Petroleum Res. J. Vol. 19 (2006); P. 49–60, 4 Figs.

Sedimentary Facies and Foraminifera of the Miocene Carbonates of the Ar Rajmah Group in Cyrenaica, NE-Libya

Esam O. Abdulsamad* and Fawzi M. Bu-Argoub**

السحنات الترسيبية ومنخربات عصر المايوسين للرواسب الكربوناتية لمجموعة الرجمة، شمال شرق ليبيا

عصام عمر عبد الصمد وفوزي محمد بوعرقوب

لقد تمت دراسة الرسوبيات الكلسية لعصر المايوسين التابعة لمجموعة الرجمة وذلك بمنطقتين مختلفتين بجنوب شرق مدينة بنغازي. وبناء على تحليل السحنات الدقيقة والمنخربات القاعية المصاحبة لها والمتواجدة بالرواسب الأحاثية، أمكن تقسيم الرسوبيات حسب تصنيف وولسن للسحنات القياسية الدقيقة المعروف بنطاقات السحنات الكلسية. وبهذه النطاقات تم تمييز ووصف 10 سحنات دقيقة مختلفة. لقد وجد أن رواسب مجموعة الرجمة قد ترسبت تحت ظروف بيئية تتواجد بمصطبات مفتوحة (تكوين بنغازي) ومصطبات بحرية وملحية محصورة (تكوين وادي القطارة) على التوالي.

وبالرغم من استبعاد تفاصيل تتعلق بالطبقية الحياتية لغياب الحفريات الدالة على العمر النسبي، فقد تمت محاولة مضاهاة المتكشفات للرواسب المدروسة و نسبتها إلى العصر المايوسيني الأوسط والمتأخر.

Abstract: *The Miocene carbonates from two different localities of the Ar Rajmah Group have been investigated and examined in the southeast of Binghazi. Based on microfacies analysis and associated benthic foraminifera recovered from the washed residues, the sediments are classified into Wilson's standard microfacies carbonate facies belts. In these shallow marine belts, 10 different microfacies have been distinguished and described. The sediments of the Ar Rajmah Group were deposited under open platform (Binghazi Formation), restricted platform and restricted lagoon-salina conditions (Wadi al Qattarah Formation) respectively.*

Biostratigraphic details are excluded due to the lack of age diagnostic-taxa. However an attempt to correlate the studied outcrops with the Middle and Late Miocene deposits has been outlined.

* Earth Sciences Department, Garyounis University. P. O. Box: 9480, Benghazi, Libya. Email: esam000@yahoo.com
** Exploration Division, Arabian Gulf Oil Company, P. O. Box: 263, Benghazi, Libya. Email: fbuargoub@yahoo.com

INTRODUCTION

The Upper Cretaceous lower Tertiary successions in Al Jabal al Akhdar of Cyrenaica, have been subjected to extensive studies. On the other hand studies on the Miocene and younger deposits have been relatively sparse. In an attempt to improve observation on the depositional history of the Miocene deposits in Cyrenaica, this paper describes in detail the palaeontological and stratigraphic features of these deposits on the basis of microfacies analysis and the matrix-free foraminifera. The obtained results, are used to reconstruct the palaeoenvironmental history of the region. In general,

each of the two main lithostratigraphic units, making up Ar Rajmah Group, represent a shallowing up sequence. These developed in various parts of a shelf-carbonate platform complex with dolomitized biotic content.

The study area is located between 31°.30' to 32°.30' N latitude and 20° to 21°E longitude (Fig. 1). The Miocene deposits of the Ar Rajmah Group have been recognized and measured from two localities in southeast Binghazi. The first is a road-cut exposure along the Soluq-Al Abyar highway and the second exposure is situated at the dam site of Wadi al Qattarah (Fig. 1).

The Ar Rajmah Group was first named by Desio (1935) as Regima Limestone, after the village of Ar Rajmah about 30 km east of Binghazi City in northern Cyrenaica where a sequence of fossiliferous Tortonian limestone is exposed (Banerjee, 1980). Barr and Weegar (1972), however, included the whole Middle Miocene sequence of northern Cyrenaica in Ar Rajmah Formation. Later work, based on the lithology and faunal content, the same deposits were dated Middle Miocene in age and divided by Klen (1974) and Röhlich (1974) into two members, namely the Wadi al Qattarah Member and the Benghazi Member. However, El-Hawat and Salem (1987) recognized a major unconformity dividing the succession into two correlatable units, led to the establishment of two separate sequences. The lower sequence, Binghazi Member, was assigned to the Middle Miocene, while the upper sequence, Wadi al Qattarah Member, was assigned to the Late Miocene. More recently, Ar Rajmah has been raised into a group and these two Middle-Late Miocene members have been raised to formations status (El-Hawat and Abdulsamad, 2004).

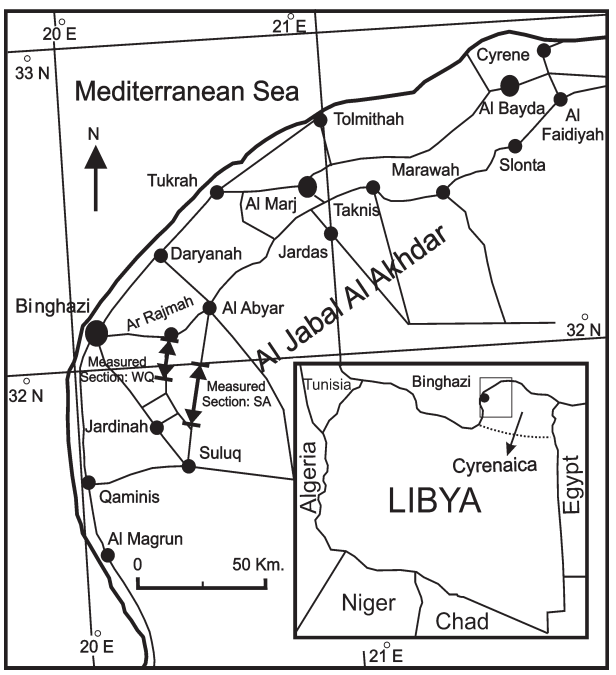


Fig. 1. Index map of NE Libya and the location of the measured sections. (WQ: Wadi al Qattarah and, SA: Soluq-Al Abyar).

In general, with the exception of El-Hawat (1980) and El-Hawat and Salem (1987), who describe the sedimentology and palaeogeography of the Ar Rajmah Group, detailed studies from the Miocene succession in northern Cyrenaica are few, whereas they are numerous from elsewhere in the Tethyan realm.

MATERIALS AND METHODS

About 40 samples, collected at a maximum interval of 7m from the visited outcrops, were processed for microfacies analysis. Hard samples were then processed for thin-section preparations. Soft samples were crushed and disaggregated by hydrogen peroxide solution and washed through a 63-μm sieve. Particular attention was given to the foraminiferal specimens, as they are the main group in the study material.

