Petroleum Res. J. Vol. 21 (2008/2009); P. 57–66, 6 Figs.

A Stratigraphic Review of the Al Bayda Formation, NE Libya: Calcareous Nannofossils versus Foraminifera

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Abstract: Different groups of Eocene and Early Oligocene fossils have been reported from the Al Bayda Formation at Cyrenaica, northeast Libya by several authors. The formation is detrital in its lower part, and separated by disconformities from both the Darnah Formation below and the Al Abraq Formation above.

In this review, it is confirmed that all Eocene taxa reported from the lower member of the Al Bayda Formation (the Shahhat Marl Member) are allochthonous, representing reworked bioclasts from the Eocene Darnah Formation. The Early Oligocene micro- and macrofossils reported by several authors from the Shahhat Marl Member and from the upper member (the Algal Limestone) of this formation are considered here as autochthonous, in situ biota, confirming its Early Oligocene age.

The contradictory conclusion of El Mehaghag and Ashahomi, 2005, based on calcareous nannofossils, that the Al Bayda Formation is Middle to Late Eocene, is not accepted in this present work**.**

Key words: Eocene-Oligocene, Cyrenaica, Shahhat Marl Member, Allochthonous, Autochthonous, Nannofossils, Foraminifera

INTRODUCTION

Larger foraminifera form an important constituent of many warm-water; shallow marine carbonates shelf-sequences. They are normally the most important age-diagnostic fossils present within these carbonate shelf deposits. They went through rapid evolution, therefore age datings based on them are considered as fine, in resolution, as those of the deeper marine planktonic foraminifera (Cavelier and Pomerol, 1986 and Racey, 1994). Consequently, they are of great use in carbonate shelf sequences, such as those of Cyrenaica, where planktonic foraminifera and nannofossils are limited to certain lithological levels representing deeper marine conditions.

The current review discusses the stratigraphy of Al Bayda Formation based on published and unpublished data collected by the authors in different occasions. The discussion aims at minimizing the contradictory conclusions about the stratigraphic position of this formation and investigating its age, based on foraminifera and other microfossils reported by different workers in the region. All foraminiferal taxa reported here are listed, authored and referenced in Abdulsamad(1999) Abdulsamad and Barbieri (1999) and Abdulsamad (2000). The nannofossils are authored and referenced in Perch-Nielsen (1985) and Hay *in* Ramsay (1977). For detailed regional background and the geological and tectonic development of the region, the reader is referred to the works of Röhlich (1978; 1980) and El Hawat and Abdulsamad, (2004).

GEOLOGICAL BACKGROUND

The Al Bayda Formation typically crops out between the towns of Al Bayda and Darnah in northern Cyrenaica, northeast Libya (Fig. 1). This formation is further subdivided into two members (Fig. 2). Röhlich (1974) introduced the term Al Bayda Formation to include the lower Shahhat Marl Member and the upper Algal Limestone Member of the Al Kuf Formation of Kleinsmiede and van den Berg (19680). The main reason for upgrading these two members to form one formation was because they corresponded to a separate cycle of sedimentation, separated from both the underlying and overlying beds by disconformities (Röhlich, 1974, p. 39). Hammuda

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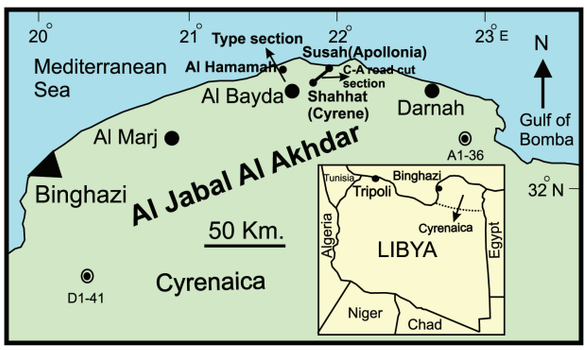

Fig. 1. Index map of NE Libya and the location of the Cyrene-Apollonia road cut section (C-A), well A1-36 and well D1-41.

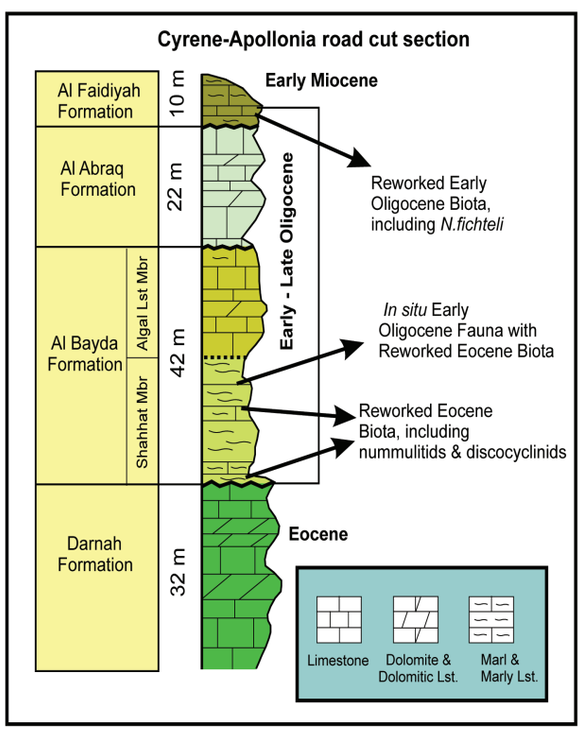

Fig. 2. Stratigraphic log of Cyrene-Apollonia road cut section.

