

2 Lithostratigraphy

In the following, the regional distribution of the different lithofacies types of the carbonaceous shales of Carboniferous to Eocene age for the five locations will be discussed.

	Sinai		Western Desert	Nile Valley	Red Sea coast
	Abu Zinema Az. (1)	Al – Maghara Mg (2)	Abu Tartur AT (3)	Esna-Idfu N (4)	Quseir Q (5)
Early Eocene				Esna Shale	
Late Paleocene				Tarawan Chalk	
Lower Paleocene - Upper Cretaceous				Dakhla Shale	
Upper Cretaceous			Duwi Formation		
Pre Campanian				Varigated Shale	
Middle Jurassic		Safa Formation			
Lower Carboniferous	Ataqa Formation				

Fig. 2: Stratigraphic column and regional distribution of the studied formations.

2.1 The area of Abu Zinema in Southwest Sinai (Carboniferous)

The Paleozoic sediments are exposed in the southern central parts of the Sinai, primarily in the Um Bogma area east of Abu Zinema and at Abu Durba (Fig. 3). These sediments have been studied in detail by Abdallah and Adindani (1963), Hassan (1967), Weissbrod (1969), Said (1980) and Issawi and Jux (1982). The lack of diagnostic fossils has made accurate dating and correlation extremely difficult and additional confusion has been created by the use of various formation names. The basal Cambro-Ordovician sequence comprises the Araba, Naqus and Wadi Malik Formations of Issawi and Jux (1982), which are equivalent to the Yam Suf Group and the Netafim Formation of Weissbrod (1969). These clastic sediments were deposited on the peneplained surface of the pre-Cambrian basement and are dominated by grits, siltstones, subarkoses and conglomerates, with few dolomite beds (Said 1990).

Issawi and Jux (1982) have interpreted some of the conglomerates to be of fluvioglacial origin, suggesting that some of these sediments may be of Silurian age whilst the upper parts are interpreted as Devonian. However, these age datings are not based on direct faunal evidence and therefore may not be totally correct. These basal Paleozoic sediments were deposited under fluvial paralic conditions and probably represent relics of a very large sediment body which originally extended over a large area, but was deeply eroded before the deposition of upper Paleozoic strata. The Carboniferous at southwest Sinai was divided from base to top into two formations, the Um Bogma Formation and the Ataqa Formation.

2.1.1 Um Bogma Formation (Lower Carboniferous)

The Um Bogma Formation provides the first reliable date for the Paleozoic sequence in Sinai. These marine carbonates are highly fossiliferous, especially in foraminifera, and have been dated as Tournaisian-Visean (Said 1990). The Um Bogma Formation lies conformably over nonfossiliferous sandstones which are generally believed to be of lower Paleozoic age. Ferromanganese minerals within the basal part of the carbonates at Um Bogma have been extensively mined for many years. South of Abu Durba the Um Bogma Formation is represented by black marine shales (122 m thick) which have yielded a similar fauna comparable to that of Um Bogma area.

