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Original article

Microfacies Analysis and Depositional Environment of the Middle-Late Oligocene Al Abraq Formation, N Cyrenaica Promontory, Northeast Libya

Akram Zafir*, Ahmed Abuharara, Ayman Nassar

Department of Geology, Faculty of Science, Omar Al-Mukhtar University, Al Bayda, Libya

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Corresponding Email. akram.zafir@omu.edu.ly
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ABSTRACT

Aims*. The present study reports the depositional processes and environment of the Middle-Late Oligocene Al Abraq Formation in northeast Libya.* ***Methods****. This study provides a detailed facies analysis to precisely interpret the paleoenvironmental context during their deposition, through out three measured sections located in N Cyrenaica Promontory.* ***Results****. Five distinct microfacies were defined based on variations in lithology, fossil content, grain composition, sedimentary texture, color, and lateral and vertical changes. Al Abraq Formation is mainly composed of yellowish white, soft to moderately hard limestone. The microfacies analysis of the studied carbonate rocks (Al Abraq Formation) enables determination of three shallow-marine carbonate facies associations: restricted a lagoon, open marine, and slope. The restricted lagoon consists mainly of foraminifera, algae, and gastropods, which indicates shallow open-marine environment above fair-weather wave base. The open marine characterized by accumulation of large quantities of glauconite which has microfossils' record that represented by gastropods, foraminifera, and echinoderms. The slope facies association consists of high percentages of larger foraminifera and some of these particles are echinoderm fragments and algae that may have formed in the upper part of the slope where the reworking of sediments by currents or storms is high.* ***Conclusion****. Microfacies of the Al Abraq Formation exhibits biotic elements that indicate shallow open shelf settings.*

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INTRODUCTION

Al Abraq Formation has been defined for the first time after the village of Al Abraq by [1]. It is disconformably underlain by the Al Bayda Formation and overlain by the Al Faidiyah Formation. This formation consists of yellowish white, soft to moderately hard limestone which partly comprises of calcarenitic to calcilutitic, as well as moderately dolomitic limestones, dolomites, and marls [1]. The microfossils' record is represented by common foraminifera *Nummulite fichtelli*, *Lepidocyclina*, and *Operculinaafricanus*. Moreover, the oysters, echinoderms, and burrowings are also present [2]. The *Nummulites* debris (broken *Nummulite* tests of partial to considerable damage) in the upper part of the formation is considered to be the result of reworking process. In fact, there is a similar lithology and biota appearance that can be clearly recognized at the Wadi Al Kuf section, although the latter also yields abundant small-sized *Nummulites viscous*. All the three studied sections (Shahat, Wadi Al Kuf, and Omar Al Mukhtar) show a shallowing-up trend in Al Abraq Formation. It is suggested by the dominance of siliciclastic components in the upper part, which are associated with a common assemblage of small thick *Operculinacomplanata* and gradual disappearance of the large and flat *Operculinids*. Other evidence is resulting from the marly limestone at the base of the formation, which bring in a considerably diverse foraminiferal assemblage of open circulation and muddy substrates. Al Abraq Formation is attributed to the transgressive global fourth-order Cycle TA4.5. The upper depositionally shallow part is ascribed to the regressive Cycle TB1.1 [3]. The recovery live cycle of N. *fichteli* from the lower part of this formation indicates Early Oligocene age, whereas the upper part is assigned to the Late Oligocene, that is based on the disappearance of in-situ *N. fichteli* and the appearance of *Operculinacomplanata*.

