Stratigraphy and Sedimentology of Upper Cretaceous to Upper Palaeocene Succession in Zimam Formation Along Wadi Tar al Kabir, NW Libya

Esam O. Abdulsamad1, Saleh A. Emhanna2, Muayid B. Asmaeil1, Ahmed A. Alwddani1, Fuad M. Rasheed1, Abdulsalam M. Alhaddad1, Emad A. Alashhab3, Ali K. Khalifa4 & Mohammed F. El Hassi4

1 Department of Earth Sciences, University of Benghazi, University Road 13, P.O.B. 9480 Benghazi, Libya
2 Department of Petroleum Engineering, University of Ajdabiya, City Road 1, P.O.B. 291 Ajdabiya, Libya
3 Department of Earth Sciences, University of Sebha, University Road 18, P.O.B. 18758 Sebha, Libya
4 Department of Geological Engineering, Bright Star University, City Road 11, P.O.B. 21864, Al Brega, Libya

Correspondence: Esam O. Abdulsamad, Department of Earth Sciences, University of Benghazi, University Road 13, P.O.B. 9480 Benghazi, Libya. E-mail: esam000@yahoo.com

Received: March 23, 2019 Accepted: April 21, 2020 Online Published: May 5, 2020
doi:10.5539/esr.v9n2p1 URL: https://doi.org/10.5539/esr.v9n2p1

Abstract
The Upper Cretaceous to Upper Palaeocene rocks of the Zimam Formation along the southwestern escarpment of the Hun Graben of NW Libya have been stratigraphically investigated from two stratigraphical sections in wadi Tar al Kabir. The field investigations led to the recognition of three members, from the oldest to the youngest, the Lower Tar Member, the Upper Tar Member and the Had Member. Eight sedimentary facies were distinguished at outcrop-scale and several microfacies were recognized and the outcome indicates that the deposits of the Zimam Formation are corresponding to two transgressive-regressive sedimentary cycles. The first cycle is attributed to the Lower Tar Member in which small planktonic foraminifera is quite common in the Campanian whereas the larger benthic foraminifera, namely, Omphalocyclus macroporus and Siderolites calcitrupoides are abundant in the Maastrichtian. The last occurrence of the latter two taxa, however, was used to delineate the contact between the Maastrichtian and Danian stages in the studied sequence.

Up-sequence the sediments of the Upper Tar Member along with the overlying Had Member correspond to the second transgressive-regressive sedimentary cycle. Herein, the Upper Tar Member is enriched by small benthic foraminifera; Neoeponides duwi and Cibicides cf. libycus, and has been ascribed to the Danian (Lower Palaeocene). The reaming sediments of Zimam Formation, however, are due to intense erosion, shaping the area into flat terrain (Jordi & Lonfat, 1963). Differently, hard dolomites and dolomitic limestone of the Had Member constitute the surface of the tableland in the study area and nearby region. The elevation in study area ranges from 300 to 400 m above sea level (a.s.l.) and the main wadis such as wadi Tar al Kabir, wadi Zimam, and wadi al Had are broad and follow the NE-SW trend till they reach the Hun Graben (see Figure 1). Their alignment is structurally controlled by following a particular fault trend. The faults display generally the downthrown blocks either towards the graben or towards its flank. Although beds in the study area are marked by horizontal to subhorizontal strata, a dip of a few degrees towards the northeast has been documented. The evolution of the fault systems responsible for the observed deformation in northwest Libya, Hun Graben and western Sirt Basin have been well documented by Westaway (1996); Abdunaser (2015); Abdunaser & McCaffrey (2015). The regional geology mapping of the study area and nearby region, however, is studied by Shakoor.

1. Introduction
The southwestern escarpment of the Hun (Hon) Graben of NW Libya is morphologically a table-land area and gently plunging towards the northeast. It constitutes the easternmost part of the enormous monotonous Al Hamada al Hamra Plateau (Figure 1). The plateau is deeply dissected by several wadis, producing step-like forms, resulting directly from tabular structures and the alternations of hard and soft sediments (Shakoor & Shagroni, 1984). The dominance of the softer sediments belonging to the Lower Tar Member and the Upper Tar Member in the area northwest and west of the oasis of Suknah (Socna) have been responsible, due to intense erosion, shaping the area into flat terrain (Jordi & Lonfat, 1963). Differently, hard dolomites and dolomitic limestone of the Had Member constitute the surface of the tableland in the study area and nearby region. The elevation in study area ranges from 300 to 400 m above sea level (a.s.l.) and the main wadis such as wadi Tar al Kabir, wadi Zimam, and wadi al Had are broad and follow the NE-SW trend till they reach the Hun Graben (see Figure 1). Their alignment is structurally controlled by following a particular fault trend. The faults display generally the downthrown blocks either towards the graben or towards its flank. Although beds in the study area are marked by horizontal to subhorizontal strata, a dip of a few degrees towards the northeast has been documented. The evolution of the fault systems responsible for the observed deformation in northwest Libya, Hun Graben and western Sirt Basin have been well documented by Westaway (1996); Abdunaser (2015); Abdunaser & McCaffrey (2015). The regional geology mapping of the study area and nearby region, however, is studied by Shakoor.
& Shagroni (1984).

Figure 1. Index map of Libya showing the major sedimentary basins of Libya and the location of the study area, modified after Abdunaser & McCaffrey (2015)

Two stratigraphical sections (TS1 and TS2) of the Zimam Formation in wadi Tar al Kabir northwest of the oasis of Suknah have been measured and systematically sampled (Figure 2). They are located between latitudes 29°.00’ and 29°.30’ N and longitudes 15°.15’ and 15°.45’ E (see Figure 2). The field investigations led to the recognition of three members, they are, from oldest to youngest, the Lower Tar Member, the Upper Tar Member and the Had Member (Figure 3). Several authors including Burollet (1960); Jordi & Lonfat (1963); Barr (1972); Barr & Weegar (1972); Eliagoubi & Powell (1980); Butt (1986); Salaj & Nairn (1987); Tmalla (1992; 1996); Imam (2001); Tshakreen et al. (2002); Tshakreen & Gasiński (2004); Shiref & Salaj (2007) and more recently Tshakreen et al. (2017) have contributed to the stratigraphy and depositional history of these rock units and their coeval deposits, both in outcrop and in the subsurface from different parts of the region.