The studied materials have been deposited at the Geological Museum, Earth Sciences Department, University of Garyounis (Binghazi, Libya).

STRATIGRAPHY

The Ar Rajmah Group is the youngest pre-Quaternary deposit in the studied area. It occupies a broad area in the northwestern region of Cyrenaica consisting of two formations, the lower Binghazi Formation and the upper Wadi al Qattarah Formation. The total exposed thickness of these deposits attains about 100m in the southern part of the studied region, while in the subsurface, it reaches more than 250m (Klen, 1974).According to this author, the Ar Rajmah Group consists of a sequence of light fossiliferous limestone and crystalline dolomitic limestone interrupted by some units of marlstone, calcareous clay and irregular lenses of gypsum at upper levels.

In the present study, the Ar Rajmah Group has been recognized and measured from the Soluq-Al Abyar and Wadi al Qattarah Sections. It is worth noting, that the upper and lower contacts in both localities are not exposed throughout the study area. In both sections, the lower Binghazi Formation has been dated as Middle Miocene based on the presence of *Lepidocyclina* (*Eulepidina*) cf. *dilatata*

(Michelotti) (Plate 1f) and *Borelis melo melo* (Fichitel and Moll) (Plate 2b). The later taxon was recognized in different local areas at the same time-interval (Berggren, 1967; Sherif, 1991; Abdulsamad, 1999; Abdulsamad and Barbieri, 1999). The disappearance of the Late Oligocene to Middle Miocene taxa, *Borelis melo melo* and the *Lepidocyclina* (*Eulepidina*) cf. *dilatata,* in the upper Wadi al Qattarah Formation, suggests a late Miocene age. This assumption may explain the occurrence of a number of lenses and irregular bodies of gypsum of the Messinian event in Cyrenaica. An attempt to correlate the studied outcrops, based on stratigraphical and palaeontological criteria, is illustrated in Figure 2.

Soluq -Al Abyar Section

This outcrop has a total exposed thickness of about 50m and consists of several limestone units ranging in age from Middle to Late Miocene (Fig. 3). The lower levels, which include a skeletal complex unit at the base, represent the Binghazi Formation. It is 20m thick, medium to thick bedded, whitish to grey and relatively soft limestones. This unit is almost dominated by large-sized and attached-pelecypods (notably, oysters), and frequently by high-spired and recrystallized gastropoda. Ovoid, inflated and infaunal echinoids (*Echinolampas*) of about 12cm in diameter mark the top of this unit. Here, the skeletal unit is terminated by the presence of 2m of medium to thick bedded and yellowish marly limestone.

The above unit, however, belongs to the Wadi al Qattarah Formation and is dominated by a yellowish to brown bioturbated limestone of about 10m thick, which rests disconformably above the skeletal complex unit. At this level, elongated pelecypoda shells of cylindrical form, are commonly found preserved in their burrows. Small gastropods (*Conus* spp.) also occur. Up-section, the studied sequence consists of a fine to coarse-grained white to earthy lower gypsum layer approximately 30cm thick, lying above the previously bioturbated unit. The gypsum exhibits white to earthy color and characterized by fine to coarse-grained. A gypsum layer of the same thickness is found in the upper part of the sequence. A massive and well-bedded dolomitic limestone of about 8m thick is sandwiched between the two gypsum layers mentioned earlier. Above the upper gypsum layer, lies a 2m thick, hard and dirty limestone. Here two sets of planar cross-beds are well developed. The upper most part of the examined sequence, however, contains a number of lenses and irregular bodies of gypsum, interbedded with soft marly limestones and infrequently hard limestones, reaching more than 10m in thickness.

Wadi al Qattarah Section

This land section ranges in age from Middle to

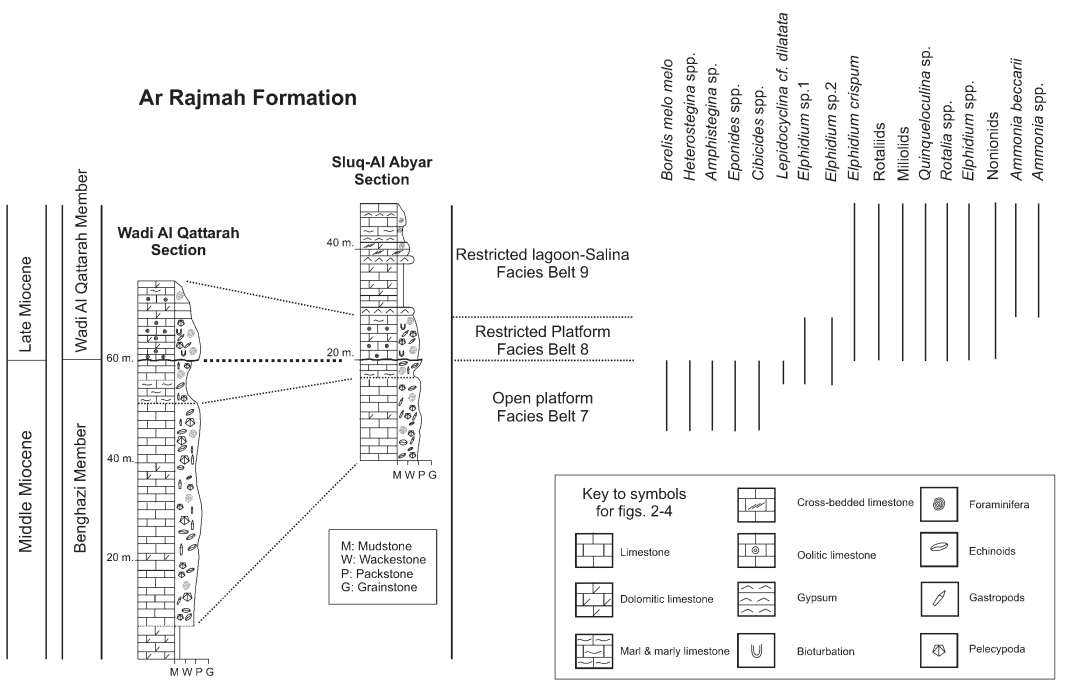
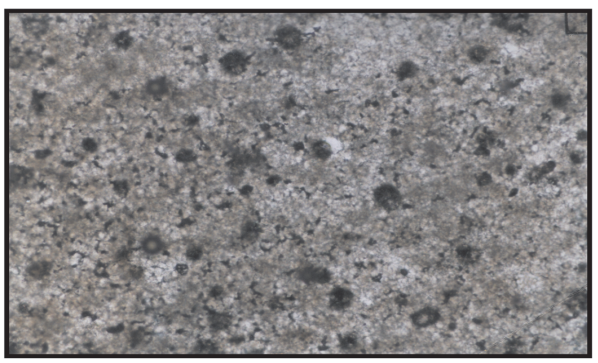
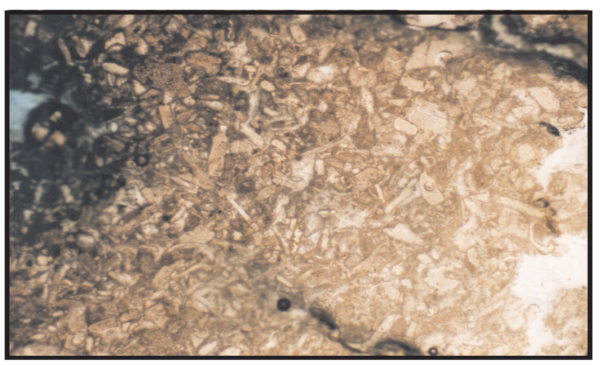


