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Upper Jurassic–Lower Paleogene lithostratigraphy and facies development in the Al Hamadah al Hamra area (Libya)

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Abstract: The 1st sedimentary complex of the Triassic to Upper Jurassic (up to Oxfordian) was deposited after long continental period of the uppermost Permian to lowermost Triassic (=about 8 Myr). This large sedimentary complex is divided by three hiatuses; two of them short only situated in the Upper Triassic sediments and by one long, corresponding to the Upper Jurassic–Barremian. After sedimentation of the continental Aptian to Albian strata of the Kiklah Formation, a new large Cenomanian to Eocene shallow marine sedimentary cycle with many gypsum lagoonal passages was deposited. They are represented by the Qasr Tigrinnah Member (Upper Turonian–Coniacian) and the Thala Member (Santonian to Upper Campanian). On the top of the Thala Member a hardground formed under arid conditions of sedimentation. The Upper Campanian/Maastrichtian Al Gharbiyah Formation was deposited in warm but humid conditions confirmed by the Fe-oxides and glauconitic levels. The Al Gharbiyah Formation with three neritic Members: the Bi'r Bu al Ghurab, the Lawdh Allaq (alternating with the Bi'r Az Zamilah Pelagic Member) and the Tar Member is represented and situated below the Upper Paleocene Tabaqah Formation, a new name. The boundary between the Maastrichtian and Danian is defined by last occurrence of *Omphalocyclus macroporus* Lamarck and by appearance of the *Postrugoglobigerina daubjergensis* (Broennimann) and *Eoglobigerina danica* (Bang). The Shurfah Formation is represented at its base by lagoonal sediments, higher up by pelagic chalky limestones and by the neritic Ammur Limestones at the top. The Kheir Formation and Gir Formation of the Ypresian and the Gedari Formation of the Lutetian are proved by planktonic foraminifers.

Key words: Libya, Ghadames Basin, Jurassic–Paleogene, paleogeography, biostratigraphy, foraminifers.

Introduction

The Ghadames Basin (Fig. 1) is a large intracratonic basin on the North African Platform, with NE-SW lineaments it extends over three countries: Hamadah al Hamra of NW Libya, southern Tunisia and east-central Algeria; formed during Early Paleozoic times. This platform has undergone a complex and polyphase history. Its effect on the Ghadames Basin has been the production of a series of fault-bounded structural highs surroundings a central depression.

The basin is bounded by the Amguid El Abiod Uplift in Algeria in the West, by the Hoggar Massif in Algeria in the South, and the Qarqaf Arch in Libya, and by the Nefusah and Dahar Uplifts in the North. To the east the basin wedges out beneath the western part of the Sirt Basin (Fig. 1).

These main tectonic elements have undergone a complex history beginning during the Late Precambrian Pan-African orogeny, and continuing throughout the Phanerozoic with repeated reactivation of older structures. The current architecture of the Ghadames Basin is the result of successive effects by several unconformities including intra/Ordovician, Late Silurian (Caledonian), Carboniferous-Permian (Hercynian), Early Cretaceous (Austrian), Late Senonian (Laramide), Late Eocene (Illyrian) and Early Oligocene (Pyrennean) phases (illustrated in the stratigraphic column Fig. 2). This complex evolution can be summarized in three main stages:

1. The Hercynian orogeny of the North African Platform resulted in one large subsiding depositional basin, displaying little regional differentiation, and formed through reactivation of the Pan-African fault system (Van de Weerd & Ware 1994).

2. Uplift and erosion of the basin during the Hercynian phase resulted in large parts of the Paleozoic section being removed in most areas.

3. Subsequently there was an episode of north-west tilting, resulting in the superimposition of a Mesozoic extensional basin on the eroded remains of the Paleozoic basin (Van de Weerd & Ware 1994; Echikh 1998).

They represent different types of depositional environments ranging from continental to transitonal and marine facies. Most of the Paleozoic sequence is thick in the center of the Ghadames Basin and thins gradually towards the southern edge of the basin which flanks (the Qarqaf Arch) and provided viable evidence of the existence of this arch as a positive feature throughout Paleozoic time. The sequence consists of thick sandy and calcareous beds with clay intercalations.

After a long stratigraphical hiatus (Salaj & M'Zoughi 1997) the Triassic sedimentary complex (Fig. 2) was laid down on continental sediments of the uppermost Permian. Some continental passages are documented on the basis of palynology with paleogeographical interpretation (Adloff et al. 1986; Bouaziz et al. 1987; Mello & Bouaziz 1987; Kamoun et al. 1994; Dridi & Maazaoui 2004; Hammuda

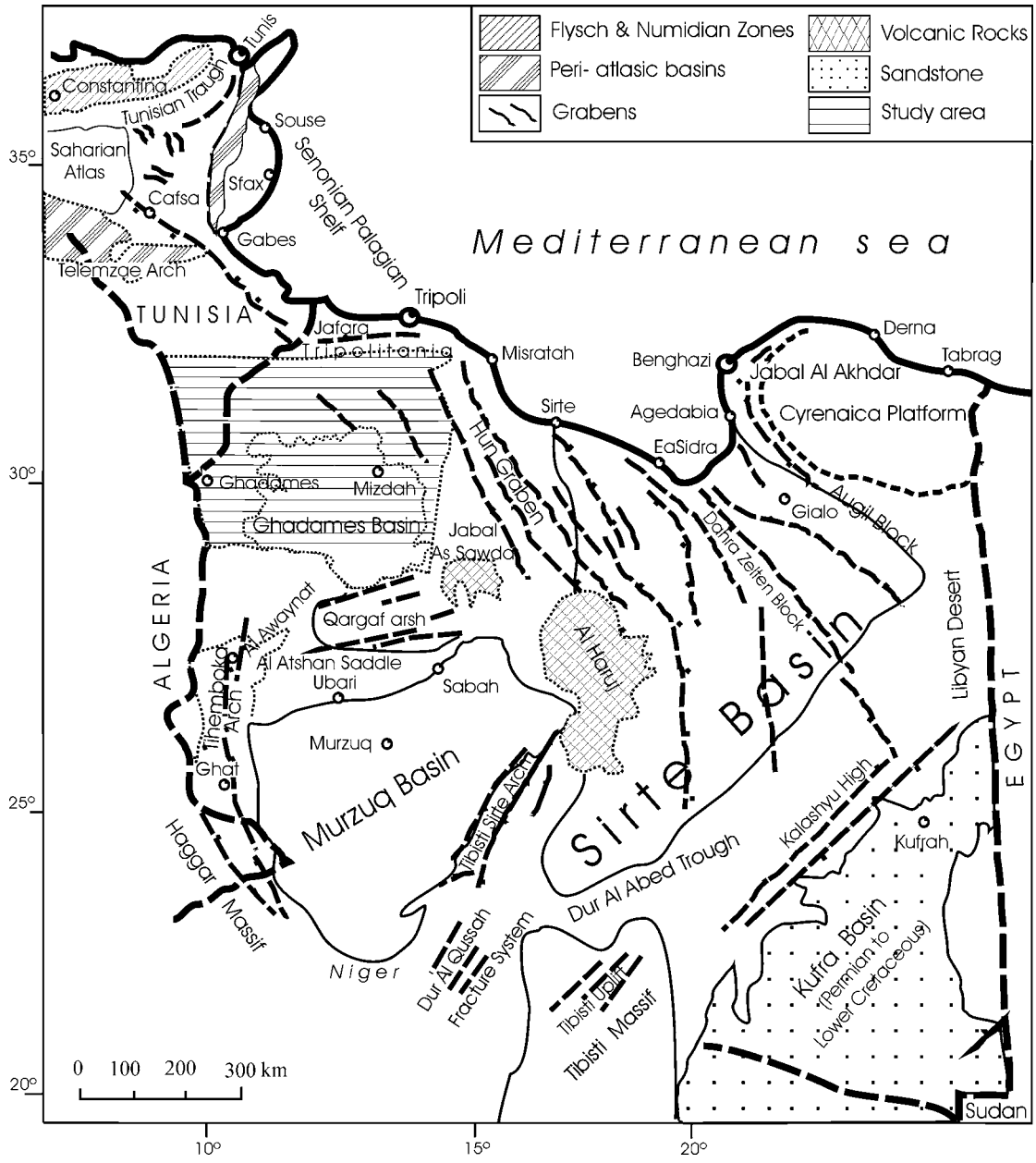

Fig. 1. Tectonic sketch map of Libya and Tunisia (after Burollet 1967, modified).

2004). Large lagoonal gypsum passages are present in the Carnian-Norian sequence. The Norian-Rhaetian (Salaj & Stráník 1970) and Jurassic sediments (Castany 1951; Burollet 1956; Bonnefous 1972; Chandoulet al. 1993) are proved only in Northern and Central Tunisia. The Jurassic facies development in Northwestern Libya (Fig. 2), as in Southern Tunisia is predominantly characterized by a lagoonal sedimentary complex (El Hinnawy et al. 1975; Novović 1977) and in the southern part of the Al Hamadah al Hamra area by continental Upper Jurassic to middle Cretaceous sediments. The Upper Cretaceous/Paleogene sequences consist mostly of marine carbonates and evaporites, representing very shallow shelf and restricted nearshore marine environments.