The stratigraphical subdivisions introduced for the study region by Jordi & Lonfat (1963) and the modification established by Shakoor & Shagroni (1984) have been adopted in the current work. The revision of the Cretaceous section incorporated the Lower Tar Member into Al Gharbiyah Formation of Nairn & Salaj (1991) leaving the Zimam Formation as a purely Palaeocene unit is not accepted here. We follow the recommendation of Tawadros (2012, p. 359) to maintain the original stratigraphical subdivisions of Jordi & Lonfat (1963) for the Cretaceous-Palaeogene deposits in the studied region.

In this work, the results of the palaeontological analysis of benthic foraminifera and mollusca of the Upper Cretaceous–Upper Palaeocene Zimam Formation are described and discussed in terms of litho-biostratigraphical attributes. The study aims to improve the stratigraphy of the region and to provide a reasonable palaeoenvironmental assessment to the studied sediments based on information derived from the microfacies, the matrix-free foraminiferal assemblages and the associated molluscan accumulation.
2. Materials and Methods

Outcrop samples of predominantly limestone and dolomitic limestone and subordinately mixed siliciclastic-carbonates (calcareous clay, marls and marly limestone), were collected from two outcrops of the Zimam Formation in wadi Tar al Kabir (see Figure 3). All samples were collected at a maximum interval of 5m; near lithologic facies changes the samples were more closely spaced. Composition, sedimentary structures, bed thickness and macrofossil content were examined using terms proposed by Tucker (2011). The majority of the limestone samples collected were subsequently processed for thin-section analysis, with several lithologies being recognized. Their litho-and bioclastic components are expressed using terms recommended by Flügel (2010).

The studied microfauna (notably, foraminifera) were recovered both in thin-sections and from the washed residues through a 63-μm sieve, whereas the macrofauna (notably, mollusca) were collected during the fieldwork. The results, however, were analyzed to provide the age/stage boundaries and are interpreted based on the first and last occurrences of age diagnostic taxa and associated biota recovered from the studied stratigraphic sections. Larger benthic foraminifera have been distinguished based on the morphological characteristic used in Renema & Hart (2012); Robles-Salcedo et al. (2013), whereas the small benthic foraminifera have been identified mostly based on the criteria used in Speijer (2003). The macrofauna have been studied based on overall morphology used in El Qot et al., 2013.

All laboratory analyses were undertaken at the Micropalaeontology Laboratory of the Earth Sciences Department of Benghazi University. Thin-section preparation, however, was taken at the Geological Laboratory of the Sirt Oil Company. The study material will have a final repository in the Geological Museum of the University of Benghazi (Benghazi, Libya).
Figure 3. Views of the studied outcrops at wadi Tar al Kabir. A. shows the outcrop view of the TS1-Section and B. shows the TS2-Section

3. Background and Stratigraphy

The Zimam Formation was first described by Jordi & Lonfat (1963) from the wadi Tar al Kabir area about 50 km northwest of the oasis of Suknah (see Figure 2). They introduced the term Zimam Formation after the nearby wadi Zimam (also Zmam) and considered it as the last sedimentary cycle of the Al Hamadah al Hamra Group (Hamada Group) of NW Libya (see Figure 1). They divided it into Tar "Marl" Member and an overlying Had "Limestone" Member. The Tar "Marl" Member, however, was further subdivided into a Lower and an Upper Tar unit by the so-called "Socna Mollusc Bed" at the base of the upper unit (see Shakoor & Shagroni, 1984). Consequent workers in the region followed basically the work of Jordi & Lonfat (1963), recognizing their three units as members of the Zimam Formation. During the preparation of the geological map of the region by Shakoor & Shagroni (1984), however, the Lower Tar "Marl" and the Upper Tar "Marl" members have been renamed as Lower Tar Member and Upper Tar Member and they treated them as two separate mappable units. The overlying Haad (Had everywhere else) "Limestone" Member has been renamed as Had Member after wadi al Haad (Had everywhere else). Our investigation in the region, nevertheless, supports the stratigraphical subdivision of Shakoor & Shagroni (1984), therefore, in the current revision; they have been treated as independent members of the Zimam Formation.

The Cretaceous-Palaeogene boundary, however, has been placed by most workers at the base of the "Socna Mollusc Bed" of the Upper Tar Member (including Jordi & Lonfat, 1963; Fürst, 1964; Lehmann, 1964; Barr & Berggren, 1980). According to Tshakreen et al. (2017), no micropalaeontological evidence for the Cretaceous-Palaeogene boundary in surface sections has ever been found so far in the region. Though, Barr (in Barr & Weegar, 1972, p. 173) and Eliagoubi & Powell (1980) suggest a Maastrichtian age for the Lower Tar Member with characteristic planktonic foraminifera. Shiref & Salaj (2007) defined the boundary between the Maastrichtian and Danian by the last occurrence of Omphalocyclus macroporus Lamarck and by the appearance of the Postrugoglobigerina daubjergensis (Broennimann) and Eoglobigerina danica (Bang). Based on foraminifera, the study of Tshakreen et al. (2017) can be considered as the first study to place the Cretaceous-Palaeogene boundary at the top of the "Socna Mollusc Bed" of the Upper Tar Member and hence, included the "Socna Mollusc Bed" at the top of the Lower Tar Member but they treated it as a separate member (see Tshakreen et al., 2017, fig. 4, p. 353). In the current research, however, we confirm their conclusion for placing the contact of the Upper Cretaceous-Palaeogene at the top of the "Socna Mollusc Bed" nevertheless we have included the later unit as the upper-most part of the Lower Tar Member. Further details concerning the Cretaceous-Palaeogene boundary in the studied region and the nearby Sirt Basin can be found in Tmalla (1992; 1996); Tshakreen & Gasiński (2004); Tawadros (2012).

According to Banerjee (1980), the Zimam Formation represents a succession of shale, limestone and dolomite occurring
in an extensive area in the Al Hamadah al Hamra from the Tunisian border east to the Hun Graben, extending south to the northern Dor el Gussa in Murzuq Basin (see Figure 1). It also occurs in the subsurface Sirt Basin. It conformably overlies the Upper Cretaceous (Santonian-Campanian) Mizdah Formation (Burollet, 1960) of the Hamada Group and is conformably overlain by the Palaeocene Shurfa Formation which represents the first sedimentary cycle of the Jabal Waddan Group (see Jordi & Lonfat, 1963).

