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New insights on the stratigraphy of Tobruq-Burdi area- Marmarica, NE Libya

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ABSTRACT

The stratigraphy of the Marmarica region in the eastern region of Libya (called Tobruq-Burdi), the nomenclature contradiction in stratigraphy has been reviewed. Three surface exposures, Wadi al Hash, Wadi al Shaigh at Tobruq area and Wadi al Rahibat Burdi area have been measured, sampled and analyzed using both the lithology and the fossil assemblages. Previous works in the area have been revised to sort out the contradiction on the stratigraphy.

A disconformity surface with different time interval have been documented at two localities. The first location is a well-known transgressive event (i.e. glauconitic bed) which was recognized at the basal part of the Oligo-Miocene Al Faidiyah Formation delineating the disconformity surface separating the Oligo-Miocene Al Faidiyah Formation from the underlying Middle Eocene Darnah Formation at Wadi al Hash and Wadi Al Shaigh sections. However, the second location exhibits an angular unconformity surface separating the Lower Oligocene algal limestone of Al Bayda Formation from the underneath Campanian Al Majahir Formation at Wadi al Rahib section in Burdi area.

Meanwhile, the upper two formations the Oligo-Miocene Al Faidiyah Formation and the overlying Middle Miocene Al Gaghbub Formation in the study area are separated from each other by disconformity of short interval time. The area was tectonically stable with extensive spatial distribution with some thickness variation in response to the paleorelief of the area of study.

On the basis of foraminiferal assemblages, the Darnah Formation is Middle Eocene, Al Faidiyah Formation is Late Oligocene, Al Gaghbub Formation is Middle Miocene at Tobruq and Burdi area. The term Al Khowaymat Formation is replaced by Darnah Formation for (the Lower Member of the so-called Al Kowaymat) and Al Faidiyah Formation for (the Upper Member of the so-called Al Kowaymat) at the studied sections in Tobruq area. Similarly, the term Lower Member of Al Khowaymat Formation is replaced by Al Majahir Formation at Wadi al Rahib section in the Burdi area.

1. Introduction

Al Khowaymat Formation of El Deftar and Issawi (1977) considered as one of the problematic exposed rock units at the northeastern part of Libya due to the different stratigraphic opinions or conclusions e.g. El Deftar and Issawi (1977); Megerisi and Mamgain, (1980); Imam (1999); Abdulsamad and Tmalla, (2008/2009). The area covered by this study occupies about 2500 km^2 in the northeastern corner of Marmarica region (Figs. 1, 2), which represents the northern portion of the 1:250,000 geological map of Al Burdia sheet NH 35-1 published by El-Deftar and Issawi, (1977). The geographical location of the three studied wadies is indicated by the following coordination: i) Wadi al Rahib Lat. 31° 47' 56.7" N and Long. 25°03'44.5" E; ii) Wadi al Hash (≈ Wadi al Hasier) Lat. 32°00'23.3" N and Long. 24°07'32.6" E and iii) Wadi al Shaigh Lat. 32°00'17.7" N and Long. 24°08'33.7" E) (Fig. 1).

2. Aims

The main purpose of this study is to:

1) Sort out the literature stratigraphic contradiction of all exposed rock units in the concerned area "Tobruq and Burdi areas".
2) Construct stratigraphical correlation based on the recognized sedimentological and paleontological reported fossils.

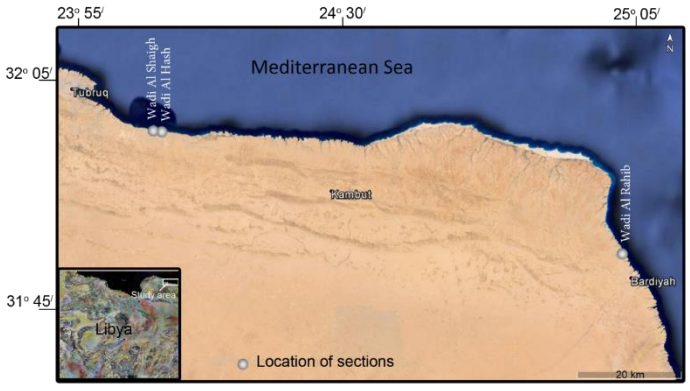

Fig. 1. Location map shows the three studied sections.

3. Materials and methods

Three wadies from west to east Wadi al Shaigh, Wadi al Hash (it is sometimes named Wadi al Hasier) and Wadi al Rahib are measured and sampled for this study (Fig. 1). Forty-two petrographic thin sections have been prepared and examined from some selected samples to perform the textural characters and the paleontological contents.

The foraminifers, however, are also investigated from the same petrographic slides, due to the extensive diagenetic process "i.e. recrystallization and/or dolomitization" especially in the older lithological units namely the Cretaceous (Al Majahir Formation) and the Middle Eocene (Darnah Formation), therefore, the separation of benthic foraminifers "*Nummulites*" and planktic "globotruncaniids and heteroheliciids" is an impossible task.

4. Previous investigations

Among the most important published studies are the IRC (Industrial Research Center) activities on the geological mapping of Libya in general and Al Jabal al Akhdar and Marmarica regions in particular are Al Burdia Sheet NH 35-1 (El-Deftar and Issaw, 1977); Bir Hacheim Sheet NH 34-4 (Sweedan and Issawi, 1977); Zawiyat Msus Sheet NH 34-3 (Mazhar and Issawi, 1977); and Darnah Sheet NI 34-16 (Zert, 1974). In addition to Scheittecatte (1972), Megerisi and Mamgain (1980); Imam (1999); El Mehaghag and Ashahomi (2005), Abdulsamad and Tmalla (2008); Muftah (2014) studied the stratigraphy of Al the Bayda Formation on the basis of their foraminiferal and/or calcareous nannofossil contents.