Material and methods

The samples for microbiostratigraphical evaluation on the basis of foraminifers come from measured profiles men-

**Note to Fig. 2:* The authors do not use the new Geological Time Scale by Gradstein et al. (2004) in Paleogene terminology, because according to our opinion, Montian does not coincide with Danian and Selandian. We do not use Selandian, because there is a hiatus in the region of Denmark (Thomsen & Heilmann-Clausen 1983, p. 351) between Danian and Selandian: i) the base of Selandian includes important conglomerates with glauconite; ii) the index species of the NP4 Zone — *Ellipsolithus macellus*, and NP5 Zone — *Fasciculithus tympaniformis* as well as foraminifers are missing.

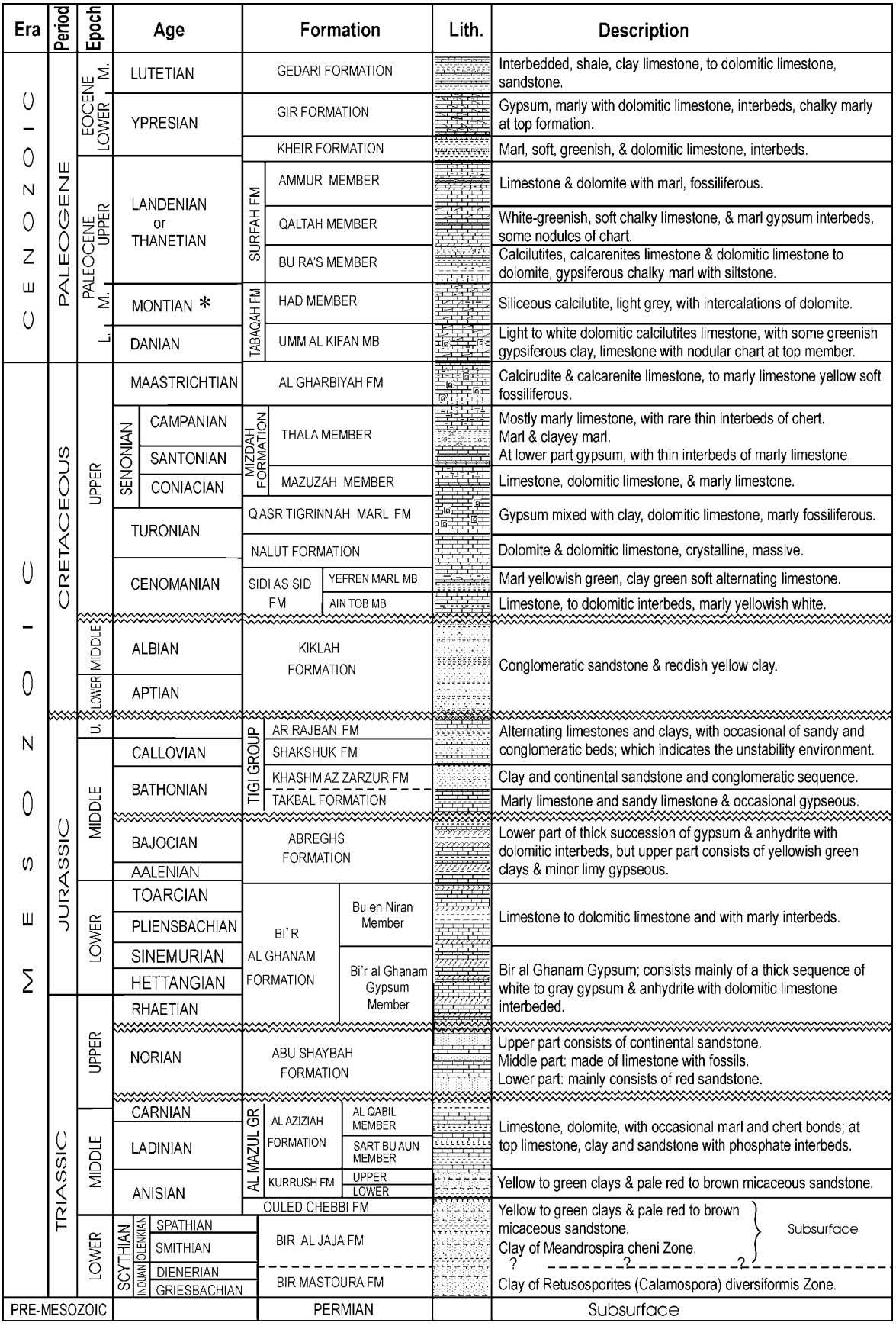

Fig. 2. Generalized stratigraphy chart of Mesozoic and Cenozoic rocks in Northwest Libya. ** Note see on the previous page.*

tioned in the Explanatory Booklets edited in the Industrial Research Centre, Tripoli, as well as from individual Mesozoic–Paleogene samples taken by one of us (Y.Sh.).

The samples were washed (with H_2O_2) on a 0.008 mm sieve. Some solid rocks (limestones, dolomitic limestones, calcareous sandstone) were evaluated from thin sections ($2\times3.5\ cm^2$) for the purpose of microbiofacial analysis, and to find their type of porosity from some Upper Cretaceous and Paleogene horizons as well as for the purpose of proving and documenting some regression and transgression processes.

Stratigraphy

A composite stratigraphic column of the Mesozoic-Paleogene rock (Fig. 2) is based on exposures along the study area (Figs. 3–4), which encompasses nine sheets of the Geological Map of Libya on a 1:250,000 scale: namely, the Tarabulus Sheet (NI 33/13), the Mizdah Sheet (NH 33-1), the Nalut Sheet (NH 32/4), Bani Walid Sheet (NH 33-2), Al Qaryat Al Gharbiyah Sheet (NH 33-5), Al Qaryat Ash Sharqiyah Sheet (NH 33-6), Hun Sheet (NH 33-11), Al Washkah Sheet (NH 33-15), Bani Walid Sheet (NH 33-2), Ghadames Sheet (NH 32-7), Al Khums Sheet (Ni 33-14) and Ra's Jdeir Sheet (N 32-16). In terms of lithostratigraphy, a stratigraphic column has been constructed on the basis of field measurements carried out in the type section of the Al Gharbiyah Formation (Al Qaryat Al Gharbiyah area), the geological map, with laboratory studies (on Bu Ra's Member) coupled with studies of thin sections. The obtained results helped to define the paleoenvironments of the area between NW Libya and SE Tunisia.

The stratigraphical assignment of these units to the Upper Senonian and Paleocene has been carried out on the basis of detailed micro- and macropaleontological investigations.

In the following, we discuss and provide the general sedimentological description of the beds forming sedimentary cycles and their main fauna. The lithological descriptions of features are discussed in the following.

Middle Jurassic to middle Cretaceous

Dogger

Khashm az Zarzur Formation (Upper Bathonian)

It consists of two lithological units, lower lacustrine clays with minor sandstone and conglomerate interbeds and of an upper continental cross-bedded sandstone sequence with clay intercalations. The lower shales contain salt and gypsum in the western part. Fresh water fauna, silicified wood and marine fauna occur in these beds indicating variable depositional environments, shallow water to lagoonal and marine (Banerjee 1980).

Age	Formation	Locality	Coordinates	Member	Coordinates	Locality
Late Paleocene Early Eocene	Bishimah Fm	From Dor al Bashashim in the Abu Njim area	30°20″N 15°40′E			
Thanetian to Early Eocene	Shurfah Fm	Near Wadi Tar southwestern Hun Graben	29°30′ N 15°40′E	Ammur Limestone Member		Near Wadi Tar in Hun Graben
				Galta Chalk Member	29°48′N16°00′E	After Al Galta spring in eastern Hun Graben
				Bu Ra's Marl Member	29°40′N16°28′E	After Wadi Bu Ra's in Jabal Waddan
Late Campanian Maastrichtian–Montian	"Zimam Fm"	Near the entrance of Wadi Tar northwest of the Socna oasis	29°05′N 15°46′E	Tabaqah Formation: Had Limestone Mb	29°30′N15°35′E	After Wadi al Had north Wadi Tar
				Tabaqah Formation: Umm al Kifan Mb	30°34′N13°12′E	After Wadi Tabaqah
				Tar Marl Member Al Gharbiyah Fm		After the Wadi Tar Al Gharbiyah Village
Santonian – Campanian	Mizdah Fm	Mizdah village on the central part of Jabal Nefusa	31°26′N 12°59′E	Tigrinnah Marl Member		Qasr Tigrinnah southwest of Gharyan town
				Mazuzah Member		Wadi Mazuzah south of Mizdah town
				Thala Member	31°25′N14°15′E	Bir Talah in the south of Bani Walid (Dor Talah)
Cenomanian to Coniacian	Qasr Tigrinnah Fm	Qasr Tigrinnah southwest of Gharyan town	32°07′07″N 12°59′E			
Cenomanian – Turonian	Nalut Fm	Nalut town on the western part of Jabal Nefusa	31°52′N 10°59′E			
Cenomanian	Sidi as Sid Fm	Sidi as Sid village in the eastern part of Jabal Nefusa	32°25′N 13°29′E			
M. Jurassic to L. Cretaceous	Kiklah Fm	Kiklah village on Jabal Nefusa	32°05′N 12°42′E	Ar Rajban Member	31°57′N12°10′E	Ar Rajban village on Jabal Nefusa
				Shakshuk Member	32°02′N11°57′E	Shakshuk village on Jabal Nefusa
				Khashm az Zarzur Member	32°03′N12°23′E	Khashm az Zarzur on Jabal Nefusa

Fig. 3. General formations age and locality names in Northwestern Libya.