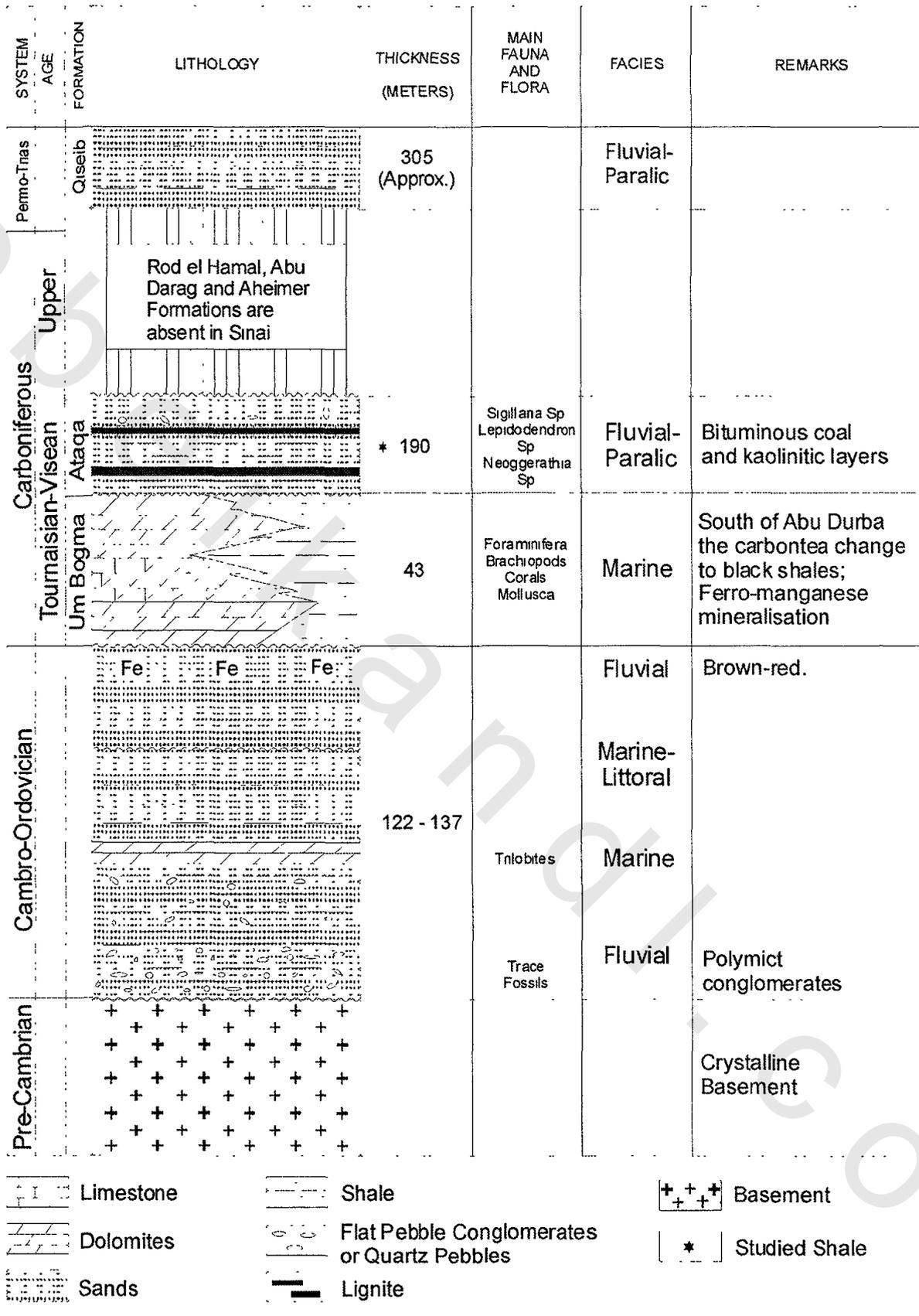


Fig. 3: Lithostratigraphic section of the Paleozoic in central Sinai showing the position of Ataqa Formation (after Said 1990)

2.1.2 Ataqa Formation (Lower Carboniferous)

The Ataqa Formation is unconformable overlying the Um Bogma Formation and consists of thick cross-bedded, very fine to fine grained sandstones. Visean flora and fauna have been identified within these sediments by Horowitz (1973). Kaolinitic layers are present within the Ataqa Formation and these are exploited commercially in the Wadi Abu Natash area. At Um Bogma the Ataqa Formation contains bituminous coal seams and is capped by a basaltic sill. Several carbonaceous shale beds (black shales) are located within the middle part of the Carboniferous sandstones of the Ataqa Formation at Bedaa-Um Thora district. Upper Carboniferous sediments were previously thought to be absent which they have described in Sinai. However, Issawi and Jux (1982) have reported the presence of Upper Carboniferous Aheimer Formation at Um Bogma.

2.2 The area of Al-Maghara coal mine North Sinai (Jurassic)

During the Jurassic period, north and central Sinai was a coastal plain and shallow shelf of low relief, separating the continental Arabo-Nubian shield to the south from the deep marine Tethyan Sea to the north. The most complete Jurassic sequence (1980 m) is exposed in northern Sinai at Gebel Maghara, which is a large breached anticline with a gentle north flank and a steep, often vertical or overturned, southern flank. Locally there are indications for a reverse thrust fault is developed through the southern flank. Gebel Al-Maghara has been subjected to many geological studies such as of Barthoux and Douville (1913), Shata (1951), Arkell (1956), Al Far (1966), Barakat (1970) and Said (1962 & 1990).