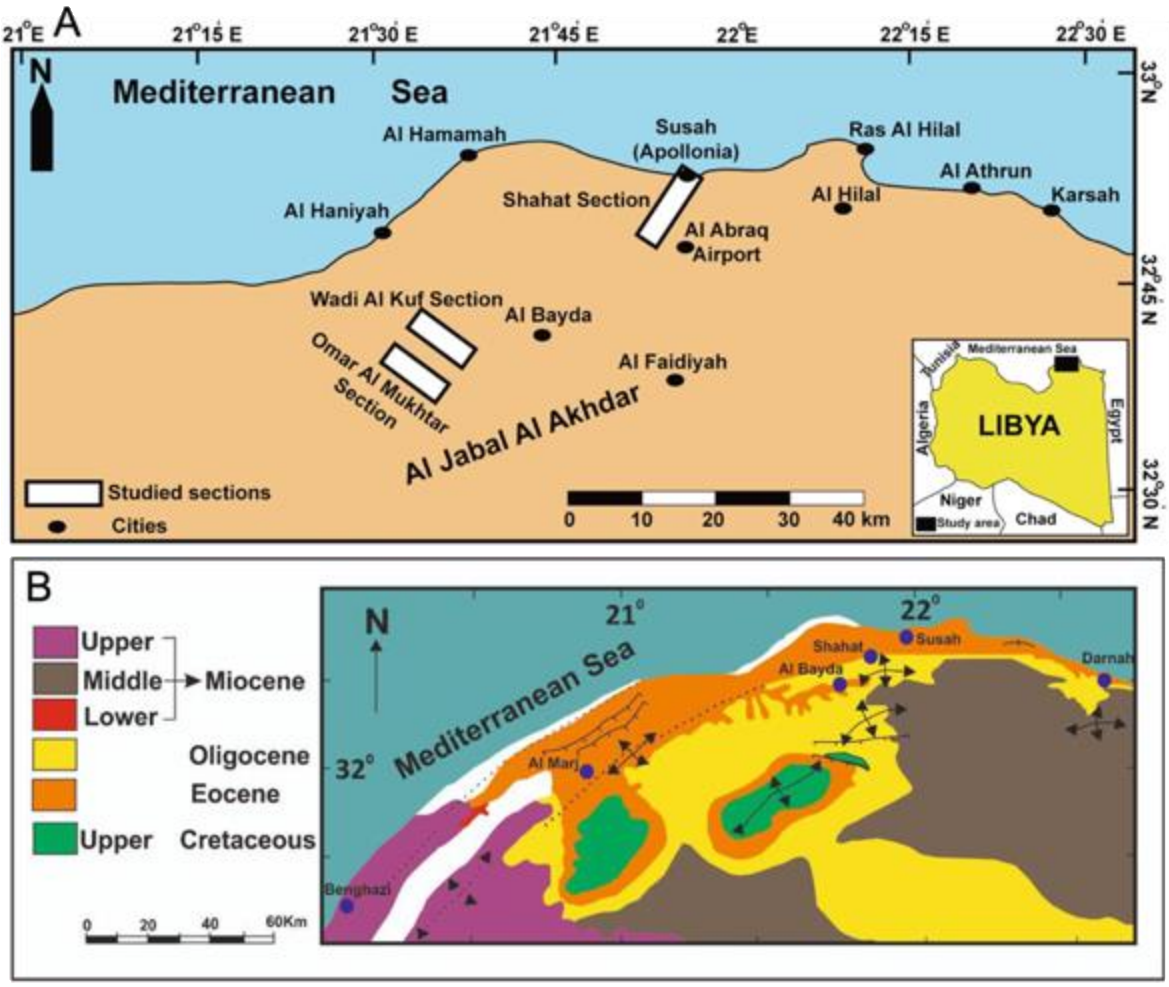

Fig 1. A- Location map of northeast Libya including the three studied sections; the location of Libya and the study area is given in inset map. B- Geological and tectonic map of Cyrenaica Promontory.

Regional Tectonic Setting and Stratigraphy

The study area is situated in north Cyrenaica Promontory in northeast Libya (Fig. 1). The Cyrenaica Promontory extends over an area of ~150.000 km^2 and consists of two major tectonic provinces separated by the Cyrenaican Fault System. Those are the Cyrenaica Platform in the south and the Al Jabal Al Akhdar in the north [4]. It is thought that the Al Jabal Al Akhdar is an inverted basin developed as a result of a dextral contractional duplex bounded by the north Cyrenaica, Cyrenaica and southern Cyrenaica dextral wrench fault systems [5]. The Cyrenaica platform formed on a splay wedge and bounded by the Al Jaghbub High to the south.

The sedimentary strata of Cyrenaica Platform have a maximum thickness of about 12000 m and unconformably overlies the Precambrian basement. It contains Paleozoic to Lower Cretaceous siliciclastic deposits accumulated in the pre-inversion phase, and Upper Cretaceous-Oligocene marine shale and shallow-water carbonates sediments (Fig. 2). The Tertiary sediments are predominantly carbonate sediments of various depositional settings developed on shallow-water detached and attached platforms.

This study aims to interpret the depositional environment of the Al Abraq Formation using detailed microfacies analysis from three measured sections located in Al Jabal Al Akhdar region. This study provides insights on the deposition of carbonate facies on carbonate platforms and can be compared to similar facies worldwide.

METHODS

Study design and setting

Fieldwork observations and detailed studies were carried out to interpret the depositional processes and environment of the Al Abraq Formation in N Cyrenaica Promontory, northeast Libya. Two field trips were done at the exposed outcrops, measuring and describing lithology, grain composition, fossil content, texture, color, thickness, vertical and lateral facies changes and recording information about the surface boundary between the rock units.

Data collection procedure

Eight rock samples were collected from three sections: Shahat (Fig. 3), Wadi Al Kuf (Fig. 4), and Omar Al Mukhtar (Fig. 5). Sample collection is based on the lithological variation, texture, fossil content, color, and grain size. The color was described using the Munsell color system. Eight rock samples were collected from the three sections for detailed laboratory description and analysis. Laboratory work including the preparation and description of Eight thin sections for petrography and microfacies study.

