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Stratigraphy and facies development of the Upper Cretaceous-Lower Tertiary succession in Wadi Feiran area, southwestern Sinai, Egypt

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With 13 figures and 1 table

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Abstract: The rocks are subdivided from base to top into the following formations: Raha, Wata, Matulla, Sudr, Esna, Thebes and Samalut. Fourteen carbonate and siliciclastic microfacies types are categorized as wackestones (ostracodal and pelagic), wackestones/ packstones (molluscan, miliolid, echinoidal and foraminiferal), grainstones (interclastic peloidal ooidal, oolitic and bioclastic), nummulitic floatstones, dolomitic shelly rudstones, bioclastic dolostones and calcareous quartz arenite. The macro- and microfaunal content as well as microfacies analysis suggest that the Upper Cretaceous - Lower Tertiary succession has been deposited in an environment ranging from shallow marine subtidal and intertidal with influx of terrigenous supply (Raha Formation), quiet open subtidal, graded to oolite shoals and tidal bars (Wata Formation), oscillating between shallow inner shelf and intertidal zone with high terrigenous supply (Matulla Formation), open deep marine outer shelf with quiet conditions (Esna, Sudr and Thebes formations) and reefal shallow marine condition (Samalut Formation).

Zusammenfassung: Oberkreide und Untertertiär im Gebiet des Wadi Feiran (SW Sinai, Ägypten) werden in folgende Formationen unterteilt: Raha, Wata, Matulla, Sudr, Esna, Thebes und Samalut. Innerhalb dieser Formationen werden 14 verschiedene Mikrofaciestypen unterschieden, die zusammen mit den Makro- und Mikrofaunen eine Interpretation der Ablagerungsbedingungen gestatten: Raha-Formation: subtidal bis intertidal mit Zufuhr von terrigenem Material; Wata-Formation: ruhige intertidale Sedimention, in Oolith- und Gezeitenbänke übergehend; Matulla-Formation: innerer Schelf bis intertidal, mit starkem terrigenem Einfluss; Sudr-, Esna- und Thebes-Formationen: ruhiger und offen-mariner äußerer Schelf; Samalut-Formation: flachmariner Riffbereich.

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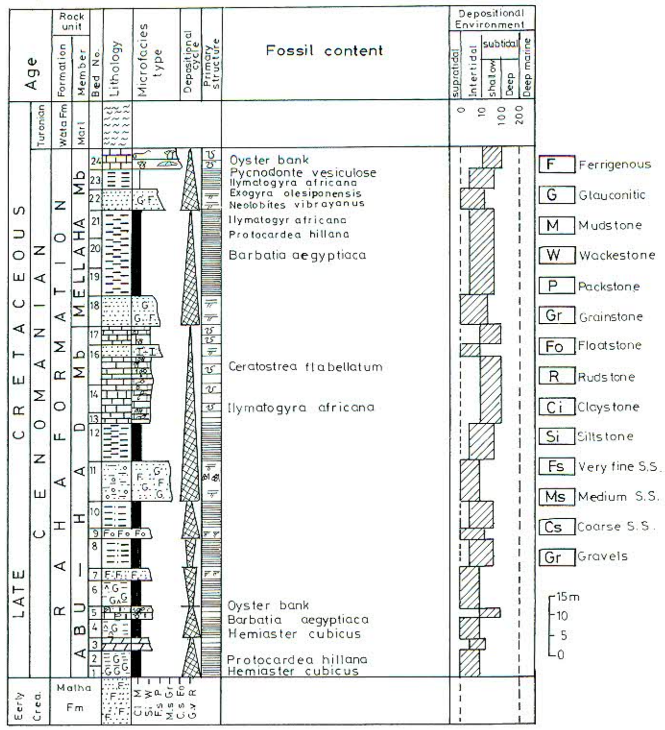

Fig. 2. Stratigraphic section, facies characteristics and depositional environment of the Raha Formation.

Age: The following identified macro-invertebrate fossils (Figs. 9, 10) *Hemiaster cubicus, Ceratostreon flabellatum, Ilymatogyra africana, Exogyra* (*Costagyra*) *olisiponensis, Pycnodonte vesiculosa, Neolobites vibrayeanus, Protocardia hillana, Pterocera incerta* and *Barbatia aegyptiaca*, indicate an age ranging from early to late Cenomanian.

II - Wata Formation (Ghorab, 1961)

It overlies conformably the Raha Formation and underlies conformably the Matulla Formation. Its thicknesses ranges from 140 to 150 m in the study area. The lower contact is characterized by increasing marl content with the first apperance of large ammonites (Abdallah & Adindani 1963).

In the study area, the Wata Formation can be subdivided into two informal members, (Fig. 3) from base to top as:

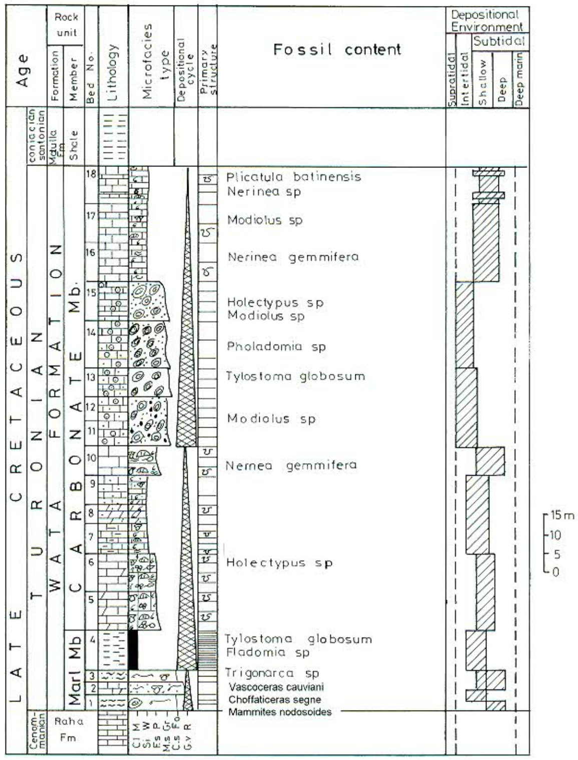

Fig. 3. Stratigraphic section, facies characteristics and depositional environment of the Wata Formation.

1 - Marl Member

It is 17-20 m thick, made up of massive, moderately hard, green marls and thin calcareous claystones rich in large ammonites e. g. *Mammites nodosoides* and others as well as few thin dolomite and argillaceous limestone interbeds.

2 - Carbonate Member

It is 110-120 m thick, mainly composed of yellow, oolitic, well bedded limestone. The fossils are rare and badly preserved, mostly in the form of internal molds of pelecypods, gastropods and echinoids.