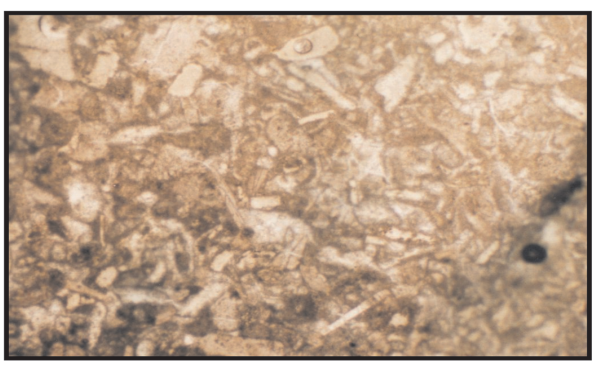
Fig. 2. Stratigraphic logs, correlation and the distribution of benthic foraminifera in Ar Rajmah Group.



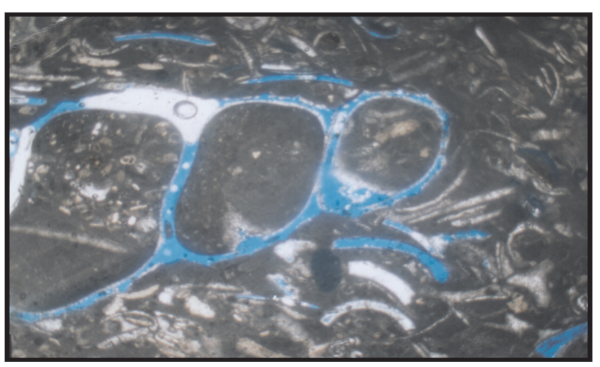
a



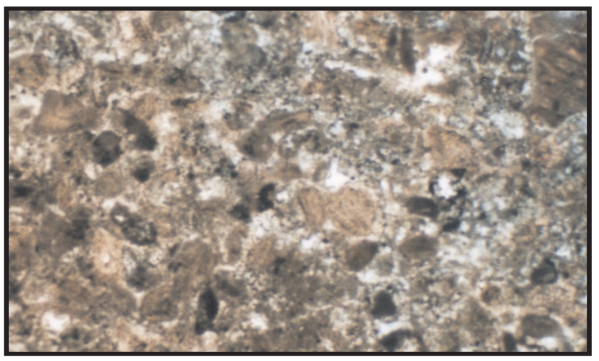
b



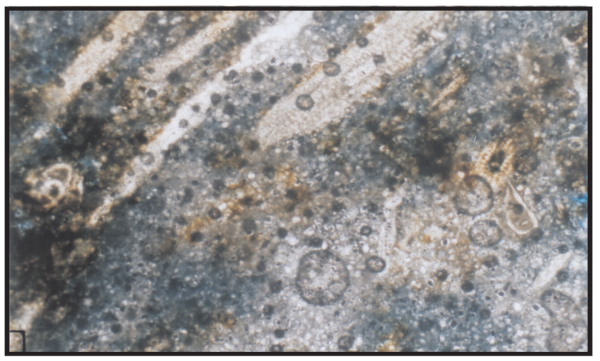
c



d



e



f

Plate - I

Plate I - a — General view of microfacies A, coarsely crystalline dolomitic limestone with faecal pellets (dark areas). Lower part of the Binghazi Formation, Wadi al Qattarah Section (Fig. 4), X 25.

Plate I - b and c — General views of microfacies B, poorly sorted wackestone to packstone with fine to coarse-grained matrix that largely consists of skeletal remnants of echinoderms and mollusk. Lower and middle parts of the Binghazi Formation, Soluq-Al Abyar Section (Fig. 3), X 25.

Plate I - d — General view of microfacies B, poorly sorted wackestone to packstone with geopetal sediment within a gastropoda. Fragments of thick-shelled pelecypods are abundant also. Middle part of the Binghazi Formation, Wadi al Qattarah Section, X 50.

Plate I - e — General view of microfacies C, packstone with pellets of micrite. Calcareous red algae and echinoderm fragments are present also. Upper parts of the Binghazi Formation, Soluq-Al Abyar Section, X 25.

Plate I - f — General view of microfacies C, wackestone with *Lepidocyclina* (*Eulepidina*) cf. *dilatata* (Michelotti). Skeletal remnants of echinoderms and mollusk are also present. Upper parts of the Binghazi Formation, Wadi al Qattarah Section, X 25.

Late Miocene and has a total exposed thickness of about 75m (Fig. 4). The base of this section is marked by the presence of a medium to thick bedded, whitish grey and poorly fossiliferous dolomitic limestone unit. It is 7m thick, followed by a skeletal complex unit of about 44m of primarily thick bedded, whitish to grey and relatively soft limestone. As in Soluq-Al Abyar Section, this unit is characterized by the presence of large-sized and attached-pelecypods and consistantly by highly-spiral gastropoda. Ovoid, inflated and infaunal echinoids are common. Unlike Soluq-Al Abyar Section, the yellowish marly limestone unit, which capped the previous unit is quite thick and reaches about 9 m. Here, the macro-fauna are reduced to remains of mollusks and echinoid spines and mark the top of the Binghazi Formation. The youngest unit, investigated in this outcrop, is about 15m thick and belongs to the Wadi al Qattarah Formation. It consists mainly of medium to thick bedded, yellowish to grey limestones. Bioturbation, dolomitization and other features of subaerial origin are quite common at these levels. This unit is separated from the underlying unit by a disconformity. The lenses and irregular bodies of gypsum interbedded with soft marly limestones, seen in the uppermost part at Soluq-Al Abyar section, are missing here.

MICROFACIES ANALYSIS

The microfacies analysis of two Miocene land-sections, namely Soluq-Al Abyar and Wadi al Qattarah, in Cyrenaica provides more detailed information than the preceding general description. Samples from two formations, Binghazi and Wadi al Qattarah, were examined and the results were presented as a number of associations summarized in Figures 3 and 4, and illustrated in plates 1-3.