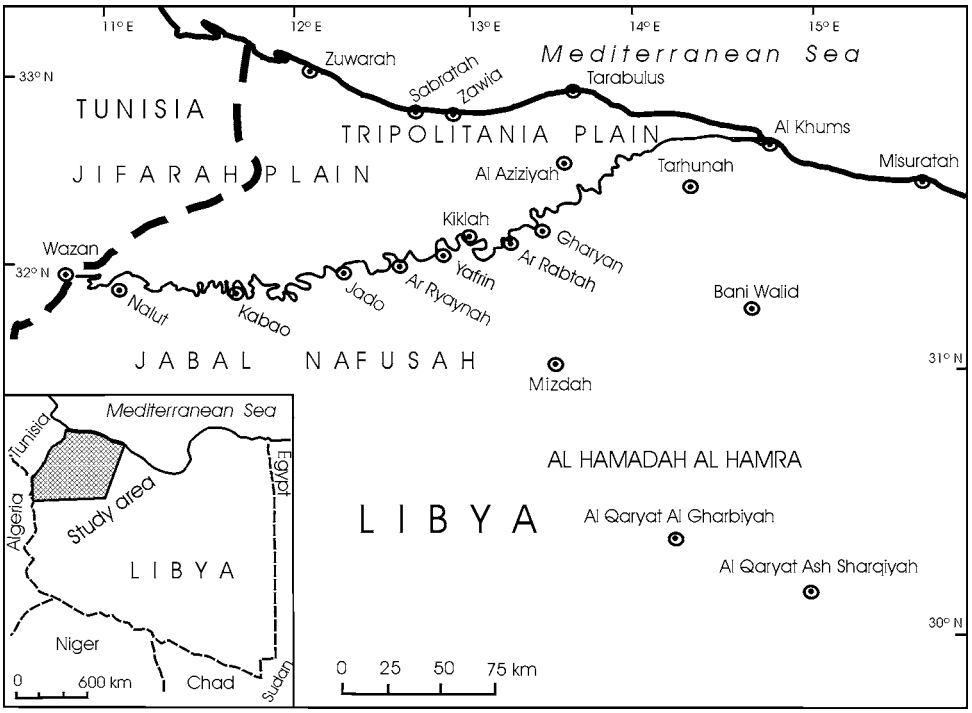

Fig. 4. Topographic map of study area in NW Libya.

Shakshuk Formation (Callovian)

It consists of alternating limestones and of highly fossiliferous clays with occasional sandy and conglomerate beds, which indicate fluctuating environmental conditions (Banerjee 1980). According to their mineral composition and to chemical analyses these rocks may be regarded as transitional from sandstone into sandy limestone (Novović 1977).

Ar Rajban Formation (Upper Jurassic to Lower Cretaceous, probably until the beginning of the Cenomanian)

It consists of two lithological units: lower conglomeratic cross-bedded sandstone with clay intercalations and upper red unit made up of alternating clays and sandstone beds, with minor carbonate bands, containing thin gypsum beds and veinlets (Novović 1977). This formation is highly fossiliferous. Numerous fossil brachiopods, bivalves, and gastropods were found. This formation is interpreted by us as Oxfordian in age.

Lower to middle Cretaceous

Kiklah Formation (Aptian–Albian)

The term was first introduced by Christie et al. (1955) after the Kiklah village (Fig. 4). It is a complex of clastic sequences with minor non-clastic intercalations with thickness varying from 0 to 65 m between the Ain Tobi Limestone at the top and the Bi'r al Ghanam Gypsum Member below in the Kiklah area. The Kiklah Formation and its members are introduced by El Hinnawy et al. (1975) and Smetana (1975). It stretches from the Tunisian border in the West to Ras At Tahuna in the East (3 km west of Wadi Ghan) where it pinches out. The age is correlable with that of the Ar Rajban Member in the western facies, to post-Oxfordian to pre-Cenomanian according to El Hinnawy et al. (1975).

In Tunisia, the Kiklah Formation is equivalent to the Budinar, Bouhedma, Gafsa and the lower part of the Fahdene Formations (Hallett 2002). The dasycladal algae reported by Salaj et al. (1998, pp. 207–210) from dolomitic limestones of Budinar Formation in Tunisia was not found at the base of Kiklah Formation in the Libyan areas.

The Kiklah Formation in some areas of Northwestern Libya including the Libyan Offshore is assigned to the Bathonian-Albian by Banerjee (1980), and its Jurassic part is subdivided from bottom to top into the Khashm Az Zarzur Member, the Shakshuk Member, and the Ar Rajban Member.

The Kiklah Formation, predominantly with its lower part in some places is included to the Upper Jurassic. It is subdivided into the members which are valid only for the Upper Jurassic. The subdivision of the Kiklah Formation from bottom to top into the Khashm Az Zarzur Member, the Shakshuk Member, and the Ar Rajban Member is not correct and in many areas, where they are present a new revision is inavoidable.

Middle–Upper Cretaceous

Sidi as Sid Formation (Cenomanian)

The term has been introduced by El Hinnawy et al. (1975). It is one of the most widely distributed rock units of Jabal Nefusa occurring from the Tunisian border east to the Mediterranean coast near Al Khums (see Fig. 3).

It is mainly a carbonate sequence with marly bands in the upper part. Lateral changes to gypsum beds alternating with marly bands are noticed at places as in the Nalut sheet area. The formation thickens eastwards. It is about 60 m thick in the western part, about 100 m in the Nalut sedimentation area, about 170 m in the Tarabulus sheet area, 180 m in the reference section at Az Zintan in the Mizdah area, and attains

up to 380 m in the Al Khums area in the eastern end (Banerjee 1980).

It should also be noted that the gypsum accumulations in the Sidi as Sid Formation increase eastwards. The deeper marine sediments increase westwards with rare remnants of planktonic foraminifers of genera *Hedbergella* div. sp. and *Praeglobotruncana* div. sp. (Banerjee 1980). The age is almost certainly Cenomanian with depositional enviroment ranges from lagoonal in the west through littoral to low energy neritic with rare remants of planktonic foraminifers of genera *Hedbergella* div. sp., *Heterohelix* div. sp. and *Praeglobotruncana* div. sp. in the east.

Nalut Formation (Cenomanian–Lower Turonian)

The term was firstly introduced by Zaccagna (1919) after the Nalut town on the western part of Jabal Nefusa near the Tunisian border where these rocks widely occur. During the recent regional geological mapping in Tripolitania, El Hinnawy et al. (1975), Mann (1975), Antonović (1977) and Novović (1977), confirmed the name of this rock unit as the Nalut Formation (Banerjee 1980).

It consists of light grey to yellow and whitish, hard, compact and massive thick-bedded, finely recrystallized dolomitic limestone and dolomite, irregular or cross-bedded and marly in some parts. Cherty nodules and concretions are common in the upper part of the sequence which is sometimes red in colour. The top is marked by softer beds, sometimes containing gypsum. The carbonates (micrites, microsparites, occasionally containing pellets) are throught to be recrystallized. Organodetrital (presumed initially algal, coral and crinoidal) nature indicated deposition in the deeper fore-reef zone to shallow circa-littoral zone influenced by pelagic sedimentation (in the North) with Cenomanian *Rotalipora* div. sp. and *Praeglobotruncana stephani* (Gandolfi) (Mann 1975, p. 33).

The Upper Cenomanian to Lower Turonian *Pseudorhapydionina dubia* De Castro (Novović 1977, p. 28) in the dolomitic limestones prove (in the South) the marine restraint to lagoonal, evaporitic, intertidal to supratidal environment with low energy, as in Central Tunisia (Salaj & Maamouri 1998, p. 375).

Qasr Tigrinnah Formation (Upper Turonian–Coniacian)

The term was introduced by Christie (1955). It extends from the Tunisian border east to the Wadi Suf al Jin (West), and from behind the Jabal Nefusa escarpment south to the Al Hamadah al Hamra plateau region (Banerjee 1980).

The Qasr Tigrinnah Formation has been studied by numerous authors, and it has been described in several publications (Christie 1955; Desio et al. 1963; Jordi & Lonfat 1963; El Hinnawy et al. 1975; Röhlich 1979; Banerjee 1980).

