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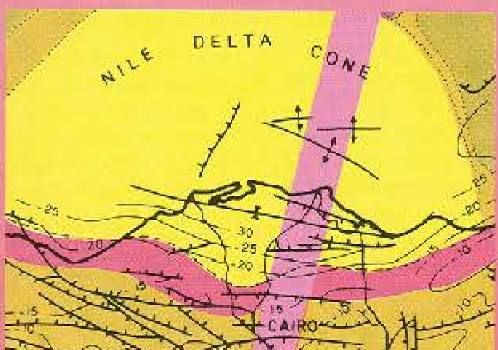
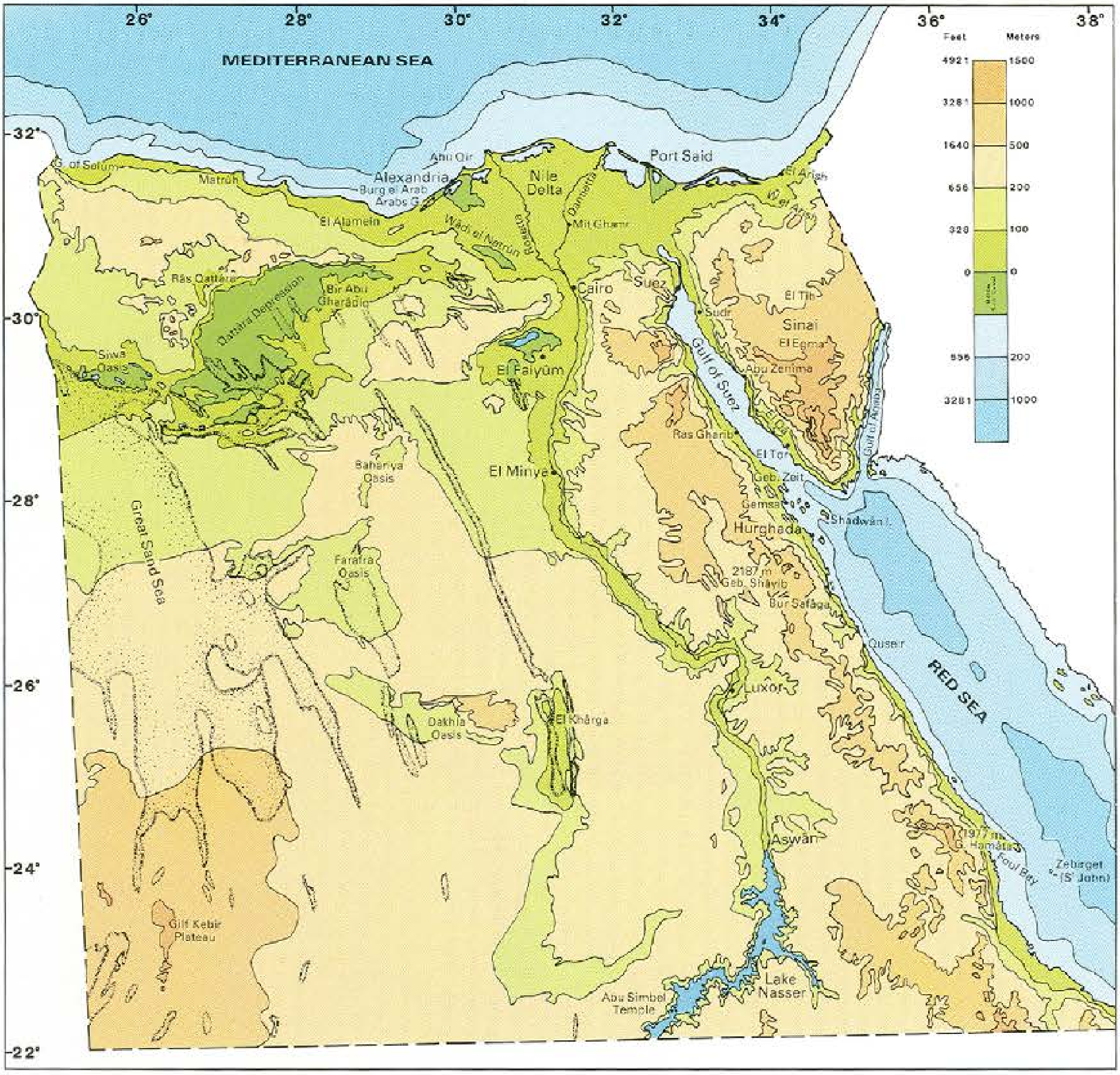
GEOLOGY OF EGYPT





MEDITERRANEAN SEA
RED SEA
Feet
Meters
Alexandria
Port Said
Nile Delta
Cairo
Suez
Sinai
Gulf of Suez
El Faiyûm
El Minya
Hurghada
Luxor
Aswân
Lake Nasser
Abu Simbel Temple
Great Sand Sea
Qattara Depression
Siwa Oasis
Bahariya Oasis
Farafra Oasis
Dakhla Oasis
El Khârga
Gilf Kebir Plateau
Ras Gharib
Quseir
Bur Safâga
Matrûh
El Alamein
El Arish
Mit Ghamr
Damietta
Rosetta

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GEOLOGY OF EGYPT

REGIONAL INTRODUCTION

Oil seepages along cracks in outcropping rock, asphalt deposits and indications of gas, have been observed since very early times; indeed the Romans named Gebel Zeit the "Mons Petroleus".

The first Egyptian oil field was discovered in 1869 while mining for sulphur. It is situated in the south western part of the Gulf of Suez on the Gemsa Peninsula. The field was put on production in 1910, producing 39°API crude from Miocene sands.

The second oil discovery was made in Hurghada in 1913 along the western coast of the Red Sea at its junction with the Gulf of Suez. This is the only oil bearing structure in Egypt that was recognized and delineated by surface geological surveying only.

In 1938 new oil was struck in Ras Gharib along the west coast of the Gulf of Suez followed by several others in the forties and fifties. Many new discoveries both on land and in the Gulf were made in the sixties, including the Belayim Marine, Gharra Marine and Morgan Fields. The main producing horizons in most of these discoveries were the Upper and Lower Miocene sands.

Meanwhile, gas deposits were discovered in the Pliocene sands of the Nile Delta, and low sulphur oil in the Upper Cretaceous sands and Lower Cretaceous carbonates and sands of the Western Desert. Since then substantial discoveries have been added steadily, the most important being the Ramadan Field situated in the Gulf to the north of the Morgan Field, the Abu Qir gas field offshore Alexandria, and the Razzaq Field in the Western Desert.

Egypt's proven reserves of oil amounted to 4.85 billion barrels at the end of 1982, and oil was produced from some 39 fields. At the same time reserves of gas amounted to around 6 trillion CFG, and condensate to 80 million barrels.

Three distinct oil provinces, the Gulf of Suez, the Western Desert and the Nile Delta, contribute to this wealth of hydrocarbons. The largest part of the production and reserves derives from the prolific area of the Gulf of Suez.

Egypt's hydrocarbons are accumulated in formations ranging in age from Carboniferous to Pliocene. The reservoirs are formed essentially by sands and sandstones and to a lesser extent by carbonates.

Each of these provinces has its own geological history and structural characteristics. Other potential oil provinces are believed to exist in presently untested areas of the Nile Basin and Western Desert.

The first part of this chapter summarizes the regional framework, and this is followed by a discussion of the main geological areas, the **Gulf of Suez**, the **Western Desert**, the **Nile Delta**, the **Sinai** and **Red Sea** areas; Fig. 1-1 shows a simplified geological map of Egypt.