(1973) also noted the unconformity separating the Eocene from the Early Oligocene detrital deposits in Darnah area.

Lithologically, the Shahhat Marl Member consists of yellow marls and marly and chalky limestones with fine to coarse-grained matrix that largely consists of skeletal remnants of echinoderms, mollusks, reworked Eocene discocyclinids and nummulitids (Plate 1: Figs. 1, 2). The upper Algal Limestone Member is characterized by poorly sorted packstone and grainstone cemented by micrite to sparite. The biotic content shows common assemblage of non-geniculate coralline red algae, nummulitids, corals, mollusks, and echinoids (Plate 1: Figs. 3, 4). The geographic extent and development of the Al Bayda Formation is shown in Figure 3 and the type locality is about 2.5 km NW of al Bayda Town, at the road leading to al Hamámah Village, where it is separated from both the underlying Darnah Formation and the overlying Al Abraq Formation by major disconformities.

Kleinsmiede and Van den Berg (1968 indicated that the basal part of their Al Kuf Formation (= the Shahhat Marl Member) was detrital with reworked Eocene fauna, in agreement with Gregory (1911). The Shahhat Marl Member was regarded by Gregory (1911) to belong partly to the underlying Eocene Darnah Formation. However, Stefanini (1923) distinguished the Eocene Darnah Formation from the Oligocene Al Bayda Formation based on the presence of an unconformable surface that separates the two formations. All the above authors confirmed that the contact between the Darnah Formation (Eocene) and the base of the Al Bayda Formation (Shahhat Marl Member) is disconformable.

The recovery of Early Oligocene fauna, including *Nummulites fichteli* and *N. vascus* by Kleinsmiede and Van den Berg (1968) and by Hanzliková *in* Röhlich (1974) allowed assigning the Al Bayda Formation to the Early Oligocene.

DISCUSSION

Based on foraminiferal assemblages, the major part of the Al Bayda Formation belongs to the Early Oligocene. This is based on the recovery of *Nummulites fichteli* (Plate 1: Figs. 4, 11) and *N. vascus* (Plate 1: Figs. 4, 8, 9) from the middle and upper parts of the formation in several outcrops and subcrops. These deposits are largely confined to the larger foraminiferal zones SB21-SB22a of Cahuzac and Poignant (1997) which essentially correspond to the planktonic foraminiferal zones P18-P19 of Berggren *et al.*(1995). This conclusion is supported by the diverse Oligocene planktonic foraminiferal assemblages, recovered from the Al Bayda Formation at Well A1-36, about 150 km southeast of the Cyrene–Apollonia road cut exposure, by Abdulsamad and Barbieri (1999). These assemblages include *Catapsydrax dissimilis, Tenuitellinata angustiumbilicata, Globigerina ouachitaensis gnaucki, G. ciperoensis ciperoensis, G. praebulloides*, *G. yeguaensis*, *G. euapertura* and *G. angulioficinalis.* The stratigraphic use of the planktonic foraminifera in this well was based on the last stratigraphic occurrence of the species *(i.e.* first appearance going down the borehole) in order to eliminate the assumption of caving (see Haynes, 1981

