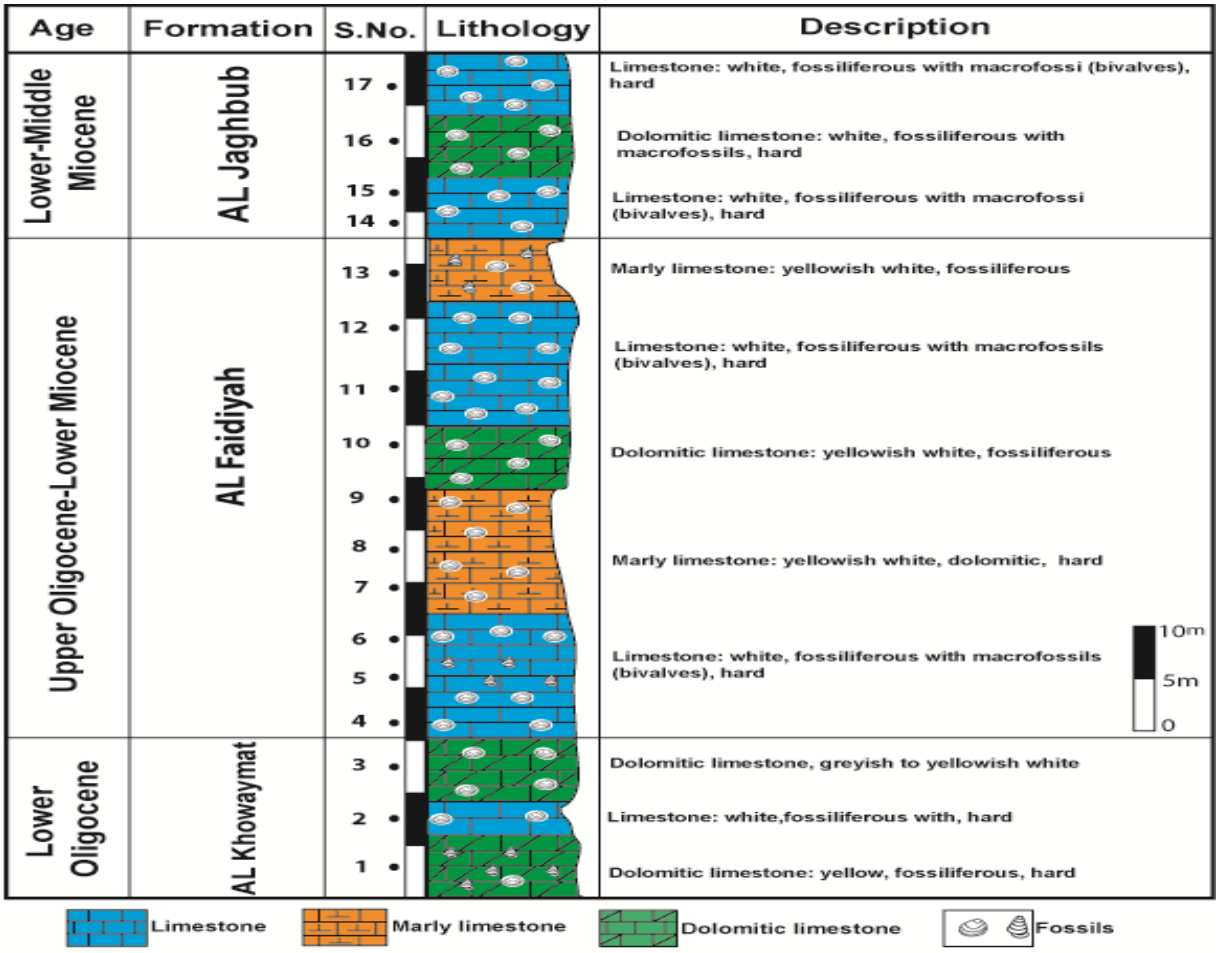

Fig.4: Lithostratighraphic column of the studied rock units at Wadi Shamas

3. Results

The common microfacies associations and their depositional environments prevailed during deposition of the Lower Oligocene and Lower-Middle Miocene rock units, exposed at Wadi Rizk and Wadi Shamas are determined. The analysis is complemented by comparison with both recent and ancient analogous carbonate systems. Diagenetic process was taken special attention utilizing comprehensive petrographic study.