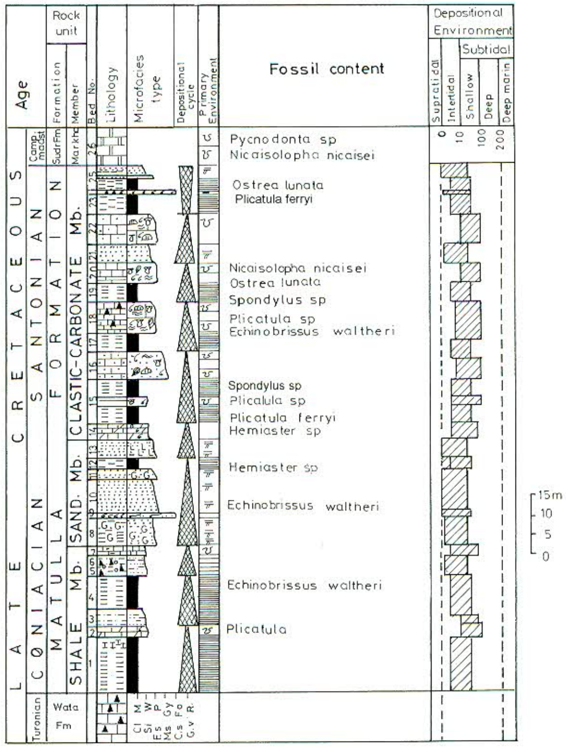

Fig. 4. Stratigraphic section, facies characteristics and depositional environment of the Matulla Formation.

The studied sections of the Wata Formation resemble to a great extent its type section except for the absence of large rudists in the upper part which characterize this units in most sections in Sinai and the Gulf of Suez.

Age: Based on the presence of *Mammites nodosoides, Choffaticeras segne, Vascoceras cauvini, Tylostoma globosum, Nerinea* sp. *Modiolus* sp., *Pholadomia* sp., *Holectypus* sp., *Hemiaster* sp., and *Trigonarca* sp. (Figs. 9, 10), the Wata Formation in the study area is of Turonian age.

III - Matulla Formation (GHORAB, 1961)

It overlies conformably the carbonate of the Wata Formation and underlies conformably the chalk of the Sudr Formation. It is ranging in thicknesses from 120 to 137 m.

The Matulla Formation can be traced in the field by the sudden change in lithology and the increase of the terrigenous input, i. e. it is located between two carbonate units and yields a Coniacian - Santonian fauna on the other hand.

In the study area it is subdivided into three members (Fig. 4), they are from base to top.

1 - Shale Member

It is 30-37 m thick, mainly composed of calcareous claystone with fossiliferous limestone and calcareous sandstone interbeds yielding *Plicatula ferryi* and *Ostrea lunata*.

2- Sand Member

It is 20-27 m thick, mainly made up of dominantly fossiliferous calcareous sandstone with few limestone and shale interbeds. Fossils are badly preserved pelecypods, gastropods and echinoids.

3 - Mixed clastic / carbonate Member

It is 45 to 70 m thick, made up of calcareous claystone, sandstone and limestone interbeds with *Plicatula ferryi* and other badly preserved pelecypod molds.

The Matulla Formation is correlated with the Themed Formation described from the east-central Sinai (ZIKO et al. 1993) in which the clastic constituents of the Matulla are partly replaced by carbonates. In the west central Sinai, CHERIF et al. (1989) raised the rank of the Matulla to group-level. Lateral variation in thickness of the Coniacian-Santonian is recorded without any facies change in the present succession. This variation in thickness may be related to the tectonic evolution of the basin floor which began in the Turonian and continued into the Senonian as reflected in the isopach maps drawn by BARTOV & STEINITZ (1977).

Age: Based on the stratigraphic position and the faunal content *Echinobrissus waltheri, Pilcatula ferryi, Pycnodonte* sp., *Nicaisolopha nicaisei, Ostrea lunata, Plicatula* sp. and *Hemiaster* sp. (Figs. 9, 10), the age of the Matulla Formation in the study area is Coniacian - Santonian.

IV - Sudr Formation (GHORAB, 1961)

It conformably overlies the Matulla Formation and underlies conformably the Esna Formation. It is ranging in thickness from 110 to 140 m. In the

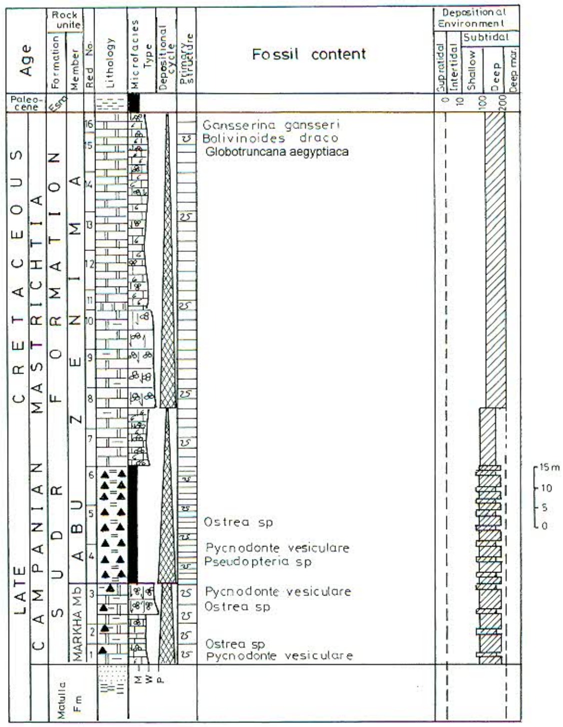

Fig. 5. Stratigraphic section, facies characteristics and depositional environment of the Sudr Formation.

study area, the Sudr Formation can be subdivided into two members (Fig. 5), from base to top:

1 - Markha Member

It is 15-20 m thick and mainly composed of massive, snow white, partly silicified chalk, intercalated with numerous, grey and brown chert bands and / or nodules flooded with *Pycnodonte* (*Phygraea*) *vesicularis*, *Ostrea* sp. and foraminiferal tests.

2 - Abu Zenima Member

It is 70-120 m thick, mainly composed of snow white bedded chalky limestone with calcareous claystone interbeds especially in the lowermost part,

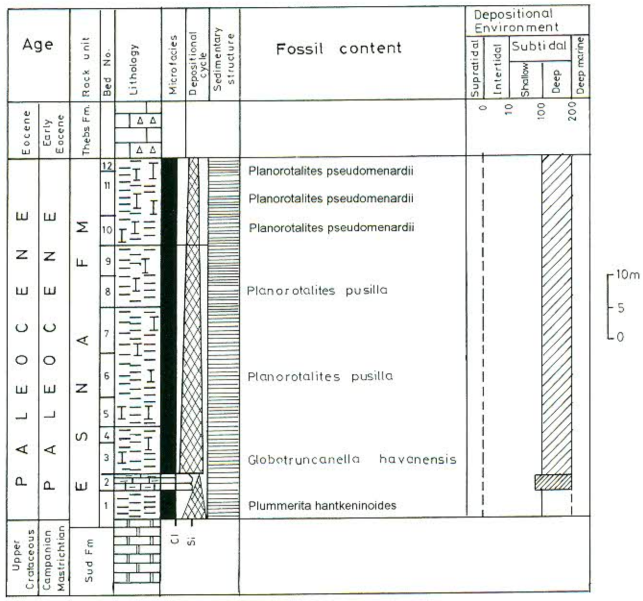

Fig. 6. Stratigraphic section, facies characteristics and depositional environment of the Esna Formation.

with several thin chert bands ranging from 3-10 cm thick. It contains the same fossils as the Markha member with slight decrease in abundance upwards and increase in planktonic foraminifera e. g. *Globotruncana aegyptiaca*.