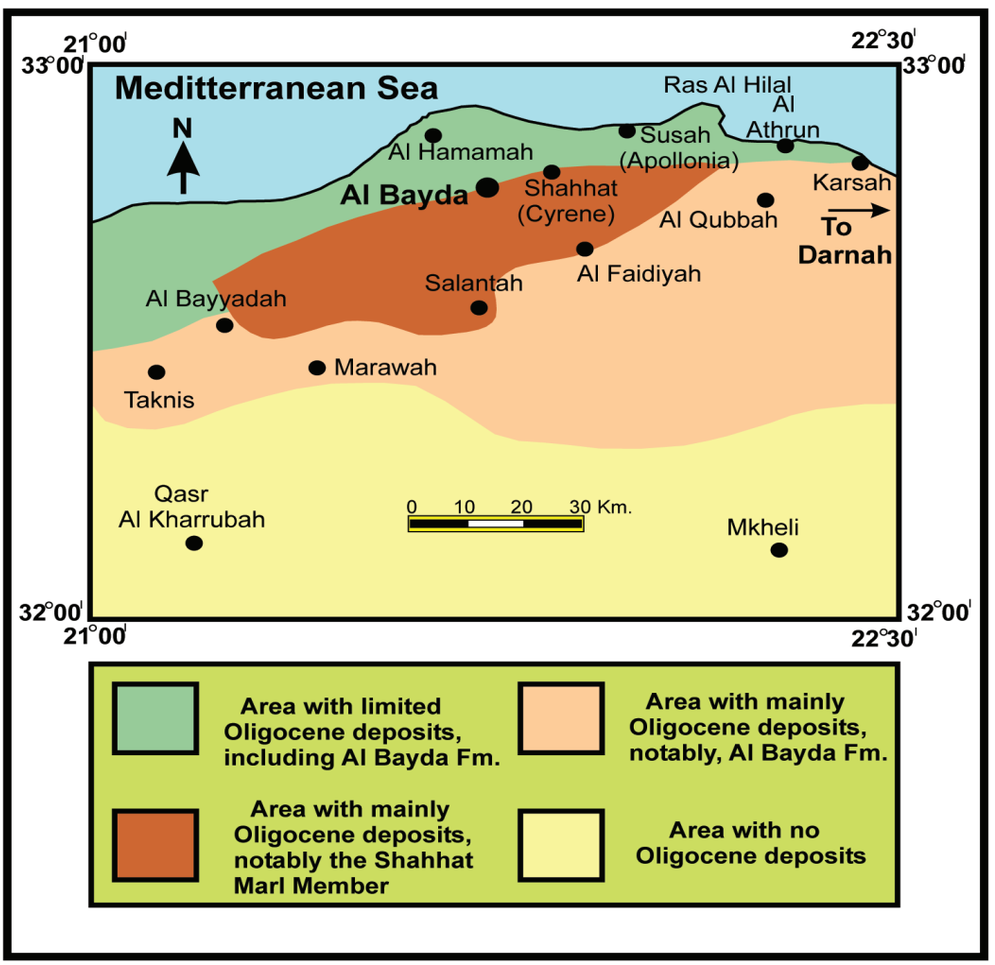

Fig. 3. Extent and development of the Al Bayda Formation in northern Cyrenaica (modified after Röhlich, 1974).

and Tmalla, 1996). However, the recovery of *Nummulites fabianii* at Wadi al Kuf, near al Bayda Town, led Moody *et al.*(2004) to assign the deposits of the Shahhat Marl Member to the Late Eocene.

In 2005, Tmalla confirmed, in a written communication to Moody-Sandman Associates, the presence of *N. fabianii* from Wadi al Kuf section. He also recovered *N. vascus* from the same deposits at the Cyrene-Apollonia road cut section (near al Bayda Town). Similar findings were also reported by Abdulsamad (1999), by Muftah and Erhoma (2002) from the same outcrop, and recently, by Abdulsamad from Daryanah-al Abyar area, near Binghazi City.

Abdulsamad and Barbieri (1999) regarded the Eocene nummulitids and discocyclinids in the Shahhat Marl deposits as reworked, and though *N. fabianii* has forms transitional to *N. fichteli*, the latter species and the transitional forms belong to the Early Oligocene (Abdulsamad, 2000). Moreover, reworked lithoclasts and bioclasts (notably, nummulitids) are major constituents of the sedimentary rocks of the Al Bayda Formation. They are considerably older than the surrounding allochems, thus confirming the presence of reworked allochthonous material in the formation. In fact, reworked specimens of nummulites (including *N. fabianii* and related forms such as *N.* cf. *fabianii* and *N.* aff. *fabianii*) have been found throughout the Late Oligocene and the Early Miocene sedimentary rocks of Cyrenaica (Plate 1: Figs. 5, 7); see also Abdulsamad and Bu-Argoub (2006). Reworking in several stratigraphic levels in the region is well known. It is caused primarily by syndepositional tectonics (El Hawat, 2005) and examples of this trend can be seen in El Hawat and Abdulsamad (2004). The recovery of reworked Cretaceous nannofossils by Haq and Aubry, 1980 in the Eocene Apollonia Formation at Wadi al Athrun section is another example of this trend. Elements of reworking have also been noted by most workers in the region, including, Abdulsamad and Barbieri (1999).

