Biostratigraphy and paleoecology of the Miocene sequence along the stretch of Qabilt Ash Shurfah to Wadi Zaqlum sections, Sirte Basin, Libya

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Abstract: The Miocene carbonate – siliciclastic deposits are widely exposed along the stretch of Qabilt Ash Shurfah to Wadi Zaqlum sections, Sirte Basin, NW Libya. These deposits overlie unconformably the Late Cretaceous Sidi As Sid Formation and overlain unconformably by Quaternary clastic deposits. Three stratigraphic sections were investigated namely, from north to south: Qabilat Ash Shurfah, Ras Al Shaqqah and Wadi Zaqlum sections. Lithostratigraphically, the Miocene sequence could be differentiated into two main rock units representing shallow deposits with relatively intermittent deep marine incursions. These are from base to top as follows: 1- Al Faidiyah Formation and 2- Al Khums Formation (represented at lower part by An Naggazah Member followed upwards with Ras Al Mannubiyah Member. Detailed foraminiferal investigations led to the recognition of three foraminiferal zones from base to top: Elphidium macellum / Miogypsina intermedia and Globigerinoides trilobus zones covering Al Faidiyah Formation and assigned it to early Miocene (Burdigalian) age and the Borelis melo melo zone which includes Al Khums Formation and dated it to Middle Miocene (Langhian to Early Serravallian) age. Detailed microfacies analysis of the rock units led to the recognition of eleven microfacies types indicating that the Miocene sequence was deposited in transgressive – regressive cycles ranged from near shore, warm shallow inner to middle shelf marine environments with development of reefal facies with slightly deep marine incursions. Such environments reflect the eustatic sea level changes related to the latter minor tectonic pluses accompanied the main Upper Cretaceous tectonic event.

Key words: Qabilat Ash Shurfah, Al Faidiyah Formation, Miocene, Foraminifera, Sirte Basin, Libya.

INTRODUCTION

Sirte Basin was tectonically developed in the Late Mesozoic time as a southerly extension from the Tethys geosyncline by block faulting and subsidence of a part of the Sahara shield (Tibesti – Sirte arch). By the advent of the Miocene period the embayment had largely been filled by carbonate and siliciclastic deposits through marine transgression (Selley, 1985). The Miocene deposits situated along the stretch of Qabilt Ash Shurfah to Wadi Zaqlum sections, Sirte Basin, NW Libya, represented basically by transgressive – regressive marine carbonate – siliciclastic sediments and characterized largely by striking lateral variation in facies and thickness. This variation is controlled mainly by the degree of erosion and relief conditions of the pre – existing underlying Upper Cretaceous rocks. The areal extension of the Miocene outcrops is smaller and occurred as relic, isolated deposits in the form of low – lying hills and hillocks dissected by several wadis around the study area. Moreover, the Miocene rocks form distinct low – lying outcrops surrounding the Upper Cretaceous topographic highs. The deposition is predominantly commenced with a siliciclastic lithofacies of coarse clastic polymictic conglomerates (that marks the unconformable contact with the underlying Late Cretaceous Sidi As Sid Formation), calcareous sandstone and thin beds of argillaceous limestone. This sequence followed upwards with sandy, argillaceous, chalky limestone in the uppermost part of the studied sections and lasted with coralline algal limestone reflecting environments of shallow to relatively deep marine conditions.

The study area is about 260 km² located in the northwestern side of Sirte Basin, nearly about 15 Km south of Al Khums City. It is bounded by the Mediterranean coastline to the north and Lat. 32° 15` to the south, as well as Long. 14° 10` to the west and Long. 14° 30` to the east (Figs. 1 & 2) The main target of the present work is to study in details the different lithostratigraphic units of the Miocene sequence and their different biostratigraphic zones as well as reconstruct the paleoenvironmental conditions prevailed during the deposition. About 120 representative samples were collected from three main stratigraphic surface sections, namely Qabilat Ash Shurfah (Lat. 32° 35` 20 N & Long. 14° 18` 23" E), Ras Al Shaqqah (Lat. 32° 28` 18 N & Long. 14° 27` 10" E) and Wadi Zaqlum (Lat. 32° 35` 20° N & Long. 14° 18` 23° E). These samples were subjected to detailed biostratigraphic analysis based on the benthonic (larger and smaller) and planktonic foraminiferal content to recognize the different Miocene biozones and determine precisely the age of the encountered rock units. In addition to that, the main microfacies types are recognized and evaluated where paleoecological interpretation was based on the environmentally diagnostic foraminiferal and coralline red algal assemblages as well as field observations and primary structures.

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RESULTS AND DISCUSSIONS

Lithostratigraphy:

The stratigraphy and to certain extent the structural setting of the exposed Miocene successions along the stretch of Qabilt Ash Shurfah to Wadi Zaqlum sections, Sirte Basin, NW Libya, have been previously discussed by different authors, among them are: Florida (1939), Desio (1939), Mann (1975), Zivanovich (1977), Mijalkovic (1977) Said (1978), Srivastva (1979), Salem & Spreng (1980), Innocenti & Pertusai (1984), Sherif (1984 & 1991) and El Waer (1991). Most of these researches concentrated on the stratigraphy but little works have been carried out on the micropaleontological studies of the area. These authors also assigned Al Khums Formation to the Middle Miocene (Langhian) age except the work of Innocenti & Pertusai (op. cit.) and El Waer (1991) who assigned this Formation as Late Miocene (Torotonian to Messanian) age. Lithostratigraphically, the Miocene deposits in the study area have been classified and discussed by few authors. The currently used lithostratigraphical subdivision of the Miocene in northeastern Libya is mainly based on the work of Mann (1975). Other significant contributions to the lithostratigraphy of this sequence (Salem & Spreng, 1980 & Sherif, 1991) are adopted in the present work. The general stratigraphical subdivision of the studied sequence is correlated to the other Miocene units in northern parts of Libya and is shown in Table 1.
Table 1: Correlation chart of the Miocene rock units in Northern Libya.

Two main rock units represent the Miocene succession will be discussed, from base to top as follows:

1- Al Faidiyah Formation:

It is the oldest Miocene rock unit exposed in the study area and represented the first transgressive marine deposits. It was first described and established by Pietersz (1968) as “Faidia” Formation. According to its type section at Qaryat Al Faidiyah on Al Bayda sheet and later on Barr & Weeger (1972) adopted it. It is subsequently modified by Rohlich (1974) to Al Faidiyah Formation to delineate the clay – carbonate sequence at its type section, Al Faidiyah village. In the studied sections this Formation is of very limited distribution and locally developed only in Ras Al Shaqqah section attaining thickness of 15 m where it overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member) with polymictic conglomerates marking this boundary and underlies conformably Al Khums Formation (An Naggazah Member). The lower part of the Formation is represented in the field by siliciclastic dominated facies typified by coarse polymictic conglomerates that onlaps and pinches out on the Upper Cretaceous limestone. These siliciclastic facies consist of 2 – 3m thick with reworked Upper Cretaceous clasts represented by subrounded to rounded, moderately sorted, grain – supported polymictic conglomerates, the good roundess of the clasts indicate long period of abrasion before accumulation. The clasts composed of bioclastic carbonate and subordinate chert of pebble to boulder sizes closely packed in matrix of sandy lime mud. This type of polymictic conglomerate could be formed as erosional channel fills and represents the first Miocene marine transgression over the uneven surface of the pre existing Upper Cretaceous rocks. The siliciclastic dominated facies grades upwards to yellowish white, fossiliferous with oyster shells, cross - bedded, coarse to pebbly calcareous sandstones of moderately sorted detrital quartz grains followed by medium to fine calcareous sandstones and calcareous mudstone with thin band of greenish grey, fissile, fossiliferous, silty claystone. The calcareous mudstone is grey, fissile partly sandy and commonly intercalated the cross – bedded sandstone. The upper part of Al Faidiyah Formation is carbonate dominated facies depicted in the presence of yellowish to whitish grey, massive - bedded, hard, sandy limestone highly fossiliferous with Pyconodonte virleti Deshayes, Ostrea frondosa Fuchsia, Pecten jossilingi Sowerby, Pecten ziziniae Blanckenhorn, Clamyx submalvinae Blanckenhorn, Clypeaster intermedius Desmoulins, Clypeaster sp. and Flabespecten burdigalensis Lamarck. Coralline red algae, echinoid and other bivalved shells represent the less common faunal assemblage. This carbonate - dominated unit is commonly interbedded with greenish grey, fissile, fossiliferous, argillaceous limestone highly fossiliferous with planktonic and benthonic foraminifers. Thin bands of calcareaeous, grey, fissile, shale (10 to 20 cm in thickness) are commonly observed in this unit.

2 - Al Khums Formation:

This rock unit was first described and established in its type locality Al Khums area by Mann (1975) for the Middle Miocene carbonate - clay / marl sequence. In the studied sections, this formation overlies conformably the early Miocene Al Faidiyah Formation as in Ras Al Shaqqah section but in Qabilt Ash Shurfah and Wadi Zaqulum sections it overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member). This rock unit sometimes crop out directly and in some places it is overlain unconformably by clastic section of polymictic conglomerates and sandstone of Pliocene – Pleistocene age. Salem & Spreng (1980) locally subdivided Al
Khums Formation in Al Khums area into two informal members, from base to top: 1- An Naggazah Member and 2- Ras Al Mannubiyah Member (Table 1). These two members are noticeably recognized in this study. Lithologically, Al Khums Formation is represented mostly by shallow water carbonate - dominated facies usually interrupted by slightly deep marine conditions. Al Khums Formation attains different thickness where it reaches about 35 m in Ras Al Shaqqah and 50 m in Qabilat Ash Shurfah section and 30 m in Wadi Zaqlum respectively. Regarding the age of Al Khums Formation, Mann (1975), Mijalkovic (1977), Said (1978) and Srivistava (1979) have assigned this rock unit as Middle Miocene (Langhian) on the basis of its stratigraphic position and paleontological evidences. But on the contrary, Innocenti & Pertusai (1984) and El Waer (1991) assigned it as Late Miocene (Tortonian to Early Messinian) on the basis of the ostracod content. In the present study, the mutual relationship of the field investigations, recorded foraminiferal biostratigraphic zones as well as coralline algal assemblage assigned Al Khums Formation to Middle Miocene age as will be explained in the nextcoming paragraphs.

1 - An Naggazah Member:

The An Naggazah Member was first introduced informally by Salem & Spreng (1980) to define the lower part of Al Khums Formation in Al Khums area, NW Libya. It overlies unconformably the Late Cretaceous Sidi As Sid Formation (Ain Tobi Member) in Qabilt Ash Shurfah and Wadi Zaqlum sections and underlies conformably Al Mannubiyah Member. This rock unit conformably overlies Al Faidiyah Formation in Ras Al Shaqqah section. The lowermost part of this member is represented by polymictic conglomerates (clasts are composed predominantly of carbonate with chert entobded in sandy carbonate matrix), this basal bed followed by pebbly to coarse sandstones grading upwards into medium to fine grained, poorly sorted calcareous sandstones, fossiliferous with gastropodes and pelecypod shell fragments. The sandstone is followed upwards with yellow to yellowish brown, irregularly to massive - bedded of ledge - forming, porous to hard, sandy, algal reefal limestone highly fossiliferous with corals, coralline algae, oyster bivalves, bryozoaa and echinoidea. These organic accumulations usually thicken to form coral patch reefs of variable thickness and located in the middle part of this unit. Many branched coral reef builds up are observed along Wadi Zaqlum. This coral patch reef is locally developed above the submarine paleohigh (uneven Late Cretaceous surface). It is massive, richly fossiliferous with diverse faunal assemblage such as bioclasts, calcareous red alge, echinoids, bryozaan, large benthonic foraminifers and bivalved shell fragments and algal rhodoliths. The most prominent organic elements is represented by in situ colonial corals. These faunal content attest to deposition in shallow clear water environments with normal salinity and open circulation. This reefal limestones overlain by another brownish yellow to yellow, partly massive, fossiliferous with bivalved shell fragments and echinoids, argillaceous to sandy algal limestone. Yellow to greyish yellow, partly massive, fossiliferous argillaceous limestone and dolomitic limestone interbedded with green gysiferous shale beds are recorded in the uppermost part of An Naggazah Member (Figs.3 & 4).

2 - Ras Al Mannubiyah Member:

This rock unit was first introduced informally by Salem & Spreng (1980) to define the upper part of Al Khums Formation in Al Khums area, in the eastern side of Ras Al Mannubiyah village, about 8 km west – southeast of Al Khums, NW Libya. It overlies conformably An Naggazah Member and underlies unconformably the Quaternary clastic sediments and sometimes capped the topmost part of the section as in Wadi Zaqlum (Fig. 4). This member is essentially composed of highly fossiliferous algal reefal limestone separated by white cream - coloured chalky limestone bed. It represented in its lowermost part by yellowish white, poorly cemented, fine to medium grained, moderately sorted, polymictic conglomeratic bed (with reefal limestone and subordinate calcareous sandstone lithoclasts), fossiliferous with oyster shell fragments and reworked corals. This bed may be probably developed during regressive phase of shoreline and changed laterally to dolomitic, fine to medium grained, moderately sorted, coarse to pebbly sandstones as in Ras Al Shaqqah section. Upwards this unit graded to light grey to greyish white, massive, ledge – forming, irregularly bedded highly fossiliferous with larger benthonic foraminfera, sity to sandy limestone interbedded with green shale and dolomitic limestone. This unit is conformably overlain by white to greyish white, irregularly bedded, crumbly, slightly fossiliferous with foraminifers and ostracods, slightly argillaceous, chalky limestone. An Naggazah Member terminated with thick bedded, yellowish to greyish white, porous, cavernous, algal reefal limestone, highly fossiliferous with coralline red algae, gastropods and other bivalved shell fragments. This unit has exhibits a characteristic honeycombed structura due to the lweathering process. The algal reefal limestone is usually capped the uppermost part of the Ras Al Mannubiyah Member by grayish yellow, cavernous fossiliferous sandy limestone beds (Figs. 3 & 5).