The formation could be divided into three broad lithological units. The lower part consists of soft, friable unbedded or thinly bedded slope-forming marls, buff to grey, yellow and greenish, with less abundant clay and with thin interbeds of limestone. The middle part consists of marls and clays with conspicuous thin bands of red to pink, yellow or whitish hard limestone, marly chalky or calcarenitic in places and generally fossiliferous (Banerjee 1980). The upper part consists of porous, white chalky limestone, dolomitic or sandy with thin marl or clay interbeds. Chert bands and nodules are common in this horizon, with occasional thin layers of sandstone at the base. Gypsum and anhydrite are reported from the western side of the Hamadah Basin. The carbonates are mostly micrites, and sparite and sparry allochemical limestones are rather rare. The formation contains a rich fossil assemblage of gastropods, brachiopods, bivalves, echinoids, ostracods and a few benthic foraminifers (Banerjee 1980). These sediments and the contained fauna indicate lagoonal (evaporitic) to shallow, warm marine subtidal to quiet neritic environment with *Boueina pygmea* Pia (Codiacea) and *Dissocladela ondulata* Reineri (Dasycladacea) (Energoproject 1975).

Antonović (1977) and Novović (1977) agreed that most of the fossils reported from the Qasr Tigrinnah are of Late Turonian–Coniacian age.

Mizdah Formation (?Upper Coniacian–Santonian–Campanian)

The name was introduced by Burollet (1960), after the Mizdah village. The Mizdah Formation is assumed to be the lateral equivalent of the upper and middle part of the Aleg Formation of Tunisia (Burollet 1956; Banerjee 1980).

Most of the Al Hamadah al Hamra surface is occupied by this formation. During the recent regional geological mapping, El Hinnawy et al. (1975), Antonović (1977), Novović (1977) and Živanović (1977) divided the Mizdah Formation into the following two members only: the Thala Member and the Mazuzah Member.

— Mazuzah Member (Upper Coniacian–?Santonian)

It occurs over a wide area from the Tunisian border east (about 5–15 m thickness) to about 25 m in the Bani Walid area, and from behind the Jabal Nefusa escarpment south to an extensive area in the Al Hamadah al Hamra plateaus.

This member is mainly composed of hard, dense, massive crystalline limestone, dolomite (dolosparite) and dolomitic limestone, light grey to yellow, blue or pinkish in colour, medium- to thick-bedded, it consists of very fossiliferous limestone particularly rich in inoceramids (Röhlich 1979; Röhlich & Youshan 1992), some of which are of considerable size. Oolites were also observed in some places. Due to its lithology, the Mazuzah Member is resistant to erosion and it covers a wide area from Al Hamadah al Hamra.

The indicated sedimentation environment was shallow water in barrier shoal with high energy, occasionally connected with the open sea (presence of ammonites). The paleocurrent is determined from the northern and northwestern direction (Banerjee 1980).

— Thala Member (?Upper Santonian–Campanian)

The Thala Member was defined by Jordi & Lonfat (1963) and described in detail by Antonović (1977). It is

represented by regressive sediments and belongs to the upper part of the Mizdah Formation (Jordi & Lonfat 1963; Chaloupsky 1979; Čepek 1979; Röhlich 1979; Salaj 1979; Megerisi & Mamgain 1980).

In general, the lithological development of the Thala Member is fairly uniform. It is characterized as a "sandwich-like" alternation of marls and clays (frequently gypsiferous) and calcilutite to fine-grained calcarenite, frequently chalky and finely laminated.

Two types of sediments are present, gypsiferous and marly limestone beds. The lower part consists of grey to reddish grey or yellow green thin-bedded limestone, marly and sandy at places. The upper calcareous part is a porous, sandy or chalky limestone (calcarenite, calcirudite) or dolomite, yellow to white, black stained on the surface. The environment was shallow water environment, with clean water of low energy, fairly mobile, of normal salinity open sea and then changed to shallow sea of subtidal to lagoonal environment in the Al Hamadah area.

"Zimam Formation" (Upper Campanian–Maastrichtian)

In the original definition, the Zimam Formation was introduced by Jordi & Lonfat (1963) after Wadi Zimam. In their subdivision of the formation they identified three members of which the Lower Tar was at the base; Salaj & Nairn (1987) showed that the formation section was made up of beds belonging to three sedimentary cycles. The cycles are separated by the presence of phosphate horizons, which provide indications of regressive phases.

Nairn & Salaj (1992) proved a revision to the Upper Cretaceous stratigraphy of Northwestern Libya, between the Thala and the "Upper Tar" Members. They studied the Qarayat al Gharbiyah area southeast of Mizdah and they provided a general sedimentological description of the "Lower Tar Member" in measured type sections; and they proposed a new formation name to the Al Gharbiyah Formation with a type section. They introduced the formation with three sedimentary cycles characterized by Upper Campanian to Maastrichtian microfauna. Three shallower neritic sequences are represented by the Bi'r Bu al Ghurab, the Lawdh Allaq (or Bi'r az Zamilah Member with pelagic facies) and the Tar Member s.s. Members.

In the following, we provide a general sedimentological and environmental description:

— Al Gharbyiah Formation (=syn. Lower Tar Marl Member s.l.; Nairn & Salaj 1992)

It has an average thickness of about 120 m in the NW Al Hamadah al Hamra. The thickness ranges from as little as 60 m in the West (Chaloupsky 1979), to as much as 190 m in the east (Čepek 1979), the Lower Tar Member attains a great thickness rapidly increasing from the West (90 to 120 m) to the East (160 to 180 m) Salaj (1979). There is a considerable variety of predominantly shallow-water deposits, which show both lateral and vertical changes. The member has a more or less uniform lithological composition of thin-bedded marl, shale, calcareous mudstone and limestone, sandy, gypsiferous, chalky and dolomitic in places. The lower part is formed by glauconitic white organodetrital (allochemical) marly limestone, slightly gypsiferous, exposed in the Mizdah and Bani Walid areas. Upward is the shaly and marly sequence, dark green to white, grey, yellowish and reddish, with occasional nests of celestite crystals as found in the Bani Walid area, having rich fossiliferous levels and limestone interbeds.

This limestone, sometimes hard, massive or saccharoidal, reddish or pinkish forms prominent plateaus in the western part of the Al Hamadah al Hamra Basin and becomes more gypsiferous, dolomitic and chalky in the upper part in the western region (Energoproject 1975).

This horizon is extremely rich in Campanian macrofauna represented predominantly by *Lopha (Actinostreon) villei* (Coquand), *Lopha Actinostreon dichotoma* (Bayle), *Ceratostreon spinosum* (Matheron), *Pycnodonte (Phygraea) vesicularls* (Lamarck), *Nicaisolopha nicaisei* (Coquand] and *Tudicla bussoni* Collignon, and Bryozoa (Cheilostomata) represented by the species: *Woodipora disparilis* (d'Orbigny) (see Fig. 5.1–4). The uppermost rocks are marl and chalky marl with dominant macrofossils as *Lopha (Actinostreon) dichotoma* (Bayle) and *Pycnodonte (Phygraea) vesicularis* (Lamarck).

This important fossiliferous horizon attaining a maximum thickness of 4 m and lying about 10 to 15 m above the base of the Al Gharbiyah Formation, marks the end of the varied development of the basal sequence of this unit.

The lower sequence of the Al Gharbiyah Formation may be divided into three parts of unequal thicknesses:

The lower part terminates by a prominent bed of fossiliferous limestone or dolomitic limestone, forming a morphologically conspicuous ledge.

The middle part consists mainly of marls and/or claystone. In the eastern part of the area, this marl horizon contains innumerable shells of oysters (*Agerostrea ungulata, Amphidonte overwegi*).

The upper part: A thin (10–20 cm) interbed of biocalcarenite in the marl layer is crowded with poorly preserved inoceramid shells and their fragments.

The upper part contains locally frequent inoceramid shells and represents the uppermost inoceramid-bearing layer in this member. Salaj (1979) spread the member in the eastern and north western parts of the Al Qaryat al Gharbiyah area and distinguished the following lithofacies developments of the Al Gharbiyah Formation as follows:

I — Al Gharbyiah Formation in the eastern area:

a — The basal part of this formation (0.8 to 3 m) is mainly formed by calcirudites with layers of greenish gypsiferous marls. The calcirudites are rich in fine detritus of molluscs, bryozoans and sponge spicules, mainly monaxone and triaxone. The lower part of the sequence in places consists mainly of chalky calcilutites with layers of chalk, which microsopically correspond to clayey biomicrite rich in benthic and planktonic microfauna. This horizon of the Upper Campanian is extremely rich in macrofauna represented predominantly by *Lopha (Actinostreon) dichotoma* (Bayle).