Imam (1999) studied outcrops in the al Bardia

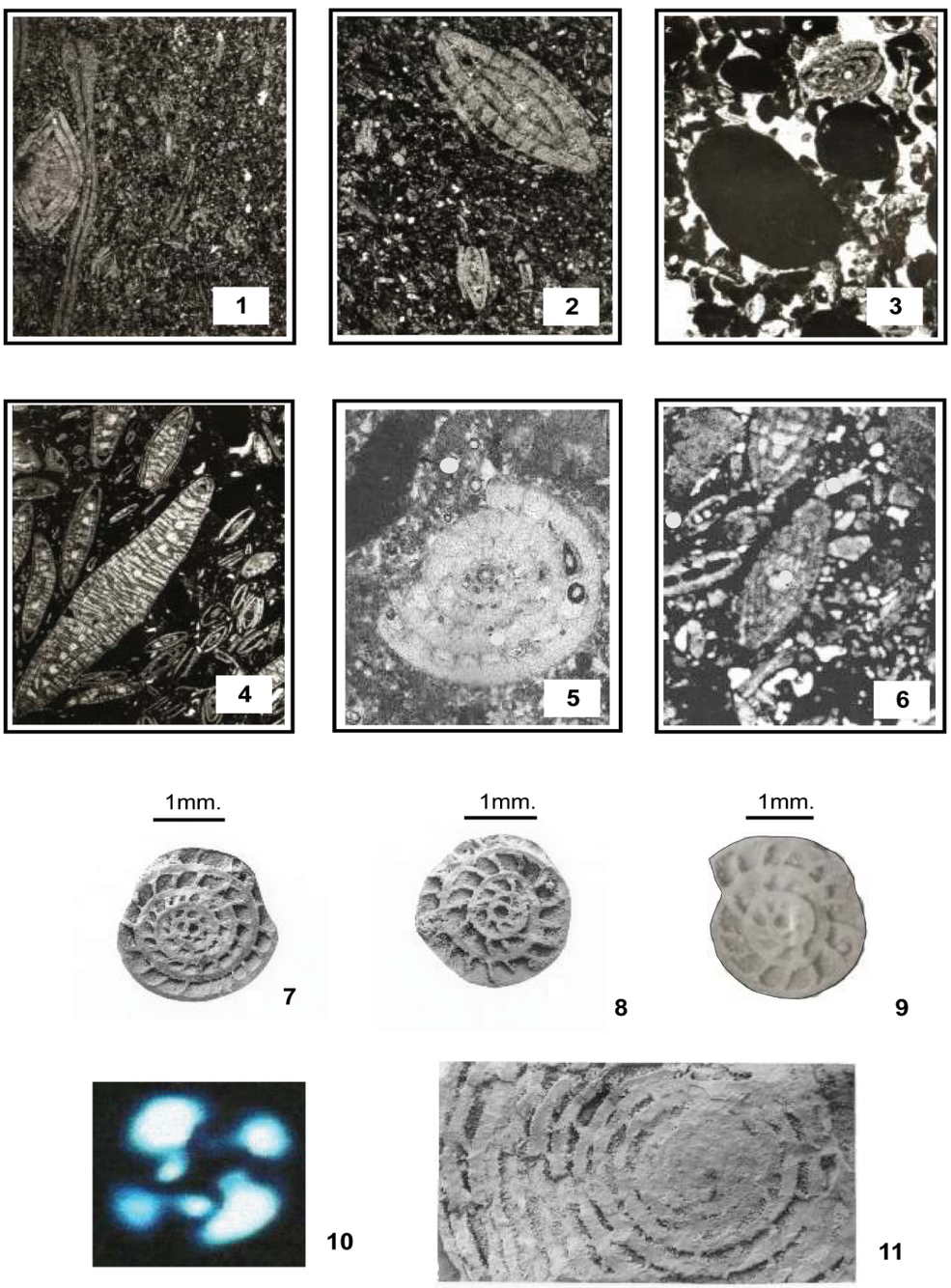

Plate - I

Plate I - 1, 2. The lower and mid-upper parts of the Shahhat Marl Member at Cyrene-Apollonia (C-A) road cut section. They show wackestone to packstone with reworked nummulitids and discocyclinids. X10

Plate I - 3, 4. The lower and upper parts of the Algal Limestone Member at Cyrene-Apollonia (C-A) road cut section. They show packstone to grainstone with N. vascus (small specimens) and N. fichteli (large specimens). X10

Plate I - 5. The lower part of the Shahhat Marl Member at Deryanah-al Abyar area (East of Binghazi). It represents wackestone to packstone with reworked N. cf. fabianii, (from El-Salmi, 2001). X10

Plate I - 6. The lower part of the Al Faidiyah Formation at Deryanah-al Abyar area (East of Binghazi) with reworked N. fichteli. This microfacies is similar to the one found in the basal part of the Al Faidiyah Formation at Cyrene-Apollonia (C-A) road cut section, (from El-Salmi, 2001). X10

Plate I - 7. N. aff. fabianii, Ain al-Dabbusiyah section, upper part of the Darnah Formation.

Plate I - 8, 9. N. vascus, at Cyrene-Apollonia (C-A) road cut section, upper part of the Shahhat Marl Member.

Plate I - 10. Cyclicargolithus abisectus, mid-upper part of the Shahhat Marl Member at Deryanah - al Abyar area (East of Binghazi), (from El-Salmi, 2001). X5000

Plate I - 11. N. fichteli, upper part of the Shahhat Marl Member at well D1-41. X10

area at the most northeastern part of Cyrenaica including what he called Al Khowaymat Formation of El Defter and Issawi (1977). Not withstanding the enigmatic status of the Al Khowaymat Formation and the recommendation of Megerisi and Mamgain (1980) to suppress the term, we still find Imam's report on the larger foraminiferal assemblage in his study relative to the present discussion. Imam (1999, p. 625) reported the following about the Lower Member of the Al Khowaymat Formation: "This unit is highly fossiliferous with larger foraminifers such as *Nummulites intermedius* dÁrchiac (= *N. fichteli* Michelotti), *N. fabianii* Prever, *N. boucheri* de la Harpe (= *N. vascus* Joly-Leymerie), *N gizehensis* (Forskål), *N. beaumonti* dÁrchiac, especially in the lowermost part of the member, *Operculina complanata* (Defrance), *Assilina* sp. and other undefined oyster shell fragments together with echinoid remains." He assigned this member, with the above mixed larger foraminiferal assemblage, to the Late Eocene (Priabonian).