The total exposed thickness of the Zimam Formation in the region is about 200 m in the west and about 100 m in the east while in the subsurface a 250 m. have been reported between the oil-wells B1-44 and A1-44 (see Figure 2). In the study area, however, the rock unit is about 80 m. suggesting that the Zimam Formation shows a considerable decrease in thickness toward the wadi Tar al Kabir area.

Figure 4 represents the different characteristics of the Upper Cretaceous-Upper Palaeocene stratigraphy in the study area. It shows the three main lithostratigraphic units of the Zimam Formation along the wadi Tar al Kabir area. They are, from oldest to youngest, the Lower Tar Member, the Upper Tar Member and the Had Member. Eight mixed carbonate-silica clastic facies were distinguished at outcrop-scale and several microfacies were recognized and discussed in the following sections. The outcome indicates that the depositions of the Zimam Formation are belonging to two transgressive-regressive sedimentary cycles (see Figure 4).

![Figure 4. The stratigraphic column of the study area showing the lithostratigraphic units and the main sedimentary facies and cycles of the Zimam Formation](image)

To demonstrate the lateral variation of the studied deposits, a correlation of these outcrops, based on stratigraphic criteria, is summarized in figure 5. Here, the stratigraphic successions are generally similar, the difference being only the slight thickness variations of individual rock units. The Cretaceous-Palaeogene contact, which has been chosen as a datum for our correlation, has been interpreted as an erosional surface of submarine origin which may be related to carbonate dissolution and clastic influx on a carbonate shelf. Detailed stratigraphic descriptions for the studied deposits are discussed below in stratigraphic order based on litho-biostratigraphical attributes.
Figure 5. Correlation chart showing the measured sections (TS1 & TS2) at wadi Tar al Kabir. The correlation is based on all documented stratigraphical criteria

4. Results and Discussions

A composite stratigraphic occurrence chart of the studied foraminifera and mollusca at wadi al Kabir is shown in figure 6. Generally, the examined sediments are containing rich assemblages of relatively few species of moderate preserved foraminifera and mollusca. The limited number of the recovered species is attributed to the facies control on the fossil range which hinders the acquisition of complete biostratigraphic data. It similarly restricts the application of a formal zonal scheme and the use of quantitative or semi-quantitative methods of biostratigraphic correlation. Moreover, the development of a locally applicable zonation requires confirmation of its lateral extent through studies on other biostratigraphically suitable sections. Although no biostratigraphic scheme is presented in the current study due to complications arising from facies changes and stratigraphic gaps, analyses of the studied faunal distribution (see Figure 6) indicate that the studied sequence exhibits distinctive age-related fossil content. A selection of significant species and their associated microfacies are illustrated in plates 1-3. In the following section, however, a brief account of the studied lithostratigraphic units and their biotal content are presented in stratigraphic order.
Figure 6. Composite stratigraphic occurrences chart of the studied foraminifera and mollusca at the study area

4.1 Lower Tar Member (Campanian/Maastrichtian)

The Lower Tar Member is about 50-70 m. thick in the type section at the mouth of wadi Tar al Kabir. It consists of dolomitic limestone alternating with calcareous clays and dolomitic marls. As most of the lower part of the member is represented by marly dolomitic limestone at the type-section a reducing thickness of about 45 m. with better lithological characteristic has been sampled in the study area. The studied sequence of the Lower Tar Member consists of three sedimentary facies (facies 1 - facies 3) and is representing the first transgressive-regressive cycle set (see Figure 4). These facies have been described in stratigraphical order as follows:

Facies 1 is consisting of massive limestone alternating with calcareous clays and marly limestone beds enriched mostly by Campanian keeled planktonic foraminifera (see Figure 4). The massive limestone is grey to yellowish in color, thin to medium bedded and hard (Figure 7). At microfacies level, however, these limestones are representing microcrystalline to fine-grained mudstone. The calcareous clays are locally laminated, soft and dark green in color whereas the marly limestone beds are yellowish in colour, quit soft and contain keeled planktonic foraminifera in which frequent forms are belonging to Rugoglobigerinidae. This stratigraphical interval is lacking any larger benthic foraminifera and has been described, based on planktonic foraminifera from the mouth of wadi Tar al Kabir, by Eliagoubi (1975; 1979) to include diverse forms belonging to Campanian/Maastrichtian. Tshakreen et al. (2017), however, ascribed the planktonic foraminifera, above this interval, as upper Campanian. Our assessment to their finding with other findings reported from coeval deposits in Sirt Basin (Barr, 1972; Tmalla, 1992; 1996), Cyrenaica (Barr, 1968) and from the Campanian/Maastrichtian deposits of Egypt (El-Naggar, 1966; 1971; Tantawy et al., 2001) led us to ascribe this interval to the Campanian. All authors, however, suggest that the planktonic foraminifera are representing a deep water environment.
Figure 7. Lower part of the Lower Tar Member at wadi Tar al Kabir (TS1-Section) showing the calcareous clays (A) and the massive limestone beds (B) of facies 1

The overlying facies 2, however, is regressive in nature and essentially made up of medium to thick-bedded of reddish limestone (Figure 8). The lithology is mostly mud-supported wackestone-packstone and consists mostly of bioclasts of rotalid larger benthic foraminifera (Plate 1, figures a; b). The limestone, particularly at the lower levels (Figure 8), contains pelecypods (notably, *Exogyra overwegi* and *Agerostrea unguilata*), gastropods (*Campanile ganesha*) and cephalopods (*Nautilus sanfilippoi*) (Plate 3, figures 1-6). Medium-sized ammonites of unknown affinity are also present (Figure 8B). Slightly gypsiferous dark-grey calcareous clays intercalation, yellowish marls and marly limestone, enriched locally by non-keeled planktonic foraminifera, are also noted.

Figure 8. Middle part of the Lower Tar Member (TS1-Section) showing thick-bedded reddish limestone of facies 2 (A), and medium-sized ammonites (B)

The consistent vertical distribution of *Exogyra* is quite significant in the studied sediments, as it is widely distributed in deposits representing Upper Cretaceous shelf habitats at water depths of less than 50 m (Dhondt et al., 1999). Therefore, the presence of this oyster in this stratigraphic interval indicates deposition in an inner neritic environment. Additionally, the presence of such oysters may indicate a relatively low salinity, possibly due to a local and temporary influence of a freshwater supply, which also caused contamination by terrigenous quartz grains (e.g., Abdulsamad & Bu-Argoub, 2006; Abdulsamad & El Zanati, 2013).