The microfacies, described in this study, are similar to those discussed by Wilson (1975) and Flügel (1982). The establishment of these microfacies is based on sedimentological criteria and nature of the biotic components,

The associations present in each formation are described below:

Microfacies A

This microfacies corresponds to the lower part of the Binghazi Formation in Wadi al Qattarah Section (Fig. 4). It consists of greyish white and medium bedded dolomitic limestones. Microscopic studies of the base of this unit, indicate a porous texture, filled occasionally with ferro-calcite cement. The outlines of original allochems have been preserved as ghost texture, while the intercrystal porosity is quite good. Up-section, this microfacies becomes more dolomitic as the original calcite matrix is replaced by dolomite. The micrite allochems (peloids) have resisted dolomitization and are only partly replaced (Plate 1a). At this level, remains of mollusks and dwarfed benthic foraminifera have been noted. Similar texture, however, has been distinguished at some levels within the upper most part of the Wadi al Qattarah Formation in Soluq-Al Abyar section.

Microfacies B

This unit represents the lower and middle parts of the exposed Binghazi Formation in the studied sections (Figs. 3 and 4). It consists of poorly sorted wackestones to packstones with fine to coarse-grained matrix which largely consists of skeletal remains of echinoderm and mollusk origin (Plate 1b and c).

Oysters (calcitic bivalves) comprise most of the bioclasts and are made-up almost entirely of large fragments reaching, at outcrop-scale, about 10 cm in diameter. The rest of the sediments consist of bioclasts set in micrite, although patches of sparite cement are present also. Syntaxial overgrowths and geopetal

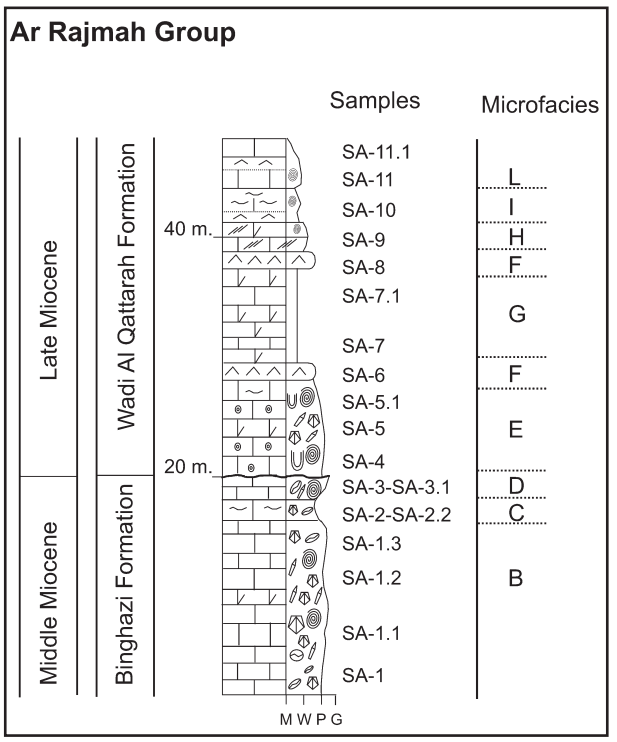


Fig. 3. Stratigraphic log and microfacies of Soluq-Al Abyar Section.

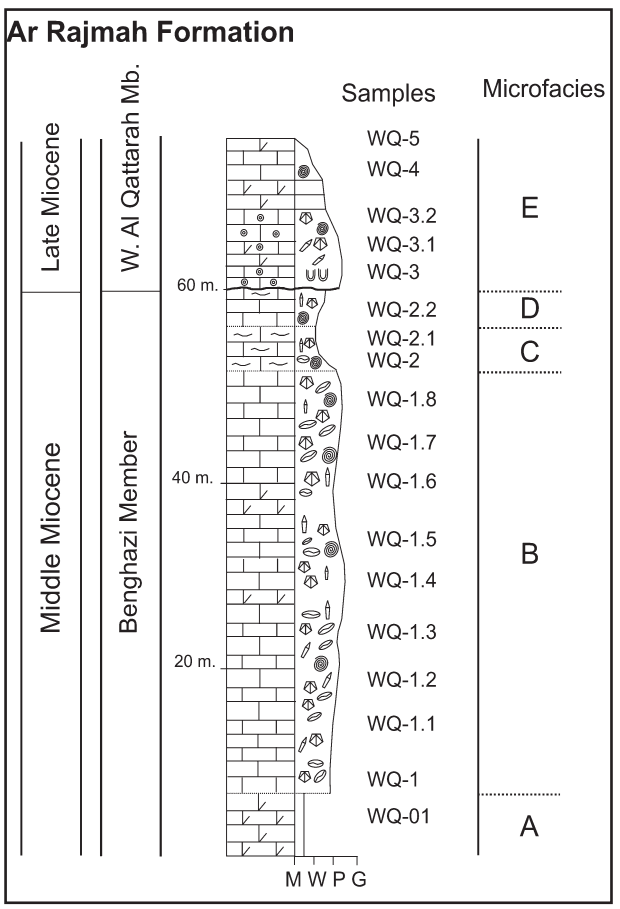


Fig. 4. Stratigraphic log and microfacies of Wadi al Qattarah Section.

fabric are frequent. Plate 1d, shows geopetal sediment within a gastropoda. On deposition, the gastropod would have had a primary porosity within its chambers (intergranular porosity). This was almost completely infilled by micrite sediment. The washed residue includes common benthic foraminifera species such as *Eliphidium* sp.1, *Eliphidium* sp.2, *Amphistegina* sp. *Cibicides* spp, *Eponides* spp, *Heterostigina* spp. and *Borelis melo melo* (Fichitel and Moll).

Microfacies C

Soft, yellowish and thin to medium bedded limestones containing microfacies C are found exposed in both sections in the upper part of the Binghazi Formation (Figs. 3 and 4). Here, the microfacies become more argillaceous than microfacies B and pellets of micrite become a dominant feature (Plate 1e). They are circular to elliptical and averaging about 0.5mm in diameter. The general lithology is represented by wackestones and packstones with essentially fine-grained matrix.

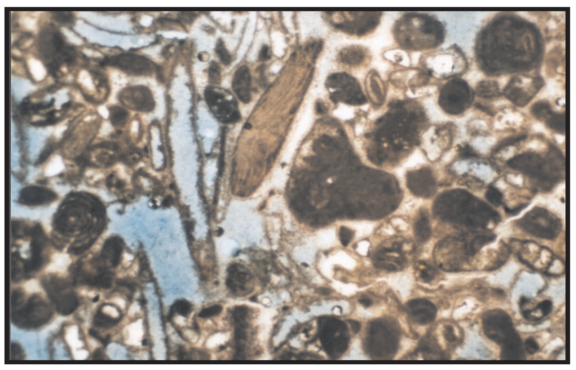
The remainder of sediment comprises a few calcareous red algae, remains of larger benthic foraminifera and a mixture of carbonate mud sediment and sparite cement. *Lepidocyclina* cf. *dilatata* (Michelotti) has been located also (Plate 1f). Other features, such as syntaxial overgrowths and geopetal fabric are infrequent. The washed residues include common benthic foraminifera species such as *Cibicides* spp. and *Eponides* spp.