Age: According to the macro- and microfossil content (Fig. 9) e. g. *Pycnodonte vesiculosa, Ostrea* sp., *Globotruncana aegyptica* and *Gansserina gansseri*, the Sudr Formation is of Campanian - Maastrichtian age.

V - Esna Formation (Beadnell, 1905, Said, 1960)

It overlies conformably the Sudr Formation and underlies conformably the Thebes Formation and ranges in thickness from 40 to 50 m. It is mainly composed of grey to green shales, which are more calcareous in the lower part (Fig. 6) and rich in microfauna.

Age: The planktonic foraminifera identified *Plummerita hantkeninoides, Globotruncanella havanensis Planorotalites pusilla pusilla* and *Planorota-*

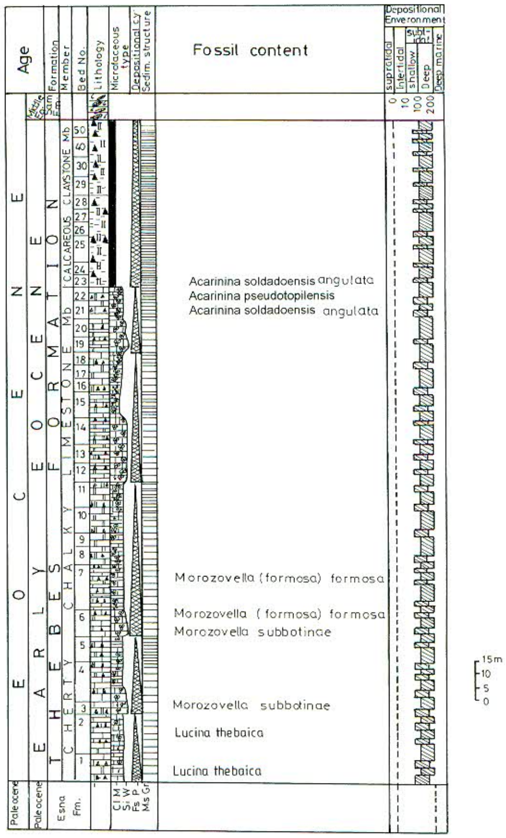

Fig. 7. Stratigraphic section, facies characteristics and depositional environment of the Thebes Formation.

lites pseudomenardii indicate the age of the Esna Formation from Late Maastrichtian to Late Paleocene.

VI - Thebes Formation (Said, 1960)

It overlies conformably the Esna Formation and underlies conformably the Samalut Formation. It is charactrized by well bedded, yellow, cherty chalky limestone with chalky calcareous claystone in the upper part. It ranges in thickness from 240 to 255 m in thicknesses.

The Thebes Formation can be subdivided into two informal members (Fig. 7), from base to top.

1 - Cherty chalky limestone Member

It is 180 to 190 m thick, mainly composed of thick, yellow, hard well bedded dolomitic limestone with dark brown chert nodules (20-100 cm in diameter) and /or bands (10 to 30 cm thick). This member is poor in megafossils but rich in microfossils.

2 - Calcareous claystone Member

It is 50-60 m thick, it consists mainly of calcareous claystone with few thin chert bands and flooded with microfossils. Lithostratigraphically, the Thebes Formation in the study area is similar to that in the type locality of the Nile Valley (SAID, 1960), except for the presence, of the upper claystone member.

It is interesting to mention that the upper calcareous claystone member of the Thebes Formation may be equivalent to the Darat Formation of VIOTTI & EL-DEMERDASH (1968) and the Waseiyit Formation of BARAKAT et al. (1988) in the Hammam Faraoun area in the West Central Sinai.

Age: Stratigraphically, this formation lies under the nummulitic limestone of the Samalut Formation with the presence of *Acarinina pseudotopilensis, Lucina thebaica* in the lower member and *Acarinina soldadoensis angulata, Morozovella subbotinae, Morozovella formosa formosa* in the upper member. According to the stratigraphic position and faunal content the Thebes Formation in the study area is of an Early Eocene age (Ypresian).

VII - Samalut Formation (BISHAY, 1961)

It overlies conformably the Thebes Formation and underlies unconformably the clastic rocks of Miocene age.

It is 80-90 m thick, mainly composed of yellow, thick bedded, hard nummulitic limestones beds (Fig. 8) rich in well preserved *Nummulites gizehensis*, which are over-crowded, and show imbrication fabric, as well as pelecypods (*Lucina* sp.; *Ostrea multicostata*) gastropods (*Gisortia* sp.) and echinoid sp. (*Echinolampas africanus* and *Schizaster mokattamensis*).

Age: The Samalut Formation belongs to the Middle Eocene age (Lutetian) due to the presence of *Nummulites gizehensis* and typical macrofossils.

Microfacies analysis

The petrographic characteristics of the carbonates and siliciclastic rocks and their diagenetic changes have been studied in 250 thin sections. The classification and terminology of these rocks are according to FOLK (1959) the depositional texture of DUNHAM (1962) with modifications of EMERY & KLOVAN (1972).

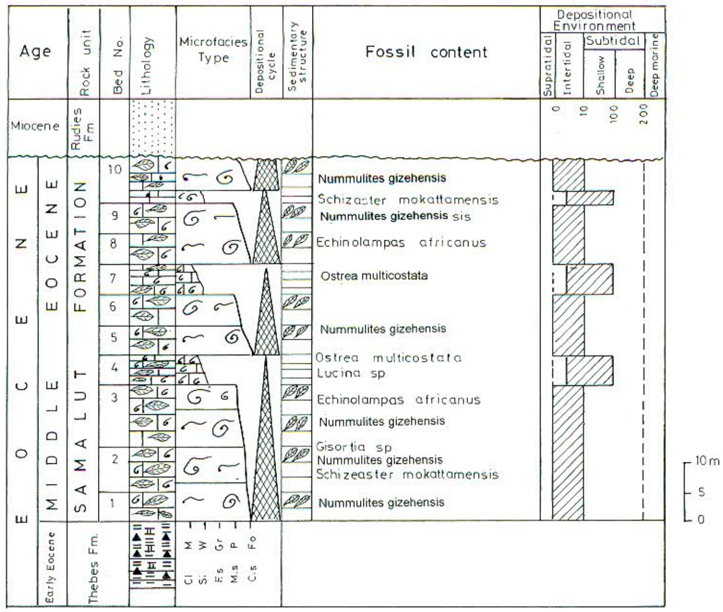

Fig. 8. Stratigraphic section, facies characteristics and depositional environment of the Samalut Formation.