As the lower and upper levels of facies 2, however, are containing a concentration of larger benthonic foraminifera, namely, *Siderolites calcitrapioides* and *Omphalocyclus macroporus* (Figures 9; 10), the facies 2 has been interpreted to deposit in moderate to the high-energy environment. These two species have no exact extant equivalents, but the spines of the former species and the robust shape of the other imply relatively shallow water, high-energy environment, probably in
seagrass meadows (Renema, 2010). They have been well-known from the Maastrichtian deposits of North Africa (Salaj, 2003). A similar age assessment has been reported from the Simsima Formation in Oman Mountains by Abdelghany (2003) and from the Upper Cretaceous of the Pyrenees by Caus et al. (2010) and by Robles-Salcedo et al. (2018). The first appearances of the former two taxa, nevertheless, were used in the studied sections to define the contacts between the Campanian and Maastrichtian with a minor biostratigraphic gap at the base of the Maastrichtian (see Figure 6). The total faunal assemblage, though, has been interpreted to represent a shallow marine carbonate platform environment.

Figure 9. Photomicrographs showing a concentration of *Siderolites calcitrapoides* at the middle part of the Lower Tar Member (A). B is a close-up view showing the external surface of an isolated specimen of *Siderolites calcitrapoides*

Figure 10. Photomicrographs showing a concentration of *Omphalocyclus macroporus* at middle part of the Lower Tar Member (A). B is a close-up view showing the external surface of an isolated specimen of *Omphalocyclus macroporus*

Up-sequence, facies 3 is corresponding to the top of the Lower Tar Member and representing the closing part of the underlying regressive cycle. It is characterized by a significant mollusca rich limestone unit known in the local literature as "Socna Mollusc Bed" (Figure 11). The limestone is yellowish-brown in color and is locally packstone in texture but shows a gradual decline of micrite in the upper levels. It appears to be as the result of decreasing water depth and increasing energy, which together led to the development of the packstone to grainstone texture (Plate 1, figures c; d). This shallowing-upward trend in facies 3 is accompanied by an increase in the number of undersized pelecypods, particularly, *Venericardia libyca* (Plate 3, figures 4a–4b) and small-sized nautiloids at outcrop-scale. This unit becomes marly dolomitic limestone (Plate 1, figure e), in the entrance of wadi al Tar al Kabir, containing fossil casts of mollusca.
The "Socna Mollusc Bed" has been considered herein to represent a Maastrichtian rather than Danian in age as previously thought. *Omphalocyclus macroporus* and *Siderolites calcitrapoides* are frequent at microfacies level and from the washed residue from the shaly intercalations of "Socna Mollusc Bed" and show no evidence of reworking as suggested in some reports. The *Siderolites calcitrapoides* is canalicate spine-bearing species and subject to lose its spines in high energy-environment. In fact, we have rarely recovered a single specimen with a complete skeleton. Spines of *Siderolites calcitrapoides* represent major constituent in some samples throughout the studies deposits of the Lower Tar Member. The association of later taxa with mostly non-keeled/single-keeled planktonic foraminifera at the base of facies 3 (Plate 1, figure f) is problematic although may suggests an opportunistic mode of life. The last occurrence of *Omphalocyclus macroporus* and *Siderolites calcitrapoides*, however, were used to delineate the contact between the Maastrichtian and Danian stages in the studied sequence (see Figure 6).

4.2 Upper Tar Member (Danian)

The Upper Tar Member attains a thickness of about 20 m. in the study area. It's worth noting, however, that the maximum thickness of more than 50 m. of the member is observed in the type area, southeastwards of the study area. According to Jordi & Lonfat (1963), the variation of facies and thickness of the Upper Tar Member in the region is attributed to the existence of palaeo-highs which provided a very shallow and nearshore conditions. The sediments of the member at the type area are often found covered by rock slumps along the steep slopes of the scarp and consequently, sampling must be treated with caution. The member in the study area, nevertheless, consists of two major sedimentary facies (facies 4 and facies 5) and is representing a second transgressive-regressive cycle set in the Zimam Formation (see Figure 4). These facies have been described in stratigraphical order as follows:

Facies 4 is representing the transgressive phase within the Upper Tar Member. This facies is consisting mostly of soft weathered yellowish marls and occasionally marly limestone contains badly preserved planktonic foraminifera at the base (Figure 12). The lithology of the marly limestone horizons, however, consists of fine to coarse-grained micritic matrix with common faecal pellets and contains unidentified small foraminifera at microfacies level (Plate 2, figure a). The biogenic components, however, are filled with micrite and impregnated with hydroxides. Up-levels, the lithology become fine-grained micrite and contain reworked rotaliid larger benthic foraminifera (Plate 2, figure b).
The washed residue throughout facies 4 includes an important assemblage of small benthic foraminifera where *Neoeponides duwi* and *Cibicides cf. libycus* represent more than 70% of the biotai components in the upper levels of this facies (Figure 13). *Neoeponides duwi* has been recognized as a regular species in Palaeocene shallow shelf deposits in southern central Egypt (Anan & Sharabi, 1988; Hewaidy, 1994). According to the Speijer (2003), however, the dominance of *Neoeponides duwi* in the Nile Valley rather represents a transgressive phase after a 50-100 m. relative sea-level fall. In fact, these two species are widely distributed in the Danian rocks of the subsurface Sirt Basin (Barr & Weegar, 1972).

It's worth noting, however, that the *Neoeponides duwi* were originally described as *Discorbis pseudoscopus* by Gohrbandt (1966, p. 36), but recently, Speijer (2003) has revised the species and assign it as *Neoeponides duwi*. Macrofauna in facies 4 are incomplete and include few medium-sized pelecypods in which locally represented by *Venericardia* sp. and *Ostrea* sp. The disappearance of the in situ Maastrichtian species "*Omphalocyclus macroporus* and *Siderolites calcitrapoides*" and the appearance of the Danian species "*Neoeponides duwi* and *Cibicides cf. libycus*" allowed locating the Upper Cretaceous and the Lower Palaeocene boundary between the underlying facies 3 and the overlying facies 4 in the studied section (see Figure 4).