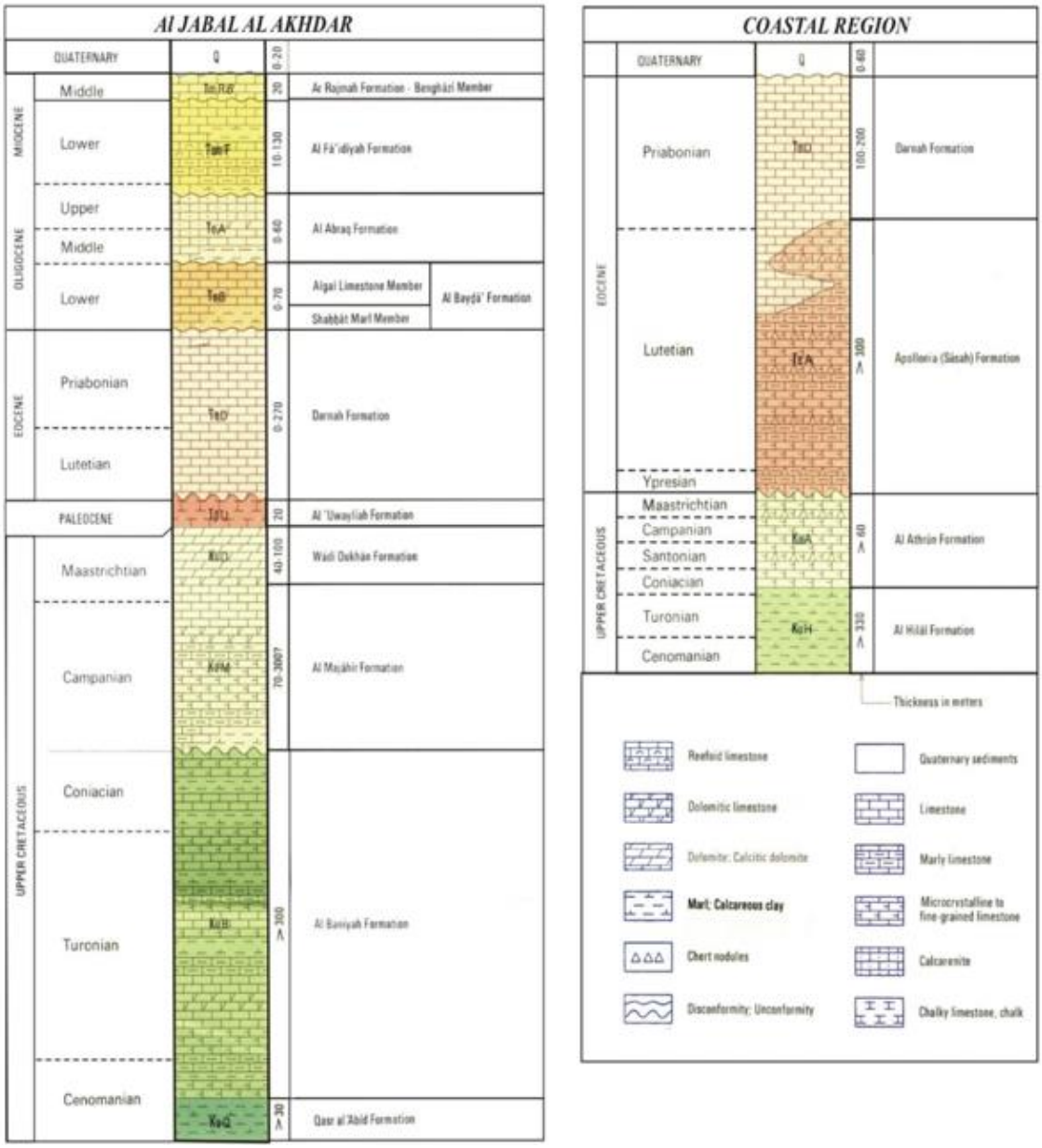

Fig. 2. Litho- and chronostratigraphy of the study area in Al Jabal Al Akhdar district and coastal region in Cyrenaica Promontory, northeast Libya [6]. The focus interval is from Middle to Upper Oligocene.

RESULTS

Microfacies analysis

In this section, we describe the microfacies associations prevailed during the Middle-late Oligocene time. Microfacies analysis is very important in determining the depositional environments and the consequences of digenetic changes. The microfacies classification follows the standard nomenclatures of carbonates developed [7]. Also, the modification reported by previous study is used to describe some microfacies that contain some components that have a larger than 2mm size [8].

Micro Facies 1 (MF1): Bioclastic packstone

This microfaciesis recognized in the Al Abraq of Shahat section (Fig. 3). Abundant allochems represented by different types of foraminifera, echinoderm spines, algae and bivalve fragments that are cemented by micrite (Fig. 6 A and B). The presence of algae indicates very shallow, warm, normal marine depositional environment and a mobile and unstable substrate with redistribution of grains by waves and currents [9]. This microfacies is similar to SMF8 and FZ6 [10,11].