Carbonate lithofacies

I - Limestones microfacies

The limestone lithofacies is more abundant than the other lithofacies, except in the Matulla and Esna formations. It forms about 30 % in the Raha, 90 % in the Wata, 40 % in the Matulla, 80 % in the Sudr, 80 % in the Thebes and 98 % in the Samalut formations. The limestone lithofacies can be differentiated into four microfacies associations as follows:

A - Wackestone microfacies

This microfacies represents about 50 % of the studied limestone lithofacies and has been identified from whole rock units.

The carbonate grains are mainly composed of skeletal particles embedded in a micrite or microsparite groundmass. These skeletal particles are essential rock building constituents.

According to the carbonate and non-carbonate grains dominance, the wackestone microfacies can be subdivided into three types:

1 - Pelagic Wackestone (Fig. 11/A)
It is most common in the Sudr and Thebes formations. Skeletal grains are mainly pelagic (globigernoid type). Most of the tests are filled with neomorphic sparite and pyrite and are embedded in a micrite matrix.

2 - Ostracod bioclastic wackestone (Fig. 11/B)
It is recorded from the Raha Formation and consists of biomorpha and bioclasts of ostracods (*Bairdia* sp.) as well as pelecypod fragments. All embedded in micrite matrix.

3 - Bioclastic wackestone/packstone (Figs. 11/C, D, E, F)
It is recorded from the Raha, Wata, Matulla, Sudr, Thebes and Samalut formations; composed of fragments of sessile benthonic bivalves, gastropods, echinoids (plates and spines), foraminifers (miliolid and biserial types).

Most of the molluscan fragments are filled with large, clear neomorphic calcite and few exhibit their original microstructure. Some scattered, fine to medium, subangular to subrounded quartz grains are present. Few phosphatic fragments (francolite) and large intraclasts of medium size, green glauconite grains are also observed.

The bioclastic wackestone / packstone microfacies can be subdivided into four subtypes, these are: molluscan bioclastic wackestone / packstone (Fig. 11/F) miliolid bioclastic wackestone / packstone (Fig. 11/D), sandy echinoidal bioclastic wackestone/packstone (Fig. 11/E) and foraminiferal bioclastic wackestone / packstone (Fig. 11/C).

Fig. 9. A: *Tylostoma globosum* SHARPE, internal mold, Wata Formation, Turonian. **B**: *Nerinea gemmifera* COQUAND, internal mold, Raha Formation, Cenomanian. **C**: *Cimolithium tenouktense* (COQUAND), internal mold, Raha Formation, Cenomanian. **D**: *Pycnodonte vesiculare* (LAMARCK), double valves. Raha Formation, Cenomanian. **E**: *Ceratostreon flabellatum* (GOLDFUSS) external view, left value. Raha Formation, Cenomanian. **F**: *Ilymatogyra africana* (LAMARCK), external view, right value, Raha Formation, Cenomanian. **G**: *Nicaisolopha nicaisei* (COQUAND), external view, right value. Matulla Formation, Coniacian-Santonian. **H**: *Rhynchostreon suborbiculatum* (LAMARCK), external view, left value. Raha Formation, Cenomanian. **J**: *Agerostrea rouxi* (DOUVILLÉ), external view, value. Raha Formation, Cenomanian. Scale bar of all figures is 20 mm.

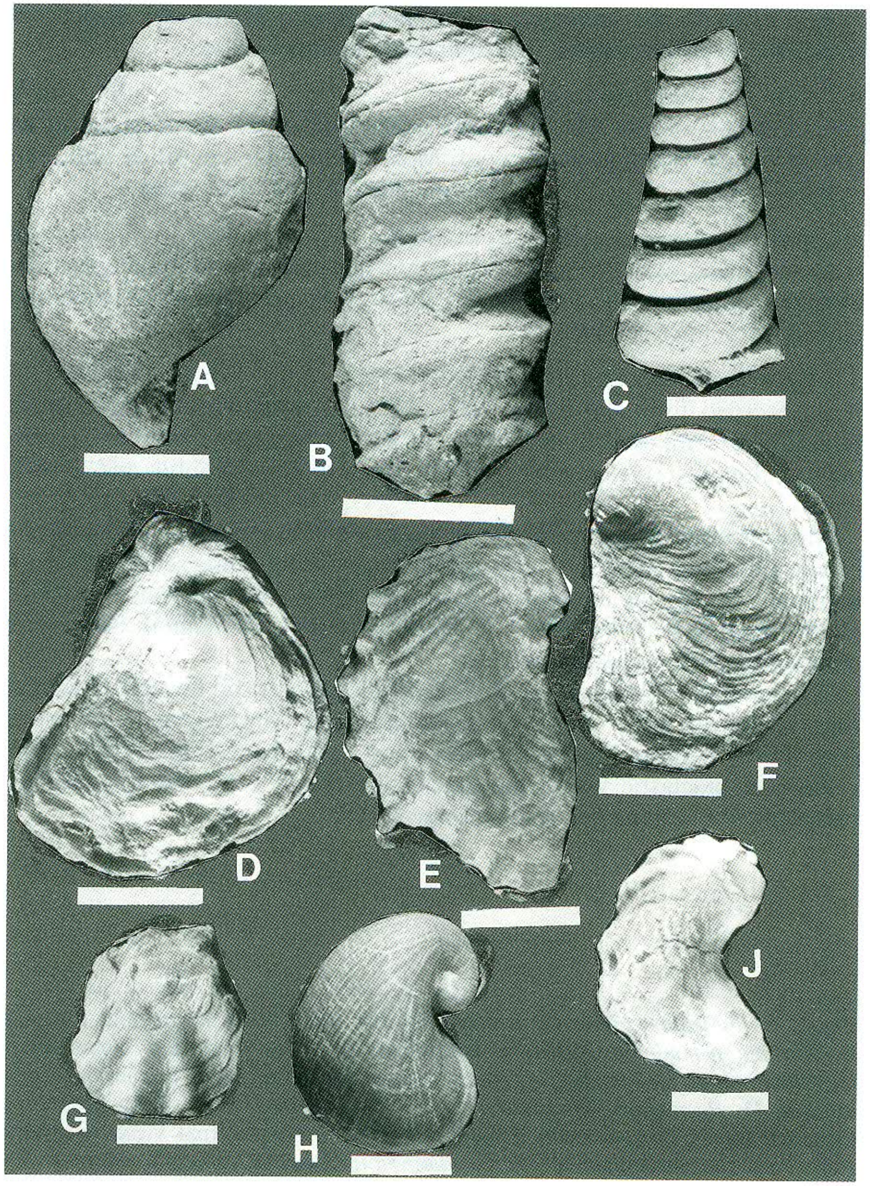

Fig. 9 (Legend see p. 275)