---

**Figure 13.** Photomicrograph showing abundant assemblage of small benthic foraminifera represented mostly by *Neoeponides duwi* and *Cibicides cf. libycus* in the upper levels of facies 4 of the Upper Tar Member.
Facies 5 representing the upper part of the Upper Tar Member and separated from facies 4 below by thin-bedded of barren fissile-shale enriched in pyrite which may reflect an oxygen-poor environment (see Figure 12). Facies 5 is consisting mostly of soft brownish and highly weathered marl. The uppermost part of the Upper Tar Member, however, is represented by fine to coarse-grained limestone grading to calcarenitic limestone at the top of the section. Pellets of carbonate mud (micrite) and a diverse fragment of older limestone and dolomite are the major components of the calcarenite. The overall lithology of facies 5 together with the overlying sediments of the Had Member indicates a shallowing-upward trend and characterizes the regressive nature of studied deposits. The washed residue of facies 5, however, contains quite frequent specimens of the Danian species, Neoeponides duwi and Cibicides cf. libycus, similar to those recovered from the underlying facies although common miliolids (notably, Quinqueloculina sp.) and nonionids are pretty common at the upper-most part of the section. Few specimens of Venericardia sp. and Cardium sp. have been noted also at outcrop-scale. The last occurrence of the Danian species marks the contact with the overlying Selandian deposits of the Had Member (see Figure 6).

4.3 Had Member (Selandian)

The sediments of the Had Member at the type-section is about 20-25 m. and consists mainly of dolomitic limestone and dolomite in three thick layers separated by chalky marl which is frequently dolomitic. In the study area, the studied sequence attains a thickness of about 20 m and consists of three main facies (facies 6 - facies 8) and together representing the last regressive segment of the Zimam Formation (see Figure 4). These facies have been described in stratigraphical order as follows:

Facies 6 is represented by thick cross-bedded yellowish-reddish dolomitic limestone (Figure 14). The lithology shows a dolomitic limestone contains more than 50% dolomite occurring as minute euhedral rhombo-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. The nature of the sediments indicates a restricted condition of deposition. The studied facies, however, has limited stratigraphic value although rare and badly preserved miliolids, nonionids and codiacean algal grains have been noted.

Figure 14. Lower part of the Had Member (TS2-Section) at wadi Tar al Kabir showing cross-bedded dolomitic limestone of facies 6

Up sequence, the sediments of the Had Member are representing facies 7 in which yellowish-brown marls interbedded locally with thin-layers of marly limestone is the main lithology (Figure 15). Here, the microfacies of the marly limestone show fine to coarse-grained micrite texture and contain small benthic foraminifera and codiacean green algal grains (Plate 2, figures c; d). Other green algae represented by several species of Cymopolia have been reported from this level elsewhere of the study region by Shiref & Salaj (2007) and the sediments have been interpreted to be deposited in a nearshore marine environment.

Up-levels, however, the codiacean green algal grains become more evident and pretty diverse longitudinal and circular sections of Ovulites can be noted (Plate 2, figures e; f). Although some micritized grains are present, most of the grains, nevertheless, are cemented by sparry calcite cement and the overall lithology is represented by grainstone texture. As Ovulites are calcareous green algae and are included in order Bryopsidales which generally live in shallow depths down to a range from 10-20 m (Wilson, 1975; Wray, 1977), this facies is interpreted to be deposited in shallow depths of the
subtidal environment under low energy conditions. The *Ovulites* are identified in the local literature as *Ovulites morelleti* Elliot indicating a Middle Palaeocene age (Conley, 1971; Barr & Weegar, 1972). *Ovulites morelleti* was distinguished from the Upper Palaeocene to Lower Eocene of Egypt by Kuss & Herbig (1993); by El-Gamal & Youssef (2000); by Dragastan & Soliman (2002) and more recently by Helal & Hussein (2015). Elliott (1955) and Radoičić (1990), however, identified this species from the Upper Palaeocene to Middle Eocene of the Middle East and the subsurface of the Western Iraq Desert respectively.

Figure 15. Middle part of the Had Member (TS2-Section) showing yellowish-brown marls interbedded with thin-layers of marly limestone

Facies 8 is representing the upper part of the studied Had Member and consist at the base by a thick-bedded, reddish-brown and well-jointed dolomitic limestone forming a reduced morphological bench at outcrop scale. Here, the lithology is similar to the underlying facies 6 though fine-grained microcrystalline is the dominant texture. Alternation of the hard dolomitic limestone and soft yellowish-green marly dolomitic limestone is quite evident towards the upper-most levels (Figure 16). The intervening softer lithology, however, contains miliolids, nonionids and *Ovulites* similar to those documented in underlying faces 7. The overall lithology of facies 8 is representing a regressive segment in the inner shelf as indicated by the limited number of micro and macrofauna. Evidence of further shallowing is indicated, at the top of the section, by the existence of common feeding burrows that delineate the final episode of the last sedimentary cycle of the Zimam Formation. The age of the Had Member, however, is tentatively ascribed to the Selandian (Upper Palaeocene) based on the last occurrence of the Danian fauna “*Neoeponides duwi* and *Cibicides cf. libycus*” and the total range of the codiacean algae *Ovulites morelleti* (see Figure 6).

Figure 16. Upper part of the Had Member (TS2-Section) showing yellowish-green marly dolomitic limestone
5. Summary and Conclusions

The Upper Cretaceous-Upper Palaeocene sequence of the Zimam Formation at wadi Tar al Kabir of NW Libya has been investigated stratigraphically. It consists of three members, namely the Lower Tar Member, the Upper Tar Member and the Had Member. Based on the lithology and fossil contents two transgressive-regressive sedimentary cycles have been recognized. The first cycle is belonging to the Lower Tar Member in which its lower part is transgressive and containing Campanian planktonic foraminifera whereas the upper part is regressive and includes a characteristic molluscan assemblage associated with rotalid larger benthic foraminifera which are representing a shallow marine environment. The closing part of the first cycle is characterized by a significant mollusca rich limestone unit known as "Socna Mollusc Bed" and has been considered here to represent a Maastrichtian rather than Danian in age as previously thought. The larger benthic foraminifera, however, were used to define the contacts between the Campanian/Maastrichtian and the Maastrichtian/Danian stages in the studied sequence. Up-sequence the sediments of the Upper Tar Member along with the overlying Had Member correspond to the second transgressive-regressive sedimentary cycles. Herein, the transgressive phase is confined to the lower part of the Upper Tar Member and includes planktonic foraminifera at the base. Based on small benthic foraminifera, the sediments of the Upper Tar Member have been assigned to the Danian (Lower Palaeocene).