Foraminiferal Biostratigraphy:

About 120 outcrop samples were collected at close intervals and examined in order to determine the ages of the individual Miocene rock units and its related units. Ages were established by biostratigraphic analysis of the
benthonic and planktonic foraminiferal assemblages. Paleobathemtric interpretation was also made when samples yielded environmentally diagnostic fauna. The continuous nature of the stratigraphic sections permit development of a detailed foraminiferal biostratigraphic framework. The Miocene foraminiferal biostratigraphy presented in this work based on the ranges and assemblages of the larger and smaller benthonic foraminifers and on the presence and distribution of the planktonic foraminifers. Detailed investigations of the foraminiferal content of the studied Miocene sequence in Al Khums area led to the recognition of three foraminiferal zones from base to top: *Elphidium macellum* / *Miogypsina intermedia* zone and *Globigerinoides trilobus* zone (early Miocene age) covering the lower and upper parts of Al Faidiyah Formation respectively. Whereas the *Borelis melo melo* zone (Middle Miocene age) includes the whole Al Khums Formation. These biozones are discussed whereas the distribution charts of these foraminiferal species are also given in figures 3, 4, and 5, where the most diagnostic foraminiferal species are mounted in two plates (Plates 1 & 2). In the following are the main foraminiferal zones recognized in the Miocene succession from base to top:

Fig. 1: *Globigerinoides succulifer* Brady, umbilical view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section,  
Fig. 2: *Globigerinoides immaturus* Le Roy, spiral view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 3: *Globigerinoides trilobus* Reuss, umbilical view, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 4: *Globigerinella siphonifera* d' Orbigny, umbilical view, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 5: *Globoquadrina dehiscens* (Cushman & Collins), umbilical view, sample 19, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 6: *Globigerina bulloides* d' Orbigny, umbilical view, sample 33, Al Khums Fm, Ras Al Shaqqah section.  
Fig. 7: *Globigerinoides trilobus* Reuss, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 8: *Globigerina angusti umbilical view* Bolli, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 9: *Globigerinoides trilobus* Reuss, spiral view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 10: *Globigerina ciperoensis* Bolli, umbilical view, sample 19, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 11: *Globigerinoides subquadratus* Brönnmimann, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 12: *Globigerinoides diminutus* Brönnmimann, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 13: *Globigerina praebulloides* D'Orbigny, umbilical view, sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 14: *Globigerina bulloides* D'Orbigny, spiral view, sample 18, Al Faidiyah Fm., Ras Al Shaqqah section.  
Fig. 15: *Globigerinella obesa* Bolli, side view, sample 75, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 1: *Miogypsina intermedia* d’Orbigny, sample 14, Al Faidiyah Fm., Ras Al Shaqqah section, x70
Fig. 2: *Brizalina alata* (Seguenza), sample 28, Al Khums Fm., Ras Al Shaqqah section.
Fig. 3: *Uvigerina barabatula* (Macfadyen), sample 30, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 4: *Siphonodosaria advena* (Cushman & Laiming), sample 98, Al Khums Fm., Wadi Zaqlum section.
Fig. 5: *Uvigerina semiornata* d’Orbigny, sample 106, Al Khums Fm., Wadi Zaqlum section.
Fig. 6: *Baggina indica* Cushman, sample 107, Al Khums Fm., Wadi Zaqlum section, x 60
Fig. 7: *Percultazonaria subaculetata* (Cushman), sample 15, Al Faidiyah Fm., Ras Al Shaqqah section.
Fig. 8: *Uvigerina graciliformis* (Papp & Turnovsky), sample 28, Al Khums Fm., Ras Al Shaqqah section.
Fig. 9: *Uvigerina striatissma* d’Orbigny, sample 68, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 10: *Uvigerina gaudryinoides* (Lipparini), sample 72, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 11: *Uvigerina semiornata* d’Orbigny, sample 17, Al Faidiyah Fm., Ras Al Shaqqah section.
Fig. 12: *Uvigerina gallowyi* (Cushman), sample 16, Al Faidiyah Fm., Ras Al Shaqqah section.
Fig. 13: *Bolivina arca* (Macfadyen), sample 32, Al Khums Fm., Ras Al Shaqqah section.
Fig. 14: *Uvigerina sp.*, sample 47, Al Khums Fm., Ras Al Shaqqah section.
Fig. 15: *Uvigerina pygmoiides* (Papp & Turnovsky), sample 72, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 16: *Uvigerina pygmoiides* (Papp & Turnovsky), sample 34, Al Khums Fm., Qabilat Ash Shurfah section.
Fig. 17: *Heterolepa dutempli* d’Orbigny, sample 35, Al Khums Fm., Ras Al Shaqqah section.
Fig. 18: *Cancrius auriculus* (Fichtell & Moll), sample 35, Al Khums Fm., Ras Al Shaqqah section.
Fig. 19: *Valvulineria sp.*, sample 35, Al Khums Fm., Ras Al Shaqqah section.
Fig. 20: *Elphidium macellum* (Fichtell & Moll), sample 35, Al Khums Fm., Ras Al Shaqqah section.

1 - *Elphidium macellum / Miogypsina intermedia* Assemblage Zone:

This zone is defined on the basis of the great abundance of the two nominated zonal taxa (*Elphidium macellum* Fichtel & Moll and *Miogypsina intermedia* Drooger) and spanned the interval from the first occurrence of shallow marine *Elphidium macellum* Fichtel & Moll and *Miogypsina intermedia* Drooger to the first occurrence of *Globigerinoides trilobus* (Reuss). It occupies the lower part of Al Faidiyah Formation from sample 13 to 15 and recorded only in Ras Al Shaqqah section (Fig. 3). The interval of this zone is characterized by low to moderate diversity of both genera and species. The planktonic foraminifers are very rare and associated commonly with the clays and marl thin bands, being represented mainly by non – diagnostic minute
tests that makes it difficult to delineate its planktonic zone. Among the planktic taxa recorded are *Globigerina ciberoensis* Bolli, *Gg. angustiumbilicata* Bolli, *Gg. praebulloides* Bolli, *Cassigerinella chipolensis* Cushman.