1. Al Khowaymat Formation (Late Eocene-Early Oligocene.)

Five samples have been thin sectioned (three samples from Wadi Shams and two samples from Wadi Rizk) and studied under the polarizing microscope. The following microfacies types are recorded:

1.1 Foraminiferal bioclastic packstone (Wadi Shamas, Sample. No.1).

1.2 Bivalve bioclastic floatstone (Wadi Shamas, Sample. No3).

1.3 Pelagic foraminiferal wackstone (Wadi Rizk, Sample. No.2).

2. Al Faidiyah Formation (Late Oligocene-Early Miocene.

Eleven thin sections are examined in Al Faidiyah Formation (seven samples from Wadi Shmas and four samples from Wadi Rizk). The microfacies associations recognized are given below from bottom to top.

2.1 Bryozoa bioclastic packstone (Wadi Shamas, Sample. No.6).

2.2 Foraminiferal bioclastic floatstone (Wadi Shamas, Sample. No.9).

2.3 Algal foraminiferal bioclastic grainstone (Wadi Shamas, Sample. No.12).

2.4 Bivalve algal bioclastic grainstone (Wadi Rizk, 5).

***3. Al Jaghbub Formation (Early-Middle Miocene*).**

Twelve thin sections have been investigated from Wadi Shamas and Wadi Rizk to represent Al Jaghbub Formation.

The most common microfacies associations detected are summarized below, from bottom to top.

3.1Bryozoa algal rudstone (Wadi Shamas, Sample. No.14).