Microfacies D

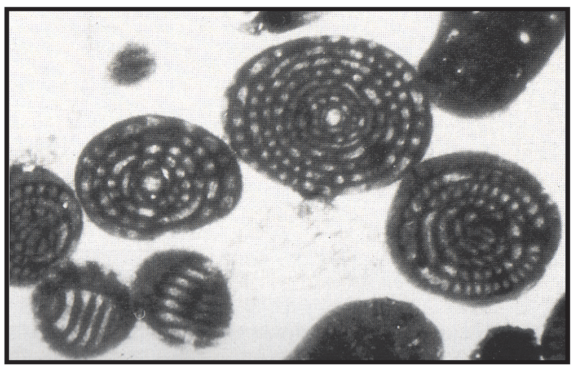
Yellowish limestone in which microfacies D is represented are relatively soft and medium to thick-bedded. This unit occupies the upper most part of the Binghazi Formation in the two studied sections (Figs. 3 and 4). The lithology of the lower levels of this microfacies mainly consists of poorly sorted packstone to grainstone (Plate 2a). Nevertheless, a grainstone with medium to coarse-grained matrix prevails in the upper levels. The allochems, however, represent a mixture of small, less regular peloids, ooids and bioclasts. The cement is mainly sparite, its crystal size and irregular shape suggest crystalline granular texture. Locally, the lithoclasts and bioclasts show signs of replacement by micrite around their margins and the geopetal structure and leaching of bioclasts becomes a characteristic feature in some levels. The bioclast component includes *Borelis melo melo* (Fichitel and Moll) (Plate 2b), debris of coralline red algae, infaunal bivalves, and bryozoa. Foraminifera species such as *Eliphidium* sp.1, *Eliphidium* sp.2, *Amphistegina* sp. *Cibicides* spp, *Eponides* spp, and *Heterostigina* spp. are present also.

Microfacies E

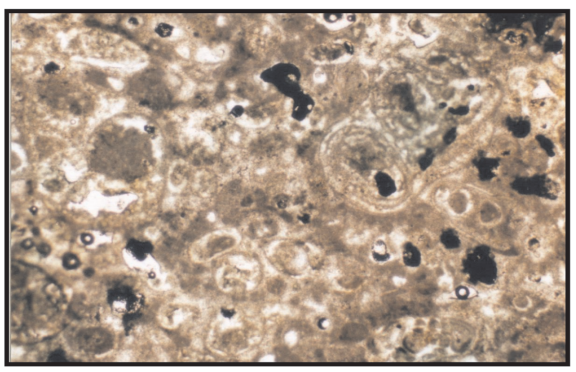
Microfacies E belongs to the lower part of the Wadi al Qattarah Formation. It has been recognized in both studied sections (Figs. 3 and 4). The limestone beds, containing this microfacies, are particularly bioturbated at the base. At microfacies level the lithology is primarily poorly sorted packstone to grainstone (Plate 2c-e). The cement is mainly sparite and the allochems are set in much carbonate mud sediment in the matrix and include common peloids, ooids and serpulid tubes. Traces of oolitic structures and micritized ooids are locally observed. Most of the bioclasts show iron oxide impregnation, but syntaxial overgrowths and geopetal fabric are infrequent in this microfacies. They include casts of ostracods and undifferentiated small benthic



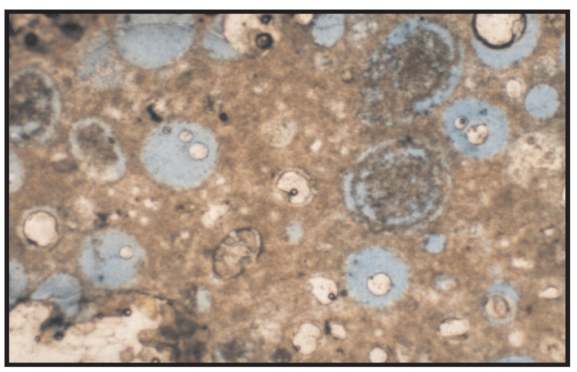
a



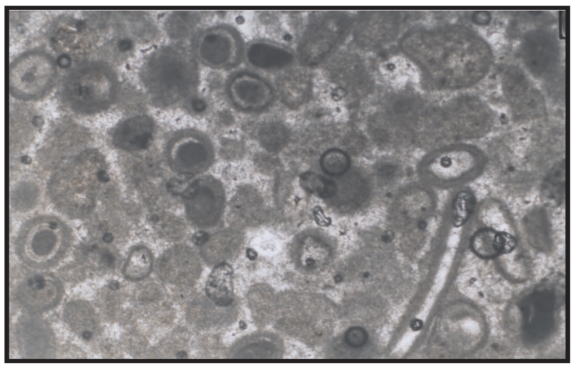
b



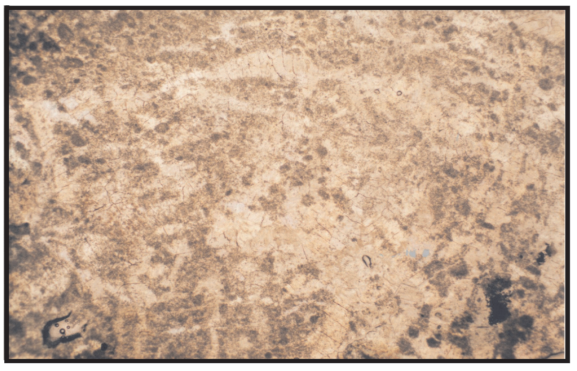
c



d



e



f

Plate - II

Plate II - a — General view of microfacies D, packstone to grainstone with a mixture of small, less regular peloids and ooids. The bioclasts component includes debris of coralline red algae, bivalves, and bryozoans. *Borelis melo melo* (Fichitel and Moll) and other smaller benthic foraminifera have been located also. Uppermost part of the Binghazi Formation, Soluq-Al Abyar Section, X 25.

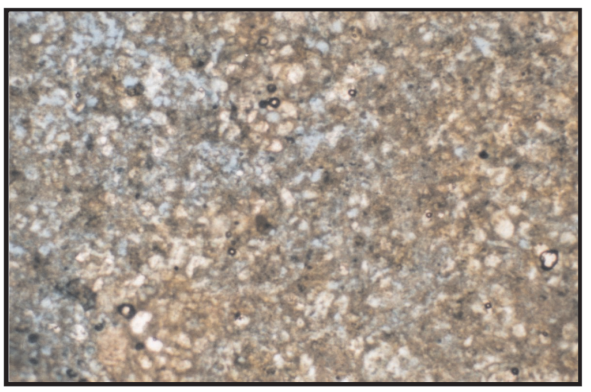
Plate II - b — General views of *Borelis melo melo* (Fichitel and Moll). Uppermost part of the Binghazi Formation, Soluq-Al Abyar Section, X 100.