5. Geological settings

Al Jabal al Akhdar anticlinorium is a part of the northern African-Arabian active margin that had been evolved following the opening of the Neotethys (Fig. 2). This area was classified by El-Arnauti *et al*., (2008) into the mobile province in the north (referred as Al Jabal al Akhdar – Marmarica Uplift) and more stable Cyrenaica platform province in the south with Marmarica terrace, Soluq Depression and Soluq Flank less stable provinces in between (Fig. 2). However, others (e.g. Elwerfalli *et al*., 2000; El Hawat and Shelmani, 1993; El Hawat and Abdulsamad, 2004) considered two provinces the Al Jabal al Akhdar (mobile north Cyrenaican inverted basin) and more stable Cyrenaica Platform to the south separated by a hinge line called the Cyrenaican fault system. El Amawy *et al*., (2010) discovered the newly introduced Al-Hilal anticline in Al Jabal al Akhdar area. Whereas, the Marmarica uplift on the other-hand is tectonically extended eastwards into the coastal area of the Western Desert of Egypt (Fig. 2). Marmarica uplift is characterized by the thick sequence with exposed rocks of mainly Tertiary (Eocene-Miocene) carbonates with a thickness ranging between 2500-3000' except at Burdi area where Scheittecatte (1972) discovered a small upper Cretaceous exposure. However, the subterraneous lower-upper Cretaceous with Jurassic successions yielded about 15000' thick sequence with the underlying 1000-2000' Triassic rocks.

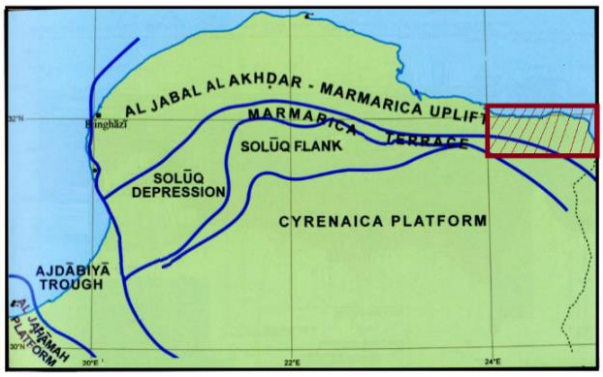

Fig. 2. Map shows major tectonic elements of Northeast Libya, (Brown rectangle represents the study area) (after El-Arnauti et al., 2008).

6. General Stratigraphy of Al Jabal al Akhdar

The pioneer workers of the Al Jabal al Akhdar and Marmarica stratigraphy include Gregory (1911), Desio (1935), Pietersz (1968) and Rholich (1974; 1980). The industrial Research Center also produced series of booklets accompanied with geologic maps to describe the geology, stratigraphy and economic resources for each sheet, including the concerned Burdia Sheet (NH35-1). The Upper Cretaceous – Paleogene stratigraphy of Northeastern Libya successions largely adopted for Al Jabal al Akhdar and Marmarica regions (Fig. 2), the so-called Al Khowaymat Formation is not included, these rock units (Fig. 3) from oldest to youngest are:

Qasr Al Abid Formation: This formation consists of marly limestone locally burrowed with Cenomanian occurrences of the diagnostic *Thomasinella punica* in shallower facies and planktic *Rotalipora cushmani* in deeper facies Muftah (2014).

Al Hilal Shale Formation: This formation consists of pelagic clay enriched with outer neritic foraminifers. Barr and Hammuda (1971) assigned a Cenomanian to Coniacian age based on seven planktic foraminiferal biozones from both surface and subsurface. This Formation dated as Late Coniacian to Early Santonian based on the recognized *Concavutruncana concavata* Zone and *C. asymetrica* Zone (El-Mehaghag and Muftah, 1996) as exposed in limited area at Al Hilal sea cliff and the mouth of Wadi al Qalah.

Al Baniyah Formation (Turonian- Santonian): It consists of dolomitic limestone and marly limestone with common *Ammonites* and *Inoceramus.* It is exposed in the south and central areas of the Al Jabal al Akhdar. It deposited under shallow marine environment.

Al Athrun Formation (Campanian – Maastrichtian): This formation exposed along the mouth of Wadi al Athrun in the Ras al Hilal area and consists of chalky limestones with common chert nodules, planktic foraminifers and *inoceramus* prisms indicating deep marine environment.

Al Majahir Formation (Campanian): It displays tilted dolomitic beds with some Cretaceous planktic froaminifers and *inoceramus*-prisms.

Wadi Dukhan Formation (Maastrichtian): It consists of dolomite with local rudist-build up that reflects the characteristic reefal environmental condition of the formation (Muftah *et al*., 2010).

Al Uwailiyah Formation (Paleocene): It consists of chalky limestone of pelagic nature with common deep benthic and planktic foraminifers (Fig. 2). There are only two exposures in Al Jabal al Akhdar the younger (Landenian) is at Al Uwailiyah village as indicated by *Planorotalites pseudomenardii* Zones Muftah *et al*., (2002). While the older (Danian) is at Jardas al Jarari as indicated by *G. daubgeriensis* Zone. However, the missing outcrops of the middle part were discussed by Tmalla (2007).

Apollonia Formation (Lower-Middle Eocene): It displays rhythmic depositional pattern of thin bedded and relatively soft marl alternating with medium bedded and hard limestone containing brown chert nodules.

Darnah Formation (Middle Eocene): This massive limestone enriched with *Nummulitesgizehensis* group representing a bank depositional setting with local reefoidal buildups. The presence of common brown chert nodules is also a characteristic feature.

Shahhat Marl (Upper Eocene): (Muftah, in press) This highly burrowed marly limestone and marl is dated as Late Eocene based on the presence of common foraminifers *Gazeryina pulcellus* and *Nummulites fabianii* (Muftah and Boukhary, 2012).

Al Bayda Formation (Lower Oligocene): It represents compact, homogeneous, algal limestone with local coral reef and large sized oysters at some places. The presence of *Nummulites vascus* and *N.fichteli* is diagnostic. It deposited under an inner ramp settings Hassan and Muftah (2008).

