

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

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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 depositions 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 calcitrapoides* 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; *Neoepionides duwi* and *Cibicides cf. libycus*, and has been ascribed to the Danian (Lower Palaeocene). The remaining sediments of Zimam Formation, however, are belonging to the overlying Had Member and 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 *Ovulites moreletii*.

Keywords: Libya, stratigraphy, sedimentology, Maastrichtian/Danian, Zimam Formation, Wadi Tar al Kabir

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 & Shagrani, 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).

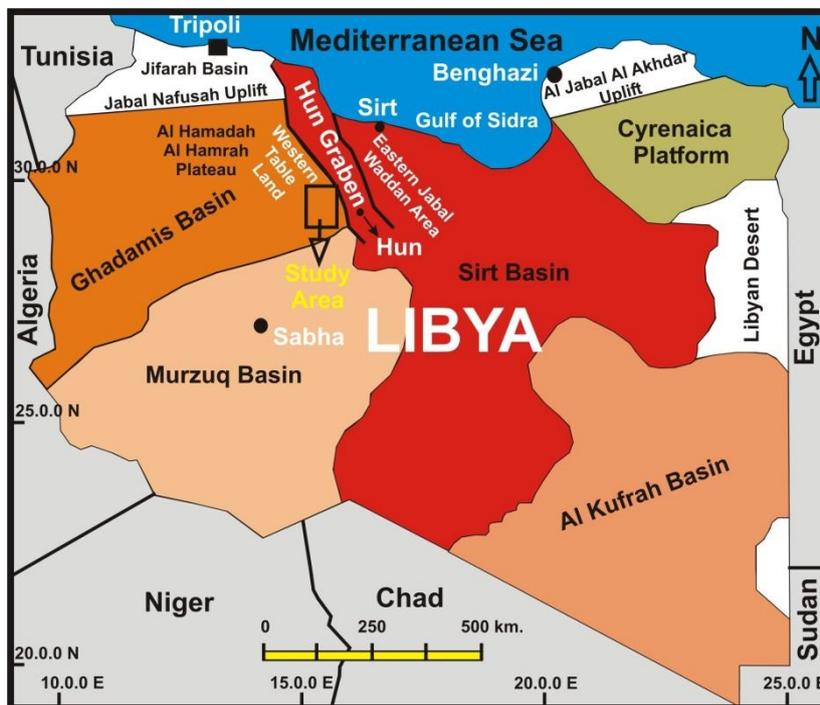


Figure 1. Index map of Libya showing the major sedimentary basins of Libya and the location of the study area, modified after Abdunaser & McCaffrey (2015)

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 Buroillet (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 Shagroni & 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.

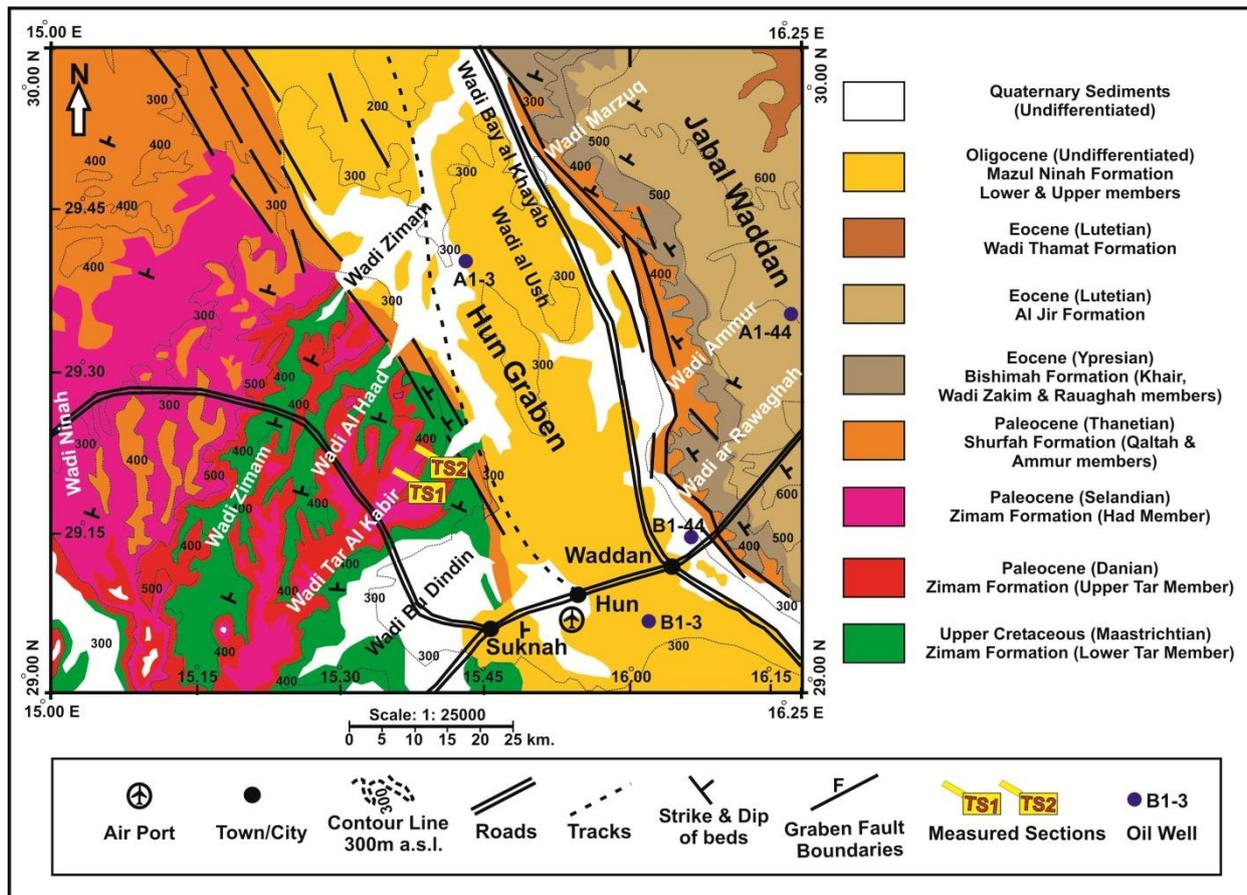


Figure 2. Geological map of the study region showing the location of the measured sections (TS1 & TS2) at wadi Tar al Kabir, modified after Shakoor & Shagroni (1984)

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).