GEOMORPHOLOGY

The Arab Republic of Egypt is situated in the northeastern corner of the African continent and extends beyond the Gulf of Suez and the Suez Canal into the Asian Near East. Its width is about 1225 km and its length from the Mediterranean to the Sudan border about 1075 km. Egypt's total surface amounts to around 1,000,000 sq km. Geographically, the country is composed of several distinct regions, namely, from east to west, the Sinai Peninsula, the Gulf of Suez and Suez Canal, the Eastern Desert with its Red Sea coastal and offshore part, the Nile valley and the Western Desert.

The Sinai Peninsula covers an area of some 61,000 sq km. It is triangular in shape with its apex formed by the junction of the Gulf of Aqaba and the Gulf of Suez, and its base by the Mediterranean coastline. The southern part of the Sinai consists of an intricate complex of very rugged mountains formed by igneous and metamorphic rocks. Part of the peninsula comprises a massively developed limestone plateau onlapping the shield in the south. The prevailing drainage system is formed to the north by the Wadi el Arish with its many affluents. The eastern and western edges are dissected by deep gorges draining into the Gulf of Aqaba and Gulf of Suez respectively. In the northern part, the regional dip slope is broken up into many large hills, followed northward by a belt of low lands, with high sand dunes along the Mediterranean coast.

The "plains" or low lands along the east and west coast of the Gulf of Suez are part of its structural and depositional province. The El Qaa plain and the El Tor plain along the central and southeastern coast are separated by an eastwest trending subsurface high. Its presence is expressed by a regional southwest dip of the formations in the El Tor plain and by a northwest dip of the strata in the El Qaa plain.

The Gulf of Suez covers an area of about 25,000 sq km. It extends along a northwest trend from latitude 27°30'N to 30°N. Its width varies from 30 to slightly over 50 km in the central part. Both the eastern and western coastal belts exhibit a sedimentary sequence which is also present offshore. Thus, originally, the Gulf must have been much wider than at present.

The Eastern Desert embraces the area between the Gulf of Suez and Red Sea to the east, and the Nile valley to the west. Its main characteristic is the rugged mountain range composed of Precambrian formations, that parallels the coast of the Gulf and the Red Sea.

The Eastern Desert and the Sinai Peninsula form in essence one and the same geomorphological unit, both areas being related to its geological structures. The northern bulge of the Nubian-Arabian shield is present in the eastern part of the Eastern Desert and in the southern part of the Sinai Peninsula across the Gulf of Suez, now separated through the development of the East African Rift system. Both the Sinai and the Eastern Desert are characterized by their young geomorphology.

The Nile valley and delta form the alluvial system that stretches for 1530 km along the terminal course of the river Nile from the Sudan border to the Mediterranean. All along this course the river receives no tributaries. The width of the cultivated alluvial plain is narrow, averaging about 10 km between Aswan and Cairo. North of Cairo, the river flows in a northwesterly direction and divides eventually into the Damietta branch to the east and the Rosetta branch to the west. Connected with the Nile valley through a narrow channel is the Fayum depression southwest of Cairo. The Nile Delta forms the vast plains between the two branches of the Nile. This plain contains the rich agricultural and industrial area of Egypt and is also the most densely populated part of the country.

The Western Desert, with its 680,000 sq km covers more than 65% of the whole of Egypt. It extends from the Nile valley to the Libyan border. Geomorphologically it is a plateau of stone desert with numerous large and deep, closed-in topographic depressions. An outstanding characteristic of the Western Desert is the almost complete absence of a drainage system and the paucity of water in general. Another particular feature is represented by the N-S trending high longitudinal dunes. In the deep offshore area, west of the Nile Delta, referred to as the Herodotus Basin (see Fig. 1-2), the sedimentary fill is likely to exceed 13,000 m.

The shelf and deep water areas of Egypt total some 43,000 sq km of shelf to the 200 m isobath and 62,000 sq km of deep water to the 3000 m isobath. Its best developed part is in front of the Nile Delta where the width of the shelf averages some 50 km between Alexandria and Port Said.

West of Alexandria the shelf narrows considerably to widen again in the Gulf of Salum near the Libyan border.

In the Red Sea, the shelf is narrow averaging some 15 km along its entire development. Only in Foul Bay does the width reach some 40 km. The Gulf of Suez itself is a very shallow water body.

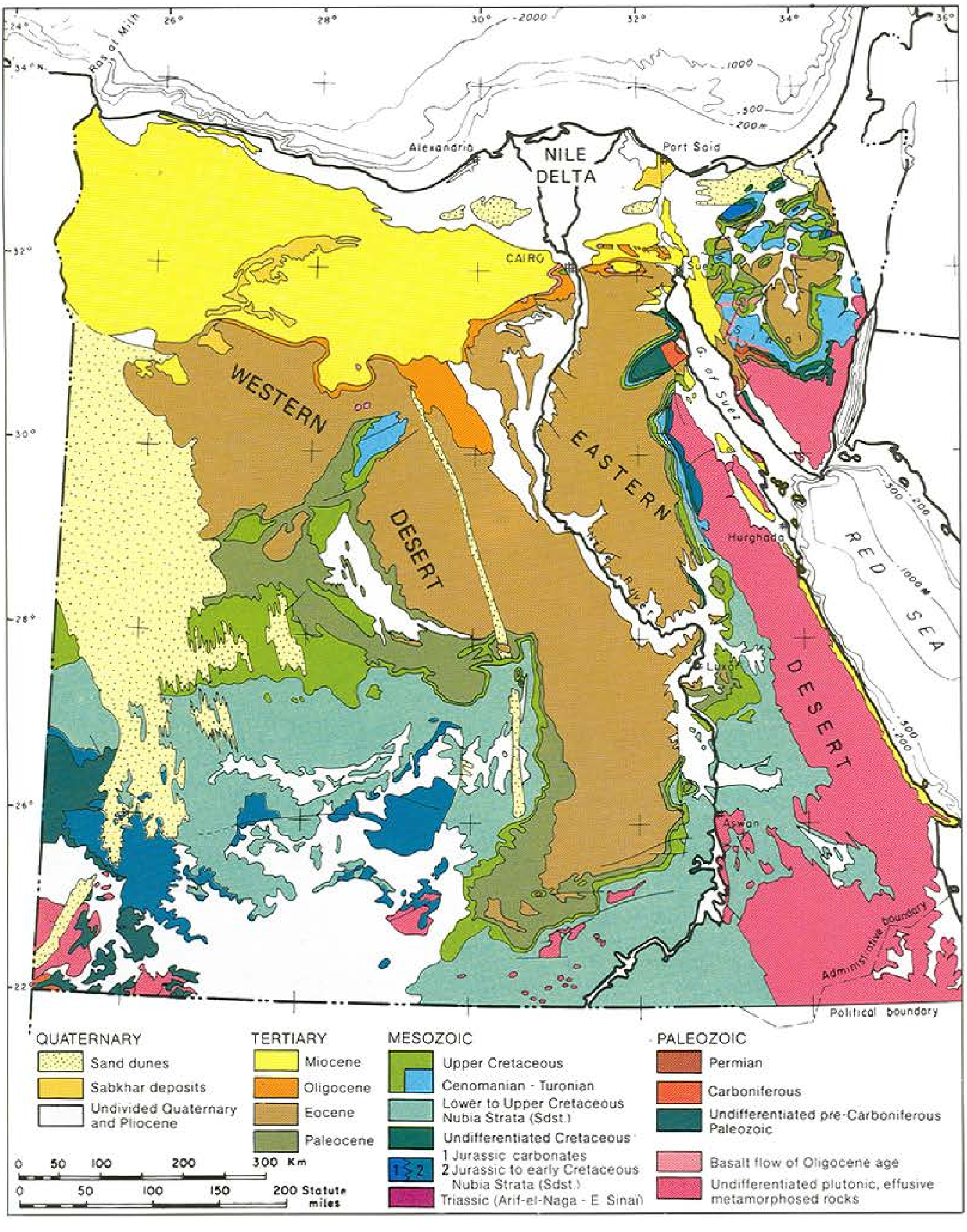


Fig. 1-1. Geological map of Egypt.