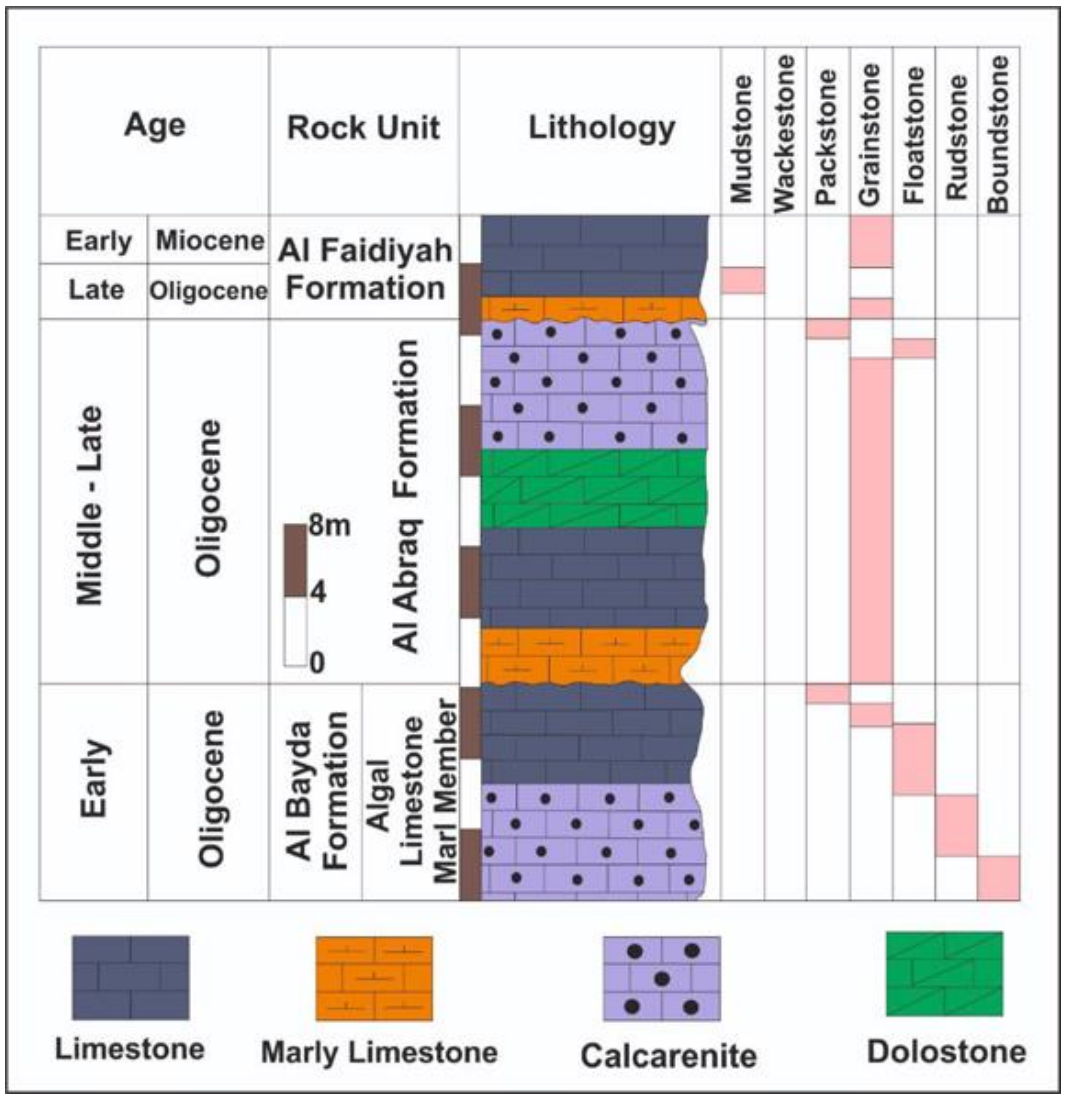

Fig 3. Geological description of Shahat section. The section is about 32 m thick and was divided into several distinct lithofacies based on variations in lithology, grain composition, fossil content, texture, color, and stacking pattern. The Al Abraq Formation, the focus of this study, is bounded below by the Al Bayda Formation and above by Al Faidiyah Formation.

Microfacies 2 (MF2): Bioclastic grainstone

This microfacies is recorded in the Al Abraq of Shahat section (Fig. 3). It displays grain-supported fabric with common grain-in-contact. Most intergranular pores are filled with calcite cement. Allochemical components of this microfacies are composed mainly of foraminifera, algae, gastropods, and echinoderms (Fig. 6 E and F). This microfacies is deposited in fore-reef position and reef slopes, or in back-reef settings and in lagoons. Earlier study reported that this microfacies was deposited in shallow open-marine environment above fair-weather wave base [4]. The microfaciesis is similar to SMF5 and FZ4 [10, 11].