It is noteworthy of mention that *Miogypsina* taxa played an important role in the age assignment of this zone. Drooger (1954; 1963; 1993) related the *Miogypsina* group (*M. intermedia* Drooger, *M. cUSHmani* Cushman, *M. complanata* Schlumberger, *M. globulina* Drooger) to Burdigalian age and equated to planktonic zone not older to N6. Souaya (1961 &1963) and Cherif (1966; 1980) recorded *Miogypsina intermedia* Drooger associated with *Oerculina complanata*, *Heterostegina heterostegina* from the Miocene deposits of Cairo – Suez road of Egypt and assigned the rocks to early Miocene (Burdigalian) age. Nasserf et al., (1992) recorded the same assemblage of the nominated zone in the Miocene sequence of Wadi Feiran, southwest Sinai, Egypt and assigned the assemblage to an early Miocene (Burdigalian) age. Moreover, Abdel Ghany & Piller (1999) recorded the *Miogypsina intermedia, M. cUSHmani* and *M. mediterranea* from the early Miocene Gharra and Sadat formations in some sections in Cairo – Suez district, Egypt and assigned to late Burdigalian age. Nassif et al. (1992) recorded the same assemblage of the nominated zone in the Miocene sequence of Wadi Feiran, southwest Sinai, Egypt and assigned the rocks to early Miocene (Burdigalian) age. Boudaghar et al. (2000 & 2001) described some such large benthonic foraminiferal assemblage from early Miocene (Burdigalian) sections in Boreno and neraby countries. More recently Hamad (2009) recorded this association from the early Miocene deposits of Sadat Formation, Sadat area, NW Gulf of Suez region. From the foregoing discussion, the lower part of Al Faidiyah Formation that encompasses this zone is frankly assigned to early Miocene (Burdigalian) age on the basis of the *Miogypina* spp. and the rare occurrence of *Globigerina* spp. Consequently, this zone could be matched with N5 / N6 of Blow (1969) and correlated to the *Globigerinoides altiaperturus* / *Catapsydrax dissimilis* zone of Iaccarino (1985) in the Mediterranean region. It is noteworthy of mention that no evidences of Aquitanian deposits were recorded in the studied area where neither of the *Miogypsina tani* Drooger (larger benthonic foraminifera) nor the *Globiquadrina dehiscens dehiscens* (planktonic foraminifera) zones are not recorded denoting that the Miocene transgression started earlier at the Late Burdigalian time.

It is interesting to mention that some striking environmental foraminiferal species characterize this zone. The co – occurrence of *Bolivina tumida, Nonion scaphum, Uvigerina gallowayi* and *Miogypsina* spp. and the low P/B ratio indicate shallow marine environments (Douglas, 1979; Van der Zwaan & Jorissen, 1991; Murray 1991, Christopher et al, 2007). Moreover, the co – occurrence of the *Ammonia beccarii* and the *Elphidium* sp. as well as *Heterolepa dutemplei* are taken as evidence of shallow marine shelf environments less than 10m (Lipps et al. 1979; Boersma, 1983; Jorissen, 1991; Murray, 1991; Abul Nasr & Salama 1999). Another feature support shallow marine shelf environments for the lower part of Al Faidiyah Formation (*Elphidium macellum / Miogypsina intermedia* zone) is the occurrence of oyster and molluscan shell fragments in the lower calcareous sandstone and the polymictic conglomerate beds that indicate near shore environment (Friedman & Sanders, 1978). All these environmental features assert that the *Elphidium macellum / Miogypsina intermedia* zone was deposited in very shallow inner shelf marine environments.

**Fig. 3:** Distribution of the Miocene foraminifera in Ras Al Shaqqah, Sirte Basin, NW Libya.
**2 - Globigerinoides trilobus Zone:**

The lower boundary of *Globigerinoides trilobus* interval zone of Blow (1969) is marked in the studied sections by the last occurrence of *Miogypsinia intermedia* Drooger. While its upper boundary is delimited by the first occurrence of *Borelis melo melo* Fichtel & Moll. It occupies the upper part of Al Faidiyah Formation from sample 17 to 20 and recorded only in Ras Al Shaqqah section (Fig. 2). It is characterized by the abundance of planktonic and benthonic foraminiferal species listed in figure 4. The benthonic foraminiferal association and the high proportion of the planktonic foraminifera over the benthonic ones as well as its association with argillaceous limestone beds (carbonate dominated facies) indicate that maximum depth of the Miocene transgression was occurred during the upper part of Al Faidiyah Formation suggesting deposition in inner to middle shelf marine environments. This is supported also by the absence of *Ammonia* and *Elpidium* couple and the first appearance of *Uvigerina barbutula* and *Cassidulina laevigata* that lived under deeper marine environments (Murray, 1991). Going upwards, a marked diminution in number and diversity of the planktonic foraminifera occurred over this interval. This sharpest decrease coinciding with the relatively rapid shallowing indicated between the *Globigerinoides trilobus* zone and the overlying *Borelis melo* zone (eustatic fall in sea level). Otherwise, a regressive phase occurred by the beginning of the *Borelis melo* zone and spanned the time of deposition of the uppermost of Al Faidiyah Formation. This interval is to great extent comparable with the global eustatic sea level lowering suggested by Haq *et al.* (1987) and combined with localized minor tectonic movement that played a role in the definition and distribution of Al Faidiyah Formation in the area.

Concerning the age assignment of this zone, many authors assigned it to the Early Miocene among them are El Kerdany (1967), El Heiny & Martini (1981), Imam (1986 & 1991 & 1997), Youssef *et al.* (1988), Rateb (1988); Haggag *et al.* (1990); Imam (1991 & 1997) who recorded this zone in the Gulf of Suez region, Egypt. Nassif *et al.* (1992) recorded the same nominated zone in the Miocene sequence of Wadi Feiran, southwest Sinai, Egypt and assigned the assemblage to an early Miocene (Burdigalian) age. Isamil & Abdel Ghany (1999) recorded also this zone in some Lower Miocene sections in Cairo – Suez road, Eastern Desert, Egypt. Imam & Refaat (2000) recorded also *Globigerinoides trilobus* zone from the early Miocene deposits of Wadi Abura and Gabal Hammam Sayidna Musa, southern Sinai, Egypt and dated it to an early Miocene (Burdigalian) age. This zone could be safely correlated with the standard planktonic foraminiferal zone N7 of Blow (1969) and also to the *Globigerinoides trilobus* zone of Iaccarino & Slavatorini (1982) and Iaccarino (1985) in The Mediterranean region. Therefore, it is safely to assigne this zone to early Miocene (late Burdigalian) age and assumes relatively open deep marine environments.

**3 - Borelis melo melo Zone:**

The *Borelis melo melo* zone is defined in the present study by the total range of the nominated zonal taxon, where its lower boundary is delineated on the first occurrence of *Borelis melo melo* Fichtel & Moll while the upper boundary is marked by its extinction where the Miocene – Pliocene unconformity is located. This zone is encountered in the studied sections covering the whole Al Khums Formation. It is characterized by the abundance of smaller and larger foraminifera (Listed in figures 4 and 5)

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**Fig. 4:** Distribution chart of Miocene foraminifera in Wadi Zaqlum, Sirte Basin, NW Libya.
The careful investigation of the argillaceous limestone beds and the white cream-coloured chalky limestone beds yielded low diversified planktonic foraminiferal association represented by: *Globigerinoides trilobus* (Reuss), *Gs. immaturus* Le Roy, *Gs. sacculifer* Brady, *Gs. subquadratus* Bronnimann, *Globigerina ciperoensis* Bolli, *Gg. praebulloides* Blow, *Globorotalia obesa* Bolli, *Gr. siakensis*, *Cassigerinella chipolensis* Cushman & Ponton, *Orbulina suturalis* Bronnimann, *Orbulina universa* d’Orbigny. These planktonic foraminiferal assemblages indicate deeper water environment than the *Borelis melo* association (shallow marine environment) and hence suggest progressive deepening of water. This zone could be correlated with the standard planktonic foraminiferal zone N8 and N9 of Blow (1969) and also to the *Praeorbulina glomerosa* and *Orbuina suturalis* zones of Iaccarino (1985) and Fornaciari et al. (1997), Foresi et al. (1998) and Jahanbakhsh & Leila, (2007) in The Mediterranean region. Consequently, this zone is assigned to Middle Miocene (Langhian to Early Serravallian) time.