GEOLOGICAL SETTING

Egypt is part of the North African Craton which, during its geological history underwent periodic transgressions from the ancient Tethys situated to the N and NE of the country.

Said (1962) distinguished four major geological provinces seen later in Fig. 1-13. These are the well defined **Nubian-Arabian shield** or massif and the surrounding shelf areas of which structural unit boundaries cannot be traced with any great precision. Thus, the shelf area is subdivided according to its salient features into the **Stable Shelf,** the **Unstable Shelf** and the **Gulf of Suez-Red Sea Graben**.

The Nubian-Arabian Shield (Craton)

This shield is exposed over large parts of the Sinai Peninsula, the Eastern Desert and, in the extreme southern part of the Western Desert. It consists essentially of Precambrian rocks. El Shazly (1977) distinguishes several stages within these metamorphic sequences of geosynclinal Archean formations with frequent intrusions of plutonic and volcanic rocks.

The Stable Shelf

This shelf embraces the area north and west of the Nubian-Arabian shield. It exhibits a gentle tectonic deformation and its sedimentary cover is mainly represented by continental and epicontinental deposits such as the Mesozoic Nubian sandstone.

The sedimentary sequence on the Stable Shelf is relatively thin with some 400 m of sediments near the Nubian-Arabian shield area and increasing to as much as 2500 m near the transition into the Unstable Shelf in the north. It is composed of sands and shales in its lower section and of shallow water carbonates in its upper part.

The Unstable Shelf

This shelf is situated north of the Stable Shelf with the transition between the two structural-depositional units following a line approximately set from the Siwa Oasis through Farafra Oasis and Suez into Central Sinai.
The sedimentary sequence of the Unstable Shelf is relatively thick with a lower part of the section composed mainly of clastic sediments, followed upsection by a middle calcareous series and topped by a blanket of biogenic carbonates.
The formations are gently folded and show signs of lateral stress. Overthrusts are reported from the northern structures. This structural deformation is related to the Laramide phase of the Alpine orogeny. The trend of these fold bundles is lightly arcuate to the northeast and referred to as the Syrian Arc.

The Gulf of Suez - Red Sea Graben

The Gulf of Suez is an area of subsidence within the stable shelf and the northern part of the Nubian-Arabian shield. It was formed originally during Early Paleozoic time as a narrow embayment of the Tethys and intensively rejuvenated during the rifting phase of the great East African Rift system in Lower to Middle Tertiary time. Great accumulations of sediments form this fast subsiding depression, interrupted at times by a general and regional uplift with subsequent erosion. Its connection with the Mediterranean Sea to the north and with the Red Sea to the south is established during early Miocene and witnessed with the distribution of Mediterranean fauna from the north as far south as the southern Red Sea.
The Red Sea originated during Oligocene time after the arching and crustal thinning in the general area of the Nubian-Arabian shield and subsequent collapse, in the context of the East African rifting. Spreading of the Red Sea floor, was and still is related to the relative motion of the various plates present in northeastern Africa and the Near East.

TECTONIC SETTING

The presence of three plates are postulated for the northeasternmost area of Africa (see Fig. 1-5). They are referred to as the **Nubian plate**, the **Arabian plate** and the **Sinai plate**. The relative motion of these plates has led to the opening of the Red Sea, the Gulf of Aqaba and, in part, to the Gulf of Suez.

The spreading of the Red Sea is without doubt due to the northeastward motion of the Arabian plate along a transform fault. Left lateral movement of the Arabian plate along the Gulf of Aqaba has also been established. The lateral displacement (Freund, 1970) amounts to about 110 km along the Dead Sea rift. The opening of the Red Sea near the Aqaba and Gulf of Suez junction is far larger than the lateral displacement along the Aqaba Gulf, see Fig. 1-2.

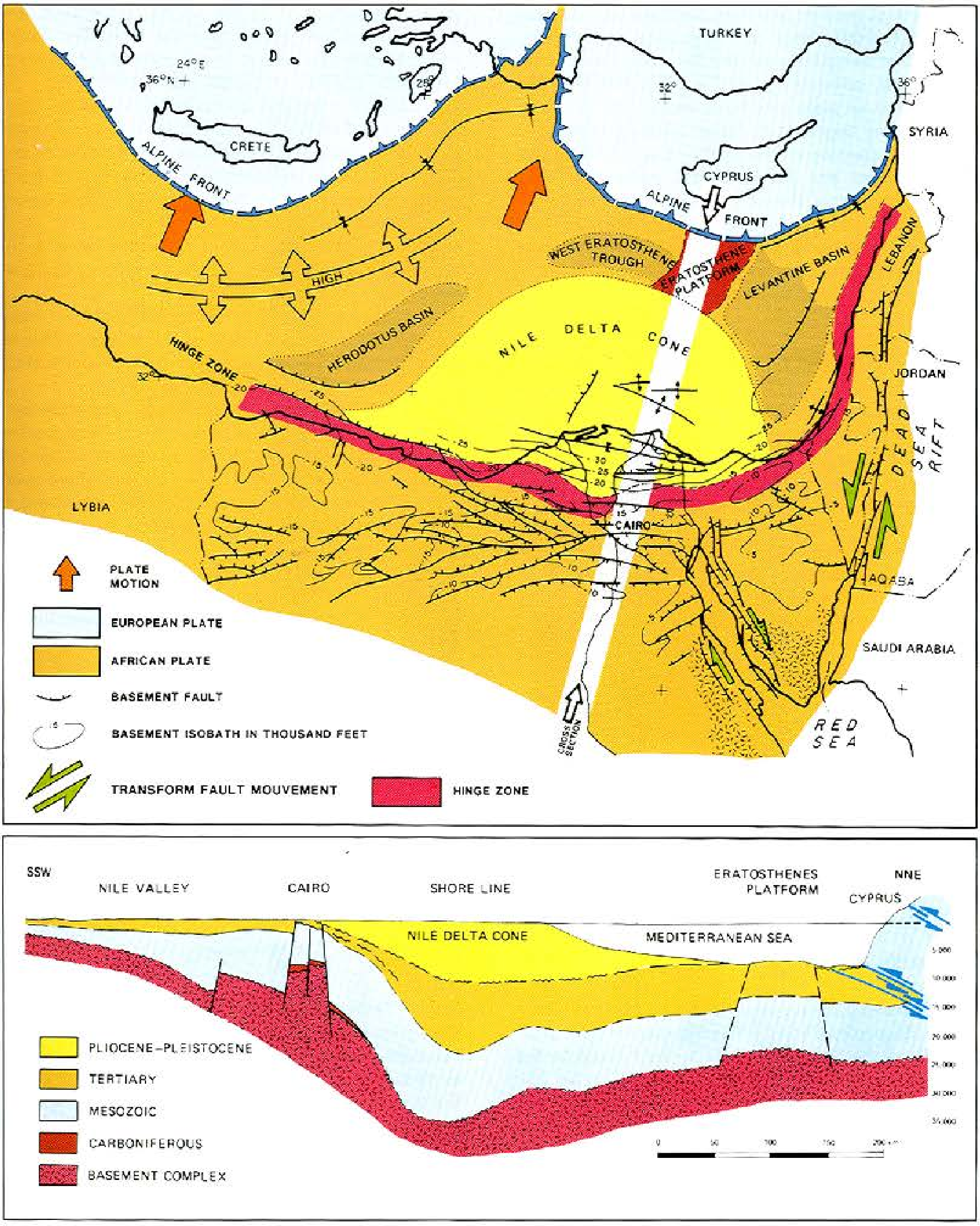


Fig. 1-2. Main structural features of Northern Egypt and the East Mediterranean Sea. The lower diagram shows a schematic cross-section along the line indicated in the upper part.