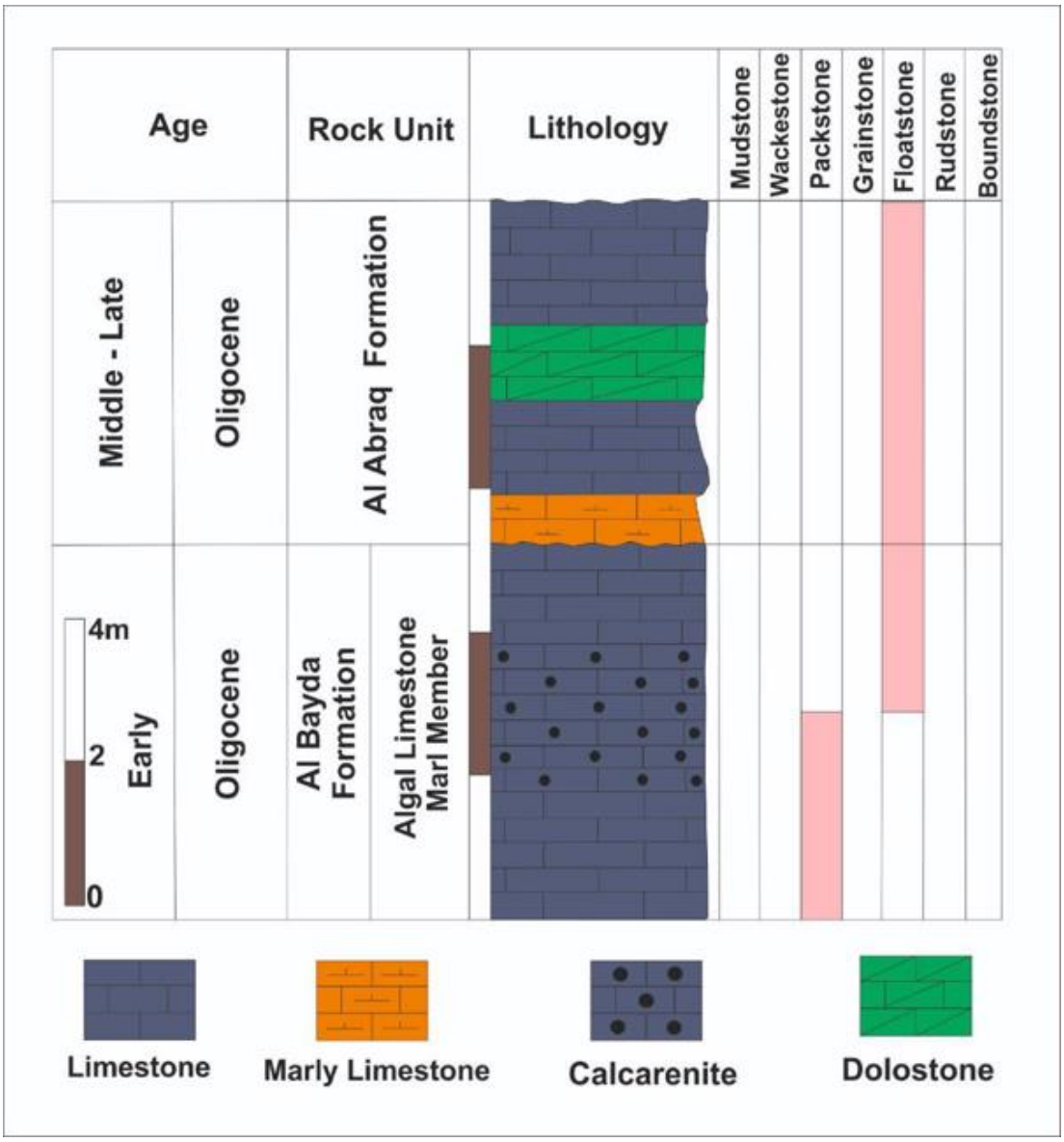

Fig 4. Wadi Al Kuf measured section. The section is about 10 m thick. The Al Abraq Formation here is entirely exposed and bounded at the base by the Al Bayda Formation.

Microfacies 3 (MF3): Echinoderm foraminifera grainstone

This microfaciesis recognized in the Al Abraq Formations of Shahat section (Fig. 3). Abundant allochems are represented by different types of foraminifera, echinoderm spines, algae and bivalve fragments that are cemented by a sparry mosaic calcite (Fig. 6 E and F). Considering the microfacies texture (dominance of bioclasts and low abundance of micrite), this microfacies was deposited in the high energy settings. It is probably accumulated in bioclastic shoals, as longitudinal bodiesparallel to the shoreline, situated over the ramp margin. This microfacies is similar to SMF18 and FZ8 [10, 11].

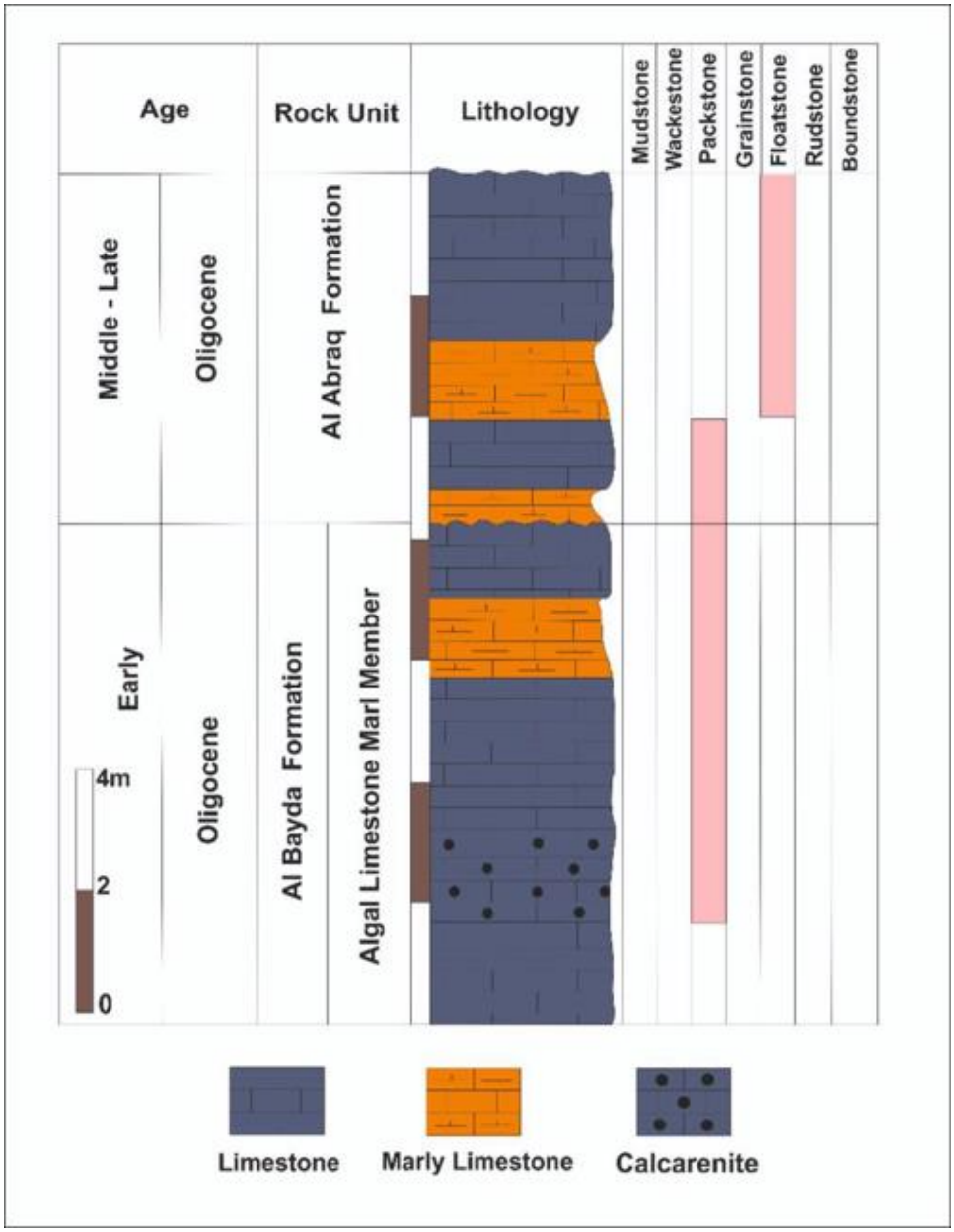

Fig 5. Omar Al Mukhtar measured section. The section is about 14 m thick. Similar to Wadi Al Kuf section, the Al Abraq Formation here is entirely exposed and bounded at the base by the Al Bayda Formation.