Al Far (1966) subdivided the Jurassic sequence below the Cretaceous at Gebel Al-Maghara into six formations of 1.980 m total thickness:

Masajid Formation (575 m)	Marine deposits	Upper Jurassic
Safa Formation (215 m)	Continental deposits	Middle
Bir Maghara Formation (444 m)	Marine deposits	Middle Jurassic
Shusha Formation (272 m)	Continental deposits	Lower
Rajabiah Formation (293 m)	Marine deposits	Lower
Mashaba Formation (100 m)	Continental deposits	Lower Jurassic.

Mashaba, Shusha and Safa Formations are supposed to be of continental origin and represent fossil plant bearing formations. Economically, significant coal seams have been found only

in the Safa Formation. The coal reserves are more than 40 million ton of sub-bituminous coal. Said (1962 & 1990) mentioned that in north Sinai the complete Jurassic section is exposed at Gebel Maghara and during the Jurassic and Cretaceous periods there was no great change in the depositional framework. The dominant rocks are limestones and dolomites. The stratigraphic column at Gebel Maghara belongs to Jurassic and Cretaceous age (Fig. 4). In the following, a lithofacies description from the base to the top of the succession is given.

2.2.1 Mashaba Formation (Lower Jurassic)

The lowermost Jurassic sediments exposed at Gebel Maghara belong to the Mashaba Formation. These clastic sediments are of Liassic age and were deposited by north flowing braided streams carrying detritus shed off the Arabian-Nubian massif. The dominance of continental clastics was probably the result of a low eustatic sea level coupled with tectonic uplift to the south. The thin basal fluvial sandstones containing large wood fragments are succeeded by interbedded shallow marine carbonates and nearshore marine clastics of the Rajabiah and Shusha formations. The carbonates are rich in lime mud having been poorly winnowed in low energy environments. Rare interbeds of well-sorted oolitic limestone are present, suggesting higher energy conditions, commonly with quartz sand grains indicating proximity to the shoreline. The interbedding of carbonates and clastics might have been caused simply by the shifting of different depositional facies across a low energy shelf (Said 1990). The Mashaba Formation consists of lime, clay and sandstone with a thickness of about 100 m. It is exposed at Wadi Sadd El-Mashaba at the base of the El-Maghara section.

2.2.2 Rajabiah Formation (Lower Jurassic)

The Rajabiah Formation is composed of a thickly bedded limestone with some marl and sandstone interbeds. This formation is of Liassic age and its thickness attains about 293 m. It is exposed at Wadi El-Mashaba and Wadi Rajabiah.

2.2.3 Shusha Formation (Lower Jurassic)

This formation consists of clastic sediments (sandstones) with thin carbonate intercalations. The formation is of Liassic age and its thickness attains about 272 m. It is exposed around Shusht Al-Maghara.