The width of the Red Sea in its northern part is about 190 km. The difference may have been absorbed by plate movements between the Sinai and the Arabian plates and, although plates are considered rigid units, the Sinai plate may have undergone deformation to some degree with foreshortening that led to the partial opening of the Gulf of Suez. A clockwise movement of the Nubian plate away from the Arabian and Sinai plates could also be taken into consideration. It is interesting to note however that the Gulf of Suez took part in the spreading only to a certain extent, and that it represents the aborted arm of the triple junction of Red Sea and Gulf of Aqaba.

STRATIGRAPHY

The sedimentary cover overlying Precambrian basement accounts for about 90% of Egypt's total surface. The sequence embraces almost all stratigraphic stages and ranges in age from Early Paleozoic to Recent, see Fig. 1-3. A marked thickening of the sedimentary wedge from south to north is evidenced with a few meters of onlapping deposits on basement exposures in Sinai and around the coastal ranges of the Red Sea, to an estimated 7000 m and more along the Mediterranean coast.

Paleozoic

This era is characterized by a prevalence of continental clastic deposits. Marine episodes are minor in space and time. The Paleozoic period finds its end with the Upper Carboniferous - Lower Permian marine deposition that followed the Hercynian orogenic phase and the subsequent erosional period.

Mesozoic

Predominantly continental deposition begins again in the Mesozoic. A Middle Triassic marine transgression from the Tethys appears to be limited to the area of northern Sinai and the Gulf of Suez. The Triassic sequence comprising triplet continental-marine-continental development, recalls the Triassic series known in Europe.

Jurassic deposits cover parts of the west side of the Gulf of Suez, northern Sinai, and large parts of the Western Desert. In southern Egypt, Jurassic continental deposits prevail. In the north, the Jurassic depositional environment was dominated by a widespread invasion of the Tethys, more extensive between the Nile valley and the Gulf. The facies change from continental to predominant carbonate deposition appears to be abrupt.

The regional thickness contours show values from less than 500 m in the northern third of the country to 2500 m plus in the Delta region. Of note is the irregular depositional pattern in the north part of the Western Desert, where the contours reflect north-east trending highs and lows.

Cretaceous formations were deposited after a regressive phase in Latest Jurassic - Earliest Cretaceous time.

Several epicontinental, local depositional lows were formed in the northern part of the Western Desert, on both sides of the present Nile Delta onshore area, in the Gulf of Suez and in northern Sinai.

The Cretaceous sedimentary section is represented by the Nubian sandstone of continental and marine origin. Further to the north widespread marine transgressions are evidenced by the well developed Aptian Alamein carbonates, by the Cenomanian-Turonian sand-limestone sequence and by the Senonian chalk-marl series.

The Late Cretaceous series are represented by a variety of marine facies, with a pronounced phosphatic development along the Red Sea coast, fluvio-deltaic deposition along the rims of the local depocenters and the basinal facies, and with dolomitic sandstones and biomicrites along the rims of the basins in northern Egypt.

Total maximum thickness of the Lower Cretaceous is up to 3000 m in the Western Desert (Marsa Matruh). In the epicontinental lows, a thickness of the series of 1500 to 2000 m can be encountered. The thickness of the Upper Cretaceous, from Cenomanian to Upper Senonian, may range from 500 to 1500 m in the depocenters.

Cenozoic

Lower Tertiary deposition began with a general transgressive phase at the end of Cretaceous.

Paleocene-Eocene formations were deposited over large areas of Egypt as far south as the border of the Sudan. Thickest Paleocene-Eocene are described from the Nile valley area south of Cairo where the sequence may reach a thickness of over 2000 m. The thickness distribution of the Lower Tertiary points to a general high area in northernmost Egypt along the Mediterranean coast. Thicknesses range from few hundreds of meters to over 1500 m. In the same time remarkable facies differences are also noted with a

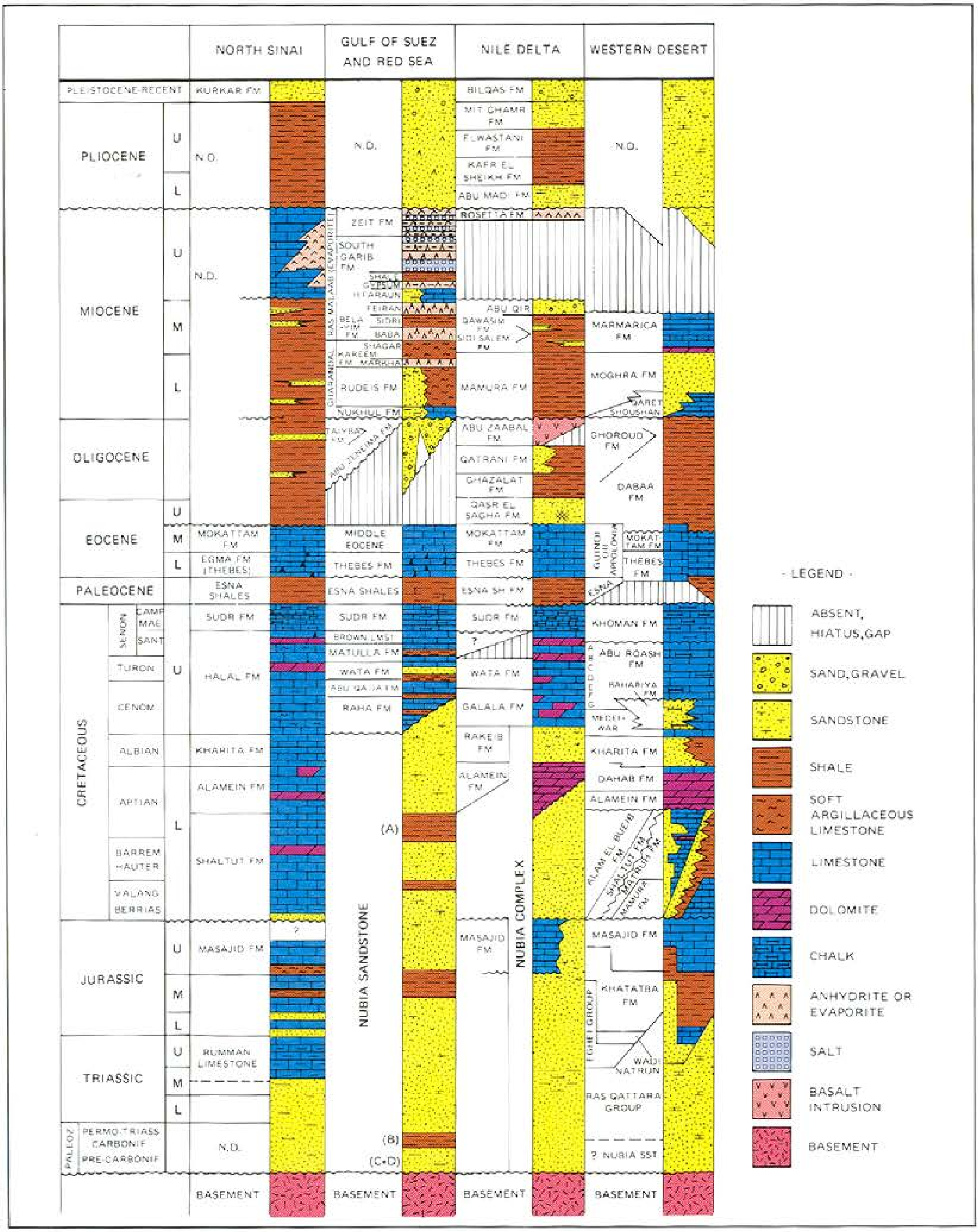


Fig. 1-3. Generalized stratigraphic columns of Egypt.

general carbonate-sand-shale deposition in the north and a predominant carbonate development in the south. Lower Tertiary basins such as the Suez graben, the Nile valley and northern Sinai are fault controlled. West of the Nile valley, however, the incipient folding of the Syrian Arc produced SW-NE trending subsidiary basins.