Al Abraq Formation (Middle Oligocene): It is marly limestone with common skeletal elements of echinoides and pelecypods as well as larger Foraminifers such as *Nummulites vascus*, *fichteli*, *Lepidocyclina* spp. and *Operculina africanus*, with local encrusted algal and seldom serpulid worm tubes. It deposited under shallow marine.

Al Faidiyah Formation (Upper Oligocene- Lower Miocene): It characterized by thin glauconitic limestone bed at the base followed by thick limestone with minor intercalation of clay and marls at places. The presence of common serpulid worm tubes, echinoids, oysters, and *Operculina complanata* and *Lepidocyclina* sp. is considered as

in-situ taxa. However, the presence of *Nummulites fichtelli* is considered reworked by El Hawat and Shelmani, (1993). Benghazi Formation (Lower Miocene): It is characterized by algal limestone with common red algae and coral reef, Oysters and *Amphistegina* sp.

Wadi Al Qattarah Formation (Upper Miocene): It is characterized by cross bedded, oolitic limestone containing miliolids (e.g. *Borelis melo*) indicating oolitic shoal in addition to thick supratidal gypsum deposits locally.

Al Jaghboub Formation (Middle – Upper Miocene): it is the lateral equivalent of Ar Rajmah group (Benghazi and Wadi al Qattarah formations). It is oolitic and/or pelloidal limestones containing common miliolids (e.g. *Borelis melo*) and cross bedded of shoal carbonate, which is changed to algal and reefoidal limestone (bryozoan and corals) in some places.

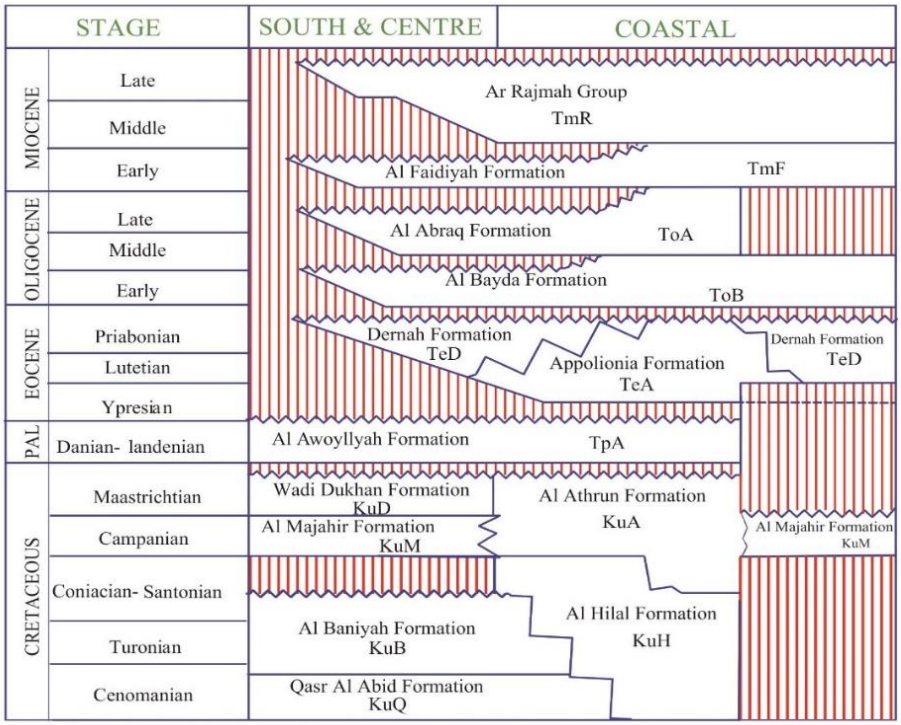

Fig. 3. Stratigraphical chart of northern Cyrenaica (Modified after El Hawat and Shelmani, 1993).

7. Stratigraphic review of the Al Khowaymat Formation

The different stratigraphic opinions of Al Khowaymat Formation with present study are summarized in Fig. 4. Rohlich (1974) and Banerjee (1980) considered the Al Khowaymat Formation as Upper Campanian-Lower Oligocene which is not accepted by others such as El Deftar and Issawi (1977) at Burdi; Mazhar and Issawi (1977) at Zawiyat Msus; Swedan and Issawi (1977) at Bir Hacheim who dated this formation as Late Eocene to Early Oligocene (Fig. 4). However, Megerisi and Mamgain (1980) dated the exposed part of Darnah Formation as the Late Eocene overlain by Al Abraq Formation which followed by Al Faidiyah Formation instead the so-called Upper Member of Al Khowaymat Formation by Mazhar and Issawi (1977) at Wadi Al Hash. On the other hand, at Wadi Al Rahib they recognized sequence of Al Majahir and Al Abraq formations.

Imam (1999) studied three stratigraphic sections in Al Burdi area using planktic and larger benthic foraminifers. These sections from west to east are, Wadi al Zeitun, Wadi al Hash and Wadi Al Rahib. He dated Middle - Late Eocene to the Lower Member of Al Khowaymat Formation at Wadi al Hash according to the recognized three-planktic foraminiferal biozones (*Turborotalia rhori*, *Globigerinatheka semiinvoluta* and *Turborotalia cerroazulensis*s. l). Similarly, he dated Late Eocene (Praiabonian) to the Lower Member of Al Khowaymat Formation at Wadi al Rahib according to the recognized two-planktic foraminiferal biozones *Globigerinatheka semiinvoluta* Biozone and *Turborotalia cerroazulensis*s. l.

At both wadies Imam (1999) also reported shallower benthic nummulitids (*N. intermedius, N. fabianii, N. boucheri, N. gizehensis, N. beaumonti* and *O. complanata*) assemblages. This identified mixed larger benthic assemblage by Imam (1999) is revised later by Abdulsamad and Tmalla (2008/2009) and given an age of Oligocene based on the presence of the in-situ *N. fichteli* and *N. boucheri*.