It is noteworthy to mention that *Borelis melo* melo (Fichtel & Moll) is the most conspicuous large benthonic foraminiferal species recorded in this zone. Many authors have discussed the biostratigraphic and paleoenvironmental significance of this taxon as Middle Miocene index species. It was first described by Colem (1958) who recorded this taxon for the *Orbulina* spp. in the Middle Miocene strata that overlying the *Miogypsina mediterranea* beds of Majorca in Spain. Eames et al. (1962) recorded it associated with *Globorotalia fohsi fohsi* / *Orbulina* spp. zone and considered it as index large foraminiferal species marking the beginning of the Middle Miocene boundary. Souaya (1963a) recognized it with the *Miogypsina cushmani* zone in the Middle Miocene of Gabal Gharra, Cairo Suez road, Egypt. Later on, Souaya (1963b) reported it from the Middle Miocene – Pliocene succession in the Red Sea, Egypt. Reiss & Givertzmann (1966) showed that the presence of *Borelis melo* in the Middle to Upper Miocene Ziqlag Formation of Israel and attributed to zone N9 of Blow (1969). Bizon et al. (1968) and Clarke & Blow (1959) Wilson (2005) reported that *Borelis melo* ranges stratigraphically from base of zone N9 to Recent deposits. Moreover, Imam (1986, 1991, 1996 and 1999 a, b) reported this taxon in the algal reefal limestone deposits of the Middle Miocene Sarbut El Gamal Formation in west – central Sinai, Egypt. In Libya, Barr & Weegar (1972) recorded this species in Al Jabal Al Akhdar as a marker for the Middle Miocene beds. Later on, Sherif (1991) recorded this taxon from the middle Miocene deposits of Al Khums Formation. Imam (1997 & 1999 a, b) also defined this taxon in the Middle Miocene Al Jaghboub Formation in Al Bardia area, NE Libya. Imam & Refaat (2000) recorded also this taxon from the Middle Miocene Hammam Faroun Member of Belayium Formation and gave it a definite zone in Gabal Hammam Sayidna Musa and Wadi Abura, southern Sinai, Egypt. Imam (2002) recorded the *Borelis melo* zone from the middle Miocene Marmarica Formation in the Salum area, Western Desert, Egypt. Abul Nase et al.
(2009) also recorded this taxon from the Middle Miocene Hammam Faroun Member of Belayium Formation from the Miocene succession in the area between Wadi suder and Wadi wardan, Gulf of Suez region. From the above mentioned discussion, the presence of Borelis melo melo Fichtel & Moll in the present work with the association of representative forms of Praeorbulina spp., Orbulina universa in the argillaceous limestone interbeds give a strong support that the Al Khums Formation is of middle Miocene age (Langhian to Early Serravallian) age and could be correlated to zone N8 and N9 of Blow (1969) and Iaccarino (1985).

**Description Of The Main Microfacies Types:**

About 40 thin sections representing the studied two rock units and the different localities have been subjected to petrographic, microfacies and diagenetic studies. The carbonate microfacies study is described according to the classification of Dunham (1962), Wilson (1975), Flügel (1982), Tucker (1984) and Tucker & Wright (1990). While the study of the siliciclastics microfacies, the work of Folk (1974), Pettijohn (1975), Pettijohn et al. (1987) are adopted in the present work. In the following section, the main microfacies types recorded in the Miocene rock units are described. (Pl. 3, Fig.)

**Microfacies types of Al Faidiyah Formation:**

In the study area Al Faidiyah Formation is recorded only in Ras Al Shaqqah surface section and represented predominantly by in its lower part with siliciclastic dominated facies (polymictic conglomerate, calcareous sandstone, subordinate thin laminae of mudstone and claystone), while the upper part is represented by carbonate dominated facies (limestone and dolomite) with carbonate – siliciclastic dominated facies (argillaceous limestone and sandy limestone). In the following are the main microfacies types recorded in Al Faidiyah Formation.

1- **Polymictic conglomeratic Facies:**

This microfacies type is well developed in the basal part of Al Faidiyah Formation in Ras Al Shaqqah surface section (sample No.12) and decrease upward in the thickness and size of the clasts. They are dark yellow to brownish yellow, polymictic, hard consolidated, clast – supported, poorly to moderately sorted, mostly of different lithoclasts (carbonates and chert with subordinate quartz). The clasts are in the form of pebble and gravel sizes, rounded to subrounded, disoriented, slightly with imbricate structure especially at the base of the bed and shows also normal graded beds. Petrographically, the matrix is made up of coarse to fine, subangular to subrounded, disoriented, slightly with imbricate structure especially at the base of the bed and shows also normal graded beds. Petrographically, the matrix is made up of coarse to fine, subangular to subrounded, moderately sorted detrital quartz grains of monocrystalline type as well as glauconitic grains embedded in micrite matrix usually corroded the quartz grains. It is noteworthy of this matrix is partially recrystallized into sparite (Aggrading neomorphism) and also slightly recrystallized into pseudospars and minute dolomite rhombs. Slightly diversified bioclastic content such as fragmented oyster shells and corals, bryozoan fragments and echinoids spines as well as reworked large benthonic foraminifers are recorded.

2- **Calcareous Sublitharenite Facies:**

This microfacies type is recorded overlying the former microfacies type and represents the second dominated siliciclastic facies in the lower part of Al Faidiyah Formation (sample No.13). In the field the sandstones are yellowish white to greenish yellow, medium to fine grained with dense subangular to subrounded detrital quartz grains, highly calcareous with glauconitic grains. Cross- bedded and lamination are the most conspicuous primary structures recorded in this facies. Thin section investigation revealed that this microfacies consists mainly of subangular to subrounded, moderately sorted, detrital quartz grains of monocrystalline type with straight to slightly undulose extinction. This quartz grains form (80%) of the total framework (Pl. 3, Fig. 2). Lithic fragments are represented by different types of lithoclasts such as chert, detrital carbonates fragments and glauconitic grains embedded in micrite matrix usually corroded the quartz grains. It is noteworthy of this matrix is partially recrystallized into sparite (Aggrading neomorphism) and also slightly recrystallized into pseudo sparites and minute dolomite rhombs. Slightly diversified bioclastic content such as echinoids spines. The matrix also shows some idiotopic, zoned with dark nucleated core and clear outer peripheries, dolomite rhombs ranging in sizes from 20 to 130m.