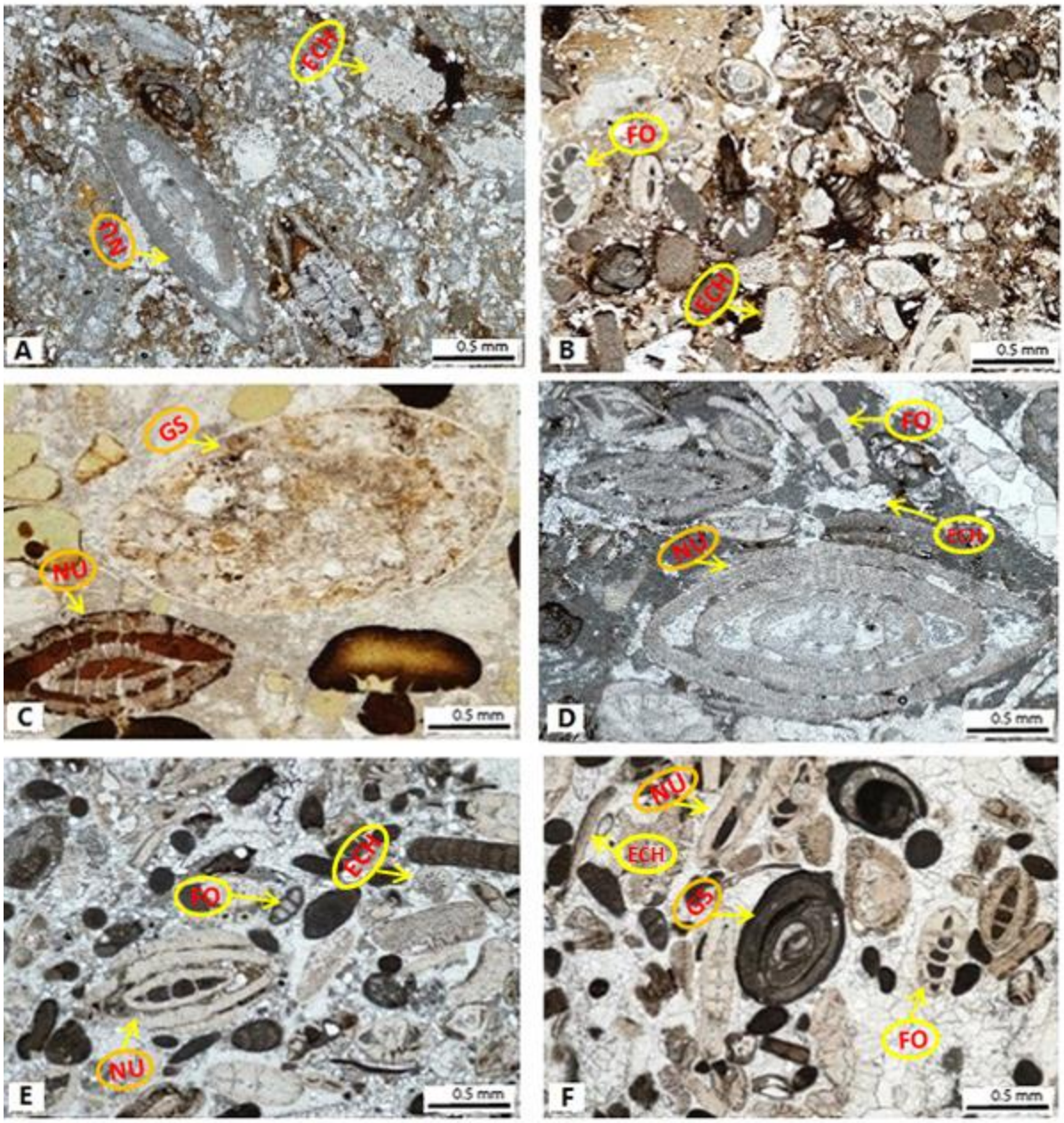

Fig. 6. PPL thin sections showing the photographs of the Bioclastic packstone, Glauconite bioclastic grainstone and Bioclastic grainstone microfacies. A and B. Bioclastic packstone. Nummulite (NU), echinoderm spins (ECH) and foraminifera (FO) are the dominant fossils. The allochems are scattered in a dark carbonate mud matrix. This microfacies presents in the Abraq Formation of Shahat section (S. No.10&27). PPL. C and D. Bioclastic floatstone. C. Gastropod (GS) and nummulite (NU) are embedded in sparry calcite cement, Al Abraq Formation of Shahat section and Omar Al Mukhtar sections (S. No.8&28). PPL. E and F. Echinoderm foraminifera grainstone. E. showing nummulite (NU) and foraminifera (FO). F. showing gastropod (GS), nummulite (NU) and foraminifera (FO). Al Abraq Formation of Shahat section (S. No.9).