In addition to that, Imam (1999) recognized Early Oligocene (Rupelian) planktic *Cassigerinella chipolensis- Pseudohastegerina micra* assemblage Biozone at Wadi al Hash section as the Upper Member of Al Khowaymat Formation, he also reported Early Oligocene shallower benthic nummulitids (*N. intermedius, N. boucheri, N.* and *O. complanata*) assemblages. On the other hand, Abdulsamad and Tmalla (2008; 2009) have confirmed the presence of Al Bayda Formation.

This Formation is unconformably overlain by Al Faidiyah Formation at Wadi al Rahib as defined by four foraminiferal biozones *Globigerina ciperoensis ciperoensis*, G*loborotalia kugleri*, *Globigerinoides primordius, Gs. altiapertura/Catapsydrax dissimilis* Biozones, which in turn followed by the Middle Miocene Al Jaghboub Formation as evidenced by the two foraminiferal biozones *Globigerinoides trilobus* and *Borelis melo melo* Biozones (Imam, 1999). On the other hand, Imam (1999) recognized in the Lower Member of Al Khowaymat Formation at Wadi al Hash *Globigerinatheka semiinvoluta* and *Turborotalia cerroazulensis* s.l. Biozones, in addition to the older Middle Eocene *Truncorotaloides rohri* Biozone. Moreover, Imam (1999) recognized in the Upper Member of Al Khowaymat Formation (Early Oligocene) *Gassigerinella chipolensis/ Pseudohastigerina micra* Biozones, while the Upper Member at Wadi al Hash is unconformably overlain by Al Faidiyah Formation as the recognized *Globigerina ciperoensis ciperoensis* and *Globorotalia kugleri* Biozones. The above-mentioned planktic foraminiferal biozones from the so-called Al Khowaymat Formation at Wadi al Hash and Wadi Al Rahib by Imam (1999) are not confirmed in this study, which is not encouraged and supported from the depositional point of view as it is mainly dolomitic in nature with shallow faunal content in particular at the Lower Member of the Al Khowaymat Formation by El Deftar and Issawi (1977). The only confirmed biozone is the *Borelis melo* biozone from Al Jaghbuob Formation.

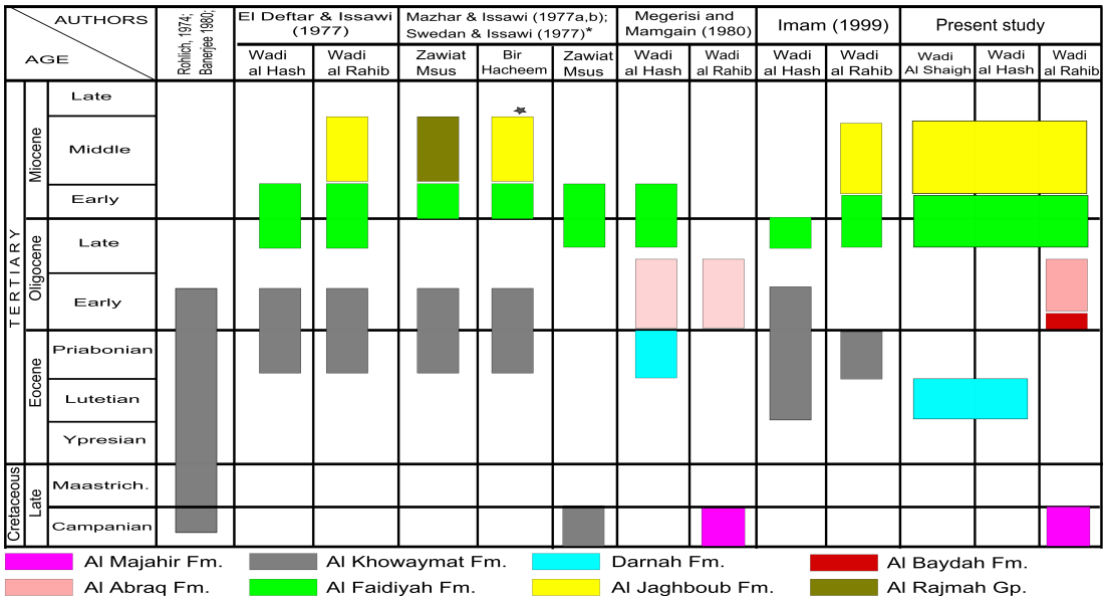

Fig. 4. Summary correlation chart of the previous nomenclatures, including the present conclusion.

8. Lithostratigraphy of Tobruq - Burdi area

Six rock units have been measured and correlated herein, from three measured sections, Wadi al Shaigh, Wadi al Hash and Wadi al Rahib (Fig. 1) they are from oldest to youngest as follows:

I- Al Majahir Formation (Campanian): This Formation is introduced by Rohlich (1974) as limestone, dolomite, dolomitic and marly limestone sequence with subordinate marls for the upper Cretaceous carbonate sequence, which is unconformably overlying the Al Baniyah Formation, and conformably underlying the Wadi Dukhan Formation in western and southern portions of Al Jabal al Akhder region. This formation is cropped out 5.5 km northwest of Burdi, near the mouth of Wadi Al Rahib (8 m thick) at northeast part of Al Jabal al Akhdar "Burdi region", corresponding the Schiettecatte (1972) unnamed Upper Cretaceous "Campanian". Schiettecatte (1972) described the angular unconformity separating the Campanian chalky limestone from the overlying Miocene sands, with highly fossiliferous argillaceous algal limestone. The rare identified foraminifers, *Globotruncana fornicate, G subcircumnodifer, G.* cf. *linneiana,* and *Heterohelix globulosa* in association to common *Gyroidina sp., Gavelinella sp., Praebulimina sp.,* and *Lenticulina sp.,* assigned a Campanian age to these open sea Schiettecatte (1972).