Oligocene time is characterized by a general uplift that affected most of the area of Egypt with concurrent deposition of coarse continental clastics over eroded surfaces and structural lows. These conditions prevailed in southern Egypt. Conglomeratic coarse and fine clastics are known as far as the Quseir and Safaga area on the Red Sea coast. Northwest of Cairo the continental environment gave way to deltaic deposition caused by a S-N developed marked river system. These deltas graded eventually from fluvio-marine into shallow marine deposition in the northern Western Desert and in the Nile Delta area.
The Miocene represents the period of strongest transformation of the area leading to the present configuration of Egypt with the Red Sea, the Gulf of Aqaba, the Gulf of Suez and the Nile Delta.

Following the Oligocene continental period, the Early and Middle Miocene marine transgression began from the Tethys onlapping large parts of the northern Western Desert. Southwest and west of Cairo, in the area of the old Oligocene river system deltaic and estuarine sedimentation still prevailed in Early Miocene time, whereas in the northern and northwestern part marine sediments were deposited in a shallow marine environment.

In the Gulf of Suez and in the northern part of the Red Sea, Lower Miocene clastics were lain unconformably over pre-Miocene formations in structural lows between lifted fault blocks or over tilted surfaces on fault blocks. High energy carbonate build-up developed along the high edges of the uplifted fault blocks. The Middle Miocene is characterized by the immense development of evaporitic series especially in the graben areas of the Gulf of Suez and the Red Sea. Thick anhydritic and calcareous sequences formed along the margins of the grabens giving way to thick salt basinward. Thickest salt is present near the junction of the Red Sea and the Gulf of Suez. An open connection from the Mediterranean through the Gulf of Suez to the Red Sea allowed the distribution of a faunal association of Miocene age and of Mediterranean type as far south as Eritrea, while the Red Sea was still separated from the Indian Ocean.
In the northern Gulf of Suez rocksalt is gradually displaced to the north by gypsum, anhydrite and carbonates.
Late Miocene and Pliocene in essence represent the final phases of Egypt's depositional history. Late Miocene is characterized by a general uplift of the northern area and erosion, and a phase of a marked restricted environment that affected particularly the eastern Mediterranean Sea.
Late Miocene crustal movements most likely led to the formation of huge lagoons in the eastern Mediterranean and Red Sea which eventually were filled by evaporitic formations.
Crustal movements continued from Late Miocene into Early Pliocene and were then substituted by a renewed and short lived transgressional period which affected the relatively narrow coastal area of northern Egypt, the Gulf of Suez and the Red Sea. The Nile river finally followed its present course and built up its huge delta, protruding over the step-faulted hinge line into the Mediterranean. In the Red Sea the Pliocene transgression followed the fracture system that had been traced during the Red Sea rifting phase, and its sediments are represented by a faunal association of Indo-Pacific origin, indicating the opening of the Red Sea to the Indian Ocean through the strait of Bab el Mandeb.

VOLCANIC ACTIVITIES

Volcanic activity in Egypt has occurred during most of its geological history. Paleozoic volcanites are reported from exposed Devonian formations in the Siwa Oasis in the Western Desert. Late Carboniferous extrusives are known to penetrate basement rocks of the Eastern Desert.
During Mesozoic time frequent volcanic activity is recorded in Late Cretaceous formations and related to the early phases of crustal disturbances during the Laramide orogenic phase. Triassic and Jurassic intrusives and extrusives are present in Sinai, the Eastern and Western Deserts.

Tertiary volcanics in the form of basalt flows, sheets and dykes occur in the Western Desert, in the Nile valley and Nile Delta. Oligocene basalts form most likely the bottom of the Red Sea graben, and dykes have been reported in some Miocene formations in the Gulf of Suez.
Youngest extrusives of Quaternary age are present on St. John's island in the Red Sea, however no adverse effects on the hydrocarbon potential of the Late Cretaceous and Tertiary sediments has been observed in Egypt.

1.1 THE GULF OF SUEZ

The Gulf of Suez and the Red Sea together with the Gulf of Aqaba are structurally and genetically closely related. They form the northern branches of the great East African Rift system.

The common structural evolution of these regional tectonic units as they appear at present, began in Oligocene-Miocene times.

Geomorphologically it can be described as a rejuvenated, slightly arcuate NW-SE trending taphrogenic depression referred to as the **clysmic gulf.**

The length of the Gulf of Suez from the south tip of the Sinai Peninsula to Suez is about 350 km. The graben, however, most likely extends from Suez further north to the Mediterranean Sea. This extension is masked by the alluvial and deltaic deposits of the Nile along which the Suez Canal was eventually built.

The Gulf is a rather shallow and narrow body of water, its average depth not exceeding 55 m. The overall water covered surface amounts to about 25,000 sq km. Several islands formed by emerging fault blocks are present near the junction with the Red Sea. The Gulf itself is bordered by a similarly structured coastal belt. The overall onshore and offshore area with oil potential is estimated to be about 38,500 sq km.

TECTONIC SETTING

Structural Development

The Gulf of Suez originated as a depositional realm that dates back to Early Paleozoic time. Contrary to the Red Sea and the Gulf of Aqaba which were formed by upwarping of the Nubian-Arabian shield with its subsequent rifting, transform faulting and final break-apart, the Gulf of Suez came into being as a result of tensional movement and subsidence along NW-SE trending normal faults, probably prior to Devonian time.

They produced a relatively narrow embayment in the foundered part of the Precambrian basement between the present Sinai Peninsula and the Eastern Desert as far as Hurghada, situated on the northern end of the Red Sea. To the north it opened into the ancient Tethys.

In Oligocene-Miocene time, during the initial events of the East African rifting, the Gulf of Suez as an area of crustal weakness followed suite and adapted itself to its present shape.
The Gulf of Suez is an intensely faulted area, and Fig. 1-4 shows a typical cross-section. The present shape of the Gulf of Suez has been determined by fracture systems which were, and possibly still are due to tectonic events caused by movements of the Nubian, Arabian and Sinai plates and the resulting East African Rift system. The NNW-SSE **Erythrean trend,** the N-S **East African Rift trend,** the NNE-SSW **Aqaba trend** and the E-W **Tethyan trend** are responsible for the development of the Gulf of Suez, as seen in Fig. 1-5.

The Erythrean trend controls to a large extent the normal faults flanking and running parallel to the present Gulf of Suez. The age of this trend is still debated. Schürmann (1966) attributes it a Precambrian age and believes the graben to be of ancient origin. This is supported by the fact that the narrow northsouth embayment is infilled with Paleozoic deposits from the north as far as Hurghada.

Youssef (1968) interprets the graben to be the result of a stress pattern over a prolonged period, but found its present shape from Upper Mesozoic onwards, caused in part by tensional movements, and in part as a result of rotational movements between the Nubian and Sinai plates.

Most likely the Gulf of Suez area was a zone of crustal weakness since Precambrian times. The East African trend gives the coast line a sort of zigzag appearance, more pronounced in the Red Sea than in the Gulf area.