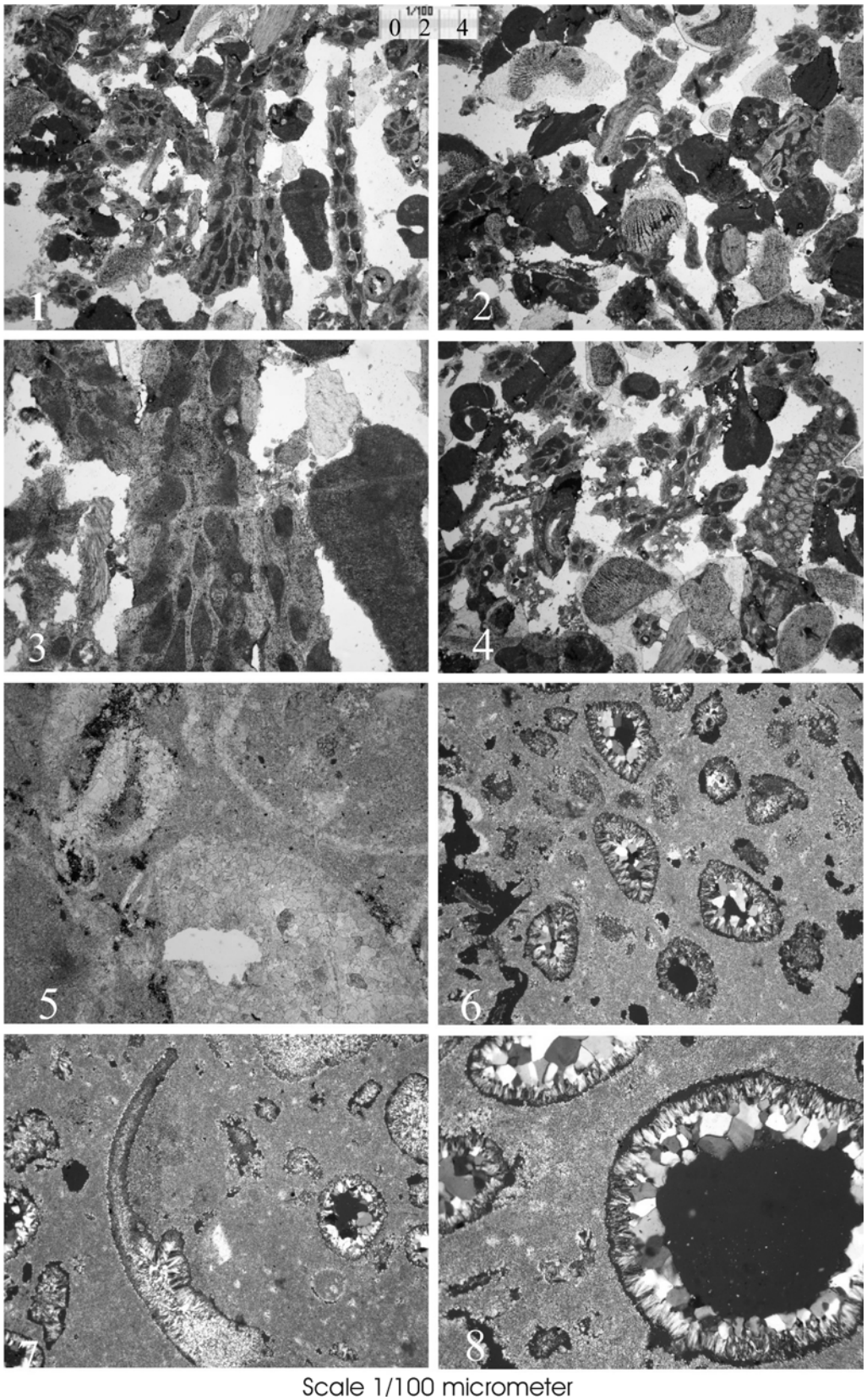

Fig. 5. Photomicrograph of thin sections. **1–4** — Photomicrograph showing thin section of bioclastic packstone of the Al Gharbiyah Fm with *Woodipora disparilis* (d'Orbigny). Al Qaryat Al Gharbiyah area. Lower Maastrichtian. **5–8** — Photomicrograph showing thin section of microbiosparite with very good porosity after the microfossils *Laffiteina bibensis* Marie and *Rotalia trochidiformis* (Lambert) with a partial to complete dolomitization in the Bu Ra's Mb.

b — In the middle part of the Al Gharbiyah Formation sequence (120 to 130 m) which is mainly formed by marls, calcarenites, and calcirudites, rich in Lower Maastrichtian macrofauna and chiefly represented by species such as: *Agerostrea ungulata* (Schlotheim), *Amphidonte overwegi* (Buch), *Inoceramus (Cataceramus) regularis* (d'Orbigny), *Plicatula hirsuta* var. *sparsicosta Pervinquiere* and *Baculites anceps* Lamarck.

c — In the uppermost part of the Al Gharbiyah Formation calcarenites with Upper Maastrichtian *Omphalocyclus macroporus* Lamarck predominate often with cross-bedding, thickness of which is often 10 to 20 m.

II— Al Gharbiyah Formation in the northwestern area:

a — The lower part of the Upper Campanian sequence is formed by gypsum-bearing, in places glauconitic marls (15 to 20 m in thickness), with an assemblage of abundance of the large valves of *Lopha (Actinostreon) dichotoma* (Bayle), and some other bivalves (see Salaj 1979).

b — The middle part of the Lower Tar Member (45 to 50 m in thickness), calcarenites and calcirudites of the Lower Maastrichtian with abundant representatives of the *Lopha* and *Inoceramus* predominate. They are represented by the species: *Lopha (Actinostreon) villei* (Coquand) and *Inoceramus (Cataceramus) goldfussianus* d'Orbigny also *Orbitoides media* (d'Archiac), with the last layers (1 to 2 m in thickness); interformational conglomerates and breccias are present.

c — The upper part (28 to 35 m in thickness) is represented by vari-coloured marls and clays with layers of calcarenites, dolocalcirudites and calcirudites with *Omphalocyclus macroporus* Lamarck (Chaloupsky 1979). At the base an about 50 to 70 cm thick calcarenite and phosphatic bed is present.

In general the macrofauna is represented by mass occurrence of bivalves (see Fig. 6), from which the following species were determined by Zaruba: *Lopha (Actinostreon) villei* (Coquand), *Lopha (Actinostreon) dichotoma* (Bayle), *Pycnodonte (Phygraea) vesicularis* (Lamarck) and *Ceratostreon spinosum* (Matheron).

The depositional sequence of the Al Gharbiyah Formation may be divided into three sedimentary cycles. The cycles are separated by phosphate horizons, which provide indications of regressive phases, as follows:

— Deposition of marls and clays with intercalations of calcarenites in the open sea near the barrier or on the barrier.

— Deposition of basal transgressive calcarenites to calcirudites-bedding on the eroded surface of the Thala Member (Fig. 7).

Bed sequence of shelly calcarenites to calcirudites of Upper Campanian was deposited evidently in the barrier zone and in the subtidal zone with high energy. The chalky calcilutites developing laterally from shelly calcarenites and calcilutites with planktonic microfauna are predominant, deposited in open sea.

— Deposition of these Upper Campanian sediments was followed by accumulation of sediments, which probably originated in a lagoon. In this phase, gypsiferous and ferruginous phosphatic calcarenites are formed. They were deposited in a subtidal zone with low energy to lagoonal area.

The shelly phosphatic calcarenite deposition took place in a subtidal to barrier zone with high energy.

Clays and marls with thick layers of shelly calcarenites and calcirudites in an open sea zone near the barrier. It is proved by plentiful macrofauna and with benthic and planktonic foraminifers of the *Globotruncana ventricosa* Zone. The varied colouring of beds is due to the transport of terrigenous material from a near emerged zone under the influence of the warm and humid paleoclimate.

Calcarenites to dolomitic calcarenites with cross-bedding were deposited in the pre-barrier zone of open sea and on the barrier. From the faunal viewpoint it is important that besides a plentiful Maastrichtian macrofauna, a microfauna is also abundant. It is represented by both the planktonic and benthic species of the *Globotruncana falsostuarti*, *Gansserina gansseri* and *Omphalocyclus macroporus* Zones.

Denomination of the Lower Tar Formation on the Al Gharbiyah Formation was carried out on all sheets of the studied area (we now propose to cancel the term the Zimam Formation).

The distinct new transgressive cycle of the Bi'r Bu al Ghurab Member is characterized by an about 80 cm thick passage of thin layered 2–5 cm thick, slacking calcarenites crowded with bryozoans (Salaj 1979; Salaj & Megerisi 1984) rich in bivalves, mainly represented by *Lopha* (*Actinostreon*) *villei* (Coquand), the moulds of embryonal stages of which are also found at the base of the first calcarenite bryozoan thin bed of the transgressive cycle mentioned. Rare specimens of *Ceratostreon (Actinostreon) villei* (Coquand) are also found in this part.

Concentrations of Fe-oxides and Fe-hydroxides (goethite), are found in some lower layers of bryozoan calcarenites, but predominantly this basal part of the Bi'r Bu al Ghurab Member is without them.