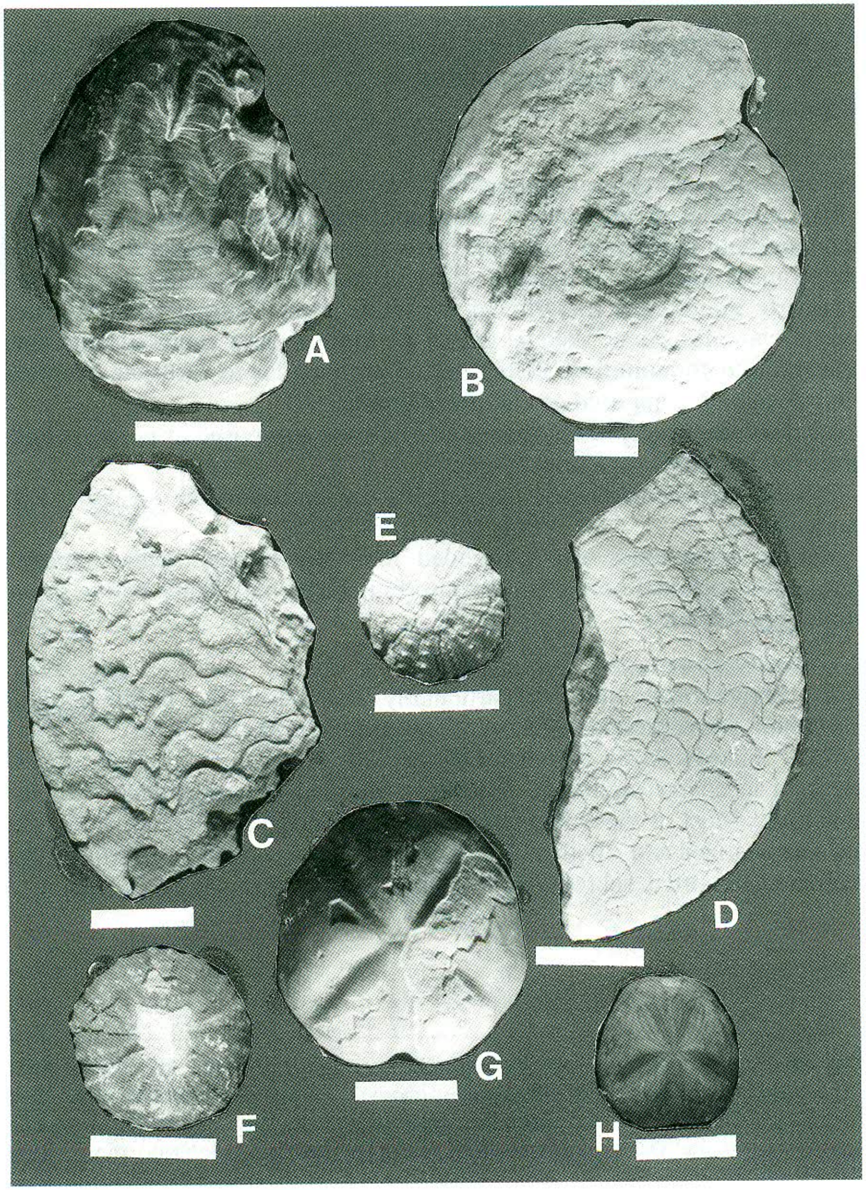

Fig. 10 (Legend see p. 278)

B. Grainstone microfacies

It is well developed in the Wata and Matulla formations and represents about 25 % of the whole limestone lithofacies. Two microfacies types are recognized.

1 - Oolitic grainstone (Figs. 12/A, B)

This microfacies represents about 60 % of the grainstone microfacies. This grain-supported microfacies is essentially composed of sand-sized ooids, showing both radial and concentric structure, and a spherical to elongated shape, most nuclei are composed of micritized carbonate fragments and few of quartz grains. The majority of the ooids are of normal type with rare superficial ones. Some skeletal grains are molluscan or echinoid fragments and miliolid foraminifers. Peloid grains are circular to oval and elliptical shapes, mainly composed of micritized grains.

Abundant intraclasts, of the calcarenite type are composed of ooids, peloids and skeletal grains cemented by micrite.

All the above mentioned constituents are embedded in sparry calcite cement.

Oolitic grainstones are subdivided into two submicrofacies types: - Intraclastic peloidal oolitic grainstone (Fig. 12/B) and sandy oolitic grainstone (Fig. 12/A).

2 - Sandy bioclastic grainstone (Fig. 12/C)

It is comparatively rare but particularly well developed in the Matulla Formation and represents 40 % of the grainstone microfacies.

This microfacies is mainly composed of abundant moderately sorted, medium to coarse molluscan fragments (dominantly pelecypods) and few echinoids. Most of these fragments show their original microstructure, few are recrystalized and silicified (chalcedony and microquartz). Abundant fine to coarse, ill-sorted, subrounded to rounded quartz grains are recorded.

Fig. 10. A: *Exogyra* (*Castagyra*) *olisiponensis*, external view, left value. Raha Formation, Cenomanian. **B**: *Vascoceras chauvini* CHOFFAT, internal mold. Wata Formation, Turonian. **C**: *Choffaticeras segne* (SOLGER), internal mold. Wata Formation, Turonian. **D**: *Neolobites vibrayeonus* (D'ORBIGNY), internal mold. Raha Formation, Cenomanian. **E**: *Diplopodia bartiouxi* FOURTEAU, aboral view. Raha Formation, Cenomanian. **F**: *Heterodiadema libyca* (AGASSIZ & DESOR), oral view. Raha Formation, Cenomanian. **G**: *Hemiastar cubicus* DESOR, aboral view. Samalut Formation, Middle Eocene. **H**: *Schizaster mokattamensis* LORIOL, aboral view. Samalut Formation, Middle Eocene. Scale bar of all figures is 20 mm.

C - Floatstone microfacies (Fig. 12/F & Fig. 13/A)
It is one of the less abundant microfacies types. It forms the most common type in the Middle Eocene rocks (Samalut Formation), where it is represented by nummulitic floatstone.

This microfacies type contains gravel size skeletal particles of *Nummulites* spp., and other bioclasts such as bivalves, gastropods and echinoids.

The large foraminiferal tests exhibit partially prefered orientation and imbrication structure, and are tightly cemented by micrite matrix. Most of these skeletal grains are micritized and recrystallized.

D. Rudstone microfacies (Figs. 12/D, E)
It is comparatively less frequent, but it is the characteristic facies of the Matulla Formation. It is represented by dolomitic shelly rudstone. This grain supported facies is mainly composed of gravel sized pelecypod fragments which are cemented by crystalline spary calcite. Most of the pelecypod fragments exhibit their original microstructure.

Intense recrystallization, dolomitization and partially silicification are the main diagenetic processes that had affected the carbonate particles. Dolomite rhombs are euhedral and zoned.