The Had Member is regressive in nature as indicated by the common occurrence of codiacean green algal grains and by the regular vertical distribution of miliolids and nonionids. Evidence of further shallowing is indicated up-section by the existence of common feeding burrows that delineate the final episode of the last sedimentary cycle of the Zimam Formation. The age of the Had Member, however, is tentatively ascribed to the Selandian (Upper Palaeocene) based on the last occurrence of the Danian fauna and the total range of the codiacean algae.

Acknowledgments

The authors would like to thank Prof. Mustafa J. Salem (the University of Tripoli at Tripoli, Libya), for his critical reading and useful suggestions for improving this manuscript. Thanks are due to Prof. Gamal M. El Qot (Benha University at Benha, Egypt), for revising the identification of the mollusca specimens. The authors are greatly appreciated to Dr. Hassan M. Hassan, Dr. Salah Egnified and Mr. Mohamed Lame (the University of Al Jufrah at Al Jufrah, Libya), for providing logistics and encouragement for carrying out this research. Our thanks are extending to the senior students of the Faculty of Natural Resources of the University of Al Jufrah at Suknah for their support and assistance during the fieldwork. We also thank the personnel of the Geological Laboratory of the Sirt Oil Company for their support in preparing some of the thin-sections. The critical and constructive comments by two anonymous reviewers and remarks from the editorial team of the Earth Science Research have greatly improved the manuscript and are much appreciated.

References

Abdelghany, O. (2003). Late Campanian-Maastrichtian foraminifera from the Simsima Formation on the western side of the Northern Oman Mountains. Cretaceous Research, 24, 391-405. https://doi.org/10.1016/S0195-6671(03)00051-x

Abdulsamad, E. O., & Bu-Argoub, F. M. (2006). Sedimentary facies and foraminifera of the Miocene carbonates of the Ar Rajmah Group in Cyrenaica, NE-Libya. Petroleum Research Journal, 19, 49-60.

Abdulsamad, E. O., & El Zanati, S. M. (2013). Miocene benthic foraminifera from the Soluq area, NE Libya: biostratigraphy and environmental significance. Journal of Mediterranean Earth Sciences, 5, 245-256. https://doi.org/10.3304/JMES.2013.002

Abdunaser, K. M. (2015). Satellite imagery for structural geological interpretation in Western Sirt Basin, Libya: Implication for petroleum exploration. Geosciences, 5(1), 8-25.

Abdunaser, K. M., & McCaffrey, K. J. W. (2015). A new structural interpretation relating NW Libya to the Hun Graben, western Sirt Basin based on a new paleostress inversion. Journal of Earth System Science, 124(8), 1745-1763. https://doi.org/10.1007/s12040-015-0631-4

Anan, H. S., & Sharabi, S. A. (1988). Benthonic foraminifera from the Upper Cretaceous-Lower Tertiary rocks of the northwest Kharga Oasis, Egypt. Middle East Research Center Ain Shams University, Earth Science Series, 2, 191-218.

Banerjee, S. (1980). Stratigraphic Lexicon of Libya. Department of Geological Researches and Mining, Bulletin no. 13, Industrial Research Centre, Tripoli.

Barr, F. T. (1968). Upper Cretaceous stratigraphy of the Jabal al Akhdar, northern Cyrenaica. In F.T. Barr, (Ed.), Geology and Archaeology of Northern Cyrenaica, Libya. The Petroleum Exploration Society of Libya. 10th Annual Field Conference, pp. 131-147.
Barr, F. T. (1972). Cretaceous biostratigraphy and planktonic foraminifera of Libya. *Micropaleontology, 18*, 1-46. https://doi.org/10.2307/1484977

Barr, F. T., & Berggren, W. A. (1980). Lower Tertiary biostratigraphy and tectonics of Northeastern Libya. In M.J. Salem & M.T. Busrewil (Eds.), *The Geology of Libya* (Vol 1, pp. 163-191). Academic Press, London.

Barr, F. T., & Weegar, A. A. (1972). Stratigraphic nomenclature of the Sirte Basin, Libya. The Petroleum Exploration Society of Libya, Tripoli.

Burollet, P. F. (1960). *Libye. Lexique Stratigraphique International*, Afrique (dir. R. Furon) Fascicule IVa. Congres Geologique International. Centre national de la recherche scientifique, Paris.

Butt, A. A. (1986). Upper Cretaceous biostratigraphy of the Sirte Basin, northern Libya. *Revue de Paléobiologie, 5*, 175-191.

Caus, E., Parente, M., & Hottinger, L. (2010). A biozonation (KSBZ) based on shallow benthic, mainly larger foraminifera from the Upper Cretaceous of the Pyrenees. In Organizing Committee (Ed.), Forams 2010, Rheinische Friedrich-Wilhelms-Universität Bonn September 5-10, 2010, Germany Abstract Volume with Program. Bonn, pp. 70-71.

Conley, C. D. (1971). Stratigraphy and lithofacies of lower Paleocene rocks, Sirt Basin, L.A.R. In C. Gray, (Ed.), *Symposium on the Geology of Libya* (pp. 127-140). University of Libya, Tripoli.

Dhondt, A. V., Malchus, N., Boumaza, L., & Jaillard, E. (1999). Cretaceous oysters from North Africa: origin and distribution. *Bulletin de la Société Géologique de France*, 1999(1), 67-76.

Dragastan, O. N., & Soliman, H. A. (2002). Paleogene calcareous algae from Egypt. *Micropaleontology, 48*(1), 1-30. https://doi.org/10.2113/48.1.1

El Qot, G. M., Abdulsamad, E. O., & Aly, M. F. (2013). Upper Cretaceous Macrofossils from Jardas Al’Abid Area, Al Jabal al akhdar northeast Libya: A Systematical Palaeontological. *Egyptian Journal of Paleontology, 13*, 185-254.

El-Gamal, M. M., & Youssef, E. A. (2000). Calcareous algae from the Late Paleocene-Early Eocene Sequence, Galala Plateaux, Gulf of Suez, Egypt. Proceeding of the 5th Int. Conf. Geo. Arab World, Cairo University, III, 1417-1432.