The logical geologic interpretation of the above mixed larger foraminiferal assemblage reported by Imam (1999) is an Eocene fossil assemblage reworked into Early Oligocene deposits. *N. intermedius* (=*N. fichteli*) and *N. boucheri* (=*N. vascus*), which he reported (p. 625) also from the Upper Member, are restricted to the Early Oligocene throughout the Mediterranean region; *Operculina complanata* (also in the upper Member) Early Oligocene – Middle Miocene, while *N. fabianii* is a typical Late Eocene species and *N. gizehensis* and *N. beaumonti*, are not younger than the Middle Eocene (see Abdulsamad, 2000).

The above larger foraminiferal assemblage encountered by Imam in his Al Khuwaymat Formation, indicates that the Lower Member is equivalent to the Shahhat Marl Member of the Al Bayda Formation of Röhlich (1974) and the Al Khuwaymat Upper Member, which is unconformably overlain by what he called Al Faidiyah Formation, is equivalent to the Algal Limestone Member of the Al Bayda Formation.

Röhlich (1974) recorded several fossils from the Shahhat Marl Member including the following ostracods: *Paracypris aerodynamica* Oertli (1956); *Pterigocythereis retinodosa* Oertli, (1956) (recorded as *P.* cf. *retinosa*); *Echinocythereis scabra* (Münster); *Cytherella gracilis* Lienenklaus (recorded as *C.* cf. *gracilis*) and *Bairdia subdeltoidea* (Münster). Oertli, (1956) described all the above ostracod species (excluding *B. subdeltoidea*) from the Rupelian (Early Oligocene) of the Swiss Molasse.

El Mehaghag and Ashahomi (2005) studied the nannofossil content of fifteen outcrop samples from the Cyrene-Apollonia road cut exposure, 10 km NE of Shahhat City. Two samples were from the uppermost part of the Darnah Formation that was barren of nannofossils and eight samples from the lower member of the Al Bayda Formation (the Shahhat Marl Member). Five samples from the upper member of Al Bayda Formation (the Algal Limestone Member) were also barren of nannofossils. They recorded and identified eighteen known nannoplankton species and two other species identified to the generic level from the Shahhat Marl Member. Only *Discoaster barbadiensis* and *Reticulofenestra dictyoda* are indicative of Late Eocene. Most of the species were recorded as rare on their Table 1. Apart from the Early Eocene species *Discoaster lodoensis* and *D. salisburgensis* (see Hay *in* Ramsay, 1977) and other long ranging species, at least eight of the recorded species are known to range into the Oligocene, including *Helicosphaera euphratis*, *Reticulofenestra umbilica, R. hillae, Dictyococcites bisecta*, *Pedinocyclus larvalis* and *Coccolithus pelagicus* (see Pearch-Nielsen, 1985). *C. pelagicus* was reported by Haq and Aubry, 1980 from the Early Paleocene deposits of El Haria Formation at El Kef section in Tunisia and from the Early to Middle Eocene deposits of Apollonia Formation at Wadi al Athrun section at al Jabal al Akhdar. The stratigraphic range of *C. pelagicus* extends to the Late Oligocene in Italy (Beckmann *et al*., 1981) and to the Late Miocene in southern Spain (Flores *et al.*, 2005).

El Mehaghag and Ashahomi (2005 p.17) concluded that the Shahhat Marl Member is Middle to Late Eocene in age and considered the two Early Eocene nannoplankton species (see above) and *Discoaster gemmeus,* as reworked. Hence, they also confirm the presence of reworked fossils in the Shahhat Marl Member of the Al Bayda Formation. They also added: "Although barren of calcareous nannofossils, the overlying Algal Limestone Member must be Late Eocene (NP20) or younger". This is in contradiction to all published literature about the area (see Kleinsmiede and van den Berg, 1968; Barr and Weegar, 1972; Röhlich, 1974; Banerjee, 1980; Abdulsamad, 2000; Muftah and Erhoma, 2002; El Hawat and Abdulsamad, 2004).

Moreover, a conflicting result to the conclusion of El Mehaghag and Ashahomi (2005) comes from

El-Salmi (2001) who recovered the Oligocene nannoplankton *Cyclicargolithus abisectus* (Plate 1: Fig. 10) from the Shahhat Marl Member in Wadi Azzad near Binghazi City.

The conclusion of El Mehaghag and Ashahomi (2005) was essentially based on a few Eocene species, which were recorded as common to rare (1 to 10 specimens per field of view) in their study. It should be noted that in terms of nannofossils, the recovery of rare and few species should be regarded as inadequate in age determination. It is worth noting that, inner-shelf sediments commonly contain as many as 1 billion of specimens/cm^3. A light-microscope smear-slide with evenly spaced nannofossils usually contains 100 000 to 1 million specimens (Siesser *in* Lipps, 1993).