3.2 Dolomitized wackestone (Wadi Shamas, Sample. No.16).

3.3 Foraminifera bryozoa grainstone (Wadi Rizk, Sample. No.14).

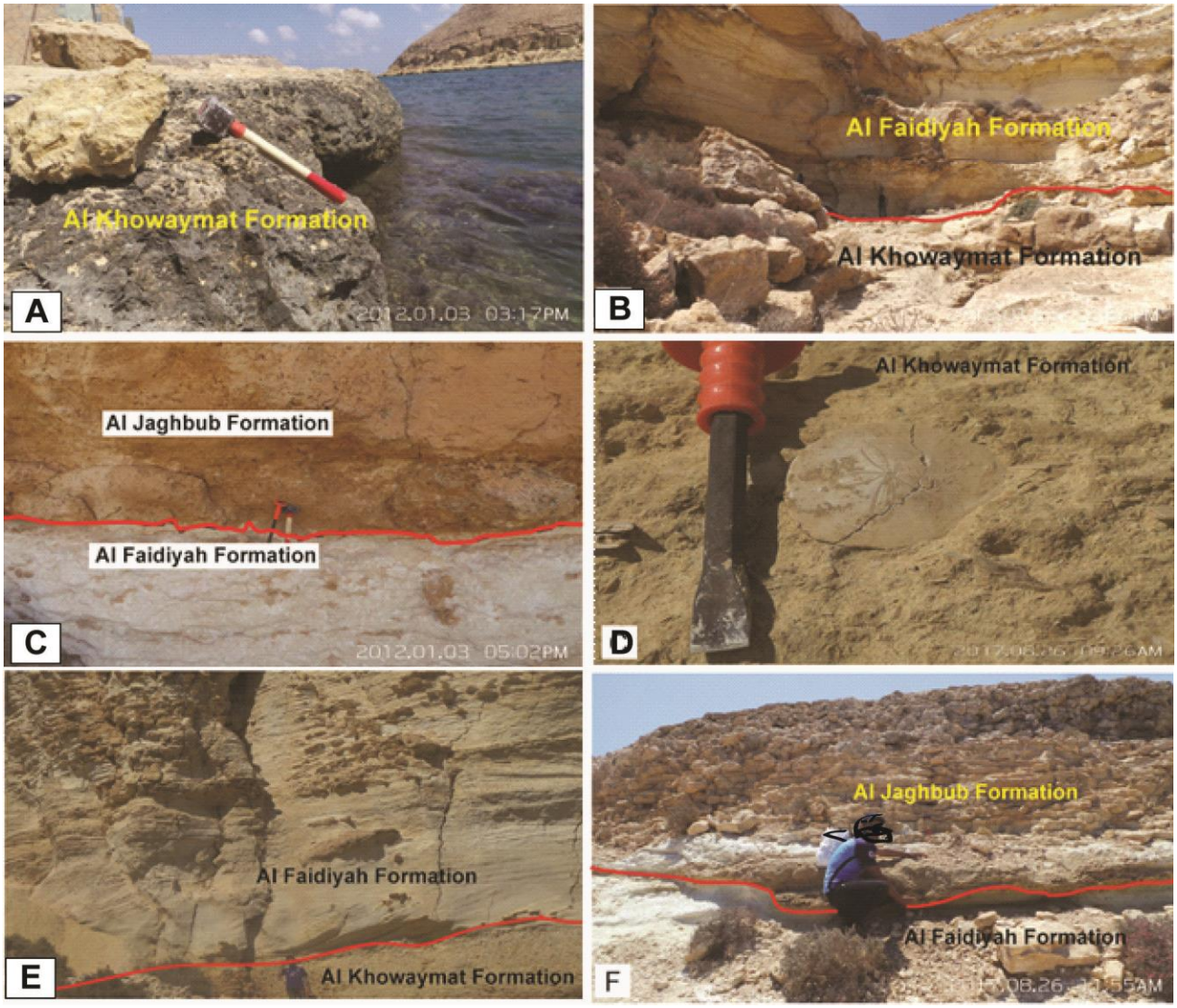

Plate 1: Field photographs showing: A) The upper part of the Al Khowaymat Formation at Wadi Shamas. composed mainly of dolomitic limestone. (Notice the color change of the lower part due to the action of seawater). B) The contact between the Al Khowaymat Formation and the Al Faidiyah Formation at Wadi Shamas. C) The contact between the Al Faidiyah Formation and the Al Jaghbub Formation at Wadi Shamas. D) Echinoderms in the Al Khowaymat Formation at Wadi Rizk. E) The contact between the Al Khowaymat Formation and the Al Faidiyah Formation at Wadi Rizk. F) The contact between the Al Faidiyah Formation and the Al Jaghbub Formation at Wadi Rizk.

4. Discussion

Microfacies associations recorded in Al Khowaymat Formation are discussed and their components are described and interpreted in the following:

Foraminiferal bioclastic packstone (Wadi Shamas, Sample. No.1) is composed of a framework micritized matrix. Allochems are tightly packed, grain supported sand to gravel-sized. They are represented by echinod spines, bryozoa, ostracods, foraminifera, bivalve fragments that cemented by mosaic sparry calcite. Echinod spines are circular or elliptical in cross-section with smaller broken fragments (Plate,2A). These recorded allochems are cemented by coarse grained, well crystallized dolomite mixed with mosaic calcite cement. Diagenesis is represented by dissolution of micritic matrix and large carbonate fragments that replaced by coarse grained sparry calcite. Due to the presences of ostracods, bryozoa, foraminifera, and bivalves, an intertidal foreshore to lagoonal setting is suggested for this microfacies. This association matches with SMF 12 and FZ 6 of Wilson (1975) and Flügel (2004).

Bivalve bioclastic floatstone (Wadi Shamas, Sample.No3) is represented by fossil debris of gravel-sized includes; ostracods, gastropods, bivalve fragments, echinoderms, bryozoa and algae floating in the micritic matrix. Sometimes allochems are cemented with drusy mosaic equant calcite crystals. Most of the internal cavities of the shells are entirely recrystallized into Sperry calcite with micritic envelope.
Diagenesis can be observed from dissolution of the carbonate mud matrix and recrystallization of medium to coarse sparry calcite surrounding the allochems. Most voids and fossil chambers show recrystallization of coarse spars. Most allochems suffered dissolution and recrystallization of spars with mosaic structure (Plate, 2B). Micritization process accompanied burial is noticed from assimilated most of the allochems boundaries which admixed into the matrix. The most common diagenetic feature is the, development of coarse-grained sparry mosaic calcite in some patches in the expense of micritic matrix. This association indicates deposition in relatively shallow marine energetic conditions with relatively high agitation (inner shelf bays). This microfacies is matching well with SMF8 and FZ7 of Wilson (1975) and Flügel (2004).