The Aqaba trend is thought to have affected the Gulf with slight rotation of fault blocks.

The Tethys trend is limited to the extreme north and is manifested by gently folding of pre-Pliocene formations. This trend is related to the Alpine Orogeny and is also referred to as the Syrian trend.

The combined effect of these tectonic events led to intense structuring and break-up into an enormous number of fault blocks composed of formations ranging in age from Precambrian to Eocene. This faulting must have occurred towards the end of Eocene, during Oligocene and slightly prior to the erosional pre-Miocene period that produced the marked unconformity surface between the Lower Miocene and the pre-Miocene formations.

The fault blocks raised and foundered in a key-board manner and changed the depositional environment within relatively small areas. Deep water deposition occurred in lows between the blocks, whereas coarse clastic formations were caught in lows of the tilted block surfaces, and reefal build-ups were formed along the high edges of the fault blocks.

Other lifted blocks emerged from the sea and were exposed to erosion.

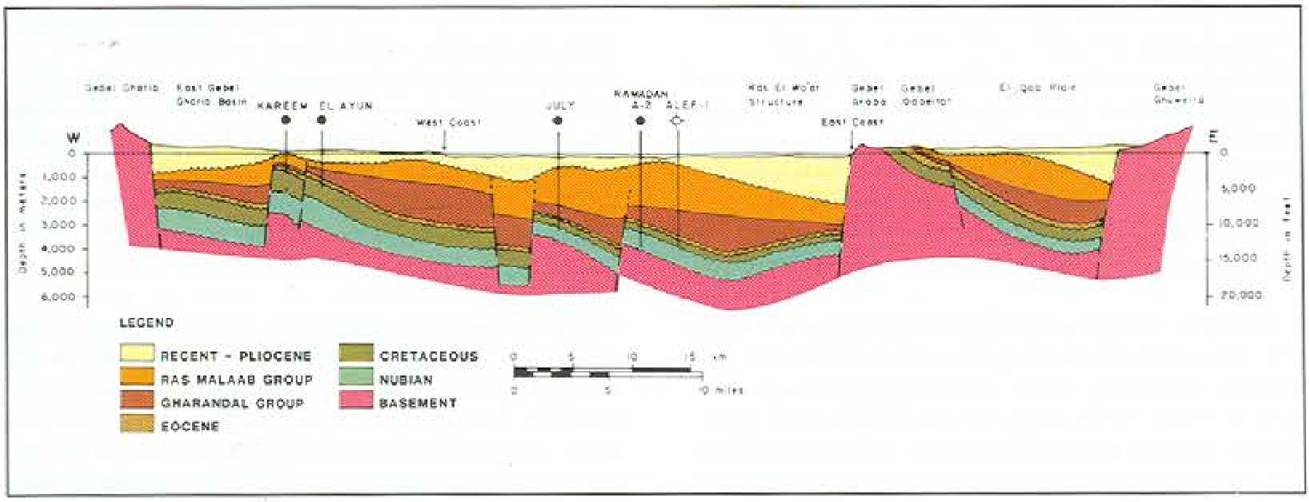


Fig. 1-4. Geological cross-section through the southcentral Gulf of Suez.

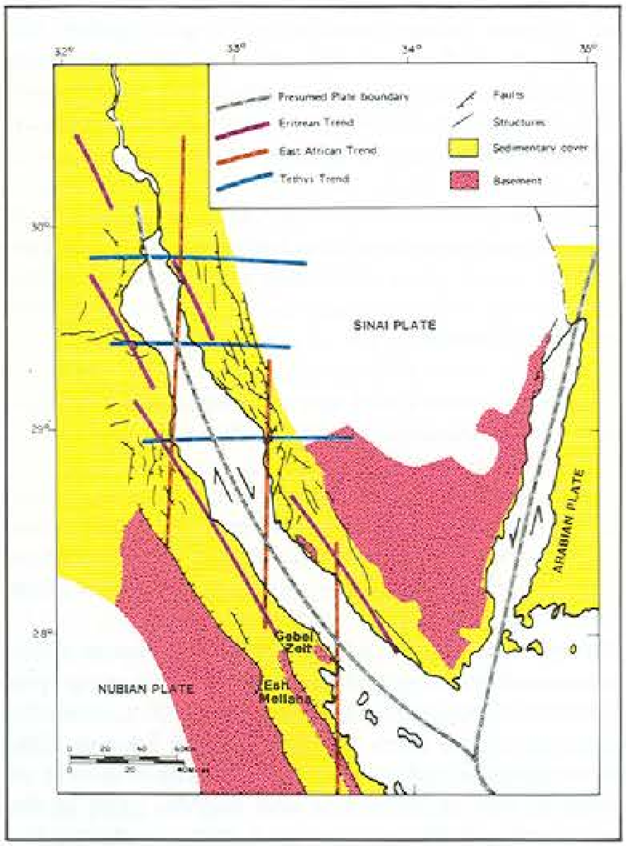


Fig. 1-5. Plate tectonic and structural trends in the Gulf of Suez.

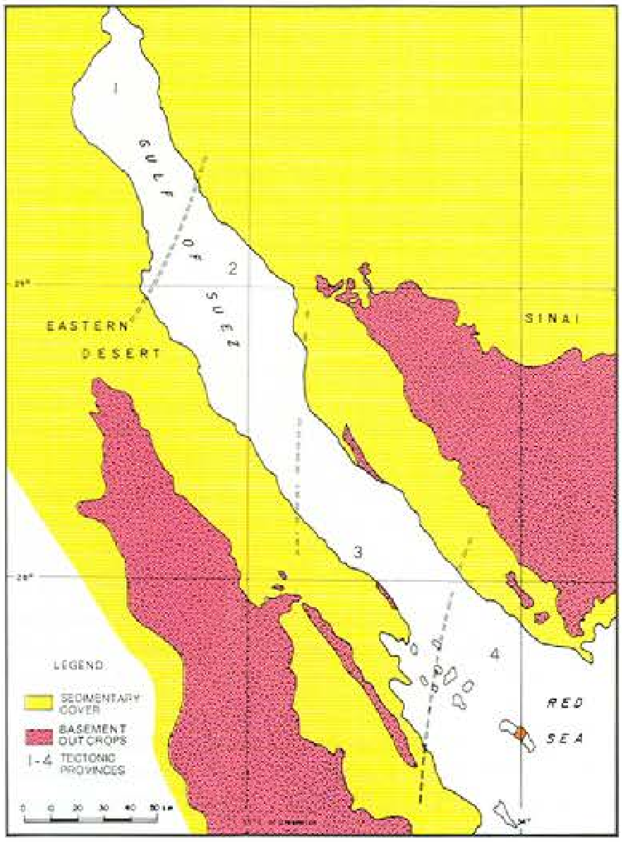


Fig. 1-6. Tectonic and structural provinces in the Gulf of Suez.