We strongly believe that the conclusions of El Mehaghag and Ashahomi (2005) need to be re-evaluated and compared with the study of other outcrops, including the type area. We also encourage that such research should consider the depositional environment and the physical gaps (unconformity/ disconformity) in the field. The lack of zonal marker species should also be commented on in such research.

Because the two samples examined by El Mehaghag and Ashahomi (2005) from the Darnah Formation, immediately below the Al Bayda Formation were barren of nannofossils, they did not mention any thing about the nature of the contact between these two formations (conformable or not). The same can be said about the contact between the Shahhat Member and the Algal Limestone Member, because the five samples they examined from the basal part of the latter member were also barren of nannofossils.

The unconformable contact between the Darnah Formation and the Shahhat Marl Member (Figs. 4 and 5) is the key for the geologic interpretation of the reworked Eocene fauna from the Darnah Formation into the Shahhat Member, which is partly detrital. Moreover, the Shahhat Marl Member was deposited in a platform fore-reef slope (Abdulsamad, 1998), where the possibility of transportation and reworking of fauna and flora were extremely high (see, for example, Hohenegger *et al.,* 1999 and Zellers and Gray, 2007). Beavington-Penney *et al.,* (2005) however, discuss examples related to the dynamics of sediment and fossil shell-transportation, in detail.

Nannofossils clearly have marked advantages for use in biostratigraphy, but there are also serious factors, which should be considered. The most important of these factors are ecologic control, diagenetic alteration and reworking (Siesser *in* Lipps, 1993). The minute size of nannofossils makes them almost destructible by mechanical abrasion. They can be carried for long distances and reworked into

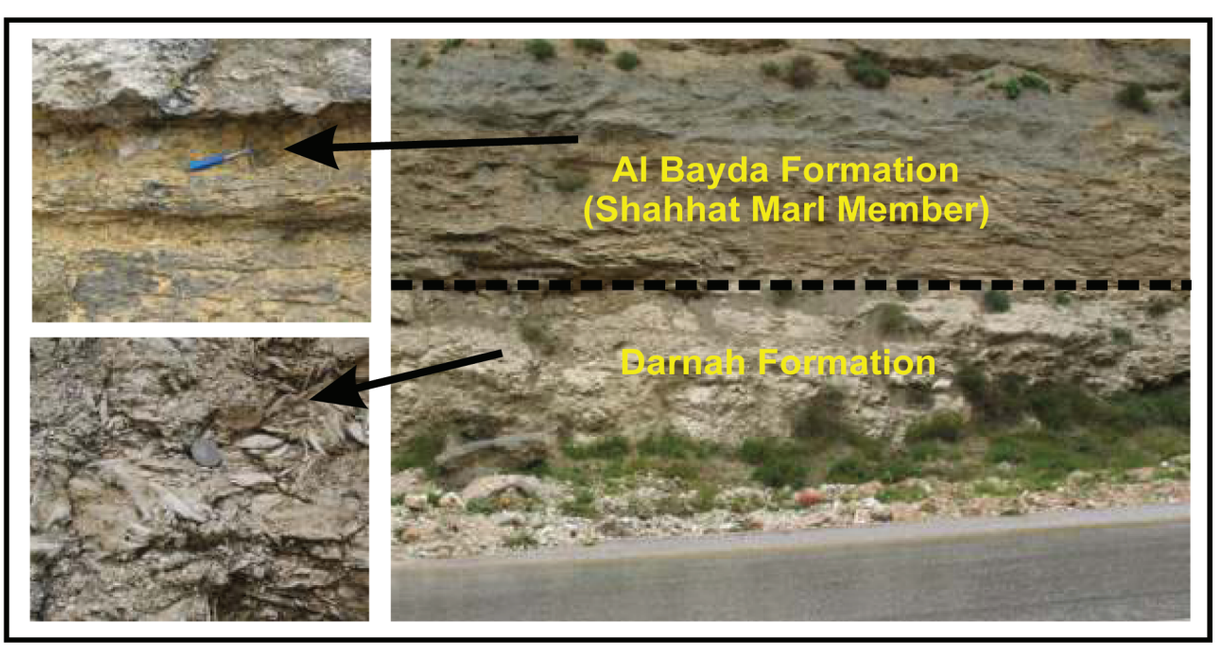

Fig. 4. The Eocene-Oligocene boundary (dashed line) at Cyrene-Apollonia road cut section, it shows the Darnah Formation (below) and the Al Bayda Formation (above), with close-up views of the lower part of the Shahhat Marl Member (left upper view) and the upper part of the Darnah Formation with A and B forms of Nummulites lyelli (left lower view).