Due to the faunal suite of the Cretaceous inlier at Wadi al Rahib, as evidence by few representatives of *Globotruncana* cf. *fornicata*, *Hedbergella* spp., *Globotruncana* sp., and *Heterohelix globulosa* as well as rare *inoceramus* prisms (Figs. 5 A&B), the Campanian age has been confirmed herein. Furthermore, the lithological character as evidenced by the presence of the late stage diagenetic process "euhedral and zonedcrystals"of dolomites and the complete absence of the chert nodules, supporting the attribution of these Campanian deposits to Al Majahir Formation as suggested previously by Megerisi and Mamgain (1980). Al Majahir Formation is the lateral co-eval of the deep marine Athrun Formation exposed in Athrun area.

Generally, the Upper Cretaceous deposits are exposed in several places such as Jardas al Abid area, Majahir area, Ras al Hilal area, and Uwayliah area. However, the Tocra-Tolmeita area was excluded and assigned as Eocene in age rather than Cretaceous based on El-Mehaghag et al., (2008). Schiettecatte (1972) is the first to introduce the Cretaceous outcrop at Burdi area and he referred to the large amplitude tectonic movement (as indicated by normal fault line) due to the creation of the Al Jabal al Akhdar anticlines.

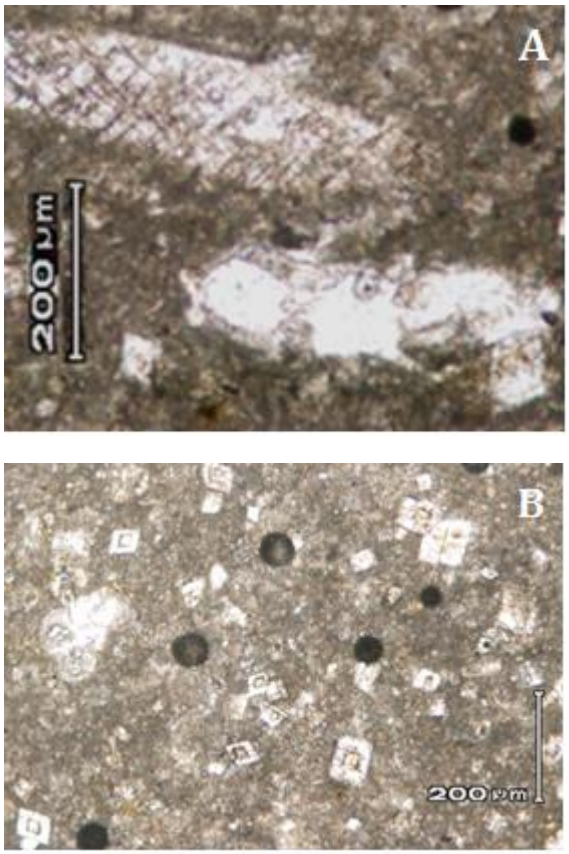

Fig. 5. A) *Inoceramus* prisms and *Globotruncana* sp.; **B)**. *Heterohelix globulosa*, Al Majahir Formation at Wadi al Rahib. (Note: scattered euhedral dolomite crystals are commonly zoned with clear rim and the inner part (core) is more cloudy).

The Cretaceous exposure was believed by previous workers to be restricted only to the section located at 1km upstream from the mouth of Widi al Rahib, and can be traced for 500 meters with dipping of 15° east with no coastal occurrences (Schiettecatte, 1972). This study confirms the presence of coastal exposure at Widi Fraigh al Rahib few meters to the North of Wadi al Rahib, and this limited exposures are due to this Cretaceous inlier at the coast of Wadi Fraigh al Rahib (~5 m) and on the right side of the Wadi al Rahib (~18 m thick) (Figs. 6&7).

Fig. 6. General view of the exposed sequence of Cretaceous/Tertiary boundary at Wadi al Rahib, Al Burdi area.

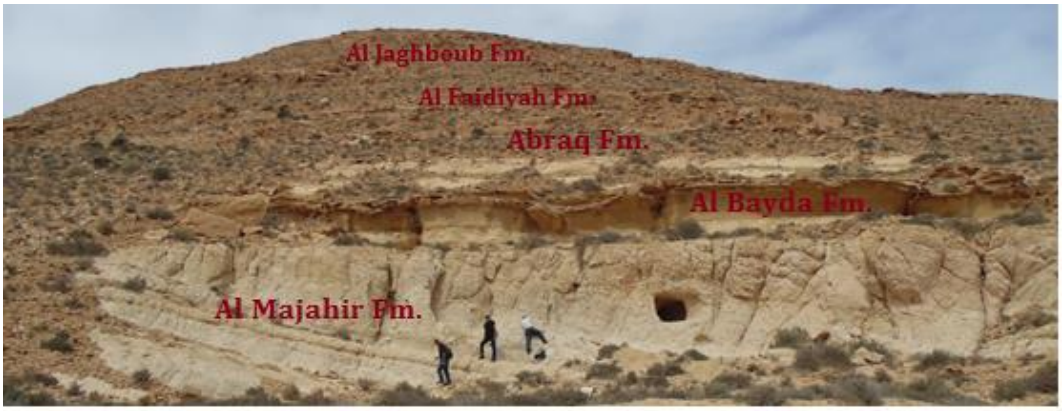

Fig. 7. View of the angular unconformity separating the horizontal Tertiary rocks (Al Bayda Formation) and the tilted rocks (Al Majahir Formation) at Wadi al Rahib, Burdi area.

II- Darnah Formation

This rock unit is well defined at Wadi al Hash with exposed thickness reaches (18 m) and Wadi al Shaigh (7 m). It is confirmed due to the predominance of the Lutetian nummulitic limestone, which assigned to the *Nummulites gizehensis* Biozone as dominance of A and B forms of the *N. gizehensis* (Schaub, 1981; Racey, 1995), additionally the presence of *Sphaerogypsina globula* in this zone is also significant. It has been deposited under inner neritic (fore bank) conditions as indicated by the presence of *Nummulites gizehensis* and *N*. sp. as well as presence of some *Nautilus* molds (Fig. 8) and rare solitary corals.