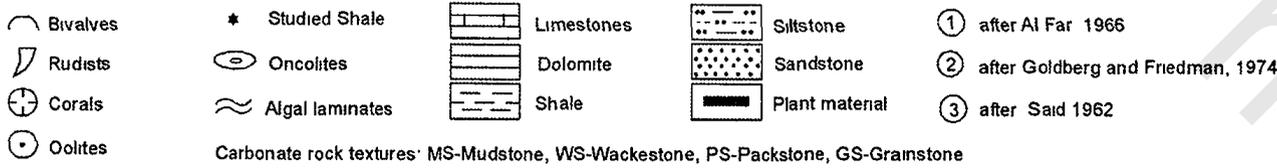
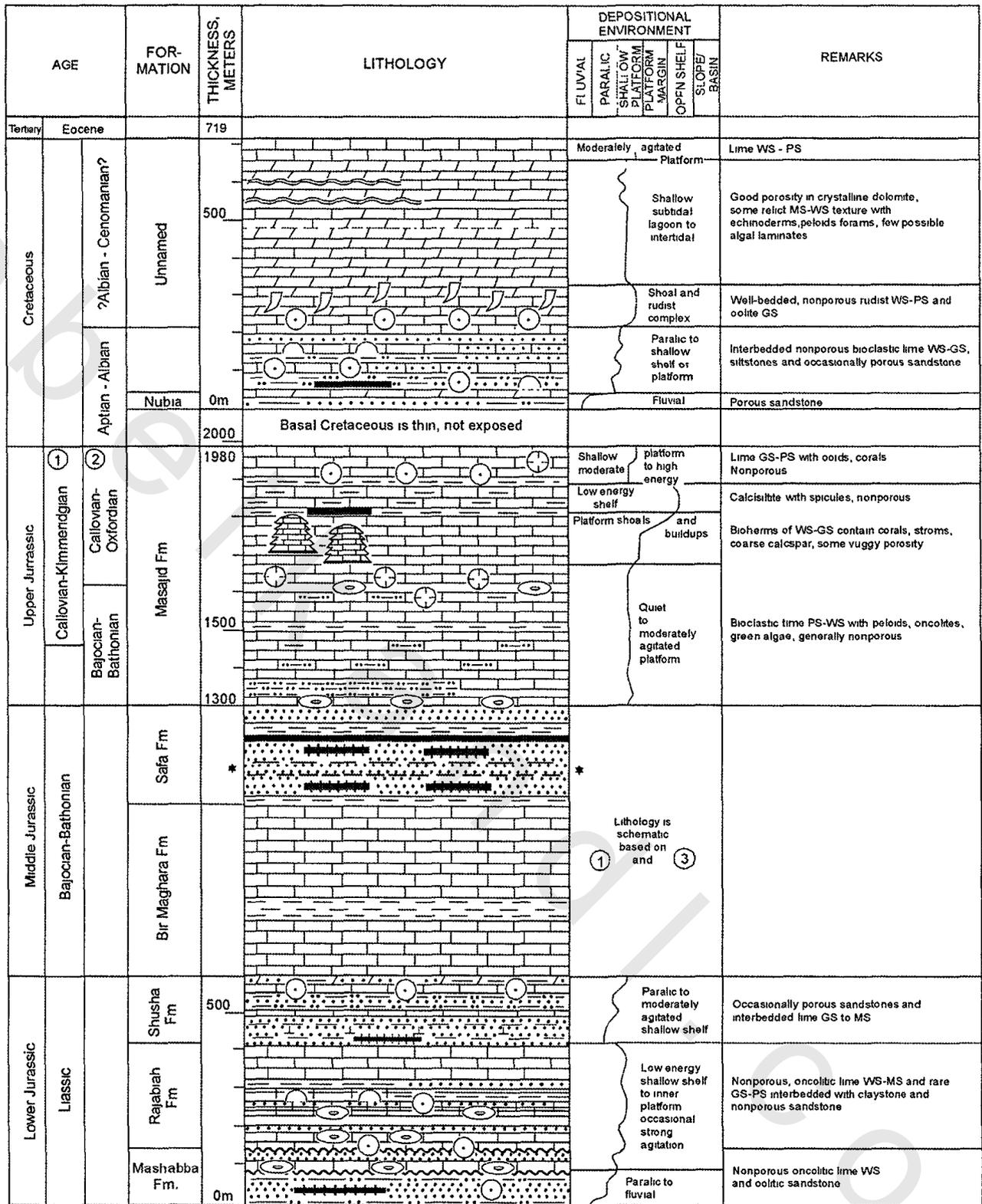


Fig. 4: Generalized lithostratigraphic column of Jurassic and Cretaceous rocks exposed at Gebel Maghara (after Jenkins et al. 1982).

2.2.4 Bir Maghara Formation (Middle Jurassic)

The Middle Jurassic sediments at Gebel Maghara can be subdivided into a lower carbonate unit (Bir Maghara Formation) and an upper clastic unit (Safa Formation) which attain a thickness of approximately 701 m (Said 1990). The Bir Maghara Formation is exposed at Bir Maghara and at Mowerib; it is of Bajocian-Bathonian age. Al Far (1966) divided the Bir Maghara Formation into three members: the Mahl Member which consists of lime and clay (type locality at Wadi Mahl), the Bir Member (located around Bir Maghara) consists of clay with some limestone interbeds, and the Mowerib Member, which consists of lime, clay and sandstone.