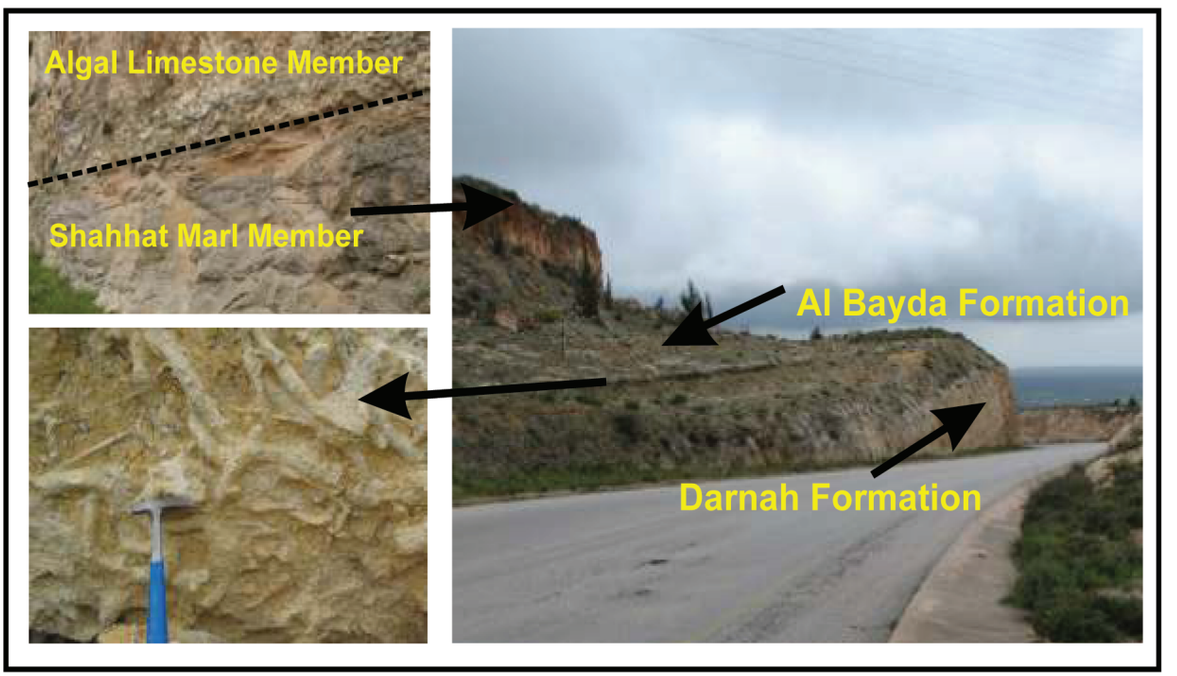

Fig. 5. The Eocene-Oligocene boundary at Cyrene-Apollonia road cut section, with close-up views showing trace fossils (bioturbation) directly above the contact (left lower view) and the contact between the Shahhat Marl and the Algal limestone members (left upper view).

younger deposits where they will not be the true indicators for neither the depositional environment nor the age of these deposits (see Pomerol, 1982). The roles of nannofossils in sedimentation, transportation, preservation and contamination, are discussed by numerous authors such as Bramlette (1958) and recently by Agnini *et al.*, (2007).

In contrary, the characteristics and typical appearance of larger foraminifera such as nummulites can usually be evaluated in order to resolve reworking problems. Identification of *in situ* (undamaged) specimens from moderately transported (partly damaged) specimens or extensively transported (considerably damaged, wave reworked) specimens can be achieved with different successes (see Beavington-Penney, 2004). Shell fragmentation by reworking can be easily differentiated from other taphonomic processes such as compaction. For example, the latter shows skeletal fragmentation at points of contact between bioclasts and fragments from individual bioclasts are found together in the rock (see for example Dodd and Stanton, 1981). Examples of compaction in nummulite accumulations, however, are discussed in Beavington-Penney (2004). Normally nummulite accumulations show evidence that both physical reworking (scouring, winnowing and imbrication) and biological processes (reproduction strategies and bioturbation) have influenced their formation (Racey, 2001). A general model for discriminating between physical and ecologically produced biofabrics is outlined by Racey (2001).

Based on lithology and faunal content, the Al Bayda Formation represents a shallowing-upward sedimentary sequence (Abdulsamad and Barbieri, 1999). Normally, the change in lithology of the Al Bayda Formation, from the yellowish soft marl and fine argillaceous limestone with allochthonous, coarse litho- and bioclasts of the Shahhat Marl Member to the generally white, hard and coarse grained algal limestone of the Algal Limestone Member, can be traced in time and space in the field. Consequently, bedsets of the Al Bayda Formation are obviously genetically related and in general harmony with Walther's Law. It is recommended to consider the Al Bayda Formation as a depositional sequence, which certainly represents a single episode of progradation (Abdulsamad, in preparation). From the stratigraphical point of view, appropriate age dating of the Al Bayda Formation can only be achieved through the analyses of all biota recovered from the total bedsets and to consider the geologic history of the region. It is inadequate to set age for the lower part (the Shahhat Marl Member) and the upper part (the Algal Limestone Member) separately. Accordingly, we feel that the suggested Early

Oligocene age for the Al Bayda Formation is more acceptable, simply because we consider the Eocene fauna and flora in the lower part of the formation as allochthonous, reworked particles, and the Early Oligocene taxa up-section as *in situ* constituents of the rock. This is supported by the confirmed hiatus between the Darnah Formation and the Al Bayda Formation, particularly at the type locality (Fig. 6).