The regression phase at the boundary of the Bu al Ghurab and the Lawdh Members and/or at the boundary of the Bi'r al Ghurab and the Bi'r Az Zamilah Members (with pelagic facies of chalks and marls) is characterized by the phosphatic level and rarely by the presence of glauconitic grains (influence of redeposited organogenic phosphatized grains, probably from freshwater lakes and as a consequence of a new transgression also connected with the formation of glauconite, under the action of a warm but humid paleoclimate, together with high iron concentration (Fe_2O_3), up to as much as 20.5 % (Nairn & Salaj 1992, p. 1625).

These, but particularly glauconitic horizons also originated in the course of sedimentation in the Lawdh Allaq Member (horizon 10/8; in Nairn & Salaj 1992, Fig. 5, page 1631) as well as in the course of pelagic sedimentation in the Bi'r Az Zamilah Member. They are the horizons (samples nos, 7/2, 7/4, 7/7, 7/8; in Salaj & Megerisi 1984) predominantly with Upper Campanian planktonic foraminifers, and dated as Upper Campanian also with *Baculites anceps* (Lamarck) and *Curvostrea thomasi* (Peron) (in Salaj & Megerisi 1984, Fig. 5, p. 212).

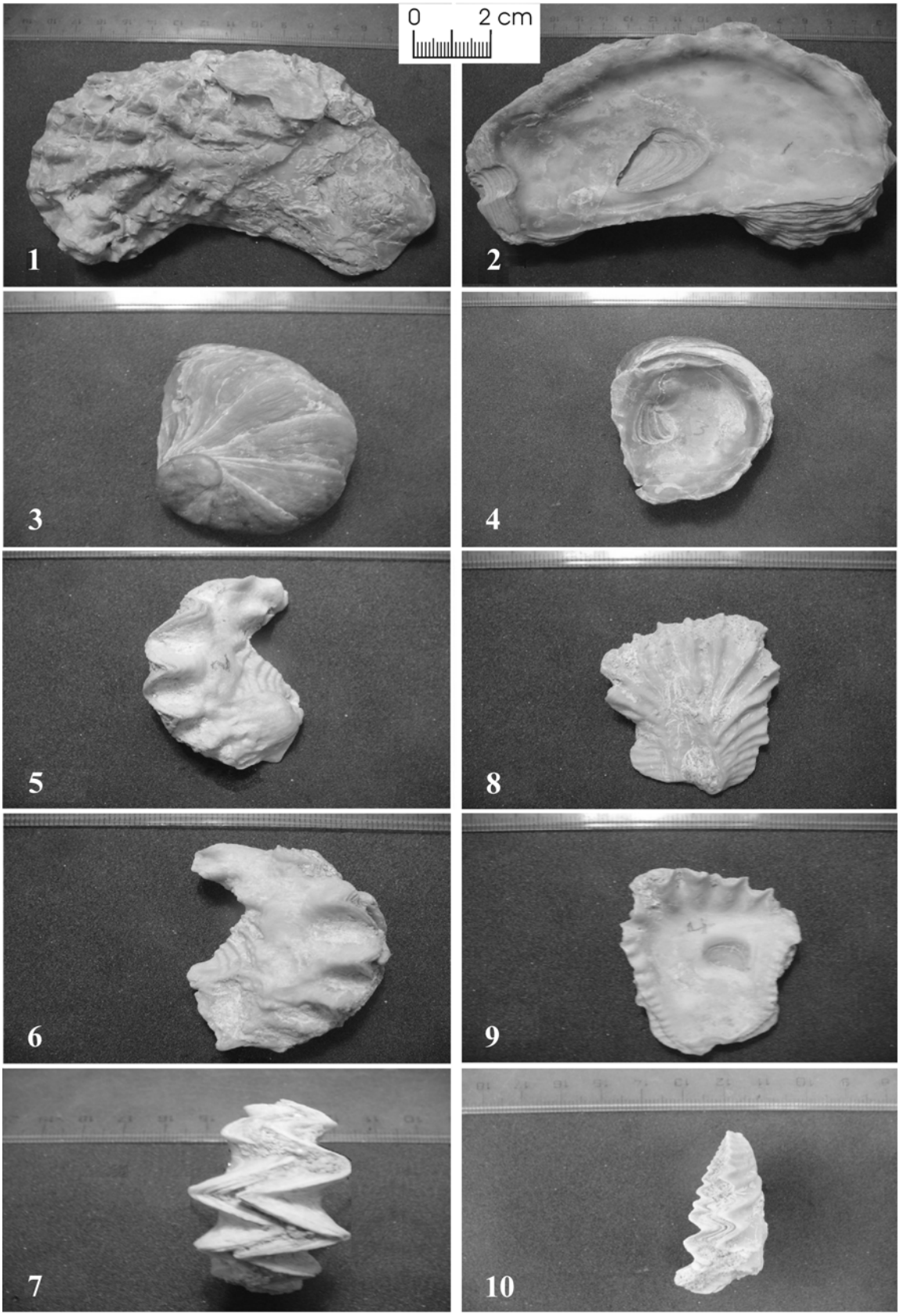

Fig. 6. Fossil assemblages. **1–2** — *Lopha (Actinostreon) dichotoma* (Bayle), Al Gharbiyah Fm, s.s., Upper Campanian. **3–4** — *Amphidonte overwegi* (Buch), Al Gharbiyah Fm, Lower Maastrichtian. **5, 6, 7** — *Agerostrea ungulata* (Schlotheim), Tar Mb, s.s., Upper Maastrichtian. **8, 9, 10** — *Ceratostreon* aff. *spinosum* (Matheron). Tar Member s.s., Upper Maastrichtian.

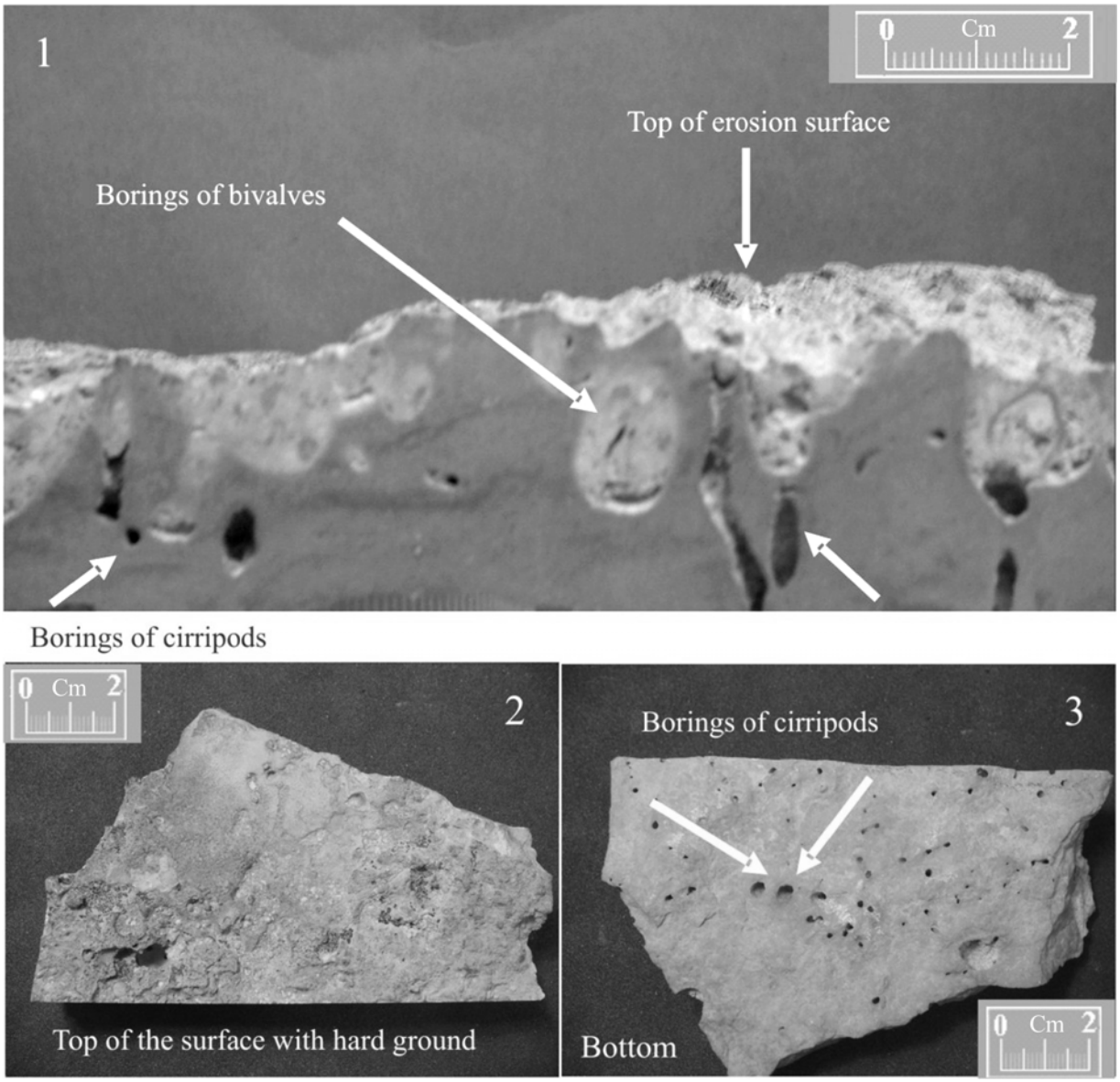

Fig. 7. Borings of infauna (cirripods and bivalves) on the last bank of the Thala Mb in Wadi Wasiq area at Lat. 30°38′04″N, Long. 13°20′48″E. **1** — Borings of infauna (cirripods and lithofags of bivalves) on the last bank of the Thala Mb (siliceous crystalline light grey) in Wadi Wasiq at Lat. 30°38′04″N, Long. 13°20′48″E. **2–3** — On the lower part of the boundary bed (at profile) with distinct borings of in fauna, transgressively on its eroded surface, the basal thin beds set on. They are formed by fine-grained calcareous organodetrital micro-conglomerates. They fill up surficial unevennesses and partly solidified borings of infauna, which are not present in the basal thin bed of the Bi'r Bu al Ghurab Mb of the Al Gharbiyah Fm.