2.2.5 Safa Formation (Middle Jurassic)

The Safa Formation is composed of well bedded silty sandstones with some beds of limestone, clay and marl. It is of Bathonian age and is exposed at Wadi El Safa and Wadi Al-Maghara. It contains sub-bituminous coals near its base which are interpreted as having been deposited in lakes or lagoons adjacent to the coastline (Said 1990).

2.2.6 Masajid Formation (Upper Jurassic)

The Upper Jurassic Masajid Formation is dominated by carbonates representing a southerly marine transgression at the end of Bathonian–Calloviaian times. At Gebel Maghara these carbonates are 680 m thick and consist of bioclastic, oncolitic, peloidal packstones and wackstones and isolated bioherms (Al Far 1966).

2.3 The area of Qusier phosphate mines in Red Sea coast (Cretaceous –Eocene)

Geologically and stratigraphically the Abu Tartur area, Esna-Idfu region (Nile Valley) and Qusier have similar sedimentary successions (Fig. 5).

The complex geology which characterizes the Qusier region is attributed to its confinement to the boundary between the Arabian-Nubian massif and the Gulf of Suez rift. Faulting with a dominant NW trend is the main feature in the region and forms complicated horsts and grabens with outcropping basement rocks covering the major part of this region.

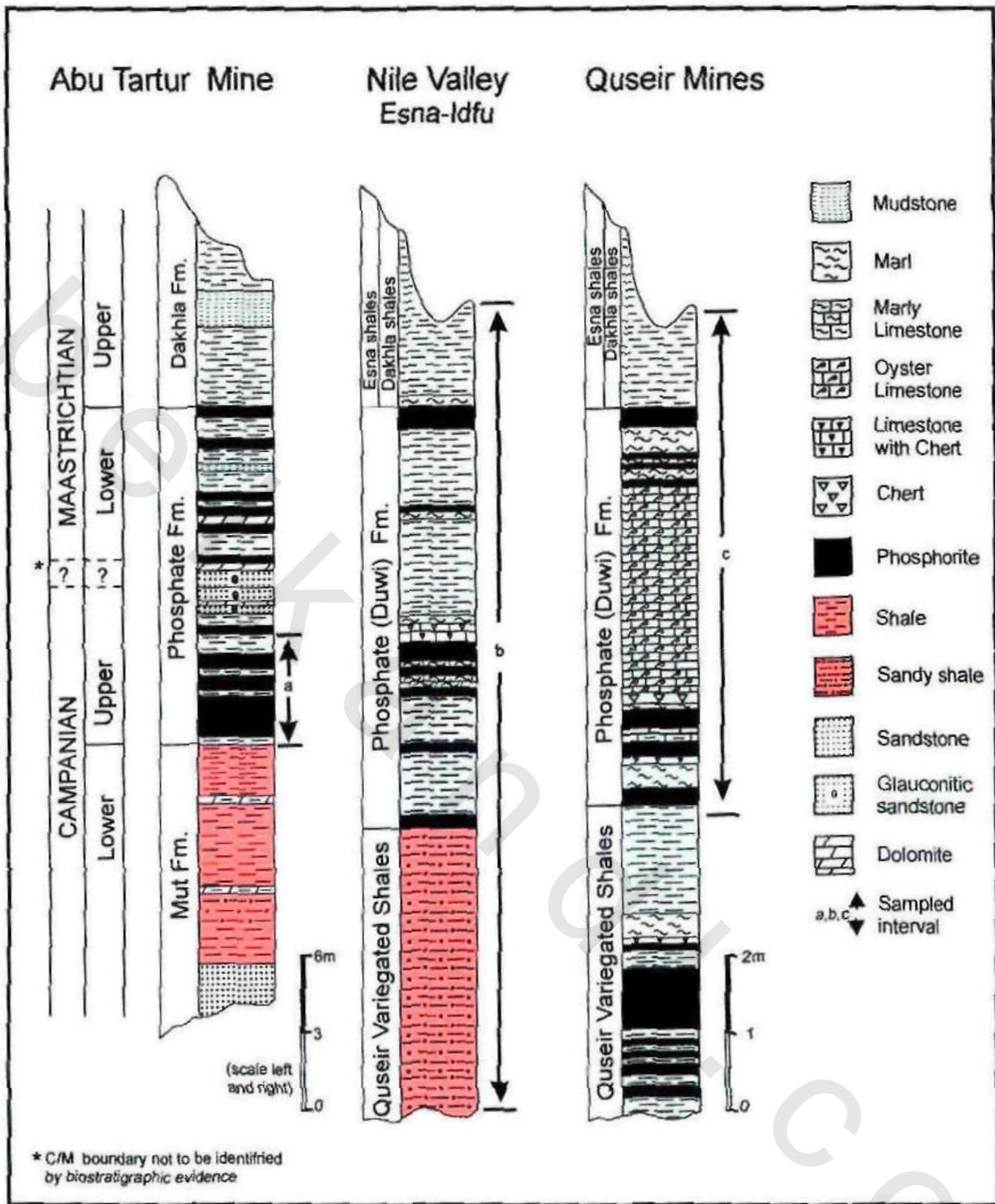


Fig. 5: Sedimentary sequences of Upper Cretaceous - Lower Tertiary rocks showing the position of the samples in the studied areas.(grey colours represent black shale facies)

The Upper Cretaceous and Lower Eocene sediments are preserved mostly in synclinal structures. They form isolated hills. The sections in Qusier and Safaga areas were described by many authors including Barron and Hume (1902), Ball (1913), Youssef (1957), Faris and Hassan (1959), El Akkad and Dardir (1966), Abdel Razik (1967& 1972), Issawi et al. (1968 &1971), Hassaan et al. (1979), Mohammed (1982), Saad (1983), Philobos et al. (1985), Ramadan (1992) and Ismael (1996).

The stratigraphy of the exposed sedimentary rocks was described under the following rock units according to Said (1962) from base to top as follows:

Nakheil Formation top