Some non-carbonate particles in the form of medium to coarse, monocrystalline subrounded quartz grains as well as iron concretions are recorded.

II - Dolostone Microfacies (Fig. 13/B)

This type represents about 15 % of the studied carbonate thin-sections. Generally, the rocks of the Matulla Formation are extensively dolomitized, while the other rock units are partially, dolomitized.

The skeletal grains of the bioclastic dolostone consist of ostracods and shell fragments.

The dolomite rhombs are of fine to medium size, subhedral and cloudy with poorly zoned crystals.

Fig. 11. A: Pelagic wackestone: globigernoid foraminiferal tests, embedded in micrite matrix, most of these tests are filled with neomorphic sparite. Thebes Formation, Early Eocene. **B**: Ostracodal bioclastic wackestone: biomorpha of ostracod shells (*Bairdia* sp.) and pelecypod shell fragments, all embedded in micrite matrix. Raha Formation, Cenomanian. **C**: Foraminiferal bioclastic wackestone/ packstone: bioclasts of molluscs and echinoids and biomorpha of biserial foraminiferal test,

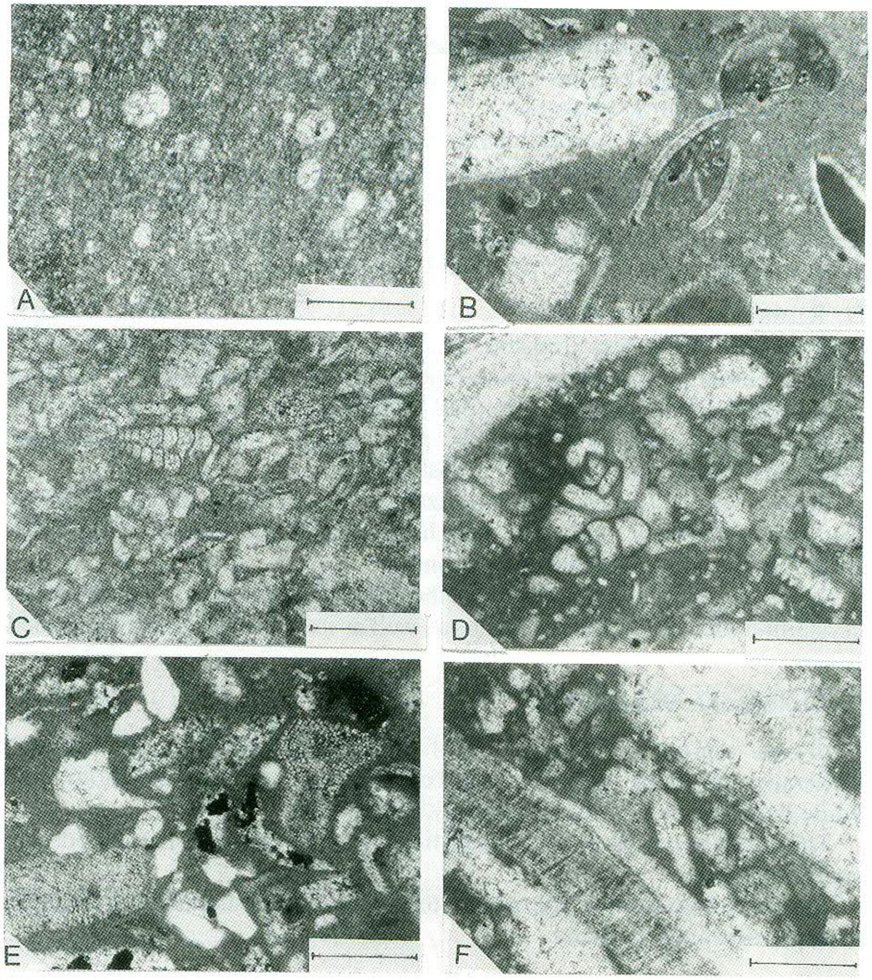

Fig. 11 (Legend see p. 279/280)

all embedded in micritic matrix. Samalut Formation, Middle Eocene. **D**: Miliolid bioclastic wackestone/packstone: biomorpha of miliolid foraminiferal tests and bioclasts of pelecypods, embedded in micrite matrix. Raha Formation, Cenomanian. **E**: Sandy echinoidal bioclastic wackestone/packstone: bioclasts of echinoidal plates and other fossils with fine to medium, moderately rounded quartz grains. Matulla Formation, Coniacian- Santonian. **F**: Molluscan bioclastic wackestone/packstone: bioclasts of pelecypods of different sizes, some of them exhibit original structure and others are recrystallized. Raha Formation, Cenomanian. Scale bar of all figures is 0.45 mm.