The middle and upper part of the Bi'r Az Zamilah Member corresponds to the *Globotruncana stephensoni* Zone (younger than the zone with *Radotruncana calcarata*). It underlies the Lower Maastrichtian strata where the microfauna of the *Globotruncana falsostuarti* Zone (level 7/7) and *Globotruncana gansseri* Zone (level 7/8) was proved (Salaj & Megerisi 1984).

The phosphate, weakly glauconitic horizon with a relatively high iron concentration Fe_2O_3 from the boundary of the Bi'r Az Zamilah and the "Lower" Tar s.s. Members, in places at the base was replaced by conglomerates (Nairn & Salaj 1992, p. 1963). *The upper part of the Al Gharbiyah Formation (=now only the Tar Member in the new taxonomic conception) corresponds in the conception of Nairn & Salaj (1992) to the Middle to Upper Maastrichtian with* Omphalocyclus macroporus *(Lamarck) (level No. 7/9 Fig. 5, p. 213) (Salaj & Megerisi 1984).* From macrofauna *Amphidonte overwegi* von (Buch) and *Meretrix tripolitensis* (Baroni) are found. From planktonic foraminifers additionally it was possible to prove the very rarely found *Gansserina gansseri* (Bolli) (in the levels 7/9 and 7/10).

It should be remarked that practically at all localities where the formation of the Lower Tar Member occurs, sev-

eral Fe-oxides horizons are found, often accompanied by more or less scattered glauconite (Nairn & Salaj 1992).

Paleocene

Tabaqah Formation, new proposed name

Type locality: Wadi Tabaqah.

Coordinates: 30º26′13″N lat. and 13º13′06″E long.

We divided the Tabaqah into two members: the Umm al Kifan Member, new proposed name, and the Had Member, corresponding to the former middle and upper parts of the Zimam Formation.

Danian

Umm al Kifan Member, new proposed name (= former Upper Tar Marl Member)

The type locality: Wádí Umm Kifan (see Salaj 1979, p. 31); coordinates: 30º34′30″N lat. and 13º12′31″E long.

The Umm al Kifan Member, new proposed name, is restricted in occurrence to the central and eastern parts of the Al Hamadah al Hamra Basin, and extends south to the northern Dor el Gussa area; it represents the first transgressive-regressive sedimentary cycle of the Tabaqah Formation (a new proposed name) for the middle part of the former Zimam Formation. The Umm al Kifan Member was deposited most likely in the pre-barrier zone to open sea zone as suggested by the nature of rocks and by presence of brackish species.

It is composed of yellowish green marl and calcareous mudstone with shaly intercalations, particularly thick and numerous in the middle part of the sequence. The interbedded limestone is of microcrystalline calcite. The tickness: 6–10 m. In the Al Qaryat al Gharbiyah area the lithology of this member is formed by light-coloured to white, in places dolomitic calcilutites scarcely laminated and slightly silicified. Intracalcilutites to chalky calcilutites and calcarenites are represented subordinally. Locally in the bottom of this sequence greenish gypsiferous clays are present in the northeastern area.

The Umm al Kifan Member was originally described as the Upper Tar Marl by Jordi & Lonfat (1963), Antonović (1977), Chaloupsky (1979), Čepek (1979), Röhlich (1979), Nairn & Salaj (1992), who explained this difference in thickness due to regression of the sea from the edges where the Maastrichtian fauna lies directly below the Had Limestone, but towards the centre of the basin.

The carbonates are sometimes fossiliferous and they may show features of current activity particularly towards the top where cross-bedding occurs and where an oolitic horizon has been described. Towards the south, the clastic content of the upper beds increases and a red colour is developed; these are interpreted as being due to the approaching to shoreline.

The Danian age of the Umm al Kifan Member is determined by the planktonic foraminifers (Salaj 1979, p. 33) represented by specimens of the *Postrugoglobigerina daubjergensis/Eoglobigerina danica* Zone with *Postrugoglobigerina hariana* Salaj and *Eoglobigerina danica* (Bang). The macrofauna, occurring very scarcely, is represented by a group of bivalves with the species: *Arca tinrhentensis* Collignon, *Pseudomiltha (Zorrita) chavani* Colignon and *Lima* sp. and small indeterminable and recrystallized gastropods. The Tar/Umm al Kifan Member boundary and thus also the Maastrichtian/Danian boundary is determined by the disappearance of the Upper Maastrichtian orbitoids, represented by *Omphalocyclus macroporus* Lamarck, which do not pass to the Danian and to the Umm al Kifan Member either.

Montian

Had Limestone Member

Antonović (1977), Živanović (1977), Čepek (1979), Röhlich (1979) and Salaj (1979) have described the member in a different type section through the Al Hamadah al Hamra. This member is a highly resistant bed of carbonate rocks-forming the second sedimentary cycle of the Tabaquah Formation and the extensive plateau of Al Hamadah al Hamra (Banerjee 1980). The most widespread sequence of all the sedimentary units in the studied area contributes to geological composition of the very extensive Hamadah al Hamra plateau. It consists mainly of dolomitic limestone and dolomite with many dasycladacean algae represented by the species: *Cymopolia elongata* (Defrance), *Cymopolia paronai* (Reineri), *Cymopolia edwardsi* L. and G. Morellet and others. We find it in Wadi Tabaqah, Hamadah al Hamra, with a restricted subtidal to intertidal marine environment with low energy.

The lower part of the Had Member consists of siliceous crystalline to microcrystalline limestone and calcilutite, both in places dolomitized, with a characteristic amount of grey coloured nodular cherts which predominate. The intercalations of endostratic breccia, calcarenite and dolomite are also present.

Dasycladacea characteristic of this facies, are present abundantly. From the microscopic point of view, gastropod biomicrosparite, sparite, dolomitic sparite to dolosparite dominates with frequent siliceous and dolomitic foraminiferal biomicrites with *Elphidiella prima* (Ten Dam) (loc.: NE of Al Ulaymát) together with fragments of dasycladal algae.

Thanetian

Shurfah Formation

Established by Jordi & Lonfat (1963) for a Paleocene sequence of shales, marl and limestones exposed near Wadi Tar (Hun area). It is divided into three members (*Orbilolites* or *Operculina* or *Operculinoides* Limestone, Galta Chalk and Bu Ra's Marl) (Banerjee 1980), of which the last member outcrops in the Mizdah, Nalut and most of Al Qaryat al Gharbiyah area, other members are present in the Eastern area.

Bu Ra's Member (*Thanetian*)

The Bu Ra's Member, established by Jordi & Lonfat (1963) and studied in detail by Goudarzi (1970), by report of the Energoproject (1975), and Živanović (1977), represents the lower member of the Shurfah Formation. It consists mainly of marls with layers of calcilutites, calcarenites and sparitic to dolomitic limestone (loc.: Shatíb al Máqitah) with *Operculina* aff. *heberti* (Munier et Chalmas) to dolomite with very good porosity (see Fig. 6.5–8) after the fossils *Laffiteina bibensis* Marie and *Rotalia trochidiformis* (Lambert). The gypsiferous chalky marl with a conspicuous finely silty disintegration is the chief lithological type of the Bu Ra's Member. The calcilutites and calcarenites locally also containing nodular cherts, clays, sometimes also with gypsum, are found in the basal part of the member.

Čepek (1979) reported that clays with gypsum become the basal part of the member in the eastern part at Al Qaryat ash Sharqiyah.

In the westernmost part of the same stratigraphic unit, conglomerates to breccias and sandstones with calcilutite matrix are equivalent to these clays, in which quartz grains as intraclasts are quite distinctly represented in the lower layers of the Bu Ra's Member. They are subangular and appear as intraclast-bearing biomicrite to biosparite under the microscope.

The sedimentary petrography of the detailed constituents and texture of the Bu Ra's Member was studied in thin sections by high power optical microscopy. Petrographically, original particles of the rocks are of two types: skeletal and non-skeletal. These particles are usually embedded in a calcite matrix or calcite cement.