Thebes Formation
Esna Shale
Tarawan Chalk
Dakhla Shale
Duwi Formation
Quseir Variegated Shale
„Nubia Sandstone“ base

2.3.1 Nubia Sandstone (Pre-Campanian)

The term „Nubia sandstone“ was first introduced to the Egyptian stratigraphy by Russegger (1937), who used the term "Sandstein von Nubien" to designate nonfossiliferous sandstone sections of Paleozoic or Mesozoic age. It is the oldest sedimentary unit and rests unconformably over the basement complex. The bed occupies many of the topographic lows in Qusier area (Said 1962). It consists mainly of well sorted, fine to coarse grained, brownish to yellowish sandstone. The thickness of this unit is about 130 m in Qusier area (Issawi et al. 1968). According to Ward et al. (1979) and Van Houten et al. (1984), this unit can be divided into three members. This unit is assigned of Pre-Campanian age (Issawi et. al.1968).

2.3.2 Qusier Variegated Shale (Pre-Campanian)

This formation was introduced by Ghorab (1956), who considered it as a separate formation and named it "Quseir Variegated Shale". The variegated shale consists of multicoloured shale (grey, brownish yellow, green, reddish, violet and blackish) alternating with yellowish sandstone at Gebel Duwi. The Quseir Variegated Shale is considered by earlier authors

(Awad and Ghobrial 1965; Abdel Razik 1970; El Naggar and Ashor 1983) as a part of the "Nubia Sandstone". The thickness of this unit is in the range of 70 m in Gebel Atshan (Said 1990). It is unfossiliferous, with the exception of rare plant remains, bone fragments and fish teeth. Seward (1935) concluded that these plants must have grown in nearby places under a humid tropical climate. The upper part of the Quseir Variegated Shale contains some phosphate bands. These phosphate bands, which range between 10 – 20cm thicknesses, are exposed within indurate sandstone in Gebel Duwi, while they are associated with shale in Wasif section (Glenn 1980). Lithologically, the upper part of the Quseir Variegated Shale is very similar to the shale lithofacies of the Duwi Formation (Glenn and Mansour 1979). The age of this formation is regarded to be Pre-Campanian (Said 1962).