However, at Wadi al Rahib, the Lower Member of Al Khowaymat Formation of Imam, (1999) is not confirmed as Late Eocene, however, instead a Late Cretaceous age (Al Majahir Formation) was confirmed due to the presence of the *Globotruncana* sp. and *Heterohelic globulosa* as well as *inoceramus*-prisms (Figs. 5a-b) which is in agreement with the work of Megrisi and Mamgain (1980). Similarly, at Wadi al Hash the Lutetian to Priabonian age of Imam (1999) is not confirmed, as Middle Eocene *Nummulites gizehensis* (Fig. 8a), *N.* cf. *N. beaumonti* and *Sphaerogypsina globule* which are hardly identified in this study due to the extensive diagenetic process (i.e. dolomitization).

Darnah Formation is uncomfortably overlain by Al Faidiyah Formation "glauconite base" however the lower boundary is not exposed. According to the lithological nature of the dolomitic limestone and fossil contents these sediments are deposited under inner neritic conditions, which is more or less subjected partially to dolomitization.

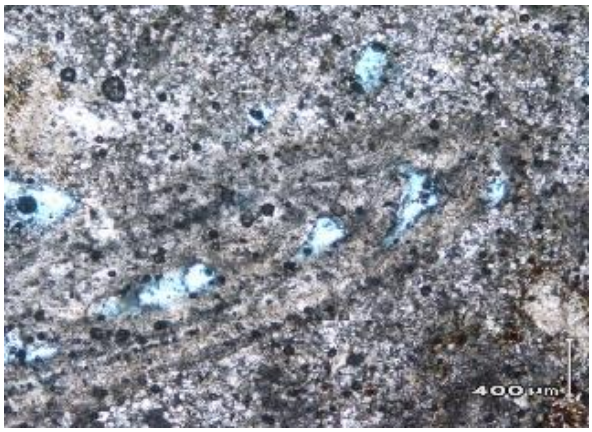

Fig. 8. *Nummulites gizehensis* in dolomitic grainstone from the Darnah Formation at Wadi Al Hash.

III- Al Bayda Formation

Al Bayda Formation received several stratigraphical studies such as Rohlich (1974); Muftahand Erhoma (2002); El Mehaghag and Ashahomi (2005); Abdulsamad and Tmalla (2008/2009). The algal Limestone of Al Bayda Formation has 10m thick exposure at Wadi al Rahib as algal limestone, white, soft – medium hard, marly, and with common coralline red algal "rhodolith" and *Operculina* sp. as well as echinoid and pelecypod fragments. The presence of Al Bayda Formation at this locality was mentioned by Abdulsamad and Tmalla (2008; 2009) as well.

IV- Al Abraq Formation

The Al Abraq Formation is only exposed at Wadi Al Rahib with 12m thickness. It was previously mapped by Megrisi and Mamgain (1980). It consists of Limestone yellow, soft-medium hard, marly, dolomitic limestone locally with common larger benthic foraminifera such as *Operculina*, *Lepidocyclina*, *Nummulites* sp., red algae, pelecypods (Oyster) and echinoids, grading to marly limestone, yellow, soft, with rich Echinoides associated with *Operculina africana* and dimorphic forms of *Lepidocyclina* (A and B forms). This lithofacies is somewhat correlated with that at Ad-Dabussiyah road cut described by El Hawat and Shelmani, (1993). A Late Oligocene age is suggested based on the larger benthic foraminifera (*Operculina africana* and *Lepidocyclina* cf. *dilitata*) and the stratigraphic position.This rock unit deposited under shoal complex settings with relatively deep inner neritic settings as suggested by the common occurrence of orthophramids.

V- Al Faidiyah Formation

This Formation is exposed with variable thicknesses (50 m at Wadi al Hash; 37 m at Wadi al Shaigh (Fig. 9); and 53 m at Wadi al Rahib). Three rock units have been recognized at Wadi al Hash from bottom to top:

a) Glauconitic dolostone unit of green color, soft, small bed, enriched with rounded to subrounded glauconite grains green to brown in color and quartz silt, cemented by dolomite. It is 1 m thick (Figs. 10 A&B).

b) Marly dolostone unit of yellowish brown, soft-medium hard, massive (12m thick) with common dolomite crystals, rare glauconite grains, with mollusks fragments and *Thallasinoides* burrows.

c) Fossiliferous limestone unit of yellowish green to light grey, medium hard, (36 m).

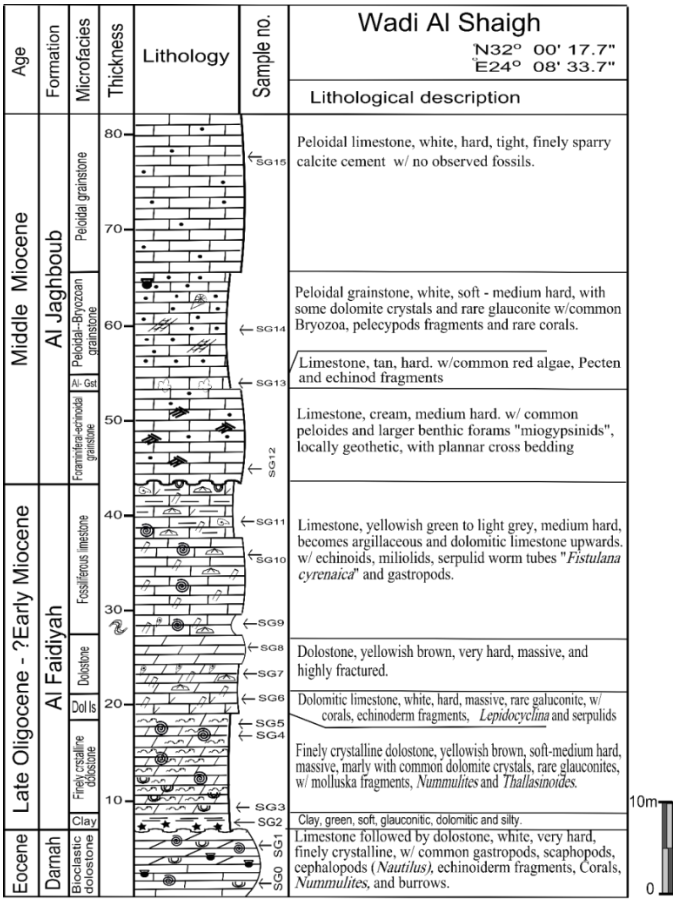

Fig. 9. Stratigraphic column of Wadi al Shaigh at Tobruq area.