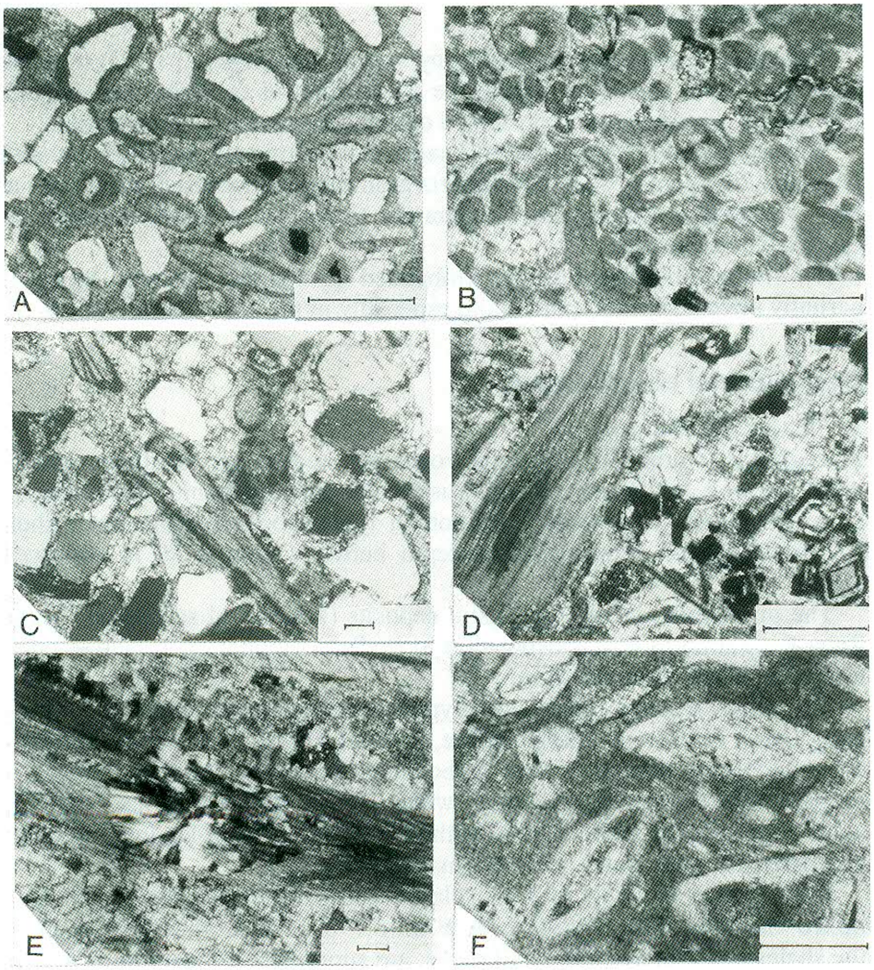

Fig. 12. A: Sandy oolitic grainstone: spherical to elongated sand size ooids, most nuclei are quartz grains and micritized clasts. Wata Formation, Turonian. **B**: Intraclastic peloidal oolitic grainstone: circular to elliptical micritized pellets, calcarenite interclasts and few spherical ooids. Wata Formation, Turonian. **C**: Sandy bioclastic grainstone: subrounded to subangular quartz grains with pelecypod fragments, embedded in sparite cement. Matulla Formation, Coniacian - Santonian. **D**: Dolomitic shelly rudstone: gravel-size pelecypod fragments, cemented by sparry calcite and euhedral zoned rhombs of dolomite. Wata Formation, Turonian. **E**: Dolomitic shelly rudstone: showing the silicification in the molluscan fragments. Wata Formation, Turonian. **F**: Nummulitic floatstone: *Nummulites* of different sizes, some of them are partially recrystallized. Samalut Formation, Middle Eocene. Scale bar of all figures is 0.45 mm.

Siliciclastic Lithofacies

This facies is represented mainly by sandstones (Figs. 13/C, D) together with calcareous claystone. Sandstone is common in the Raha and Matulla formations. This facies is represented only by calcareous quartz arenite.

This microfacies type is mainly made up of dominant quartz grains with few lithic fragments. Most of the quartz grains are monocrystalline, coarse to fine, rounded to subangular, moderately to well sorted and without recognizable orientation.

All framework elements are embedded in sparitic cement, which is partially affected by dolomitization, especially in the Matulla Formation.

Depositional environment

1 - Raha Formation

Macrofossils studied in the Raha Formation (echinoids, bivalves, gastropods) as well as the microfauna (ostracods and benthonic foraminifers), show favourable conditions, common in typical open marine inner shelf environment with a predominant depth between 20 and 30 m (ZIEGLER 1967).

The predominance of siliciclastic deposits (shales and sandstone) in the Raha Formation indicates deposition in shallow subtidal open marine environment, not far from the shore.

The most frequent microfacies types are calcareous claystone, glauconitic, lithic, calcareous quartz arenite, bioclastic wackstone, molluscan rudstone and sandy dolostone. This carbonate microfacies types are equivalent to the standard microfacies type 9, which is considered by WILSON (1975) and FLÜGEL (1982), to be formed in the facies belt 7 (shelf lagoon with open circulation in quiet water below normal wave base).

Rare graded bedding in some clastic rocks, indicates deposition in a mixed intertidal flat (REINECK & SINGH 1980) while the lamination in the shales and bioturbation in all rocks, are supporting deposition in weakly turbulent condition (FRIEDMAN 1964).

The mixed siliciclastics and carbonates of the Raha Formation (Fig. 2) had been probably deposited in a shallow subtidal and intertidal open marine environment with high influx of terrigenous material with flucluating energy conditions between quiet to moderate (tidal flat or coastal lagoon) with a suggested depth of less than 50 m.

2 - Wata Formation

The lithologic characteristics (limestone with thin marl and claystone intercalations at the base) of the Wata Formation probably indicate deposition in the subtidal part of the inner shelf under quiet conditions and open circulation (WILSON 1975).

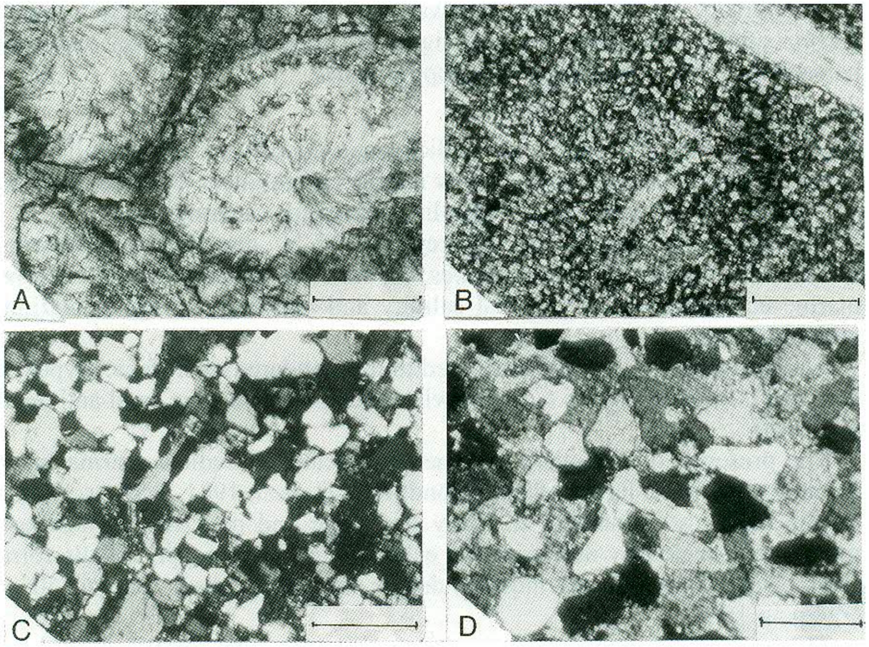

Fig. 13. A: Nummulitic floatstone: gravel-size *Nummulites* and other bioclasts. The *Nummulites* tests are partially recrystallized. Samalut Formation, Middle Eocene. **B**: Bioclastic dolostone: fine euhedral dolomite rhombs with molluscan fragments. Matulla Formation, Coniacian - Santonian. **C**: Quartz arenite, fine to medium, rounded to subrounded quartz grains embedded in carbonate cement. Matulla Formation, Coniacian- Santonian. **D**: Calcareous quartz arenite: medium, to coarse, rounded to subangular quartz grains, all embedded in sparite cement. Matulla Formation, Coniacian- Santonian. Scale bar of all figures is 0.45 mm.

The essential microfacies types are packstone, grainstone, wackestone, rudstone and floatstone. These types could be attributed to the standard microfacies types 9, 14, 15 and 24 and facies belts 6, 7 and 8 (Wilson 1975, Flügel 1982). The fauna is represented by cephalopods, echinoids, ostracods, bivalves, gastropods and benthonic foraminifers, especially in the basal part which indicate deposition in a shallow open-marine environment. The preservation of these fossils indicate deposition in a very quiet environment (Wilson 1975).

In summary, the Wata Formation was probably deposited on a quiet open marine subtidal shelf (Fig. 3), grading in the upper part to shoals and tidal bars (presence of oolitic beds in the upper part).