Plate II - c and d — General views of microfacies E, poorly sorted packstone to grainstone with common ooids, peloids and serpulid tubes, the bioclasts includes casts of ostracods and poorly preserved small benthic foraminifera such as miliolids and rotalids. Lower part of the Wadi al Qattarah Formation, Soluq-Al Abyar Section, X 25.

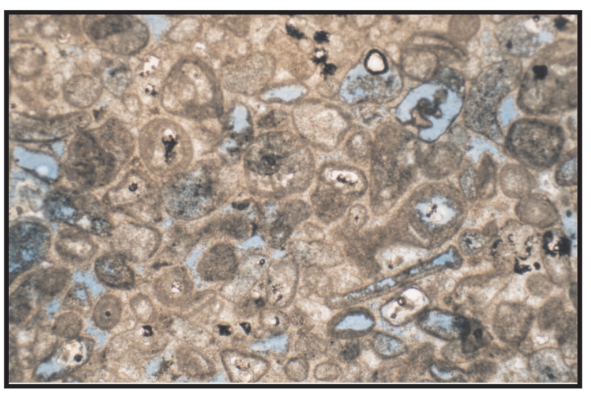
Plate II - e — General view of microfacies E, poorly sorted packstone to grainstone with common ooids and peloids. The bioclasts includes casts of pelecypods and poorly preserved small benthic foraminifera. Lower part of the Wadi al Qattarah Formation, Wadi al Qattarah Section, X 25.

Plate II - f — General view of microfacies F, show sediment composed entirely of gypsum and impregnated by micrite. Middle part of the Wadi al Qattarah Formation, Soluq-Al Abyar Section, X 25.

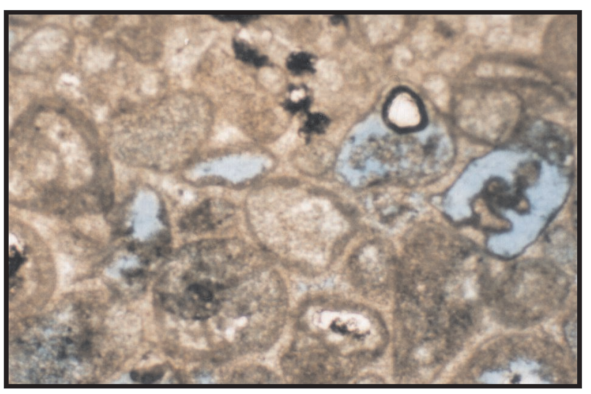
a



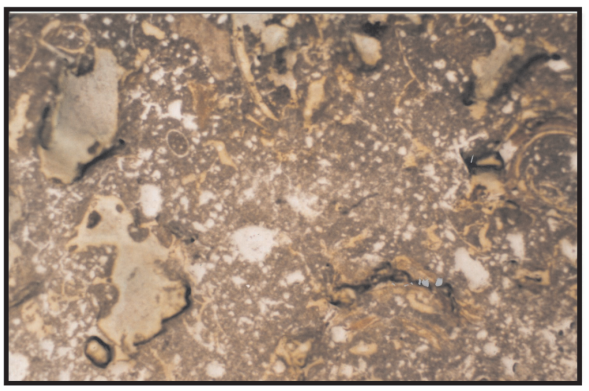
b



c



d



e

f

Plate - III

Plate III - a and b General views of microfacies G, show a dolomitic limestone containing more than 50% dolomite. Grains of gypsum, iron oxide crystals and tiny unidentifiable bioclasts can be noted. Middle part of the Wadi al Qattarah Formation, Soluq-Al Abyar Section, X 25 and X 50 respectively.

Plate III - c and d General views of microfacies H, packstone to grainstone. Ooids (< 2 mm in diameter) with a rather poorly preserved concentric structure can be noted. The bioclasts includes poorly preserved miliolids, and rotalids. Upper parts of the Wadi Al Qattarah Formation, Soluq-Al Abyar Section, X 25 and X 50 respectively.

Plate III - e General view of microfacies I, poorly sorted wackestone to packstone. The bioclasts includes fragments of thick-shelled pelecypods, gastropods and echinoids. Some casts of ostracods and dwarfed benthic foraminifera can be noted also. Most-upper parts of the Wadi al Qattarah Formation, Soluq-Al Abyar Section, X 25.

Plate III - f General view of microfacies L, mudstone with less than 10 % allochems. The bioclasts includes unknown tiny benthic foraminifera and possible casts of radiolarian. Upper part of the Wadi al Qattarah Formation, Soluq-Al Abyar Section, X 25.

foraminifera. The washed residues include common small benthic foraminifera such as *Eliphidium* sp.1, *Eliphidium* sp.2, *Elphidium crispum* and *Quinqueloculina* sp.. Poorly preserved miliolids, nonionids and rotalids are present also.

Microfacies F

This microfacies belongs to the middle part of the Wadi al Qattarah Formation. It has been recognized only in Soluq-Al Abyar section (Fig. 3). Two beds of about 30 cm thick exhibiting white to earthy colour have been sampled. They have similar texture and characteristics. The thin-sections studied show sediment composed entirely of gypsum impregnated by micrite (Plate 2f). The gypsum consists of a network of irregular crystals. It was probably replacing anhydrite due to the diagenetic reactions which may occur in evaporites. In the uppermost part of the Wadi al Qattarah Formation, some gypsum lenses are interbedded with microcrystalline limestone. Here, fine fibrous gypsum is found partially filling and replacing the particles and the matrix. Particular details concerning the gypsum and related microfacies were reported by El Hawat (1980).

Microfacies G

A massive and well-bedded dolomitic limestone containing microfacies G is exposed within the middle part of the Wadi al Qattarah Formation. It was recognized in Soluq-Al Abyar section only (Fig. 3). The thin-sections studied from this unit show a dolomitic limestone containing more than 50% dolomite (Plate 3a and b) occuring as minute euhedral rhomb-shaped crystals. The unaltered limestone surrounding the dolomite shows a patchy texture of micrite and sparite. Some grains are recrystallized and iron oxide crystals substitute others. Recognizable grains of gypsum have been located in this microfacies, particularly in the upper levels. Rare and poorly preserved small benthic foraminifera have been recovered from the washed residue, including *Rotalia* spp., *Ammonia* spp, and *Quinqueloculina* sp.

Microfacies H

Cross-bedded limestone containing microfacies H is found in the upper parts of the Wadi Al Qattarah Formation in Soluq-Al Abyar Section (Fig. 3). The lithology is mainly oolitic packstone to grainstone (Plate 3c and d). However, the original sediments have been partly replaced by dolomite. Locally, the crystals are faintly zoned and the rhombic shape of dolomite can hardly be recognized. Ooids (< 2mm in diameter) with a rather poorly preserved concentric structure characterize most of thin-sections studied in these levels. It is possible that the texture was partly lost by micritization, although it might also have been lost during inversion of an original aragonite ooid to calcite. Other grains however, show iron oxide impregnation, and minute borings filled with micrite after the death of algae (endolitihic type) can be noted also.