Fig. 10. A) The glauconitic bed; B) abundant glauconite grains which are delineating the unconformity surface between Middle Eocene Darnah Formation and Late Oligocene Al Faidiyah Formation at Wadi al Hash.

Fig. 11. Close view of Serpulid worm tubes (*Fistulana cyrenaica*) in Al Faidiyah Formation at Wadi al Hash.

The age of the Al Faidiyah Formation is Early Miocene as dated by El Hawat and Shelmani (1993); Mazhar and Issawi (1977); and Swedan and Issawi (1977). However, it has been dated as Late Oligocene – Early Miocene by Megerisi and Mamgain (1980); El Deftar and Issawi (1977); Rohlich (1974); and Imam (1999).

On the other hand, at Wadi al Shaigh five microfacies have been recognized from bottom to top**:**

i) Glauconitic clay unit: It is green color, soft, silty with common glauconite grains and dolomite cement (2 m thick);

ii) Microcrystalline dolostone unit: It is yellowish brown, soft-medium hard, massive, marly, with common dolomite crystals, rare glauconite grains, with mollusks fragments, *Nummulites* and *Thallasinoides* burrows (10 m thick);

iii) Dolomitic limestone unit: Limestone, grainstone texture, white, hard, massive, rarely glauconitic with corals, larger benthic foraminifera (*Lepidocyclina dilitata)*, and Serpulid worm tubes (*Fistulana cyrenica*) and echinoderm fragments (2.5 m thick);

iv) Dolostone unit: Yellowish brown, very hard, massive, highly fractured with worm tubes skeletal fragments (6 m thick); and

v) Fossiliferous limestone: Yellowish green – light grey, medium hard, becoming argillaceous and dolomitic upwards, with echinoids, gastropods, milliolids, and Serpulid worm tubes (*Fistulana cyrenica*) (16.5 m thick). However, at Wadi al Rahib section it can be divided into two units, *i) Glauconitic clay:* It is green color, soft, thin, enriched with glauconite grains (1 m thick). and *ii) marly dolostone grading to fossiliferous dolostone:* It is yellow, soft-medium hard. It yields common *Operculina sp., Lepidocyclina* sp., miliolids, pelecypods, echinoids, colonial Coral and serpulid worm tubes (*Fistulana cyrenaica*) becoming limestone locally (49 m thick). This rock unit is deposited under fluctuating sea level conditions between very shallow to shallow neritic environment as suggested by the lithological nature and fossils contents, the appearance of common *Fistulana cyrenaica* at some level (Fig. 11) indicates low sedimentation rate.

VI- Al Jaghboub Formation

At Wadi al Shaigh section it measures 38 m thick sequence, where four microfacies have been recognized from bottom to top i) foraminiferal-echinoidal grainstone; ii) Algal grainstone; iii) Peloidal bryozoan grainstone; and iv) Peloidal grainstone, iii) (Fig. 12 A&B). However, at Wadi al Hash it measures 52 m, where two units are recognized the lower gypsiferous clay unit which consists of clay, green, soft, with gypsum crystals (i.e. small sized rose gypsum), yielding vertebrate teeth with fragments of mollusks and echinoids (2 m thick) and the overlying Limestone unit (50 m thick) consists of grainstone textured limestone, cream, medium hard, cross bedded (Fig. 13) and goethitic in parts with algal peloids in places, containing red algae, miliolids, corals at separate horizons with the diagnostic Middle Miocene miogypsinids.

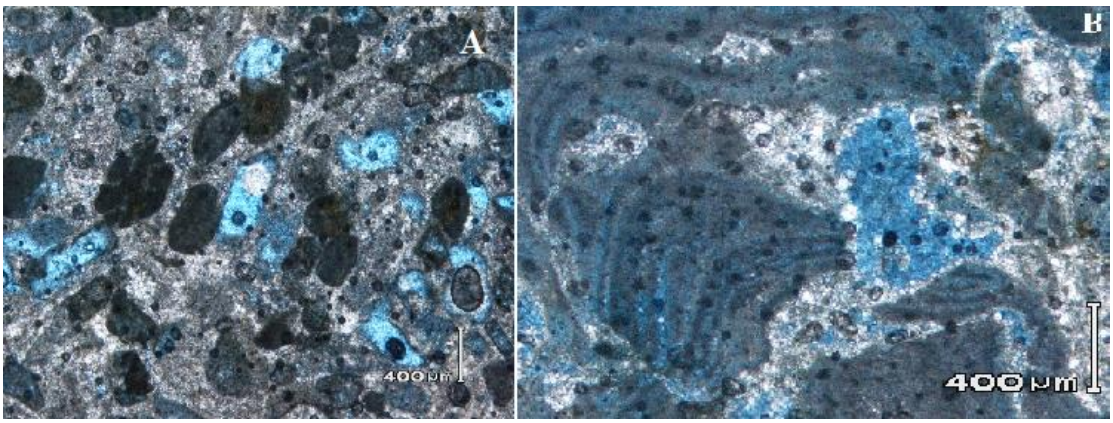

Fig. 12. Photomicrographs of Al Jaghboub limestone; A) showing scattered ellipsoidal grains of an algae of peloids limestone textures; B) destructive fabric of red algae by dolomite crystals, the spar filled holes within the skeleton at Wadi al Hash section.