2.3.3 Duwi Formation (Campanian – Maastrichtian)

In 1900, Barron noted the presence of phosphate beds in the Eastern Desert. Youssef (1949 & 1957) described the Duwi Formation and classified the exploited phosphate in Gebel Duwi into three beds, the upper (Atshan bed), the middle (Duwi bed) and the lower (Hammadat bed). Said (1962) extended the use of the term Duwi Formation to laminated gray clays and chert phosphatic bands at Safaga and subdivided the whole section in the Red Sea area into three members: Atshan or "A" member separated from the middle Duwi or "B" member by an oyster limestone bed 6-16 m in thickness, and lower Abu Shegela or "C" member, separated from the middle member by a shale unit of variable thickness (6-10 m).

The Duwi Formation in the Quseir-Safaga coastal region comprises a heterogeneous suite of shallow marine rocks that lies stratigraphically above the Quseir Variegated Shale and below the Dakhla Shale. The Duwi Formation consists of phosphorite, shale, siliceous claystone, glauconitic sandstone, chert, dolostone, marl and reefal limestone (Glenn and Mansour 1979).

The Duwi Formation can be subdivided into three members, the lower "C" member, separated from the middle member by variegated shale of non marine to marginal marine origin, similar to those of the underlying Quseir Formation. In some places such as the Younis mine this member comprises three beds separated from each other by shale beds. It ranges in thickness from 20 cm to 1 m. In Zoug El Bohar mine the "C" member forms a lens that ranges in thickness from 3 to 7 m. The phosphorites of the "C" member are characterized by medium to coarse grains, reddish in colour and of friable consistence. This member is exploited in Abu Shegala, Younis and Zoug El Bohar Mine. The middle "B" member is well developed at

Gebel Duwi. It is made up of three phosphate beds, separated by thin shale, marl, and silicified limestone beds. Its thickness ranges from 20 to 90 cm and colour from gray, pale gray to yellowish. An important marker in this member is a thick oyster limestone bed which caps and intercalates this member. This member is exploited in Galal, Um Resifa and Zoug El Bohar mines in Quseir area and in Rabbah mine in Safaga area. The upper member "A" is made up of three phosphate beds separated by thin shale, chert and marl beds. It ranges in thickness from 10-120 cm. The colour varies from pale white to pale gray. It is exploited in Younis, Galal, Wadi El Anz and Um Resifa mines in Quseir area, Wasif and Rabbah mines in Safaga area and "B" mine in Hamrawin area. The Duwi Formation in Quseir–Safaga region is of Campanian age in its lower part and Maastrichtian in the upper part (Youssef 1957).

A Maastrichtian age is given for this formation by Youssef (1949, 1957), Said and Sabry (1964), El Akkad and Dardir (1966) and Issawi et al. (1968, 1971). Dominik and Schaal (1984) assigned the age of the Phosphate Formation (Duwi Formation) to Upper Campanian to possibly Early Maastrichtian on the basis of ammonites and vertebrate remains. The microflora content of drilled cores from the Younis mine puts a Maastrichtian age to the upper part of the black shales which lay on top of the Duwi Formation. An Upper Campanian to Early Maastrichtian age, therefore, may be assigned to the underlying Duwi Formation in this area (Schränk and Ganz 1984).

2.3.4 Dakhla Shale (Danian – Lower Paleocene)

The term Dakhla Shale was first introduced by Said (1961) to describe 130 m of gray shale becoming calcareous toward the top, exposed at Mut in the Dakhla Oasis, conformably overlying the Duwi Formation and underlying the Tarawan Chalk. It consists of a series of marls and shales which vary in thickness from one place to another. It is subdivided into two members namely Beida Shale Member (10 m) at the top and Hamama Marl Member 27 m at the base (Abdel Razik 1972). The lower member at Wasif is usually composed of argillaceous gray or reddish limestone with gypsum veinlets, while at Gebel Duwi it is composed of varicoloured (yellowish, white and brownish) marl. The upper member consists of gray to green shale, yellowish in some parts, and fissile with gypsum veinlets. This member is conformably overlain by the Tarawan Chalk. The contact is marked by an abrupt change from gray shale with gypsum veinlets into brownish, reddish limestone and chalky white limestone. The lower part of this formation is assigned to a Danian age, while the upper part is of lower Paleocene age (Youssef 1957).