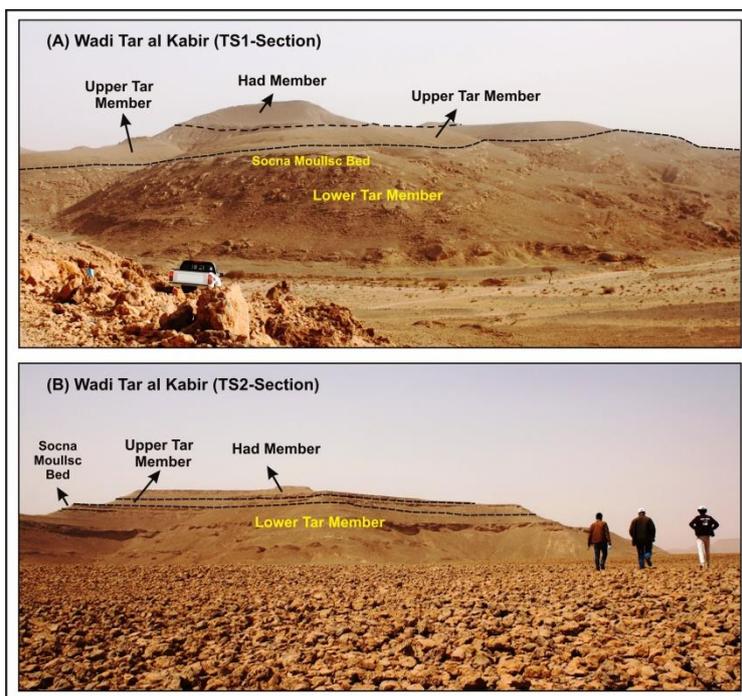


Figure 3. Views of the studied outcrops at wadi Tar al Kabir. A. shows the outcrop view of the TS1-Section and B. shows the TS2-Section

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 & Shagrani, 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 & Shagrani (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 & Shagrani (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 (Buroillet, 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).

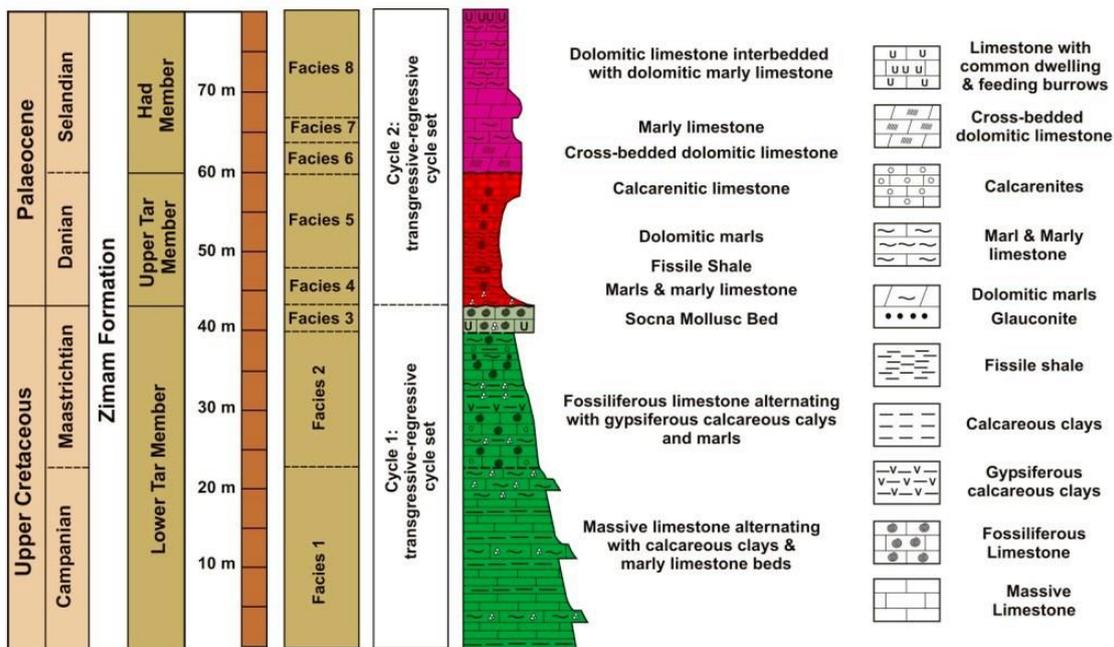
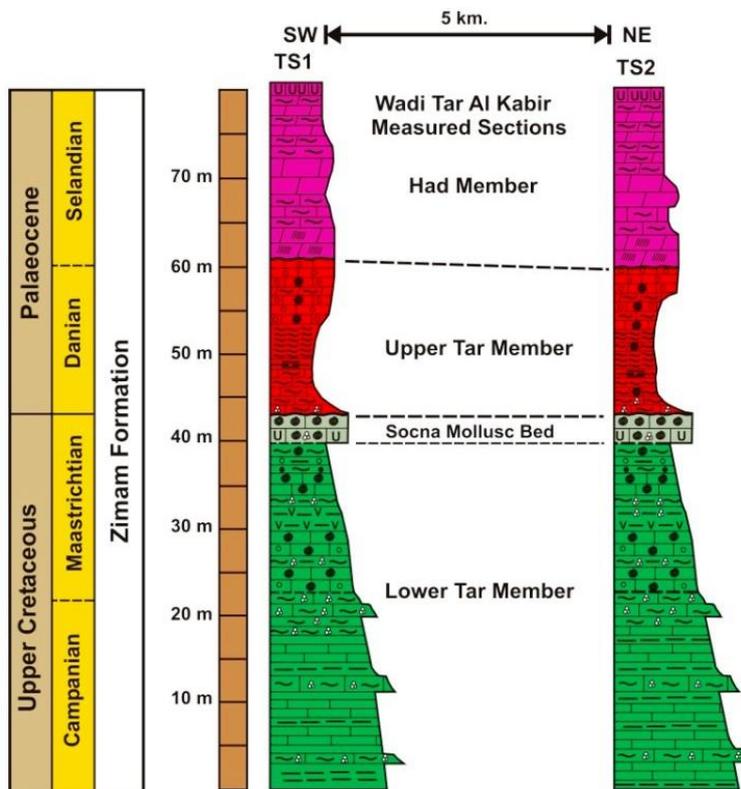