SUMMARY AND CONCLUSION

Based on the above discussion, it seems that both foraminifera and calcareous nannofossils are in harmony as regards the age of Al Bayda Formation. Both groups show some reworking of Eocene taxa in the lower part and if we consider the presence of the Oligocene nannofossil (*Cyclicargolithus abisectus*), then the middle (top part of the Shahhat Marl Member) and the upper parts of the formation belong to the Early Oligocene. It is obvious, however, that the conflicting conclusions regarding the age of Al Bayda Formation are largely related to misinterpretation of the fossil record. It is inadequate to jump to conclusions based on rare and poorly preserved taxa without considering the depositional history of the region and ignoring the physical gabs present in the field. Unfortunately, similar attempts regarding other rock units in Cyrenaica have been seen in the recent years (see for more details Tmalla, 2007). Some of the problems influencing biostratigraphic interpretation are local variation in species ranges, phenotypic variation, preservation, contamination, reworking of older sediments and infrequent misidentification of species. These problems can be minimized by using quantitative faunal analysis (see Keller, 1985). Other palaeontologic strategies dealing with sedimentary displacement and stratigraphic disorder can be found in Cutler and Flessa (1990) and in Finger *et al*. (2007) respectively.

In conclusion, the present review, suggests that the Al Bayda Formation is mainly Early Oligocene in age based on the recovery of *Nummulites vascus* (Plate 1: Figs. 4, 8, 9) and *N. fichteli* (Plate 1, Figs. 4, 11) and other fossils from the formation (see above). The Eocene biota in the lower Shahhat Marl Member is confirmed as reworking by almost all workers in the region. Based on the above discussion, the present work does not agree with the conclusion of El Mehaghag and Ashahomi (2005) that the Al Bayda Formation at the Cyrene Apollonia road cut section is Middle to Late Eocene. Further more, the latter authors confirmed the presence of reworked Eocene nannofossils in the Al Bayda Formation and, at least, eight of the species they recorded from the formation, range into the Early Oligocene.

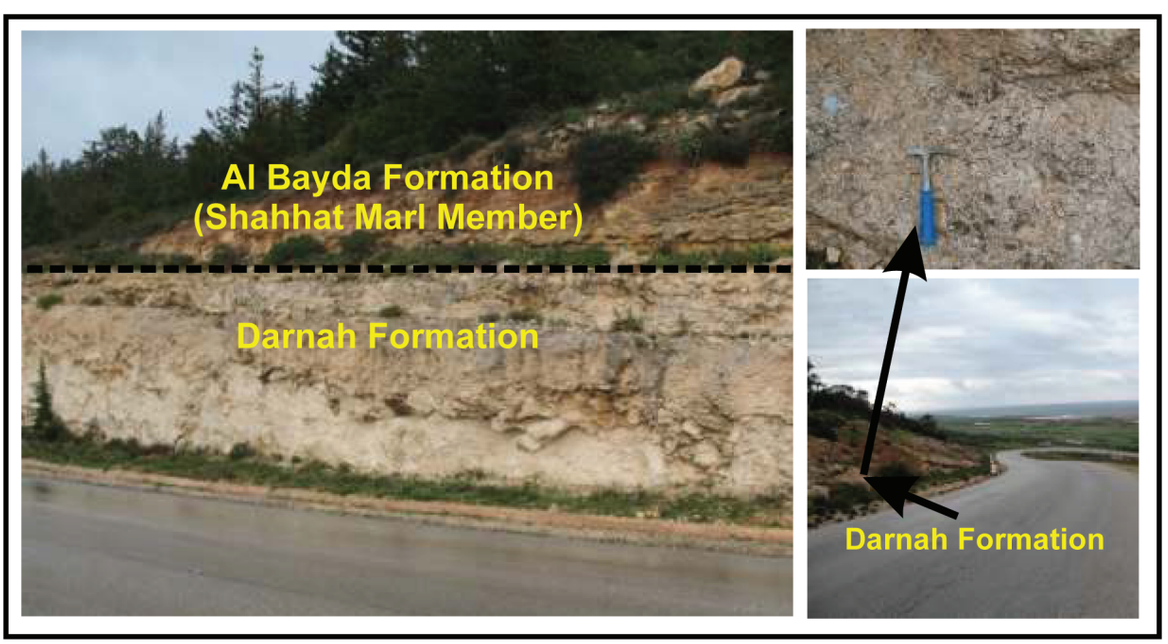

Fig. 6. The Eocene-Oligocene boundary (dashed line) at the road leading to Al Hamámah (the type locality of the Al Bayda Formation, 2.5 km NW of Al Bayda), it shows also the lower part of the Darnah Formation (bioclastic limestone unit with gastropods, pelecypods and small sized-nummulites) near the coast of Al Hamámah.

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