A notable feature of Quseir, lower Dakhla and Duwi Formation is the presence of black shale within and above the phosphatic beds. Some of these shales are reported to have caught fire (Shahin et al. 1986). These shales often contain abundant foraminiferal tests, fish debris, pecten, scattered pyrite grains and phosphatic grains. The average oil content of weathered black shale samples is 19gal/t (Tröger 1984). Malak et al. (1977) suggested that these black shales were deposited in stagnating, reducing, slightly alkaline water with an upper oxygenated surface zone in which green algae lived and acted as the main source of organic matter.

2.3.5 Tarawan Chalk (Landanian-Late Palaeocene)

The term "Tarawan Chalk" was first introduced by Awad and Ghobrial (1965) to describe 45 m of chalk exposed at Gebel Teir in the Kharga Oasis. The Tarawan Chalk is 3.10 m thick at Wasif and 10 m thick at Gebel Duwi. It is conformably overlying the Dakhla Shale and underlying the Esna Shale. The boundary between the Tarawan Chalk and the underlying and overlying formations is marked by an abrupt change in lithology shown by compactness, carbonate content and colour (Ramadan 1992). Tarawan Chalk consists of chalky limestone, white, argillaceous in the lower part and chalky in the upper part. It is assigned to a Landanian age (Issawi et al. 1968).

2.3.6 Esna Shale (Early Eocene)

Beadnell (1905) introduced the term "Esna Shale" to describe a succession of laminated green and gray shaley clay at the locality Gebel Owenia, opposite Esna, northeast of Sebaiya. The Esna Shale lies conformably over the Tarawan Chalk with sharp contact, marked by white chalk limestone and is conformably overlain by the Thebes Formation, where the contact is marked by pink argillaceous limestone bands. It measures 14 m in thickness in Wasif and 32 m at Gebel Duwi (Ramadan 1992).

According to Hassaan et al. (1979) the Esna Shale is subdivided into two members: a calcareous shale member, consisting of gray to green, fissile and highly fossiliferous shale with gypsum veinlets, and an argillaceous limestone member of whitish gray colour. This Formation is assigned to the Upper Paleocene (Landinian) at the base and Lower Eocene (Ypressian) at the top (Issawi 1972).

2.3.7 Thebes Formation (Early Eocene)

Said (1960) introduced the term "Thebes Formation" to describe the thick limestone section which overlies the Esna Shale at the Thebes type section in Gebel Gurnah opposite Luxor. In the study areas, it attains about 285 m in thickness in the Duwi range, about 250 m in Hamadat and 166 m in Gebel Anz (Said 1990). It consists of thinly bedded limestone with noticeable flint bands or flint nodules and chert concentrations, interbedded toward the top by a marl bed.

Snaveley et al. (1979) divided the Thebes Formation of Gebel Duwi into three "informal members" representing different stages of deposition. The lower member rests conformably on the Esna Shale and consists of about 40-60 m of laminated to thinly bedded limestone and chalk as well as massive bioturbated chalk beds and chert bands. This member indicates a deep water phase of a predominately pelagic depositional environment. The middle member is made up of thinly bedded limestone and chalk, interbedded with nodular limestones, intraformational conglomerates, reworked and benthonic foraminifera, lime sands and rare chert. This unit is about 100 to 120 m thick according to Snaveley et al. (1979) and about 200 m thick according to Strougo and Abu Nasr (1981). This heterogeneous accumulation of carbonates is indicative of progressive shallowing and outward progradation of a shallow water depositional environment. The upper member is thin (10 to 15 m thick), it present. It is made up of fine grained limestone locally interbedded with oyster shells and shell hash. The distribution of this member probably indicates a period of local uplift coupled with a period of rapid sea level drop. This formation is assigned to the Early Eocene (Strougo and Abu Nasr 1981).

2.3.8 Nakheil Formation (Oligocene)

The Nakheil Formation was named by El Akkad and Dardir (1966). It is widely spread in the Quseir – Safaga district and may reach a thickness of about 60 m or more. This formation is made up of two types of deposits: very coarse breccias beds and fine grained lacustrine deposits. The Nakheil Formation occupies the slopes of the Thebes Formation on the down thrown side of the faults. It is closely associated with the early faulting which must have taken place after the deposition of the Thebes Formation. The Nakheil Formation is nonfossiliferous and assumed to be of Oligocene age (El Akkad and Dardir 1966).