Eliagoubi B. A. (1975). *Maastrichtian (Upper Cretaceous) Foraminifera of North Central and Northwestern Libya.* (Unpublished doctoral dissertation). University of Idaho, Idaho, USA.

Eliagoubi, B. A. (1979). *Systematic paleontology of Maastrichtian (Upper Cretaceous) Foraminifera of North Central and Northwestern Libya.* Arab development institute, Tripoli, Libya.

Eliagoubi, B. A., & Powell, J. D. (1980). Biostratigraphy and Paleoenvironment of Upper Cretaceous (Maastrichtian) Foraminifera of North-central and Northwestern Libya. In Salem, M.J., & Busrewil, M.T. (Eds.), *The Geology of Libya* (Vol 1, pp. 137-153). Academic Press, London.

Elliott, G. F. (1955). Fossil calcareous algae from the Middle East. *Micropaleontology, 1*(2), 125-131. https://doi.org/10.2307/1484164

El-Naggar, Z. R. (1966). Stratigraphy and planktonic foraminifera of the Upper Cretaceous-Lower Tertiary succession in the Esna-Idfu region, Nile Valley, Egypt. *British Museum (Natural History) Bulletin*, Supplement 2, 279 p.

El-Naggar, Z. R. (1971). The genus Rugoglobigerina in the Maastrichtian Sharawna Shale of Egypt. In A. Farinacci (Ed.), *Proceedings of the II Planktonic Conference, Roma 1970* (pp. 421-476). *Edizioni Tecnoscienza, Rome.*

Flügel, E. (2010). *Micrface of carbonate rocks: analysis, interpretation and application*. Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-03796-2

Fürst, M. (1964). Die Oberkreide-Paleozän-transgression im östlichen Fezzan. *Geologische Rundschau, 54*, 1060-1088. https://doi.org/10.1007/BF01820772

Gorhrbandt, K. H. A. (1966). Upper Cretaceous and Lower Tertiary Stratigraphy along the western and south-western edge of the Sirte Basin, Libya. In J. J. Williams & E. Klitzsch (Eds.), *South-Central Libya and Northern Chad. A Guidebook to the Geology and Prehistory* (pp. 33-41). Petroleum Exploration Society of Libya.

Helal, S. A., & Husein, A. W. (2015). Biostratigraphic Zonation and Eocene Chlorophythal Algae, Assiut-Minia Stretch, Nile Valley, Egypt. In *Eighth International Conference on the Geology of Africa* (Vol. 7, pp. 27-54).

Hewaidy, A. G. A. (1994). Biostratigraphy and paleobathymetry of the Garra Kurkur area, southwest Aswan, Egypt. *Middle East Research Center Ain Shams University, Earth Science Series, 8*, 48-73.

Imam, M. M. (2001). Biostratigraphy of the Upper Cretaceous-Lower Eocene succession in the Bani Walid area,
northwest Libya. *Journal of African Earth Sciences, 33*(1), 69-89. https://doi.org/10.1016/S0899-5362(01)90091-0

Jordi, H. A., & Lonfat, F. (1963). Stratigraphic subdivision and problems in Upper Cretaceous - Lower Tertiary deposits in northwestern Libya. *Revue de l’Institut Français du Pétrole, 18*, 1428-1436.

Kuss, J., & Herbig, H. G. (1993). Biogeography, facies and taxonomy of Early Tertiary green algae from Egypt and Morocco. *Bollettino della Società Paleontologica Italiana, spec.*, 1, 249-280.

Lehmann, E. P. (1964). Tertiary-Cretaceous boundary facies in the Sirte Basin. *Proc. 22nd Int. Geol. Cong. New Delhi, 3*, 56-73.

Nairn, A. E. M., & Salaj, J. (1991). Al Gharbiyiah Formation, Upper Campanian-Upper Maastrichtian (northwest Libya). In M. J. Salem, O. S. Hammuda & B. A. Eliagoubi (Eds.), *Third Symposium on the Geology of Libya* (Vol. 4, pp. 1621-1636). Elsevier, Amsterdam.

Radoicic, R. (1990). Paleogene Dasycladalean algae from the subsurface of the Western Iraqi Desert. *Bulletin de l’Académie Serbe des Sciences et des Arts, Classe de Sciences Mathématiques et Naturelles, Sciences Naturelles, 32*, 91-103.

Renema, W. (2010). Is increased calcarinid (foraminifera) abundance indicating a larger role for macroalgae in Indonesian Plio-Pleistocene coral reefs? *Coral Reefs, 29*, 165-173. https://doi.org/10.1007/s00338-009-0568-7

Renema, W., & Hart, M. B. (2012). Larger benthic foraminifera of the type Maastrichtian. *Fossils of the type Maastrichtian (part 1): Scripta Geologica Special Issue, (8)*, 33-43.

Robles-Salcedo, R. G., Rivas, G., Vicedo, V., & Caus, E. (2013). Paleoenvironmental distribution of larger foraminifera in Upper Cretaceous siliciclastic-carbonate deposits (Arén Sandstone Formation, south Pyrenees, northeastern Spain). *Palaios*, 28, 637-648. https://doi.org/10.2110/palo.2012.p12-125r

Robles-Salcedo, R. G., Vicedo, V., & Caus, E. (2018). Latest Campanian and Maastrichtian Siderolitidae (larger benthic foraminifera) from the Pyrenees (S France and NE Spain). *Cretaceous Research, 81*, 64-85. https://doi.org/10.1016/j.cres.2017.08.017

Salaj, J. (2003). Southern Tethyan development of larger foraminifers: Palaeogene palaeobiocacies in Tunisia and Libya. In M. J. Salem & K. M. Oun (Eds.), *The Geology of Northwest Libya (Ghadamis, Ifjarah, Tarabusals and Sabratah Basins)*. Second Symposium on the Sedimentary Basins of Libya, held in Tripoli, November 6-8. 2000, Volume I. Earth Science Society of Libya, Tripoli, pp. 313-336.

Salaj, J., & Nairn, A. E. M. (1987). Age and depositional environment of the Lower Tar“Member”of the Zimám. *Palaeogeography, Palaeoclimatology, Palaeoecology, 61*, 121-143. https://doi.org/10.1016/0031-0182(87)90044-7

Shakoor, A., & Shagroni, Y. (1984). *Geological Map of Libya 1: 250,000, Sheet Hun NH 33-11 and Explanatory Booklet*, Industrial Research Centre, Tripoli.