Figure 4. The stratigraphic column of the study area showing the lithostratigraphic units and the main sedimentary facies and cycles of the Zimam Formation

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.



For used symbols see figure 4

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.

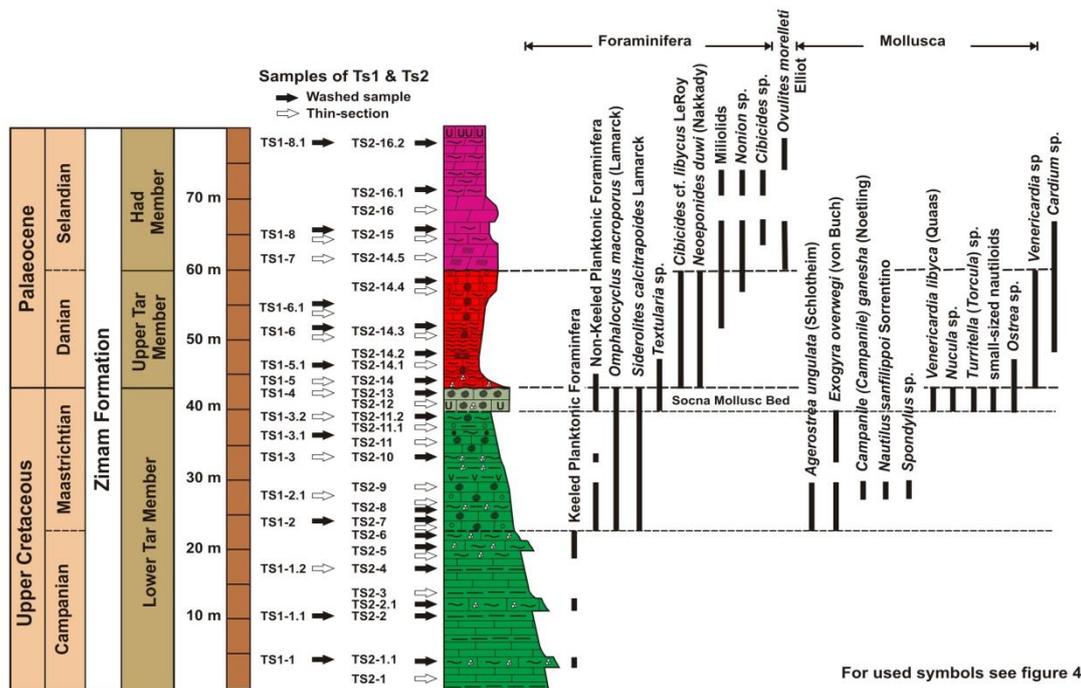


Figure 6. Composite stratigraphic occurrences chart of the studied foraminifera and mollusca at the study area

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.

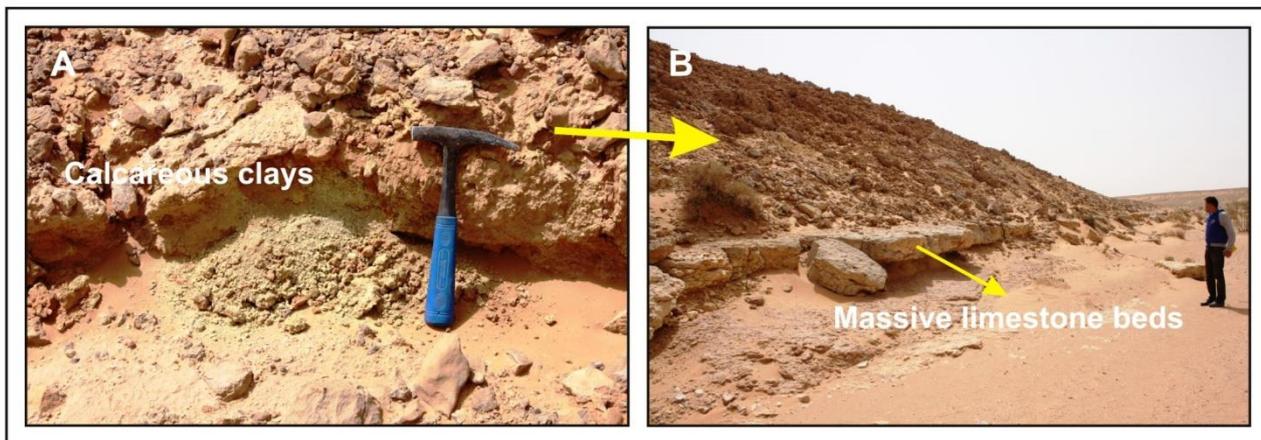


Figure 7. Lower part of the Lower Tar Member at wadi Tar al Kabir (TS1-Section) showing the calcareous clays (A) and the massive limestone beds (B) of facies 1

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 rotaliid larger benthic foraminifera (Plate 1, figures a; b). The limestone, particularly at the lower levels (Figure 8), contains pelecypods (notably, *Exogyra overwegi* and *Agerostrea ungulata*), gastropods (*Campanile ganesha*) and cephalopods (*Nautilus sanfilippo*) (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.