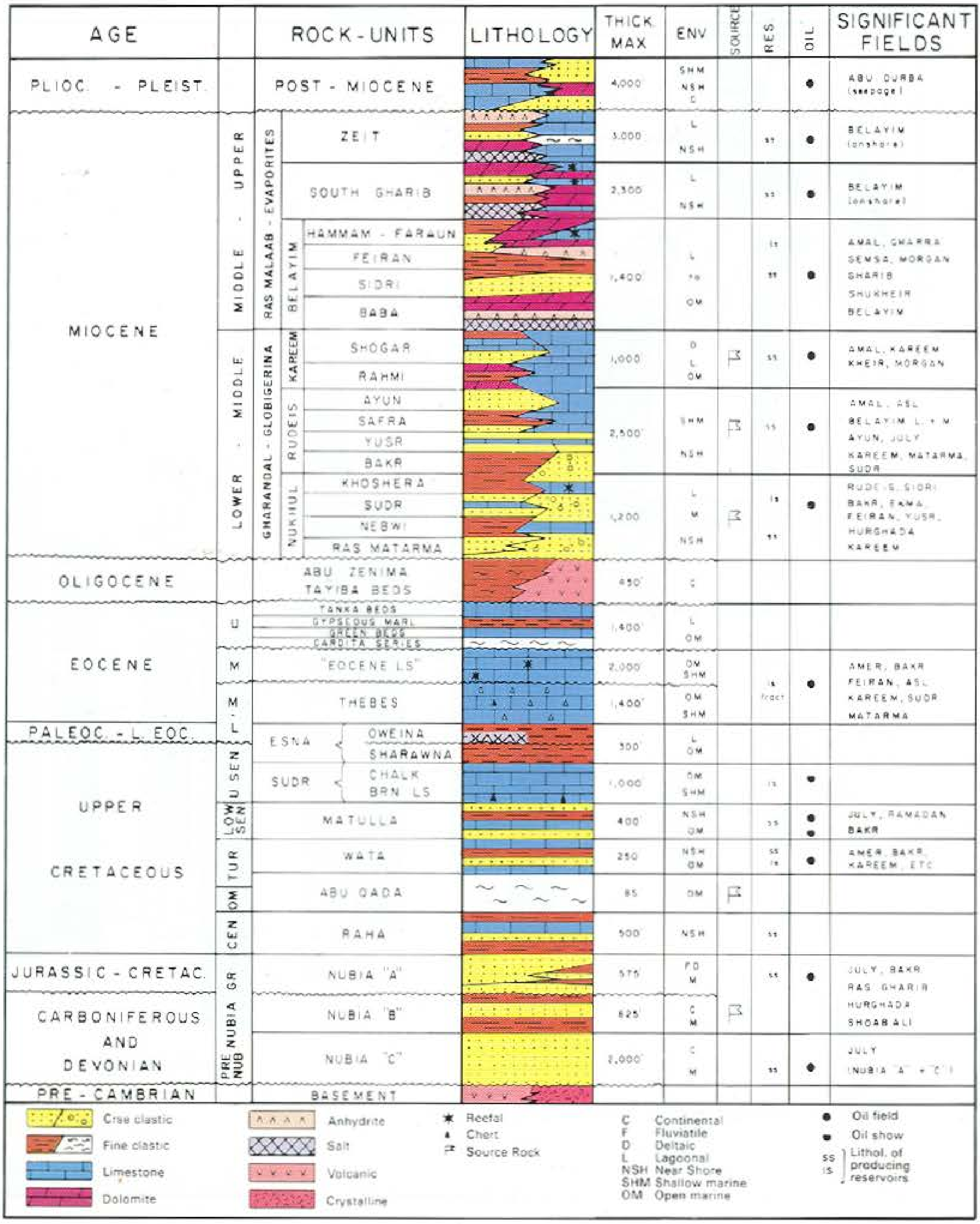


Fig. 1-7. Generalized litho-stratigraphy of the Gulf of Suez.

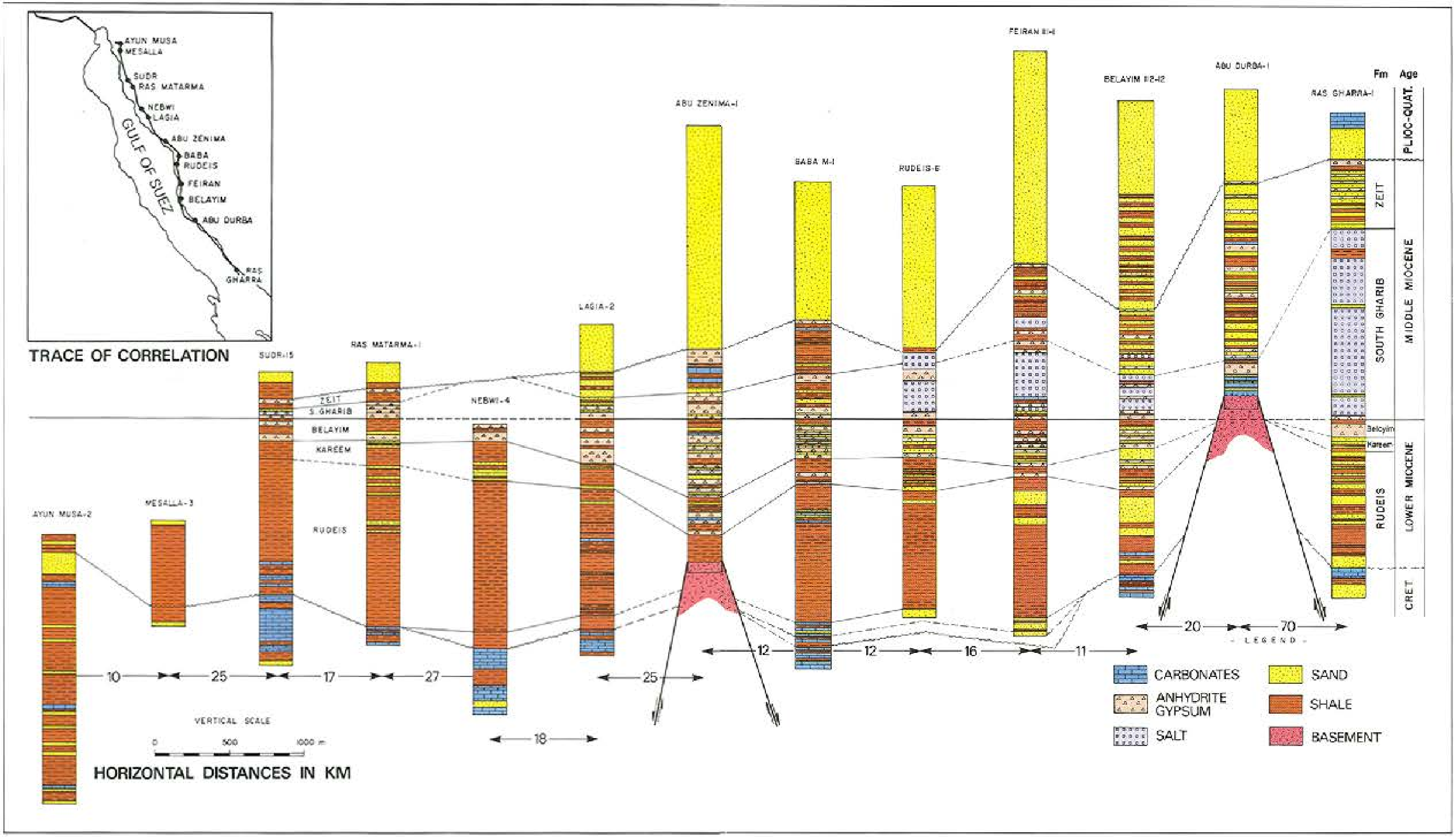


Fig. 1-8. Stratigraphic correlations along the east cost of the Gulf of Suez.

reach a maximum thickness of about 400 m. They make up one of the main pay zones in the Hurghada, Ras Gharib, Ramadan, and July Fields.

Carboniferous

The Devonian sandstone is overlain by the Lower Carboniferous marine black shales of the **Nubia B**. They appear to be a poor source rock due to their low content of organic matter and because they are highly indurated. They may, however, function as adequate seals. Maximum thickness of the Carboniferous black shales is about 200m. The Nubia B Formation has been encountered in the Ras Gharib, Morgan, Kareem, Bakr and other more recent fields.