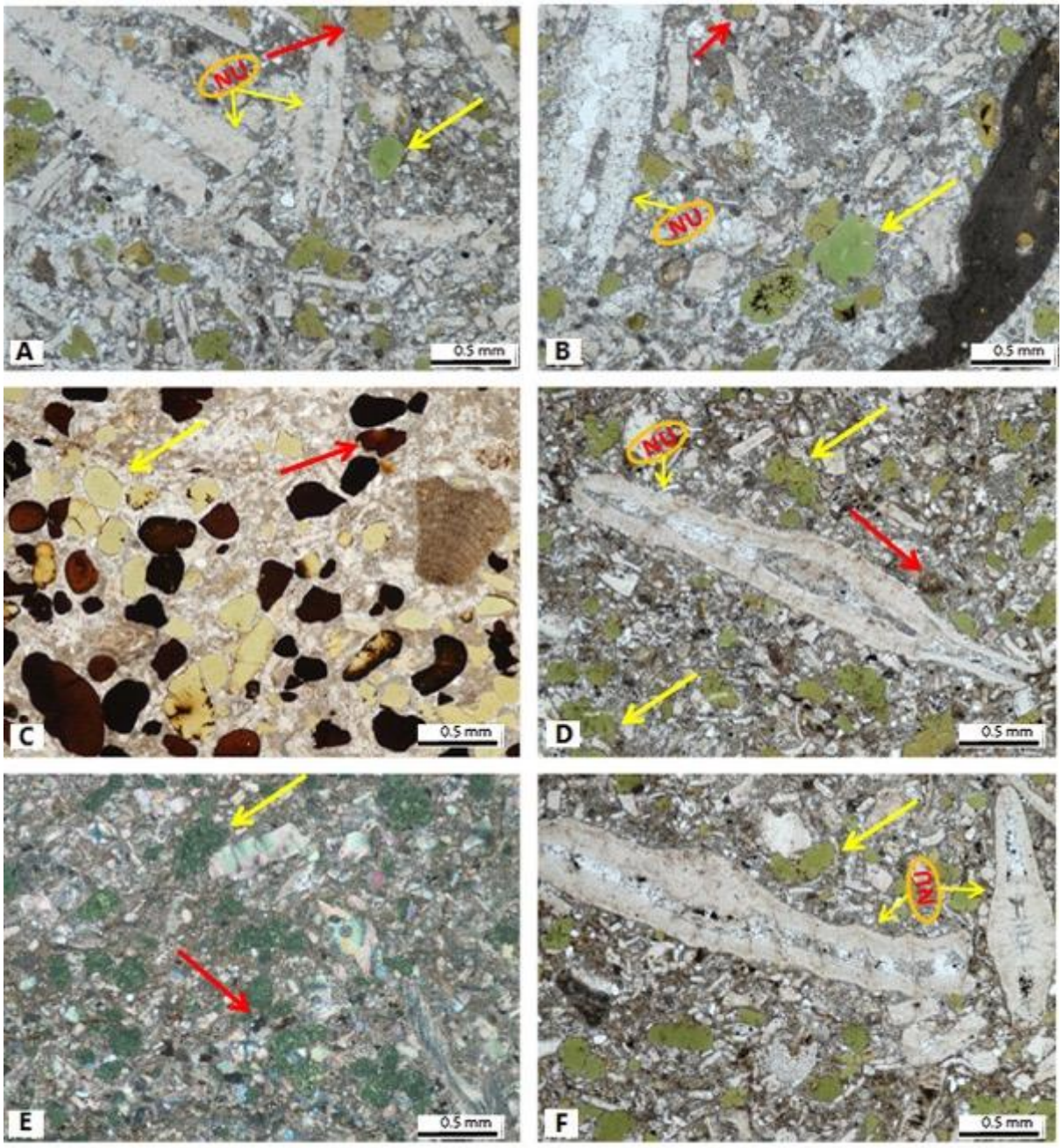

Fig 7. PPL thin sections showing the photographs of glauconite bioclastic grainstone (A, B, C, D, E, and F). The thin sections showing nummulite (NU). The green color of glauconite grains (yellow arrow). The brown color of the glauconite grains (red arrow) may be due to oxidation effect after emergence of this unit.

Microfacies 4 (MF 4): Bioclastic floatstone

This microfacies occurs in the Al Abraq Formations of Wadi Al Kuf and Omar Al Muktar sections (Figs. 4 and 5). This microfacies is characterized by dominance of high percentages of larger foraminifera. Some of these particles are echinoderm fragments, algae and quite a common neomorphosed and occasionally worn or coated by a dark micritic envelopes (Fig. 6 C and D). This microfacies is deposited in fore-reef position and reef slopes, or in back-reef settings and in lagoons. The microfacies resembles SMF5 and FZ4 [10, 11].

Microfacies 5 (MF5): Glauconite bioclastic grainstone

This microfacies is encountered in the Al Abraq Formations of Shahat section (Fig. 3) and it is characterized by accumulation of large quantities of glauconite. The brown color of the glauconite grains may be due to oxidation effect after emergence. Allochems are represented by gastropods, foraminifera, and echinoderms (Fig. 7). The presence of glauconite indicate low rate of sedimentation with normal marine salinity and weakly reducing environments [12]. Because glauconite is slow to form, it is usually common with a transgression of relative sea level [13]. This microfacies resembles SMF18 and FZ8 [10, 11].

Depositional model

A conceptual depositional model showing the lateral distribution of the carbonate facies is illustrated in Figure (8). This model was generated based on the microfacies analysis. It shows that some of the microfacies were formed in shallow carbonate platforms and others were developed in deeper settings.