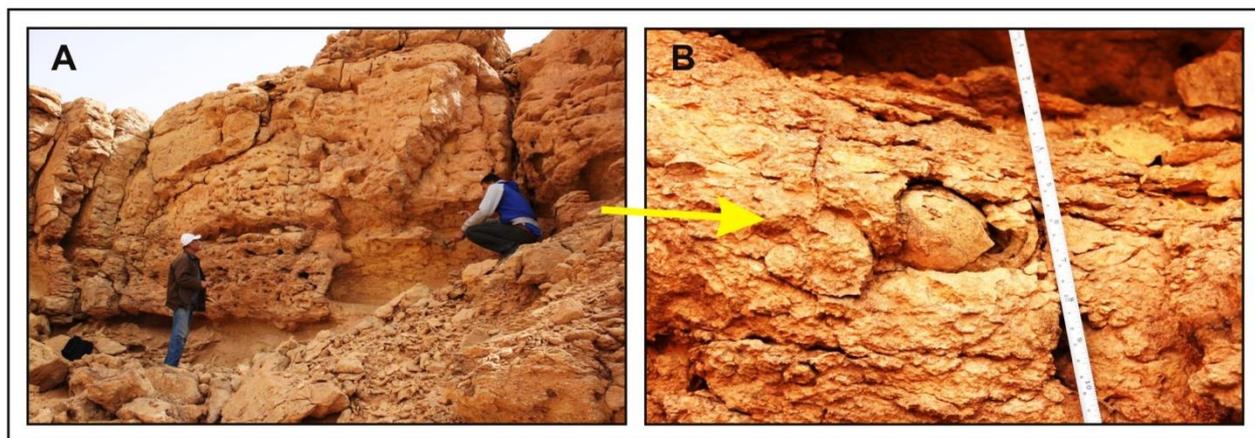


Figure 8. Middle part of the Lower Tar Member (TS1-Section) showing thick-bedded reddish limestone of facies 2 (A), and medium-sized ammonites (B)

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 benthic foraminifera, namely, *Siderolites calcitrapoides* 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 Simsim 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.

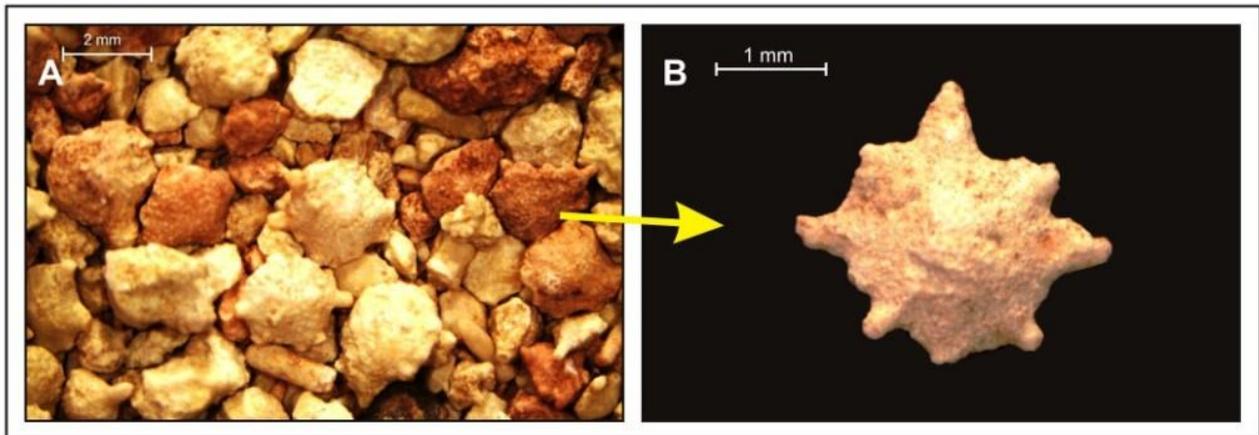


Figure 9. Photomicrographs showing a concentration of *Siderolites calcitrapoides* at the middle part of the Lower Tar Member (A). B is a close-up view showing the external surface of an isolated specimen of *Siderolites calcitrapoides*

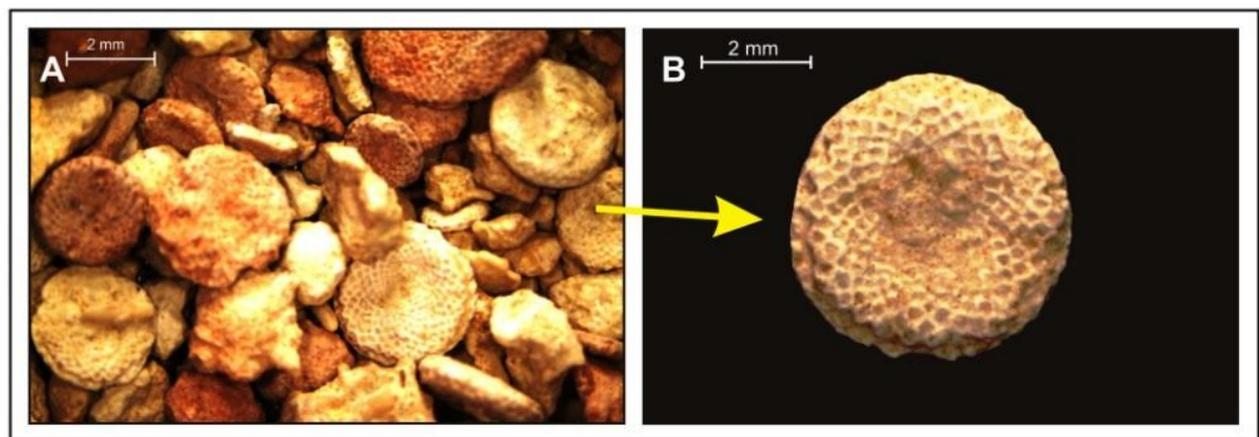


Figure 10. Photomicrographs showing a concentration of *Omphalocyclus macroporus* at middle part of the Lower Tar Member (A). B is a close-up view showing the external surface of an isolated specimen of *Omphalocyclus macroporus*

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.