3- **Sandy Bioclastic Packstone / Grainstone Facies:**

This facies type is distinguished at the upper part of Al Faidiyah Formation at Ras Al Shaqqah section covering the samples Nos. 15 & 17. It is composed mainly of skeletal bioclastics forming more than 60% of the total framework, intraclastic particles 20% and detrital quartz grains of 20%. Petrographically, the bioclasts are represented commonly by molluscan shell fragments, echinoid spines, fragmented corals and coralline red algae such as Lithophyllum spp. and Lithoporella spp. Small amount of minute size planktonic foraminifera (mainly of the family Globigerinoides) and large benthonic foraminifers such as Operculina spp., Miogypsina spp. and Amphistegina spp. (Pl. 3, Fig. 3 ). The intraclasts are depicted in the presence of dark carbonate clasts of micritic composition, some detrital subangular chert clasts and subangular to subrounded, fine to medium, moderately sorted detrital quartz grains of monocrystalline type as well as glauconitic and argillaceous patches. All these
constituents are embedded in micrite matrix that partially recrystallized into microsparite cement.

4- Argillaceous foraminiferal Wackestone/ Packstone Facies:
The rocks of this facies is recorded in the upper part of Al Faidiyah Formation (samples Nos. 16 & 18) and commonly interbedded with the previous sandy bioclastic packstone / grainstone facies. In the field it is composed of grey to dark yellowish grey, hard, partly massive, fossiliferous argillaceous limestone interlayered with thin laminae of whitish grey fossiliferous mudstone. Thin section investigations revealed that this facies consists mainly of more than 80% of the total framework of planktonic foraminifera in the form of *Globigerina* spp., *Globigerinoides* spp. and *Globorotalia* spp. as well as small tests of benthonic foraminifera such as *Bulimina* spp., *Bolivina* spp., and *Cancris* spp. Minor amounts of detrital silt – sized quartz grains, angular chert lithoclasts and dark micritic carbonate pellets (20%) are also existed (Pl. 3, Fig. 4). These biogenic constituents are entbodded in microcrystalline micrite matrix with argillaceous materials.

5- Dolomitic silty Wackestone Facies:
This facies type is recorded only in the uppermost part of Al Faidiyah Formation at Ras Al Shaqqah section (sample No. 19). In the field it is composed of grey to dark grey, hard, massive, fossiliferous dolomitic limestone. Thin section investigation revealed that it consists predominantly of porous clotted micrite with moderately preserved planktonic and benthonic foraminiferal tests. Other bioclastic constituents are manifested in the presence of echinoid and other shell fragments (Pl. 3, Fig. 5) as well as badly preserved reworked skeletal coralline algae. Glauconitic grains and scattered silt - sized quarts grains are also embedded in the micrite matrix. Dolomitization affected the micritic matrix in the form of fine grained, 4 –20 µm in size, dolomite rhombs with cloudy core and clear outer rims This facies type reflects deposition in shallow shelf marine environments representing slightly regressive environment toward the end of Al Faidiyah Fm. depositional time.

Microfacies types of Al Khums Formtion:
In the study area Al Khums Formation is represented predominantly by carbonate-dominated facies (sandy algal limestone 60% and chalky limestone 30%, dolomitic limestone 10%) and subordinate siliciclastic facies in the form of minor thin laminae of sandstone, mudstone and claystone. In the following are the main microfacies types recorded in this unit:

1- Dolomitic Sublitharenite Facies:
This microfacies type is recorded in the lower part of Al Khums Formation (An Naggazah Member). It is recorded in Wadi Zaqlum section (sample No. 94), Ras Al Shaqqah (sample Nos. 20 & 21) and Qabilt Ash Shurfa (sample Nos. 60 & 61). In the field the sandstone is cross- bedded, laminated, yellow to yellowish white, medium to fine grained with dense subangular to subrounded detrital quartz grains, moderately sorted, highly calcareous with dolosparry calcite cement. Thin section investigation revealed it consists predominantly of subangular to subrounded, moderately sorted, detrital quartz grains of monocrystatine type that constitutes more than 80% of the total framework. Few detrital quartz grains of polycrystalline nature with undulose extinction are also observed (Pl. 3, Fig. 6). The lithoclasts are represented by chert and detrital microcrystalline carbonates fragments embedded in micrite matrix. This facies type shows some fossiliferous thin laminae with benthonic foraminifera in the form of small tests of *Nodeseria* spp. and *Bolivina* spp. and reworked skeletal coralline algae (*Lithoporella* spp. and *Lithophyllum* spp.), bryozoans fragments as well as echinoid spines. The matrix is usually corroded the quartz grains depicted in the presence of engulfed quartz grains. The matrix also shows some idiopotic, zoned with dark nucleated core and clear outer peripheries, dolomite rhombs ranging in sizes from 10 to 100µm.

2- Algal Coral Framestone / Boundstone Facies:
This facies type is represented in the field by coralline patch reefal deposits. The geometry of this unbedded facies suggests a biothermal development rather than biostromal development that locally developed above the submarine paleohighs. It is located in the lower part of Al Khums Formation (An Naggazah Member) and recorded in Wadi Zaqlum section (sample No. 101), Ras Al Shaqqah (sample Nos. 24 & 30) and Qabilt Ash Shurfa (sample Nos. 63 & 64). This facies is represented by fairly high proportion, thick accumulation of organic organisms commonly contain scattered in situ hermatypic corals, molluscan shell fragments, bryozoans, ostracods, large benthonic foraminifers (*Borelis melo melo* Fichtel & Moll, *Amphistegina lessonii* Brady, *Oerculina complanata* Defrance, *Miogypsina* sp., *Ammonia* sp. (Pl. 3, Fig. 7) and rhodoliths up to 5 cm in diameter (frame builders) bounded by highly diversified coralline red algae in the form of *Lithophyllum* spp., and *Lithoporella* sp. Petrographic investigation revealed that the ground mass of this microfacies type is composed essentially of bioclastic constituents (70%), coralline red algae (20%) and 10% of detrital quartz grains tightly packed in granular sparry calcite cement. It is noteworthy of mention that some corals are partially recrystallized into pseudospar or dolomitized into coarse granular rhombs while the interseptal cavities are filled
with micritic matrix.

3- Algal dolomitic Facies (Algal Wackestone / Packstone Facies):
This facies type is recorded in the upper part of Al Khums Formation (Ras Al Mannubiyah Member). It is greyish white, to yellowish grey, massive hard, fossiliferous with algae and oyster shell fragments, dolomitic limestone. Petrographically, this facies is composed mainly of abundant crustose coralline red algae such as Lithophyllum spp., Mesophyllum spp., Lithoporella spp. and Corallina spp (Pl. 3, Fig. 8). Other bioclastic components are represented by fragmented corals and molluscan shell fragments, benthonic foraminifera and echinoids spines. The lithoclasts are represented by subangular to subrounded, fine to medium, moderately sorted detrital quartz grains and chert clasts embedded in dolomitized microporous cement. Dolomitization has also affected the matrix where idiomorphic rhombic dolomite crystals with distinct cloudy zoning (dark nucleated core and clear outer rim) make up about 20% of the matrix.