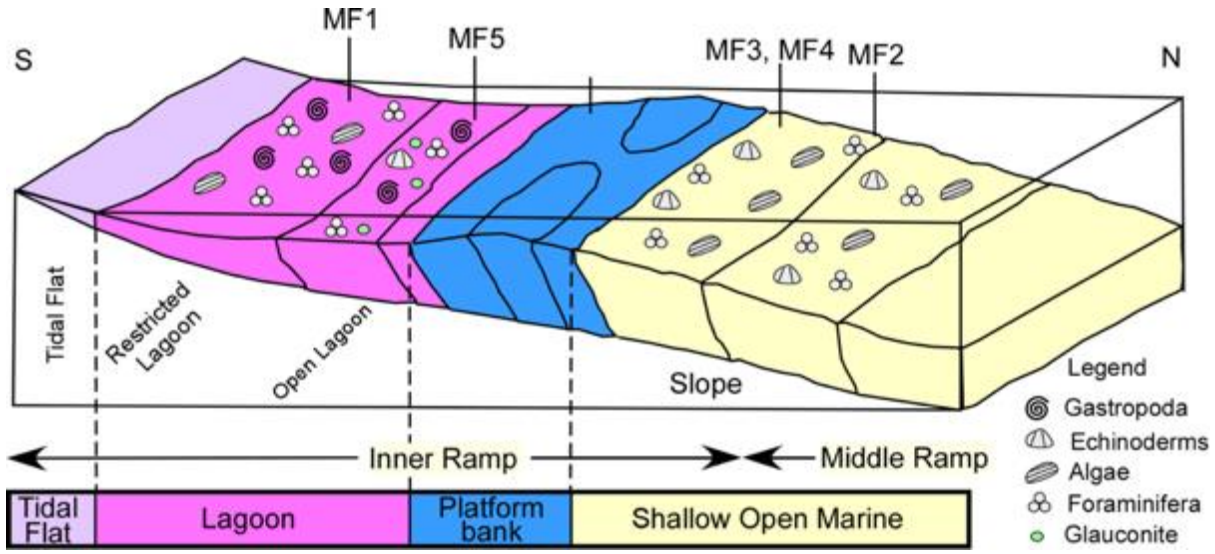

Figure 8. Three-dimensional (3D) depositional model illustrating the depositional environment of the Al Abraq Formation interpreted from microfacies analysis. The interpreted microfacies of the Al Abraq Formation developed in three facies associations. They are restricted lagoon, open lagoon, and slope.

DISCUSSION

Depositional Processes and Environment

To understand the depositional processes as well as to interpret the depositional environment depending on field relationships, the fossil sequence record (fossil types), particularly small-sized foraminifera such as (*Nummulites*, coralline red algae, and bivalve) and facies analysis are the main standard steps to interpret the depositional environment of carbonate rocks which illustrated in Figs. 3, 4, 5. The recorded microfacies of Al Abraq Formation were accumulated in three different facies associations (Fig. 8). These facies associations are restricted lagoon, open marine lagoon, and slope. Firstly, the restricted lagoon facies association that contains bioclastic packstone and foraminifera grainstone microfacies. Deposits of this environment were accumulated in very low or quiet water below the fair-weather wave base (Fig. 8). Secondly, open marine lagoon facies accumulated in open circulation probably below the fair-weather wave base. Microfacies of the second facies association include foraminifera, echinoderm foraminifera wackestone, bioclastic packstone. Thirdly, facies association contain bioclastic floatstone. These deposits were accumulated in slope setting, which may have formed at or in the upper part of the slope where the reworking of sediments by currents or stroms is high (Fig. 8). Therefore, the associations reflect shallow marine carbonate rocks that were accumulated in most of northeast Libya [14]. These shallow settings reflect the occurrence of shallow sea (epicontinental sea) during the deposition of studied succession. The interpretation was mainly dependent upon the high abundance of small-scale *Nummulites*. Moreover, the studied formation contains small-sized *Nummulites viscous*, *Nummulite fichtelli*, *Lepidocyclina*, and *Operculinaafricanus*, which may indicate shallow or coastal setting and open shelf, perhaps inner to mid ramp depositional environment.

CONCLUSION

The study of three sections of Al Abraq Formation presented in this work deals with the lithostratigraphy, microfacies analysis, and the depositional processes during the age of middle to late Oligocene. The delineation of five microfacies within Al Abraq Formation is based on changes in lithology, grain composition, fossil content, texture, color, and lateral and vertical lithological changes. This formation consists of yellowish white, soft to moderately hard limestone. The microfacies of the Al Abraq Formation exhibits biotic elements that indicate shallow open shelf settings. The subdivision into five microfacies, Echinoderm foraminifera grainstone, bioclastic packstone, bioclastic wakestone, bioclastic floatstone and Glauconite bioclastic grainstone, is mainly related to lithological evidence, this microfacies being typified by abundant glauconite pellets that, at the outcrop scale, produce an appearance of dark spots. The identified depositional environments are: a restricted lagoon that consists of foraminifera, algae, and gastropods, open marine that has accumulation of large quantities of glauconite which has microfossils' record that represented by gastropods, foraminifera, and echinoderms, and slope that has high percentages of larger foraminifera and some of these particles are echinoderm fragments and algae. However, analysis of carbon and oxygen isotopes is recommended for better understanding of the paleo-environment and depositional processes of Al Jabal Al Akhdar formations.

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Disclaimer

The article has not been previously presented or published, and is not part of a thesis project.

Conflict of Interest

There are no financial, personal, or professional conflicts of interest to declare.

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