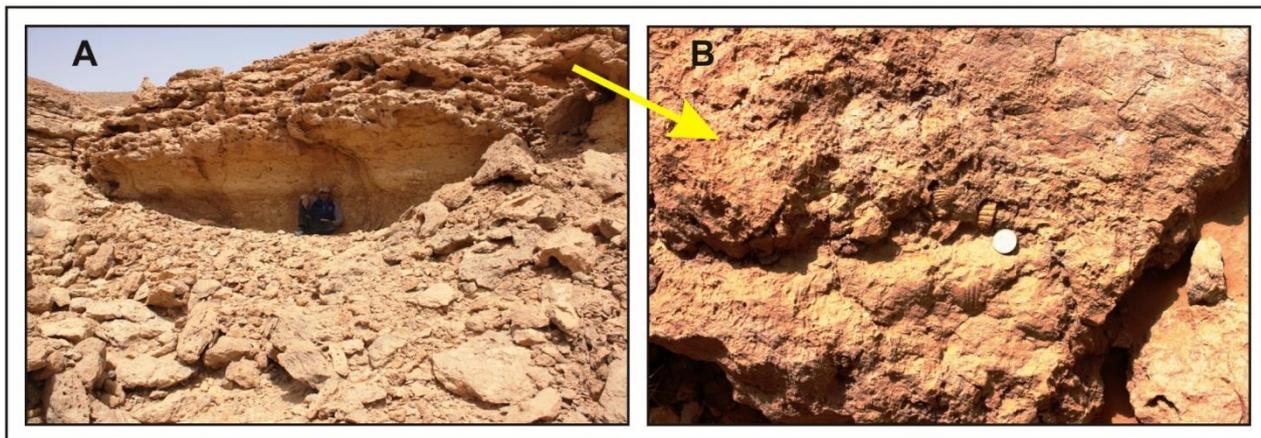


Figure 11. Uppermost part of the Lower Tar Member (TS2-Section) showing "Socna Mollusc Bed" (A). The close-up view show small-sized pelecypods (B)

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 canaliculate 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 studied 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 suggest 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).

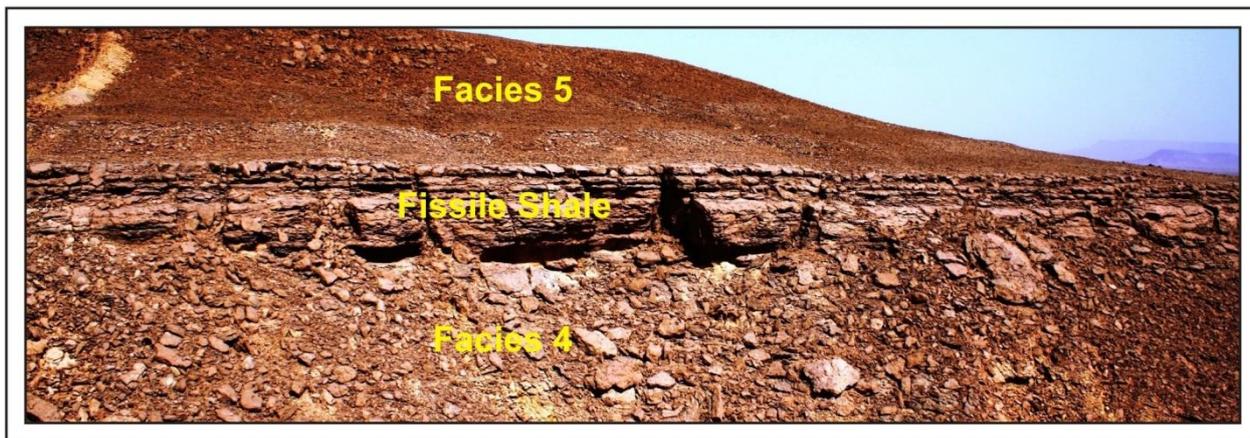


Figure 12. Upper Tar Member (TS2-Section) at wadi Tar al Kabir showing thin-bedded fissile shale separating facies 4 below from facies 5 above

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 biotal 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.

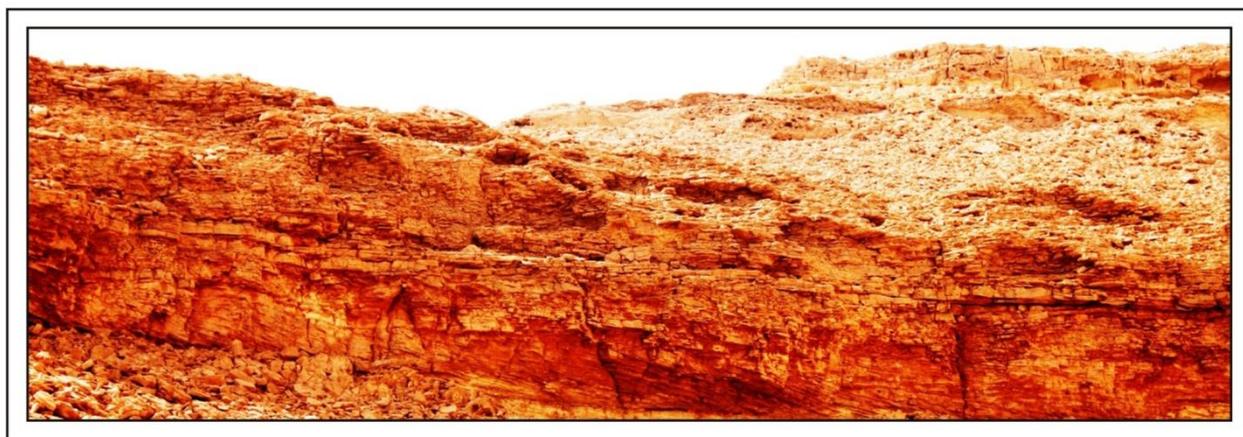


Figure 14. Lower part of the Had Member (TS2-Section) at wadi Tar al Kabir showing cross-bedded dolomitic limestone of facies 6

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 calcitic 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 moreletti* Elliot indicating a Middle Palaeocene age (Conley, 1971; Barr & Weegar, 1972). *Ovulites moreletti* 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.