4- Sandy Foraminiferal Wackestone / Packstone Facies:
The rocks of this facies are recorded in the middle part of Al Khums Formation (Ras Al Mannubiyah Member). In the field it is distinguished by its greyish white to grey, crumbly, partly massive, fossiliferous argillaceous chalky limestone that interlayered with thin laminae of whitish grey fossiliferous mudstone. Petrographically, this facies consists mainly of more than 70% of the total framework of small sized planktonic foraminifera in the form of Globigerina spp., Globigerinoides spp. and Globorotalia spp. (Pl. 3, Fig. 9) as well as small tests of benthonic foraminifera such as Bulimina spp., Bolivina spp., Minor amounts of detrital silt – sized quartz grains, angular lithoclast and dark micritic carbonate pellets (30%) are also existed. These biogenic constituents are entombed in microcrystalline micrite matrix with argillaceous materials.

5- Sandy Bioclastic Algal Packstone / Grainstone Facies:
This facies type generally represents the coralline algal limestone beds in the uppermost part of Al Khums Formation (uppermost part of Ras Al Mannubiyah Member) in the three studied sections, in Ras Al Shaqqah (samples from 47 – 50) and in Wadi Zaqlum (samples from 112 – 117) and in Qabilat Ash Shurfah (samples from 83 – 90). This facies type forming prominent white to yellowish white, massive to porous, fossiliferous, cavernous (with honeycomb structure) coralline algal limestone. Petrographically, this facies is composed mainly of bioclasts and skeletal coralline algae in the form of algal nodules which presents the most conspicuous component of this facies (80% of the total framework), intraclastic grains (15%) and lithoclasts and detrital quartz grains of 5% of the total framework. The bioclasts are represented by molluscan shell fragments, echinoid plates and spines, bryozone fragments and fragmented corals (20% of the total bioclasts). The other bioclastic types are depicted in the presence of in situ coralline algal nodules. Other bioclasts are occurred in the form of subordinate amounts of planktonic and benthonic foraminifera e.g. Borelis melo, Amphistegina spp., Textularia spp. and miliolides (Pl. 3, Fig.10). The intraclasts are showed in the presence of subangular to subrounded, fine to medium, moderately sorted detrital quartz grains with subordinate chert clasts and reworked carbonate pebbles. All these constituents are embedded in sparry calcite cement suggested deposition under high-energy shallow marine environments favorable for reef growth. Sparry calcite cement usually blocky and coarse and developed syntactially around the echinoid spines and fragments. Moreover, some of the bivalve shells are partially leached leaving moulds filled with drusy calcite.

Depositional Environments Of The Studied Miocene Sequence:
The paleocological interpretation (vertical oscillation of the depositional environments) in this study is based essentially on the mutual relationship of the lithofacies, field observations, the environmentally diagnostic planktonic and benthonic foraminiferal assemblages and the coralline red algal content, together with the different microfacies association types recorded as well. Ras Al Shaqqah succession is taken as a reference section as it represented by the two Miocene rock units. The rocks of this facies is composed mainly of abundant crustose coralline red algae such as Lithophyllum spp., Mesophyllum spp., Lithoporella spp. and Corallina spp (Pl. 3, Fig. 8). Other bioclastic components are represented by fragmented corals and molluscan shell fragments, benthonic foraminifera and echinoids spines. The lithoclasts are represented by subangular to subrounded, fine to medium, moderately sorted detrital quartz grains and chert clasts embedded in dolomitized microporous cement. Dolomitization has also affected the matrix where idiomorphic rhombic dolomite crystals with distinct cloudy zoning (dark nucleated core and clear outer rim) make up about 20% of the matrix.

4- Sandy Foraminiferal Wackestone / Packstone Facies:
The rocks of this facies are recorded in the middle part of Al Khums Formation (Ras Al Mannubiyah Member). In the field it is distinguished by its greyish white to grey, crumbly, partly massive, fossiliferous argillaceous chalky limestone that interlayered with thin laminae of whitish grey fossiliferous mudstone. Petrographically, this facies consists mainly of more than 70% of the total framework of small sized planktonic foraminifera in the form of Globigerina spp., Globigerinoides spp. and Globorotalia spp. (Pl. 3, Fig. 9) as well as small tests of benthonic foraminifera such as Bulimina spp., Bolivina spp., Minor amounts of detrital silt – sized quartz grains, angular chert lithoclast and dark micritic carbonate pellets (30%) are also existed. These biogenic constituents are entombed in microcrystalline micrite matrix with argillaceous materials.

5- Sandy Bioclastic Algal Packstone / Grainstone Facies:
This facies type generally represents the coralline algal limestone beds in the uppermost part of Al Khums Formation (uppermost part of Ras Al Mannubiyah Member) in the three studied sections, in Ras Al Shaqqah (samples from 47 – 50) and in Wadi Zaqlum (samples from 112 – 117) and in Qabilat Ash Shurfah (samples from 83 – 90). This facies type forming prominent white to yellowish white, massive to porous, fossiliferous, cavernous (with honeycomb structure) coralline algal limestone. Petrographically, this facies is composed mainly of abundant crustose coralline red algae such as Lithophyllum spp., Mesophyllum spp., Lithoporella spp. and Corallina spp (Pl. 3, Fig. 8). Other bioclastic components are represented by fragmented corals and molluscan shell fragments, benthonic foraminifera and echinoids spines. The lithoclasts are represented by subangular to subrounded, fine to medium, moderately sorted detrital quartz grains and chert clasts embedded in dolomitized microporous cement. Dolomitization has also affected the matrix where idiomorphic rhombic dolomite crystals with distinct cloudy zoning (dark nucleated core and clear outer rim) make up about 20% of the matrix.
shallow marine inner shelf environments as evidenced by the low planktonic/benthonic ratio, the co-occurrence of *Heterolepa dutemplei* and *Ammonia becarii* with the predominance of *Elphidium* spp., and *Nonoin scaphum* in addition to low diversity of its coralline red algal content together with their microfacies.

Fig. 1: Polymictic conglomeratic Facies, subrounded to subangular detrital chert clasts in argillaceous micritic matrix with some dolomites rhombs, Al Faidiyah Fm., Ras Al Shaqqah section.

Fig. 2: Calcareous sublitharenite Facies, subrounded to subangular detrital quartz grains with lithic fragments of feldspars and glauconitic grains in microcrystalline calcitic matrix, Al Faidiyah Fm., Ras Al Shaqqah section.

Figs. 3: Sandy bioclastic Packstone/Grainstone Facies, subrounded to subangular detrital quartz grains with dark micritic clasts and bivalved shell fragment in sparry calcite cement, Al Faidiyah Fm., Ras Al Shaqqah section.

Fig. 4: Sandy bioclastic Packstone/Grainstone Facies, benthonic foraminifera, *Textularia* sp., with coralline red alga and minute planktonic foraminifera in micritic matrix, Al Faidiyah Fm., Ras Al Shaqqah section.