Pelagic foraminiferal wackstone (Wadi Rizk, Sample. No.2) is composed mainly of cryptocrystalline carbonate (micrite) matrix enriched with allochems. Allochems are represented by well-defined scattered pelagic foraminiferal, curved bivalves and echinoderms, ostracods, algae, and bryozoa floating within the matrix (Plate, 2C) Diagenesis process accompanied burial has noticed from sparitization of most foraminiferal chambers. Deposition of this microfacies was prevailed within relatively quiet less energetic marine conditions; mid to outer shelf setting is suggested. This association is concordant with SMF9 and FZ7 of Wilson (1975) and Flügel (2004). While the microfacies detected in Al Faidiyah Formation include the following associations; Bryozoa bioclastic packstone(Wadi Shamas, Sample. No.6) where allochems are represented mostly by numerous altered bryozoa, echinoderms, bivalves and foraminifera that embedded in a cryptocrystalline carbonate matrix. Some fossils stained with iron (Plate,2D). Diagenetic alterations in this microfacies are represented by dissolution and replacement with sparry calcite crystals that filled most foraminiferal chambers. This facies was deposited in quiet less energetic marine conditions. Mid to outer shelf marine setting is suggested for this microfacies. This association matches with (SMF3) and (FZ1) of Wilson (1975) and Flügel (2004).
Foraminiferal bioclastic floatstone **(Wadi Shamas, Sample. No.9),** this microfacies is made up of echinoderms, nummulites, gastropods, bivalve fragments, bryozoa and algae. The internal cavities of the shells are entirely recrystallized into coarse crystalline sparry calcite (Plate 2E). Diagenesis in this microfacies are represented by dissolution, recrystallization and dolomitization. This microfacies indicates deposition in relatively energetic shallow marine conditions (inner shelf bays. This microfacies is matching with SMF8 and FZ7 of Wilson (1975) and Flügel (2004).

Algal foraminiferal bioclastic grainstone **(Wadi Shamas, Sample. No.12),** consists of numerous allochems and coarse sparry calcite. The allochems are generally represented by bryozoa, bivalves (oyster), gastropods, coralline red algae, echinoderms and foraminifera (Plate, 2F). The internal cavity of the shells is entirely recrystallized into, mosaic coarse crystalline calcite. The cement is coarse to medium sparite filled pore spaces and partly filled shell cavities.

Bivalve algal bioclastic grainstone **(Wadi Rizk, Sample No.5)** consists of numerous allochems and coarse interlocking mosaic of sparry calcite. The allochems are represented by bivalve fragments, coralline red algae, bryozoa, ostracods that cemented with sparry calcite (Plate, 3A). The internal cavity of the shells is entirely filled with coarse crystalline calcite mosaic, indicating active recrystallization process during burial process. The cement is coarse to medium sparite filled pore spaces and partly filled cavities of most shells. Diagenesis is evident from recrystallization features seen in the sparite cement and partially to complete replacement of the allochems.
Microfacies associations recorded in Al Jaghbub Formation (Early-Middle Miocene) Formation are discussed and their components are described and interpreted in the fol