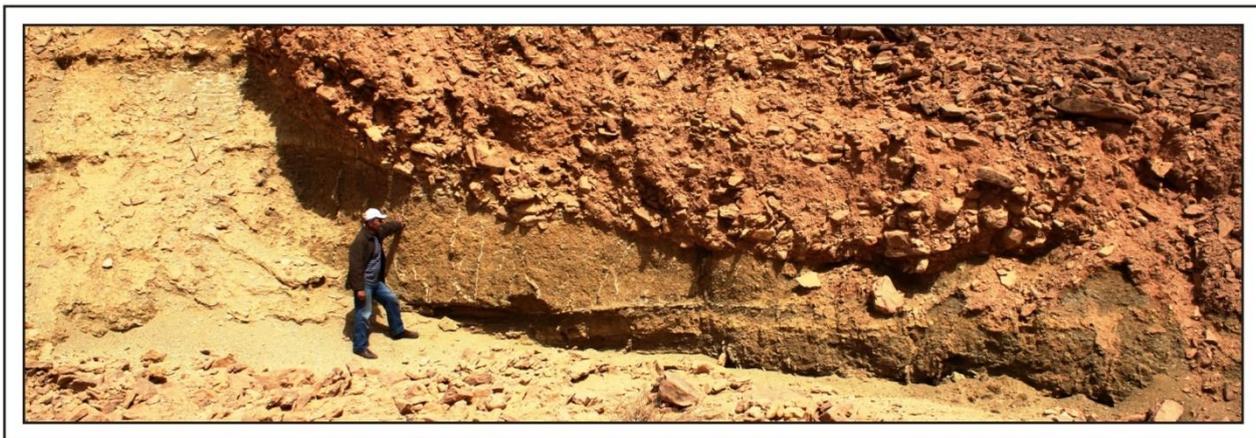


Figure 15. Middle part of the Had Member (TS2-Section) showing yellowish-brown marls interbedded with thin-layers of marly limestone

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 moreletti* (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 rotaliid 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.

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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 "Socna Moullsc 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 (*Ovulites*). 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 *Ovulites morelleti* Elliot. Small foraminifera are also present and are rather evident in microfacies f. Facies 7, Had Member.

Plate 3. Figures 1a-1c. *Nautilus sanfilippo* 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 libyca* (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. Broken shell of *Campanile* (*Campanile*) *ganesha* (Noetling). Lower level of facies 2, Lower Tar Member.