1. Skeletal particles: the skeletal elements composition shows a relative abundance of foraminifers, molluscs, brachiopods fragments and Ostracoda. Pellets, peloids are also present. The foraminifers increase with higher water depth and more open circulation, but molluscs and brachiopods commonly occur in rock types deposited in normal shallower marine environments.

2. Dolomite, sparry calcite and anhydrite in crystals and as micrite supported elements are most commonly associated with it and they constitute about 60 to more than 85 % of the rocks

The thin section petrographic studies of the Bu Ra's Member rocks show that the porosity consists mainly of vuggy texture (after dissolution of the foraminiferal tests) also developed as a result of leaching out of void-filling and replacement by anhydrite and dissolution, but the rock texture is affected by solution processes and dolomitization to different degrees. However, all the pore spaces are composed predominantly of fine crystalline fabrics with a common occurrence of bioclastic lithofacies.

The limestone framework consists of a relatively wide range of particles ranging from muds, pellets, peloids, intraclasts and a diversity of bioclasts. These particles are usually embedded in calcite matrix or in calcite cement. Diagenesis seems to have been very effective as is shown by the almost complete obliteration of the original textures through recrystallization of both the particles and their matrix.

Strong diagenesis and recrystallization of the rocks is largely due to dolomitization and makes their microscopic identification difficult. Gypsum crystals often enhance the destructional effect so that primary sedimentary texture becomes completely obliterated or is preserved in relics only. The prevailing sparite and microsparite contain abundant lighter lenticular shapes. Diagenetic processes caused almost complete obliteration of the sedimentary textures in most cases. These processes included cementation, compaction, recrystallization and dolomitization. The latter was selective in some cases and pervasive in others. The thickness varies from 33 m near Wadi Tar to about 5 m in the area between the Wadi Zamzam and As Sadadah in the Bani Walid sheet area.

The lithological, petrographical and paleontological characteristics of the Bu Ra's Member are indicative of shallow to very shallow water, and a neritic to littoral environment of deposition. Salaj (1979) confirmed that the environment is shallow water with low energy supratidal to intertidal parts of the basin. The Bu Ra's Member has been assigned to Thanetian in age, corresponding thus to the dating of Barr & Weegar (1972).

Qaltah (Galta) Member (Thanetian)

The name was introduced by Burollet (1960) after the Al Galta spring, on the eastern margin of the Hun Graben. Later it was ranged as the middle member of the Shurfah Formation by Jordi & Lonfat (1963). It is composed of white and greenish, soft, friable, chalky limestone and marl.

Sandy limestone with gypsum interbeds and limestone with interbeds and irregular nodules of chert occur in the Al Qaddahiyah area.

South of the type locality, extending over a wide area, the upper part of the sequence 10–15 min thickness is developed as yellow fossiliferous, soft, dolomitic marls and marly chalky limestone. The thickness is about 48 m in the Wadi Tar area, about 40–45 m south of Jabal as Soda and 40–50 m in the Bani Walid-Qaddahiyah area.

The sediment was deposited in a relatively quiet shallow to very shallow marine environment. Čepek (1979) and Salaj (1979) assigned the Qaltah Member to Thanetian age by using the faunal evidence. The age is proved by miliolid foraminifers such as *Idalina sinjarica* Grimsdale.

Ammur Member (*Upper Paleocene*)

"Orbitolites Limestone Member*"*. The Ammur Member was introduced by Burollet (1960), or by Jordi & Lonfat (1963) as the '*Operculinoides* or *Operculina* Limestone'. Later, the Ammur Member, was applied again according to the new type section established in the Wadi Ammur (Shakoor & Shagroni 1984).

It is a grey, yellow to greenish or dark brown cavernous weathering limestone and dolomite with marls and chalky marls containing *Orbitolites complanatus* Lamarck and *Lockhartia* sp. (Banerjee 1980). The depositional environment of the Ammur Member is characterized by presence of algae, abundance of the diverse miliolid foraminifers and rare *Operculina canalifera* d'Archiac (Jordi

& Lonfat 1963), as a typically shallow water restraint back-reef — subtidal to intertidal environment (protected shelf, with low energy; Barnolas et al. 1990), corresponding probably to the Upper Thanetian.

Upper Paleocene–Lower Eocene

Kheir Member the lower part of the Bishimah Formation

This formation was defined and subdivided by Jordi & Lonfat (1963) into the Kheir Marl Member, Rouaga and Gir Gypsum Member. Only the Kheir Member was studied. The Kheir Member consists of grey, dense, hard, and thick-bedded to massive micritic limestone with nodules of green chert in the upper part and interbeds of calcarenite and marly limestone. The thickness varies between 30 to 40 m, but increasing to 150–200 m in (Al Qaddahiyah area) the type area where the rock types are mainly chalky limestone and chalky marl with pelagic foraminifers. In the Sirte Basin Barr & Weegar (1972) described the Upper Paleocene *Morozovella velascoensis* Zone from the lower part and the Lower Eocene *Morozovella subbotitina* Zone from the upper part of the Kheir Member.

This age of the Kheir Member is confirmed by the fact that the lower part of the Rouaga Member on Hun Sheet (Shakoor & Shagroni 1984) and in the Al Washkah area (Woller 1978) contains representatives of the alveolines from the *Alveolina oblonga* Zone (Hanzlikova in Woller 1978; Salaj 2003), which already corresponds to the higher part of the Lower Ypresian.

The Al Hamadah al Hamra facies is characterized by friable greenish yellow and ochrous marl and dolomitic marlstone, richly inter-layered with green clay and associated with gypsum abounding throughout the whole vertical extent, especially in the middle and upper part of the Bishimah Formation.

The middle part of the Bishimah Formation is presented by thin to thik intercalations.

Conclusions and discussion

Our results on the Upper Jurassic to Lower Paleogene lithobiostratigraphy contribute to the regional geology of Northwestern Libya, with application for geological mapping and for the oil exploration industry. Especially we were studying the sedimentology and facies characteristics of the Al Gharbiyah, the Tabaqah. We propose a new name for the Shurfah Formation with the redefinition of the Tar Member (=formerly the Lower Tar Member), the upper part of the Al Gharbiyah Formation and the Umm al Kifan (formerly the Upper Tar Member), the upper part of the Tabaqah Formation. However, the high porosity of these formations in the deeper zone or below the Shurfah Formation in the western part of the Al Hamadah al Hamra is important from the point of view of oil accumulation.

Our results are also good for stratigraphic interpretations and applications, especially throughout the Campanian to the Lower Eocene sedimentary formations, for finding criteria of sedimentary conditions in correct application of the knowledge on the archipelago zone facies in the Campanian to Lower Eocene, represented by the Al Gharbiyah and the Shurfah Formations. In the Upper Senonian this archipelago zone was connected with other Upper Senonian to Lower Eocene formations in the Libyan offshore zone and with the Cyrenaica Platform in Eastern Libya.

This archipelago zone in its stratigraphic development and sedimentary interruptions is very similar to the Gosau facies in the Western Carpathians and Eastern Alpine belts. In the both areas the *Inoceramus* Marls, *Orbitoides* Limestones are existing and in places the pelagic red marls with planktonic foraminifers are present. These facies correspond to the shallow neritic facies, with slight influence of pelagic sedimentation and many stratigraphical hiatuses. The tectonic evolution in both areas was totally different, the Alpine in the northern areas in the Alps and Western Carpathians, and the epeirogenetic in the South on the Saharian Platform, in the Al Hamadah al Hamra areas.

The application of our knowledge to the humid paleoclimatic events during the Campanian and Early Paleogene successions on the basis of the presence of red marls and ferrugineous concretions in many stratigraphical levels, which are especially studied in the Cyrenaica Platform (Salaj 2004), is also possible in lithofacies development of the Al Gharbiyah Formation and all Paleogene rock units of Western Libya.

To improve the precision of our knowledge on the facies development and stratigraphy of the Mesozoic and Paleogene sequences it is necessary to carry out new geological research to resolve some important problems:

— Precision on the age of the very shallow marine to continental-fluviatile sediments (well BM1-1) below the uppermost Dinerian foraminiferal *Meandrospira cheni* Zone at the base of the Bir al Jaja Formation.

— The precision on the age of the Norian–Rhaetian–Sinemurian sediments of the Abu Shayban Formation and the Bi'r al Ghanam Gypsum Member and determination of the duration of its hiatuses.

— Detailed study of the lagoonal Pliensbachian–Toarcian sediments of the Bu en Niran Member (upper part of the Bi'r al Ghanam Formation) and paleontological research to find the possibility of approving the age of some important fossil levels corresponding to the marine incursion in these lagoonal sediments.

— The pebbles of detrital conglometatic sediments of Tigi Group and the Kiklah Formation, considered herein, as Aptian–Albian in age.

— The paleomicrobiofacies of carbonate sediments with the detailed paleontological (macro-, microfauna, nannoplankton and palynomorphous) studies of post-tectonic Cenomanian to Coniacian lagoonal sediments (Sidi as Sid Formation, Nalut Formation, Qasr Tigrinnah Marl Member and the Mizdah Formation).

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