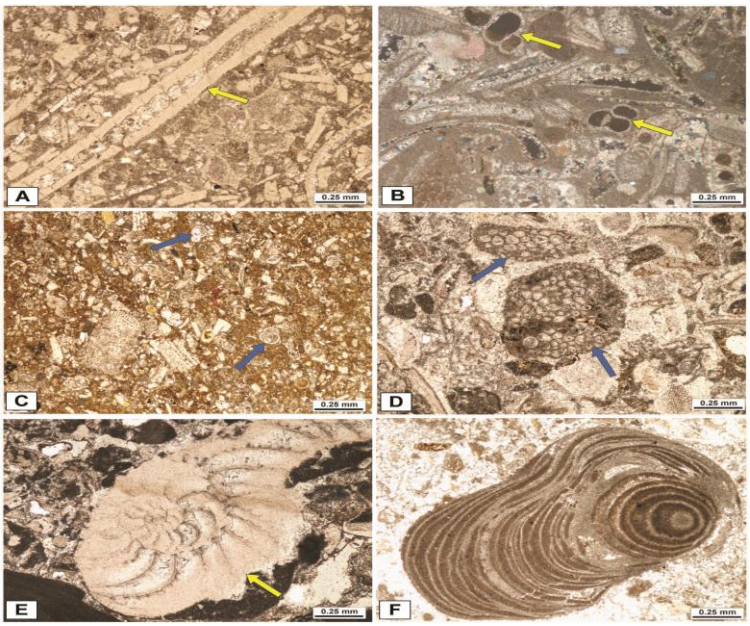

Plate 2: Photomicrographs showing: A) Foraminiferal bioclastic packstone microfacies. Al Khowaymat Formation, S. No. 1,Wadi Shamas PPL. B) Bivalve bioclastic floatstone microfacies. Bivalve fragments and gastropods (arrows) are scattered in a micritc matrix, Al Khowaymat Formation, S. No. 3, Wadi Shamas XPL, C) Pelagic foraminiferal wackestone microfacies. Planktonic foraminifera are abundant, Al Khowaymat Formation, S. No. 3,Wadi Rizk PPL. D) Bryozoa bioclastic packstone microfacies, Al Faidiyah Formation, S. No. 5, Wadi Shamas PPL. E) Algal foraminiferal packstone/floatstone microfacies. The bivalve fragments are recorded with its large size, Al Faidiyah Formation, S. No. 9, Wadi Shamas PPL. F) Algal foraminiferal bioclastic grainstone microfacies, Al Faidiyah Formation, S. No. 10, Wadi Shamas PPL

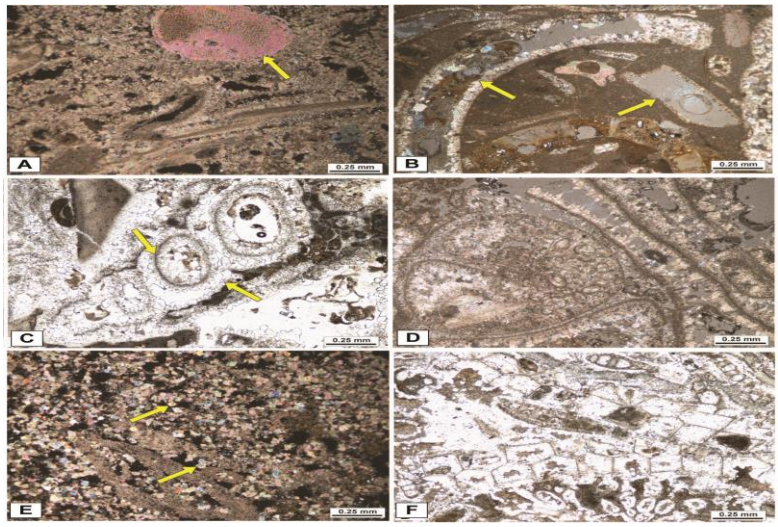

Plate 3: Photomicrographs showing: A) bivalve algal bioclastic grainstone microfaces. Echinoderm plates are recorded (arrow), Al Faidiyah Formation, S. No. 5 new, Wadi Rizk XPL. B) Bivalve bryozoan floatstone microfacies. Bivalve fragments are encountered and filled with drusy calcite (arrows), Al Faidiyah Formation, XPL, S. No. 9, Wadi Rizk. C) Bivalve grainstone microfacies. Gastropods are abundant (arrows), Al Faidiyah Formation PPL, S. No. 10, Wadi Rizk. D) bryozoa algal rudstone microfacies, Al Jaghbub Formation, S.No. 15,Wadi Shamas (XPL). E) dolomitized wackestone microfacies. Dolomite rhombs (arrows) are observed in the groundmass, Al Jaghbub Formation, S.No. 15,Wadi Shamas XPL. F) Foraminifera bryozoa grainstone microfacies, Al Jaghbub Formation, S. No. 11, Wadi Rizk PPL.

5. Conclusion

The paleoenvironmental conditions deduced from the microfacies associations identified in the Early Oligocene - Middle Miocene sedimentary rock units allow for recognizing different depositional environments. Three microfacies associations are exhibited by Al Khowaymat Formation; these are foraminiferal bioclastic packstone, foraminiferal bioclastic wackestone and bivalve bioclastic floatstone indicating deposition within intertidal to shelf lagoon conditions related to regressed sea level to shallow energetic marine conditions with relatively high agitation due to the presence of bivalves and shell banks.

The Al Faidiyah Formation reveals three microfacies associations varied between packstone, floatstone and grainstone rich with algae, bivalves, bryozoans and foraminifera indicating deposition in continuous sea level rise from shallow energetic marine conditions to mid - outer shelf marine settings. The Al Jaghbub Formation offered four

microfacies associations includes, packstone, floatstone, dolomitic wackstone and rudstone enriched with bryozoa, algae, bivalves and foraminifera indicating deposition started during a stable phase of maximum sea level rise during inner shelf marine setting with minor shallow marine fluctuations where a marked sea level drop and shallow intertidal and supratidal warm coastal sedimentation occurred.

Conflict of interest: The authors declare that there are no conflicts of interest.

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