The washed residue, however, includes *Ammonia beccarii* (Linnaeus), and *Elphidium crispum* (Linnaeus). Poorly preserved miliolids, nonionids and rotalids are present also.

Microfacies I

A soft yellowish marly limestone characterizes the most upper parts of the Wadi al Qattarah Formation in Soluq-Al Abyar Section (Fig. 3). The lithology is poorly sorted wackestone to packstone (Plate 3e). The grains are bioclasts, largely fragments of thick-shelled pelecypods, high-spired gastropods and echinoids. Some casts of ostracods and dwarfed benthic foraminifera are located also. All bioclasts are supported by a matrix of carbonate mud but also much sparite cement. Up-section however, the lithology becomes slightly argillaceous and the bioclasts shows iron oxide impregnation with geopetal fabric. *Ammonia beccarii* (Linnaeus), *Elphidium crispum* (Linnaeus), *Rotalia* spp., *Ammonia* spp, and *Quinqueloculina* sp. were recovered from the washed residue.

Microfacies L

This microfacies is represented by medium to thinly bedded soft grey limestone. It was identified from the upper levels of the Wadi al Qattarah Formation in Soluq-Al Abyar Section (Fig. 3). The lithology is mudstone, being a matrix-supported limestone with less than 10% allochems (Plate 3f). The allochems are represented mainly by rare unidentified tiny benthic foraminifera and possible casts of radiolarian. The occurrence of slight compacted burrows (probably produced by immature *Chondrites*) filled by calcite and other diagenetic material is locally observed. The washed residue however, includes few poorly preserved and tiny benthic foraminifera such as

nonionids, rotalids eliphidids, miliolids and ammoniids.

THE PALAEOENVIRONMENTAL HISTORY

Wilson (1974 and 1975) distinguished various types of carbonate facies and developed a general scheme of Standard Facies Belts (SFB) ranging from 1 (basinal deposits) to 9 (platform evaporates). The microfacies and associated biota studied, integrated with other data derived from the literature, confirms that the carbonates of the Ar Rajmah Group were deposited between SFB 7 and SFB 9. In other words, the sediments were laid down under open platform (Binghazi Formation), restricted platform and restricted lagoon-salina conditions (Wadi al Qattarah Formation) respectively (Fig. 2). In the following section, an attempt to reconstruct the palaeoenvironmental history is presented.

Binghazi Formation

This rock-unit comprises four microfacies; they are from bottom to top A, B, C and D, and are composed essentially of bioclastic wackestones to packstones. In the upper part of this unit, a gradual decline of micrite is noted upward, leading to a grainstone texture in the uppermost parts of microfacies D.

The bioclasts include abundant pelecypods, gastropods, common calcareous red algae, bryozoan and echinodermal fragments. A shallowing trend is indicated by the influx of encrusting algae and oysters. The oysters, *in situ* in this unit, may indicate a relatively low salinity (Shepard and Moore, 1960; Wiedemann, 1972) possibly due to a local and temporary influence of a fresh water supply, which also caused the contamination by terrigenous quartz grains. These carbonate sediments and associated biota are believed to have been deposited in SFB 7 (Wilson, 1975).

The presence of common benthic foraminifera such as *Eponides* spp., *Cibicides* spp. *Heterostegina* spp., *Lepidocyclina* cf. *dilatata* (Michelotti), *Amphistegina* sp. and *Borelis melo melo* (Fichitel and Moll) are quite significant. These microfauna are common in normal marine sediments and have a wide range of depth and temperature tolerance (Murray, 1973). The recovery of the larger foraminifera species such as, *Borelis*, *Heterostegina* and *Lepidocyclina* whose depth distribution is largely determined by their symbionts (Leutenegger, 1984) suggest that their depth range is limited to the euphotic zone (Hottinger, 1983). Because of their symbiotic relationships, larger foraminifera are well adapted to oligotrophic conditions (Hallock, 1988) and typify warm water habitats (Murray, 1973). Moreover, it has long been recognized that, *Borelis* indicated shallow water up to 33m deep with a temperature around 30°C (Bandy, 1960; Bignot and Guernet, 1976). These conditions confirm that open platform shelf lagoons (*i.e*. SFB 7) apparently dominated the study area during the time of deposition of most of the Middle Miocene.

Wadi al Qattarah Formation

Wadi al Qattarah Formation consists of two parts: a lower unit which includes microfacies E and an upper unit represented by five microfacies (F, G, H, I and L). The microfacies E consists essentially of poorly sorted oolitic packstone and grainstone. The predominantly undersized pelecypods, gastropods, together with little-diversified benthic foraminifera (particularly, miliolids, rotalids and elphidiids) are thought to indicate restricted platform conditions (Murray, 1991).

The disappearance of the alveolinids (*Borelis*) confirms this belief and moreover, indicates that the source area containing them was not available any more. The occurrence of *Elphidium crispum* (Linnaeus), *Elphidium* spp. and *Quinqueloculina* sp. are indicative of the inner shelf and thrive in water between 0-50m deep (Murray, 1968 and 1973).

At outcrop scale, the base of this unit is generally intensively burrowed, due to the scarcity of sediment supply which gave bottom-dwelling organisms the opportunity to burrow into sediment and eventually led to the formation of hardgrounds. In general, the nature of the microfacies and associated microfauna suggest that deposits of the lower part of the Wadi al Qattarah Formation were deposited in SFB 8 of (Wilson, 1975).

The remaining microfacies of the upper unit of the Wadi al Qattarah Formation consist primarily of wackestone to packstone and locally of mudstone and gypsum. Ooids with a rather poorly preserved concentric structure has been located in these levels; they are similar to those described from the protected lagoons of the Arabian Gulf (Loreau and Purser, 1973). A SFB 9 (Wilson, 1975) is assigned to this stratigraphic interval. In general, the upper unit of

the Wadi al Qattarah Formation exhibits a gradual disappearance of the microfauna in upward direction and the foraminifera are limited to a few miliolids, rotalids and ammoniids. The overall nature of the microfacies and the scarcity of the microfauna refer to restricted lagoon-salina conditions which occupied the studied area during the time of deposition of the upper part of the Late Miocene. On the contrary, the patchy occurrences of *Ammonia beccarii* (Linnaeus) and *Elphidium crispum* (Linnaeus) from this stratigraphic level are related to storm-induced transport.

CONCLUSIONS

Ten different microfacies were identified from two outerops within the study area, in terms of Wilson standard carbonate facies belts. The depositional history of the studied sediments indicate an overall shallowing upward trend, from open platform (Binghazi Formation) to restricted platform and restricted lagoon-saline conditions (Wadi al Qattarah Formation).