Fig. 5: Argillaceous foraminiferal Wackestone/Packstone Facies, planktonic foraminifera *Globigerinoides* spp, filled with sparry calcite cement (Intragranular cementation) associated with other planktonic foraminifera in micritic matrix, Al Faidiyah Fm., Ras Al Shaqqah section.

Fig. 6: Dolomitic silty Wackestone Facies, minute dolomitic rhombs with fine to silt sized quartz grains and echinoid spine in argillaceous micritic matrix, Al Khums Fm., Qabilt Ash Shurfah section.

Fig. 7: Sandy foraminiferal Wackestone/Packstone Facies, Large sized foraminiferal tests, *Lithophyllum* sp and *Textularia* sp with dark micritic patches and very fine detrital quartz grains in partially recrystallized micritic matrix, Al Khums Fm., Ras Al Shaqqah section.

Fig. 8: Sandy bioclastic algal Packstone/Grainstone Facies, transverse section in corallite showing septa and columella, the cavity filled with coarse sparry calcite. (10): enlarged section of echinoid spine filled with micritic matrix, Al Khums Fm., Wadi Zalqum section.

Fig. 9: Algal coral Framework/Boundstone Facies, (1): benthonic foraminifera, Texturalia sp. with dark peripheries and long slender echinoid spine, Al Khums Fm., Wadi Zalqum section.

Fig. 10: Algal dolomicritic Wackestone/Packstone Facies, (3): foralgalith of peripheral filaments and subangular detrital quartz grains in partially dolomitic sparry calcite cement, Al Khums Fm., Qabilt Ash Shurfah section.
Fig. 7: Suggested Depositional environments of the studied Miocene sections Sirte Basin, NW Libya

associations, all these characters indicate shallow marine conditions with depth less than 20m (Douglas, 1979; Boersma, 1983; Murray, 1991). Going upwards, this previous zone is overlain conformably by *Globigerinoides trilobus* zone (upper part of Al Faidiyah Formation) which has been formed in an environments deeper than the underlying zone (inner to middle shelf environments reflecting increasing in the water depth of the basin). This deepening upward is supported also by high planktonic / benthonic ratio and the presence of deep benthonic foraminiferal species such as *Uvigerina barbatula*, *Bulimina alazanensis*, and *Cassidulina laevigata*. All these evidences indicate inner to middle shelf marine environments. By the beginning of the middle Miocene (Langhian to Early Serravallian) times, tectonic pluses occurred and caused an episoid of relative regression of the sea and reactivation of some of the main faults in the area. This short regressive phase corresponds to the presence of siliciclastics (coarse to medium calcareous sandstones) at the lowermost parts An Naggazah Member of Al Khums Formation (Figs. 8 & 9). Then the water depth increases gradually through the advent of the sea water where shallow marine carbonate dominated facies increases upwards. Bioherinal limestones are locally developed as patch reef on the structurally paleohighs. It is abundant with corals, bryozoa, shell fragments, large benthonic foraminifera and well-diversified coralline red algae. This shallow marine condition was prevailed all over the deposition of An Naggazah Member and continued to the lower part of Ras Al Mannubiyah Member. But by the beginning of the deposition of middle part of Ras Al Mannubiyah Member (chalky limestone), the conditions changed to slightly deep marine environments (inner to middle shelf) where the planktonic / benthonic ratio increased accompanied by low diversity of coralline red algae. Then the sea become so shallow (inner shelf) that thick sequence of algal reefal limestones were deposited in the upper part of Ras Al Mannubiyah Member of Al Khums Formation. This lowering of the sea level cannot be interpreted on the basis of the eustacy but some localized uplift should take in consideration which enhanced the effect of the sea level lowering during the end of the deposition of Ras Al Mannubiyah Member (regressive phase).

**Summary & Conclusions:**

The study of the transgressive Miocene deposits in Al Kums area, NW Sirte basin, Libya are focused mainly on three stratigraphic sections; they are Qabilat Ash Shurfah, Wadi Zaqlum and Ras Al Shaqqah sections. The study revealed valuable informations on the lithostratigraphy, biostratigraphy (both of foraminiferal and algal association) and the main different depositional environments. The lithostratigraphic studies allowed to subdivide the Miocene succession into two main rock units, arranged from base to top as follows: 1- Al Faidiyah Formation (early Miocene) and 2- Al Khums Formation (middle Miocene). The Al Faidiyah Formation is locally developed only in Ras Al Shaqqah section (15m thick) where it overlies unconformably the Late Cretaceous Sidi As Sid Formation and underlies conformably the Al Khums Formation. This unit is differentiated in the field into two main lithofacies types. The lower lithofacies is siliciclastic dominated one
(polymictic conglomerates and calcareous sandstone with few shale and argillaceous limestone thin bands) and typified with the Elphidium macellum / Miogypsina intermedia assemblage zone. The upper part is carbonate-dominated facies (sandy limestone interbedded with argillaceous limestones) encompasses the Globigerinoides trilobus Zone. The field observations, foraminiferal assemblage and coralline algal association as well as the microfacies types indicate that the lower part of the formation was deposited in alluvial fan followed upward with invasion of the proper shallow marine water environment meanwhile its upper part was deposited under relatively deep marine conditions (middle shelf environments) with fluctuation in the sea level. The Al Faidiyah Formation is assigned to early Miocene (late Burdigalian) age on the basis of its foraminiferal and coralline algal content. The overlying Al Khums Formation (middle Miocene) is recorded in the three studied sections, attaining a thickness of 35 m, 40 m and 50 m in Ras Al Shaaqah, Wadi Zaqlum and Qabilat Ash Shurfah sections respectively. It commonly outcrops directly and sometimes over lain by Quaternary deposits. Where it overlies unconformably the Late Cretaceous Sidi As Sidi Formation as in Wadi Zaqlum and Qabilat Ash Shurfah sections and overlies conformably the early Miocene Al Faidiyah Formation. In the field, it is represented mostly by shallow carbonate-dominated facies ranged from fossiliferous algal sandy limestone and argillaceous limestone beds at the lower part of the formation (An Naggazah Member) to coralline nodular limestone and subordinate dolomitic limestone and argillaceous to chalky limestone interbeds in the upper part (Ras Al Mannubiya Member). This unit includes the large benthonic foraminiferal Borelis melo melo zone. The field observations, foraminiferal and coralline algal content as well as the microfacies types recorded, suggest that this formation was deposited in shallow warm marine environments (inner shelf facies) with relative sea level fluctuations from inner to middle suites. The high diversity of the foraminiferal content with the other macrofaunal one indicates open circulation as well. The presence of the large benthonic foraminifera such as Borelis melo melo and Heterostegina costata costata, in addition to the rarity of planktonic foraminiferal species Orbulina universa, O. suturalis in the argillaceous to chalky limestone strongly asserted that this formation is assigned to middle Miocene (Langhian to early Serravallian) age.

Fig. 8: Correlation chart of the studied Miocene sections, Sirte Basin, NW Libya
Fig. 9: Suggested Depositional environments of the studied Miocene sections, Sirte Basin, NW Libya

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