PLATE 1

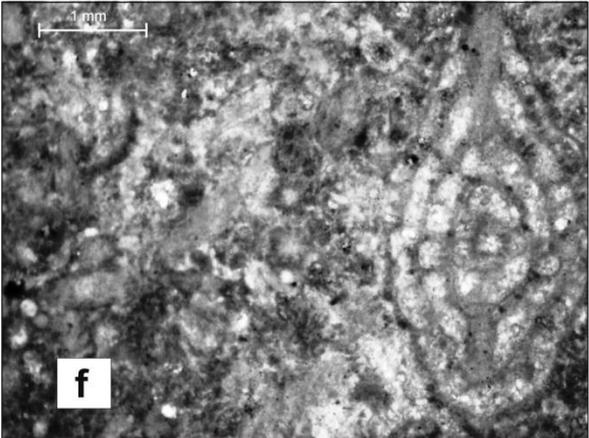
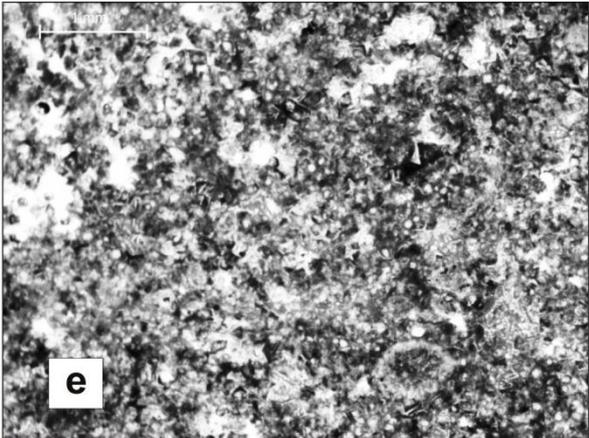
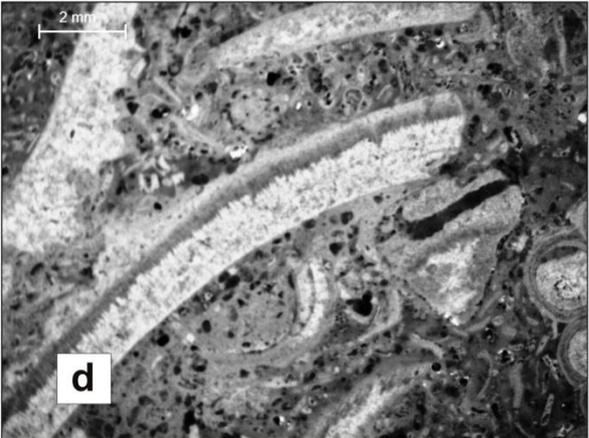
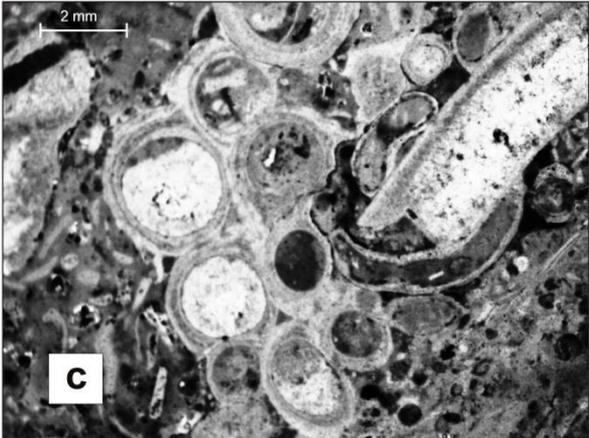
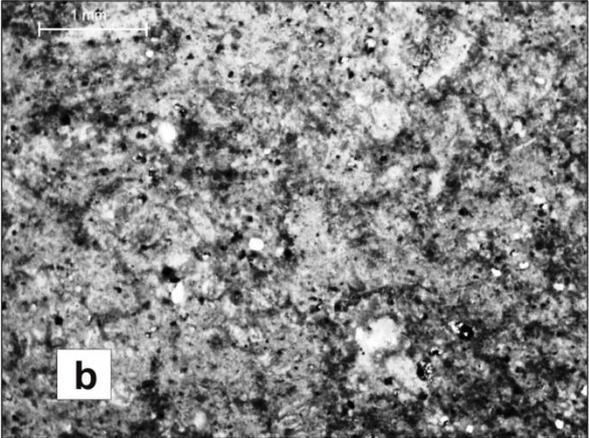
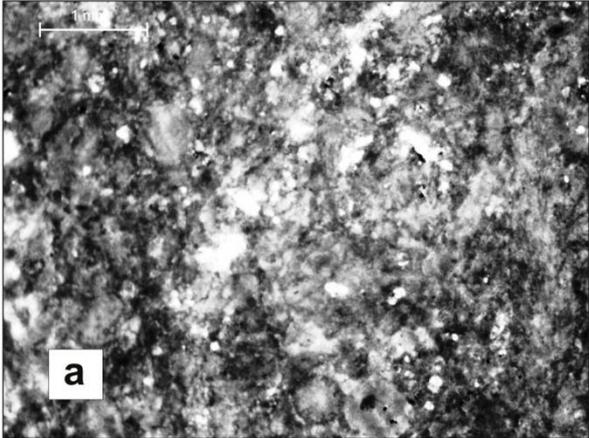
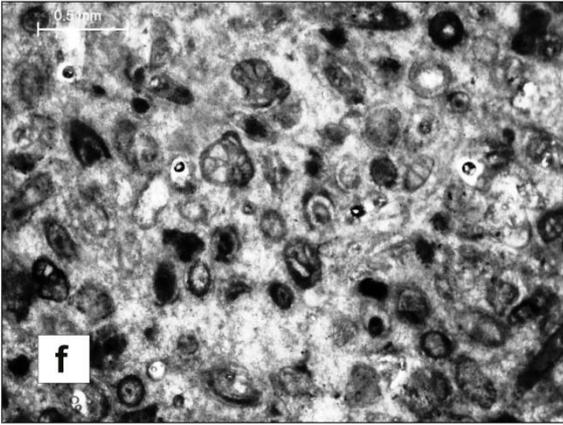