Fig. 13. Close view of low angle cross-bedding in Al Jaghboub Formation at Wadi al Hash**.**

Meanwhile, at Wadi al Rahib four microfacies have been recognized from bottom to top; i) Peloidal Limestone unit, (4 m) white, soft, chalky, common peloids, highly cross bedded, with miogypsinids and miliolids. In addition to Oysters; ii) Algal Limestone unit, (1.5 m) yellow, hard to medium hard with common red algae; iii) Marly Limestone unit:, (4.5 m) yellow, soft to medium hard, common pelecypods, burrowed, and few red algae; and iv) Skeletal Limestone unit: (15 m) white, medium hard, cross bedded, with diagnostic miogypsinid, and sparse *Balanus* sp., bryozoan fragments red algae, echinoids and *Pecten*, the latter is increased in number

upwards. This Formation is deposited under shallow marine environment with somewhat lagoonal affinity at some places as interpreted by the presence of the miliolids and the dolomitization process.

The stratigraphic correlation (Fig. 14) shows that the western area at Al Bardia (Wadi al Rahib) the Al Majahir (Upper Cretaceous) rocks are exposed at its base, however, in the eastern area at Tobruq vicinity (Wadi Al Shaigh and Wadi Al Hash) the Darnah nummulitic rocks are exposed at its base. On the other hand, the algal limestone of Al Bayda Formtion and the overlying Abraq Formation are preserved only in the western area at Al Bardia (Wadi al Rahib). The area as a whole subjected to regional transgressive event as indicated by the glauconitic bed at the base of Al Faidiyah Formation in all studied sections. The glauconitic bed "i.e. transgressive event" is largely used in Al Jabal al Akhdar as a marker bed for the basal unit of Al Faidiyah Formation. Al Faidiyah Formation in general displays a considerable thickening towards the east (Wadi al Rahib), this increase in thickness is in response to the paleo-relief during the deposition of this rock units. Al Jaghboub Formation is capped Al Faidiyah Formation at all traverse with variable thickness, the thickest measured part being at Wadi Al Hash.

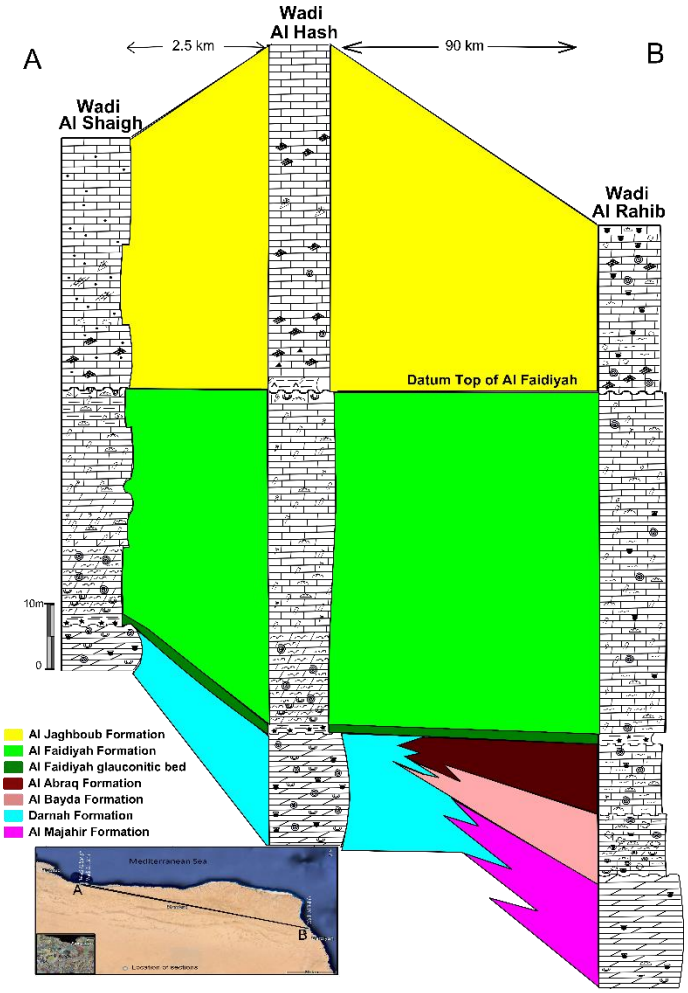

Fig. 14. Stratigraphic correlation shows the lateral variation on lithotypes of the Pre-transgressive glauconitic bed.

9. Conclusions

The stratigraphic validity of Al Khowaymat Formation (El Deftar and Issawi, 1977) in the previous literatures has been reviewed and the following are suggested:

- Confirm the presence of Majahir Formation (Upper Cretaceous) at Wadi al Rahib as suggested previously by Megerisi and Mamgain (1980) rather than Upper Eocene Al Khowaymat Formation (Lower Member) of other workers.
- Confirm the presence of uppermost part of Darnah Formation at Wadi Al Hash rather than the Middle-Upper Eocene Al Khowaymat Formation (Lower Member) of Imam (1999), and the Upper Oligocene-? Lower Miocene Al Faidiyah Formation rather than the Lower Oligocene Al Khowaymat Formation (Upper Member) followed by the Middle Miocene Al Jaghboub Formation rather than the Upper Oligocene Al Faidiyah Formation of Imam (1999).

The present study confirms that the Oligocene Abraq Formation is partly preserved at Wadi Al Rahib section as suggested previously by Megerisi and Mamgain (1980).

Among the established planktic foraminiferal biozones of Imam (1999) only *Borelis melo* Biozone is confirmed in this study, the others are not confirmed. The sporadic spatial Upper Cretaceous exposures at Burdi area including the introduced outcrop of Wadi al Rahib at the coast are structurally induced.

A newly Oligocene vertebrate teeth site has been discovered herein in Wadi al Hash, and an extensive excavation is highly recommended for future investigation.

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