Shiref, Y., & Salaj, J. (2007). Upper Jurassic—Lower Paleogene lithostratigraphy and facies development in the Al Hamadah al Hamra area (Libya), *Geologica Carpathica, 58*(1), 3-18.

Speijer, R. P. (2003). Systematics and paleoecology of the foraminifer Neoeponides duwi (Nakkady) from the Paleocene of Egypt. *Micropaleontology, 49*(2), 146-150. https://doi.org/10.2113/49.2.146

Tantawy, A. A., Keller, G., Adatte, T., Stinnesbeck, W., Kassab, A., & Schulte, P. (2001). Maastrichtian to Paleocene depositional environment of the Dakhla Formation, Western Desert, Egypt: sedimentology, mineralogy, and integrated micro- and macrofossil biostratigraphies. *Cretaceous Research, 22*, 795-827. https://doi.org/10.1016/j.cres.2001.0291

Tawadros, E. E. (2012). *Geology of North Africa*. Taylor and Francis Group, London. https://doi.org/10.1201/b11419

Tmalla, A. F. A. (1992). Stratigraphic position of the Cretaceous-Tertiary boundary in the northern Sirt Basin, Libya. *Marine and Petroleum Geology, 9*, 542-552. https://doi.org/10.1016/0264-8172(92)90065-M

Tmalla, A. F. A. (1996). Latest Maastrichtian and Paleocene planktonic foraminiferal biostratigraphy of Well A1a-NC29A, Northern Sirt Basin, Libya. In M. J. Salem, A. J. Mouzugh, & O. S. Hammuda (Eds.), *The Geology of Sirt Basin* (Vol. 1, pp. 195-232). Elsevier, Amsterdam.,

Tshakreen, S. O., & Gasinski, M. A. (2004). Cretaceous-Paleogene boundary problem in Libya: the occurrence of the foraminiferal species *Abathomphalus mayaroensis* (Bolli) in the Western Sirt Basin. *Geological Quarterly, 48*, 77-82.

Tshakreen, S. O., Gasinski, M. A., & Jerzykiewicz, T. (2002). Late Cretaceous and Early Paleogene foraminiferalid of the western Sirt Basin (Libya). In J. Michalik; N. Hudácková; B. Chalupová & D. Starek, (Eds.), *Esseweca
Conference. Paleogeographical Paleoecological Paleoclimatic Development of Central Europe. Abstract Book. Institute of Geology, Slovak Academy of Science, Bratislava, pp. 83-84.

Tshakreen, S. O., Gasinski, M. A., Machaniec, E., & Maćzniak, A. (2017). Campanian-Maastrichtian foraminiferal stratigraphy and palaeoenvironment of the Lower Tar Member in the Wadi Tar section, Western Sirte Basin (Libya). Annales Societatis Geologorum Poloniae, 87, 349-362. https://doi.org/10.14241/asgp.2017.019

Tucker, M. E. (2011). Sedimentary rocks in the field: a practical guide (geological field guide). Wiley-Blackwell, Chichester.

Westaway, R. (1996). Active tectonic deformation in the Sirt Basin and its surroundings. The geology of Sirt Basin: Amsterdam, Elsevier, 3, 89-100.

Wilson, J. L. (1975). Carbonate facies in geologic history. Springer-Verlag, Berlin, Heidelberg, New York. https://doi.org/10.1007/978-1-4612-6383-8

Wray, J. L. (1977). Calcareous algae. Elsevier Scientific Publishing Co., Amsterdam, Oxford, New York.

Explanation of Plates

Plate 1. Figures a; b. Photomicrographs showing mud-supported wackstone-packstone with common rotaliid larger benthic foraminifera. Lower Tar Member, facies 2. Figures c; d. Photomicrographs showing mud-supported packstone to grainstone texture with gastropods (c) and pelecypoda shell fragments (d). Lower Tar Member "Soema Moullse Bed", facies 3. Figure e. Photomicrograph showing marly dolomitic limestone containing fossil casts of mollusca at the entrance of Wadi al Tar al Kabir, Lower Tar Member. Figure f. Photomicrograph showing longitudinal section of Siderolites calcitrapoides Lamarck (right) and planktonic foraminifera (left) at the base of facies 3. Lower Tar Member.

Plate 2. Figure a. Photomicrograph showing marly limestone consists of fine to coarse-grained micritic matrix with common faecal pellets and contains unidentified small foraminifera, facies 4, Upper Tar Member. Figure b. Photomicrograph showing marly limestone with fine-grained micrite and contain reworked rotaliid larger benthic foraminifera, facies 4. Upper Tar Member. Figures c; d. Photomicrographs showing marly limestone with fine to coarse-grained micrite texture and contain small benthic foraminifera and codiacean green algal grains, facies 7, Upper Tar Member. Figures e; f. Photomicrographs showing mostly grainstone texture enriched in longitudinal and circular sections of codiacean green algal grains (Ovalites). Some of these grains have a thin-micritic wall; others are totally infilled with micrite sediments. The circular section in the center of microfacies e is representing a typical section of Ovalites morrleti Elliot. Small foraminifera are also present and are rather evident in microfacies f. Facies 7, Had Member.

Plate 3. Figures 1a-1c. Nautilus sanfilippoi Sorrentino. 1a & 1c: side views; 1b: aperture view. Lower level of facies 2, Lower Tar Member. Figures 2a-2c. Exogyra overwegi (von Buch). 2a: exterior view; 2b: side views; 2c: interior view. Lower level of facies 2, Lower Tar Member. Figures 3a; 3b. External views of intact shells of Plicatula? sp. Upper levels of facies 2, Lower Tar Member. Figures 4a; 4b. Venericardia libya (Quass). 4a: posterior view of intact shell. 4b: external view. Top of facies 3, Lower Tar Member. Figure 5. Agerostrea ungulata (Schlotheim). Lying cemented by its left valve along anterior-posterior axis. Upper levels of facies 2, Lower Tar Member. Figure 6. Brocken shell of Campanile (Campanile) ganesha (Noetling). Lower level of facies 2, Lower Tar Member.
Copyrights
Copyright for this article is retained by the author(s), with first publication rights granted to the journal.
This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).