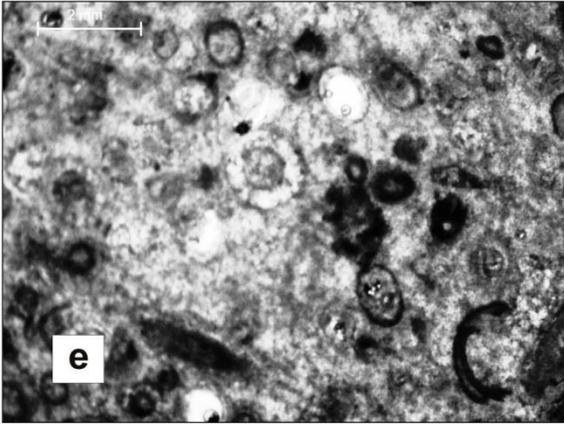
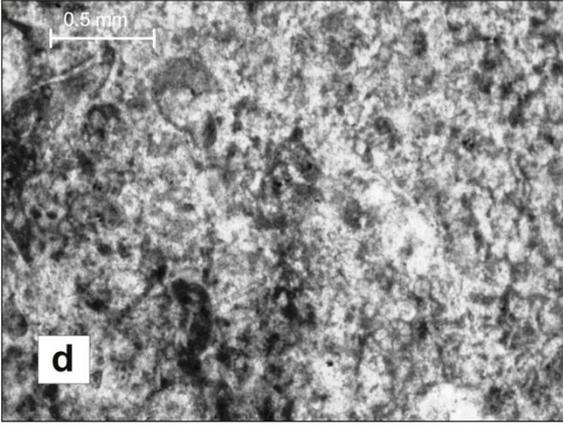
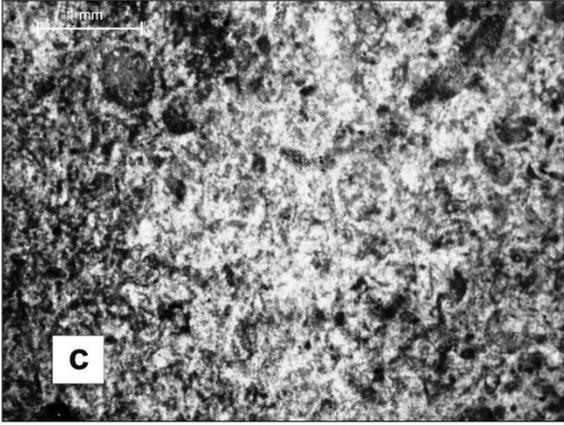
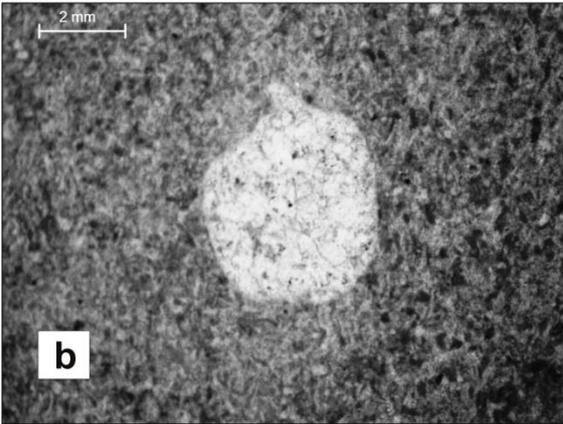
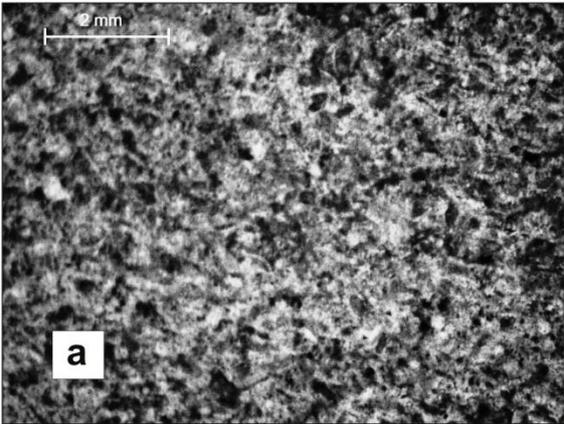
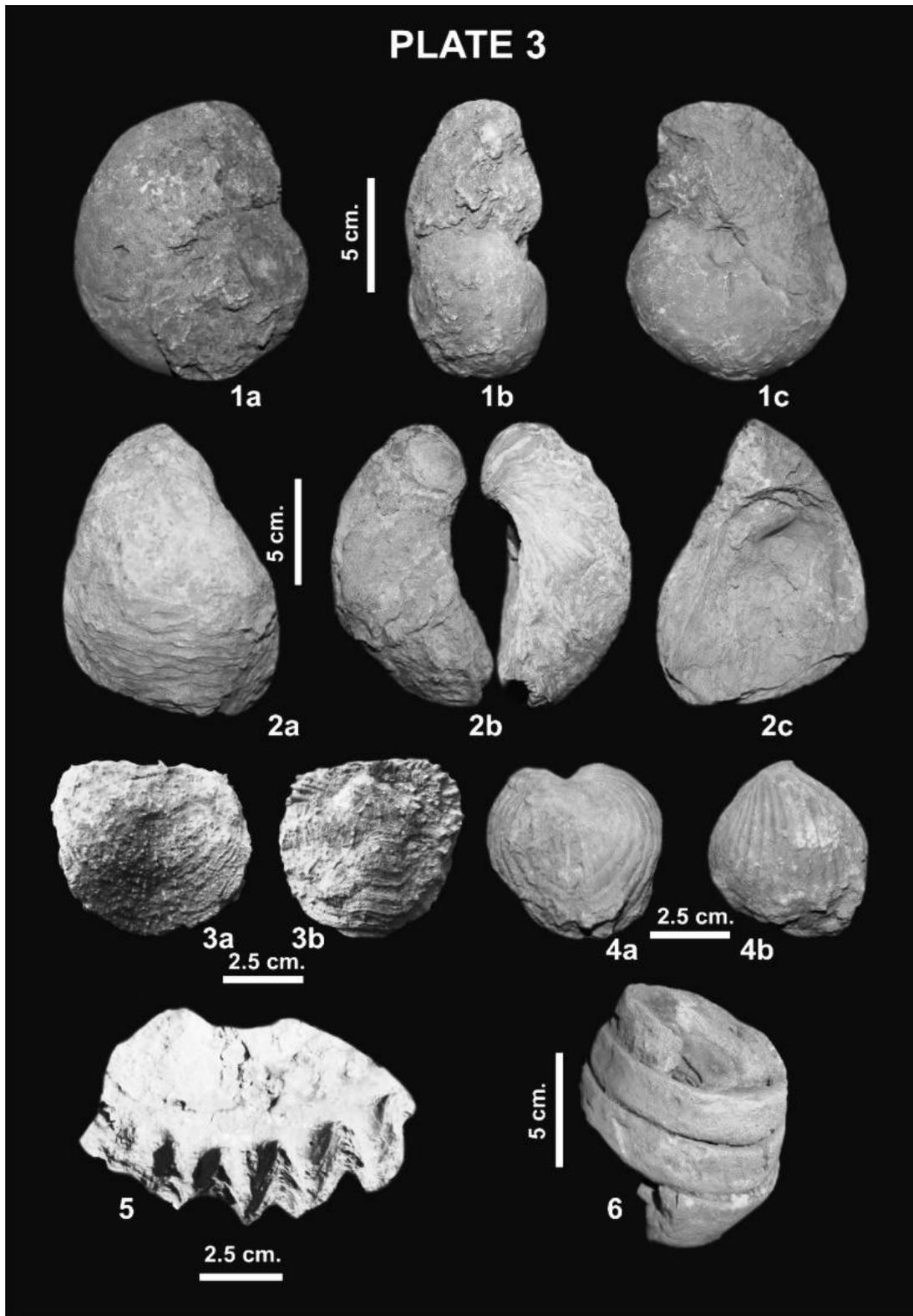


PLATE 2





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