3 - Matulla Formation

The predominance of glauconitic siliciclastic deposits in the Matulla Formation reflect deposition in a shallow marine environment that was close to a land mass which continuously supplied terrigenous sediments.

The carbonate microfacies are represented by grainstone, packstone, wackestone, floatstone and dolostones, deposited in a reducing open shallow marine environment with normal salinity and low rates of sedimentation, with turbid water in some parts.

The microfacies types are attributed to the standared microfacies types 9, 11 and 12 and facies belts 6 and 7 (winnowed platform edge sand and open platform).

The presence of phosphate fragments indicates a shallow marine inner subtidal zone with sligtly reducing condition (Tucker 1981, Flügel 1982).

The fossils are abundant in many limestone and marl beds. These are mostly represented by molluscs and echinods. Most pelecypod shells form shell banks. These fossils indicate depths ranging between 20 and 50 m (Ziegler 1967).

The primary structures are mostly thick beds, with small scale cross-bedding and local graded beds. These structures point to sedimentation by a gentle current of pulsating velocity as common in a mixed intertidal flat (Reineck & Singh 1980).

The mixed siliciclastic- carbonates of the Matulla Formation (Fig. 4) were deposited in open oscilating shallow marine depositional environment between shallow inner shelf and intertidal zone under fluctuated energetic condition, not far from the shore.

4 - Sudr Formation

This unit is composed mainly of siliceous, argillaceous chalk with thin chert bands and calcareous claystone interbeds. These lithologic characteristics indicate deposition on a deep subtidal shelf and quiet marine conditions (below the wave base).

Fossils are represented by pelagic foraminifers with few benthonics and ostracods as well as large pelecypods in the lower part. These fossils indicate open marine conditions.

Microfacies are represented by pelagic wackestone to packstone and calcareous claystone. These microfacies types can be compared with standard type 3 and facies belt 3 of Wilson 1975 and Flügel (1982), placed in the deep shelf margin.

Table 1. Selected classifications and nomenclature of the Createaceous-Lower Tertiary rocks in the Sinai and the Gulf of Suez.

Age	Author / location	Ball (1916) W. Sinai	Moon & Sadek (1923) W. Sinai	Ghorab (1961) Gulf of Suez	Said (1962, 1990) C. & N. Sinai	Issawi et al. (1981) W. Sinai	Abu Khadrah et al. (1987) Gulf of Suez	Shahin & Kora (1991) E. Central Sinai	Ziko et al. (1993) E.C. Sinai	Present work W. Sinai
Early Tertiary	Late Eocene	Eocene Rocks	Basaltic still-Red beds-gypseous marl				Tayiba Fm. Tanka Fm. Thal Fm.			
Early Tertiary	Middle Eocene	Eocene Rocks	Cardita series chalky limestone		Plateau Limestone: Mokattam Fm.; Chalky nummulitic limestone	Mokattam Fm. Samalut Fm.	Rod El Awad Fm.		Samalut Fm.	Samalut Fm.
Early Tertiary	Early Eocene	Eocene Rocks	Nummulitic series with bands of flint		Plateau Limestone: Egma limestone; Limestone with flint	Thebes Fm.	Waseiyit Fm.		Thebes Fm.	Thebes Fm.: Chalky Claystone Mb.; Cherty Claystone Mb.
Early Tertiary	Paleocene	Esna Shale	Shale similar to Esna Shale		Esna Shale	Esna Fm.	Esna Fm.	Esna Fm.	Esna Fm.	Esna Fm.
Late Cretaceous	Campanian Maastrichtian	Companian Maastrichtian rocks	Companian Maastrichtian white chalk	Sudr chalk: Abu Zenima Mb.; Markha Mb.	Chalk	Sudr Fm Duwi Fm.	Sudr chalk Thelemt Fm.	Sudr chalk: Abu Zenima Mb.; Markha Mb.	Sudr chalk: Abu Zenima Mb.; Markha Mb.	Sudr Fm.: Abu Zenima Mb.; Markha Mb.
Late Cretaceous	Coniacian Santonian	Santonian rocks	Santonian rocks	Matulla Fm.	Turonian Santonian	Nubia Fm.	Matulla Fm.	Matulla Fm.	Themed Fm. / Matulla Fm	Matulla Fm.: Clastic carbonate Mb.; Sand Mb.; Shale Mb.
Late Cretaceous	Turonian	Turonian rocks	Turonian rocks	Wata Fm.	Turonian Santonian	Wata Fm.	Wata Fm.	Wata Fm. Abu Qada Fm.	Wata Fm.	Wata Fm.: Carbonate Mb.; Marl Mb.
Late Cretaceous	Cenomanian	Cenomanian rocks	Cenomanian rocks	Abu Qada Fm. Raha Fm.: Meilaha Mb; Abu Had Mb.	Cenomanian	Galala Fm.	Galala Fm.	Galala Fm.	Galala Fm.	Raha Fm.: El-Melha Mb; Abu Had Mb.
Early Cretaceous		Nubia Sandstone	Lower Cretaceous		Lower Createaceous "Nubia sandstone"	Amir Fm.	Mallha Fm.	Mallha Fm.	Mallha Fm.	Mallha Fm.

The chalk facies of the Sudr Formation (Fig. 5) was deposited in an open marine environment under quiet conditions, below the wave base.

5 - Esna Formation

The lithologic characteristics of the Esna Formation (planktonic foraminiferal shale) indicate a deep shelf environment with quiet water. The main microfacies is calcareous foraminiferal mudstone.

The lamination is the essential primary structure within this formation which supports deposition in quiet water condition.

The calcareous shale facies of the Esna Formation was most probably deposited on a deep outer shelf under quiet conditions (Fig. 6). These facies represent the maximum transgression which took place during the Paleocene - Early Eocene time.

6 - Thebes Formation

The lithologic characteristics of the Thebes Formation (cherty limestone and calcareous claystone) support deposition in a basinal and open shelf sea environment below the normal wave base and with a low rate of sedimention (JENKYNS 1978). The microfacies examined in this formation are pelagic wackestone / packstone and calcareous claystone. These facies types can be compared with standard microfacies type 3 and facies belt 1 of WILSON (1975) and FLÜGEL (1982), which indicate open sea shelf and basinal environments.

Fossils are represented by abundant planktonic foraminifera with few bivalves, which indicate outer shelf.

The depositional environment of the Thebes Formation (Fig. 7) represents continuation of the open marine shelf condition of the Esna Formation with fluctuating regressive pulses of the sea (cherty facies).

7 - Samalut Formation

Lithologically the Samalut Formation is formed of nummulitic limestone. The dominant microfacies types are nummulitic floatstone and wackestone / packstone. This facies reflects deposition and accumulation in a shallow marine environment slightly subjected to current action.

The moderate sorting, parallel orientation, imbrication and preservation of the *Nummulites* indicate gentle current action.

The Samalut Formation represents a regressive or shallowing phase in Middle Eocene (Fig. 8).

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