Despite the lack of age diagnostic taxa, the deposits of the Ar Rajmah Group, in the studied succession can be tentatively attributed to the Middle and Late Miocene.

ACKNOWLEDGEMENTS

We are especially grateful to Prof. A. El-Hawat (Garyounis University) and Prof. M. Busrewil (Al-Fateh University) for their critical reading and useful suggestions for improving the manuscript. Many thanks are due to Mr. D. Huffman (Arabian Gulf Oil Company) for the kindly improvement of the English text. Our thanks are due also to Mr. R. Al-Augali and Mr. M. Moktar from the geological laboratory of the Gulf Oil Company, for their technical support. We are extremely grateful to the personnel of the geological laboratory and the postgraduate unit of the Earth Sciences Department, University of Garyounis, especially Mr. N. Al-Selini, Mr. F. El-Emami, Mr. A. El-Shaafi and M. Busheha who processed part of the samples and assisted during the field work.

REFERENCES

Abdulsamad, E. O., 1999. Stratigraphy and palaeobiogeography of Tertiary larger foraminifera from AI Jabal al Akhdar (Cyrenaica, NE Libya). *Giornale di Geologia*, **61**, 75-98, Bologna, Italy.

Abdulsamad, E. O. and Barbieri, R., 1999. Foraminiferal distribution and palaeoecological interpretation of the Eocene-Miocene carbonates at AI Jabal AI Akhdar (NE Libya). *J. Micropalaeontology*, **18**, 45-65.

Bandy, O. L., 1960. General Correlation of Foraminiferal Structure with Environments. *Proc. 21st Int. Geol. Congr.,* Norden,.**22**, 7-19.

Banerjee, S., 1980. *Stratigraphic Lexicon of Libya.* Department of Geological Researches and Mining, Bulletin **13**, *Industrial Research Centre,* Tripoli, Libya.

Barr, F.T. and Weegar, A.A., 1972. Stratigraphic Nomenclature of the Sirte Basin, Libya. *The Petroleum Exploration Society of Libya*, Tripoli, Libya.

Berggren, W.A., 1967. Biostratigraphy and planktonic foraminiferal zonation of the Tertiary System of the Sirte Basin of Libya, North Africa. In: P. Brönnimann and H.H. Renz (Eds), *Proceedings of the First International Conference on Planktonic Microfossils*, **I**, 104-120. E.J. Brill, Leiden.

Bignot, G. and Guernet, G., 1976. Sur la présence de *Borelis curdica* (Reichel) dans le Miocéne de l'ile de Kos (Greece). *Géologie Méditerranéenne*, Ann. Univ. Provence, **3** (1), 15-26.

Desio, A., 1935. Studi geologici sulla Cirenaica, sul Deserto Libico, sulla Tripolitania e sul Fezzan Orientale. *Missione Scientifica della Reale Accademia d'Italia a Cufra*, 1-3, Roma, Italy.

El-Hawat, A. S., 1980. Intertidal and storm sedimentation from Wadi al Qattarah Member, Ar Rajmah Formation (Middle Miocene), Al Jabal al Akhdar. In: M.J. Salem and M.T. Buserwil (eds), *The Geology of Libya*, **II**, 449-461, Academic Press, London.

El-Hawat, A. S. and Salem, M. J., 1985. Stratigraphic reappraisal of Ar Rajmah Formation, Miocene, Al Jabal al Akhdar, NE Libya: case of field sedimentological approach. VIIIth Cong. Med, Neogene Stratig. (Abs.), Budapest. *Ann. Inst. Geol. Publ. Hung.*, Budapest, 206-208.

El-Hawat, A. S. and Salem, M. J., 1987. A case study of the stratigraphic subdivision of Ar Rajmah Formation and its implication on the Miocene of Northern Libya. In: Proc. VIIIth Cong. Med, Neogene Stratig., Budapest. *Ann. Inst. Geol. Publ. Hung.*, Budapest, **LXX**, 173-184.

El-Hawat, A. S. and Abdulsamad, E. O., 2004. The Geology of Cyrenaica: A Field Seminar. Special publication, *Earth Sciences Society of Libya*, Tripoli, Libya. 130 p

Flügel, E., 1982. *Microfacies Analysis of Limestone*. Springer-Verlag, Berlin. 130 p.

Hallock, P., 1988. Diversification in Algal Symbionts-bearing Foraminifera: A Response to Oligotrophy? *Proceedings of the Third International Symposium on Benthonic Foraminifera. Revue de Paleobiologie*, Special volume,789-797.

Hottinger, L.,1983. Process Determining the Distribution of Larger Foraminifera in space and time. *Utrecht Micropaleontological Bulletins*, **30**,. 239-253.

Klen, L., 1974. Geological Map of Libya, 1:250 000. Sheet Benghazi (NI 34-14). Explanatory booklet, *Industrial Research Center*, Tripoli, Libya.

Leutenegger, S., 1984. Symbiosis in Benthic Foraminifera: specificity and host adaptations. *Journal of Foraminiferal Research*, **14**,16-35.

Loreau, J. P. and Purser, B. H., 1973. Distribution and ultrastructure of Holocene ooids in the Persian Gulf. In: B. Purser (ed.) *The Persian Gulf*, 279-328. Springer-Verlag, Berlin.

Murray, J. W., 1968. The living foraminifera of Christchurch Harbour, England, Micropaleontology, **14**, 148-150.

Murray, J. W., 1973. *Distribution and Ecology of Benthonic Foraminifera*. Heinemann, London, 265 p.

Murray, J. W., 1991. *Ecology and Palaeoecology of Benthic Foraminifera*. Longman Group Limited, London, 397 p.

Röhlich, P., 1974. Geological Map of Libya, 1: 250 000. Sheet Al Bayda (NI 34-15). Explanatory booklet, *Industrial Research Centre*, Tripoli, Libya.

Shepard, F. P. and Moore, D. G., 1960. Bays of Central Texas Coast. In: Recent Sediments, North-west Gulf of Mexico, 1951-1958. *Am. Asssoc. Petrol. Geol.*. Publication, Tulsa, 117-152.

Sherif, K. A. T. 1991. Biostratigraphy of the Miocene in Al Khums area, northwestern Libya. In: M. J. Salem, O.S. Hammuda and B.A. Eliagoubi, (eds), *The Geology of Libya*, **IV**, 1421-1455. Elsevier, Amsterdam.

Wiedemann, H. U., 1972. Shell deposits and shell preservation in Quaternary and Tertiary estuarine sediments in Georgia, *USA. Sediment. Geol,* **7**, 103-115.

Wilson, J. L., 1974. Characteristics of carbonate platform margins. *Bull. Am. Assoc. Petrol. Geol.,* **58**, 810-824.

Wilson, J. L., 1975. *Carbonate Facies in Geologic History*, Springer-Verlag, Berlin.