Permo-Carboniferous and Permo-Triassic

The worldwide Hercynian orogenic phase affected also the general area of Egypt, and led to strong folding and uplifting with subsequent peneplanation. A marked and major unconformity surface separates the Lower Paleozoic series from the Upper Paleozoic-Mesozoic sedimentary sequences.

Permo-Carboniferous continental formations of considerable thickness were encountered in Ayun Musa well 2, in the extreme northeastern coastal belt of the graben, and Permo-Triassic red shales and sandstones are reported from Abu el Darag on the northwestern coast and from Sinai.

Mesozoic

Jurassic

In all the above mentioned localities the Paleozoic continental sequence has been found overlain by thick Jurassic carbonates and marls which indicate the first significant subsidence of the Gulf area.

Cretaceous

A relatively thin wedge of barren continental to shallow marine sandstone separates marine Cenomanian rocks from the underlying Paleozoic formations. This sandstone, generally referred to as the **Nubia A** forms the reservoir of some of the wells of the Ras Gharib Field. Its stratigraphic position is debated, some authors place it in the Lower Cretaceous, while others consider it to be of Upper Cretaceous (Cenomanian) age.
The Upper Cretaceous is represented by a section of limestones, sandstones minor shales of Cenomanian to Turonian age grading upsection into a chalky series of Senonian age. Danian has not been recognized so far in the Suez graben area. Its absence may be due to local non-deposition or erosion and points to local unconformities.

Cenozoic

Tertiary

The marine transgression continued into the Lower Tertiary with the deposition of Paleocene chalks and marls, Lower and Middle Eocene carbonates and marls. Pyritic and cherty limestones, micrites and reefal build-ups are frequent. Where these formations have been drilled they are strongly fractured and fissured, all with appreciable porosities.

Oil is produced from Eocene carbonates in the Bakr and Sudr Fields.
The shales contained in the **Esna** Formation are considered a potential source rock.

The thickness of the Lower Tertiary formation varies considerably, depending on which part of a structure is being evaluated. Fig. 1-9 illustrates a complete local stratigraphic column from the El Qaa plain.

In many places the Lower Tertiary has been encountered completely exposed with Miocene resting unconformably on Cretaceous and older formations. The development of the Lower Tertiary sequence as a whole indicates, however, a period of extended subsidence associated with the foundering of the Suez graben. A general regional uplift and the regression of the sea closed this first depositional phase of the Gulf of Suez area.

Oligocene

Continental shales and pebbly sandstones of questionable Oligocene age are reported from the area of Sudr and from Abu Zenima on the northeastern coast of the Gulf. They are barren of fossils and their stratigraphic position is arbitrary. They are placed below the basalt flows in the area of Abu Zaabal. Fig. 1-9 is an example of a column which exhibits basalt below the Abu Zenima Formation in the El Qaa plain.

The Oligocene therefore, was a period of a general uplift with the coastline of the Suez embayment shifted northwards to the general area of Zafarana.

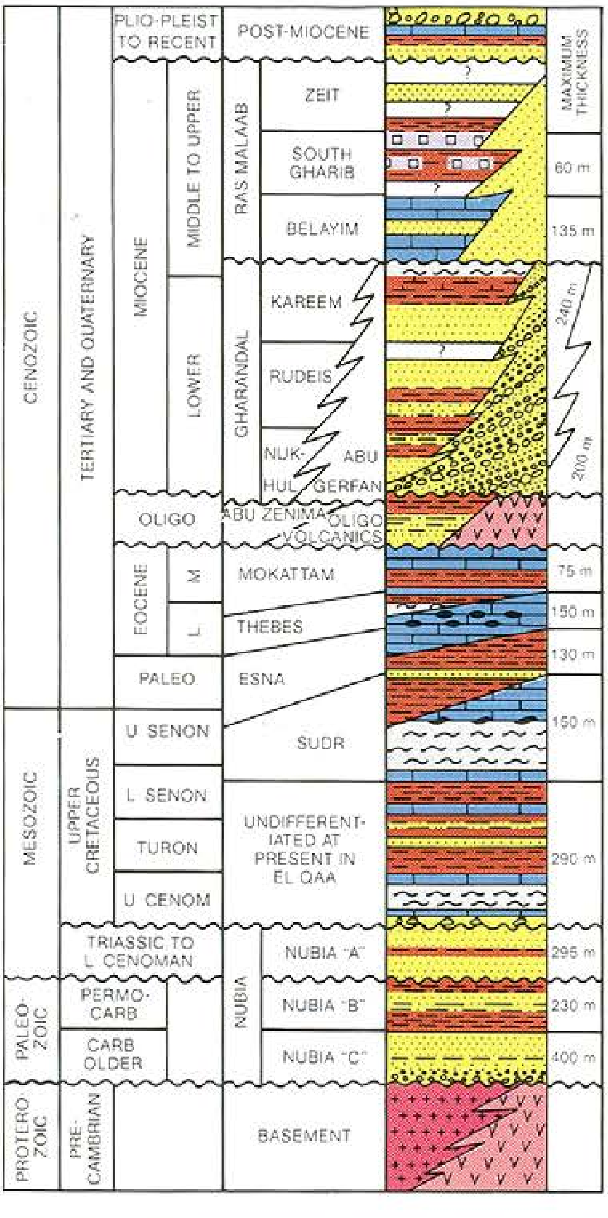


Fig. 1-9. Litho-stratigraphic column from El Qaa area in the south of the Gulf of Suez.

Basalt flows appear to be abundant in the northern part of the Suez graben and their position between the underlying Paleogene and overlying Neogene is likely to indicate the beginning of the renewed foundering of the Suez graben.

Miocene

The Miocene sequence of the Gulf of Suez is commonly subdivided into Lower Miocene, referred to as the Gharandal Group and Middle Miocene referred to as the Ras Malaab or Evaporite Group. Both groups are important, the lower containing the richest source rocks in combination with excellent reservoirs deposited under most favorable structural conditions, and the upper group providing the most efficient seal for both Miocene and the pre-Miocene reservoirs.

The aggregate thickness of these two groups is about twice that of the pre-Miocene formations. It indicates a fast subsidence of the graben area within a short period of time and a predominantly restricted depositional environment.

No Upper Miocene formations have been recognized in the graben area. Their absence is due to non-deposition as a result of the late phases of the Alpine orogeny that led to a major unconformity between the Upper Middle Miocene and the Pliocene deposition. Fig. 1-10 shows the major unconformities which affected the Neogene sequence.

The **Gharandal** Group is subdivided into three stratigraphic units which can be recognized in almost the entire graben area, except for the outer flanks. The lower unit, the **Nukhul** Formation contains carbonates and high energy reefal buildups on pre-Miocene topographic highs, and sands and shales in the lows between fault blocks and on tilted surfaces of fault blocks.

The **Rudeis** Formation overlies the Nukhul and is composed essentially of highly fossiliferous shales and marls referred to as the **Globigerina Marls,** and sandstones. This formation is oil bearing in Belayim Land, Belayim Marine, Morgan and other fields. The Rudeis grades upwards into the Kareem across a laterally extended anhydritic level.

The **Kareem** Formation is again predominantly, shaly, but with frequent intervals of sandstones. Shales of the Rudeis and of the Kareem Formations are considered by some authors to be the main source rocks of the Gulf area. The interbedded sands provide excellent reservoirs with porosities ranging from 11 to 24%.

The thickness of the Globigerina Marls exceeds 2200 m in the northern part of the Gulf thinning to less than 200 m at the Red Sea - Gulf of Suez junction.

The rich oil-fields of Morgan, July, Belayim Land and Belayim Marine have their main pay zones in these formations. The thickness of the Gharandal Group is about 1400 m, with the Nukhul Formation being 350 m thick and the Rudeis and Kareem Formations exceeding 1000 m on average.

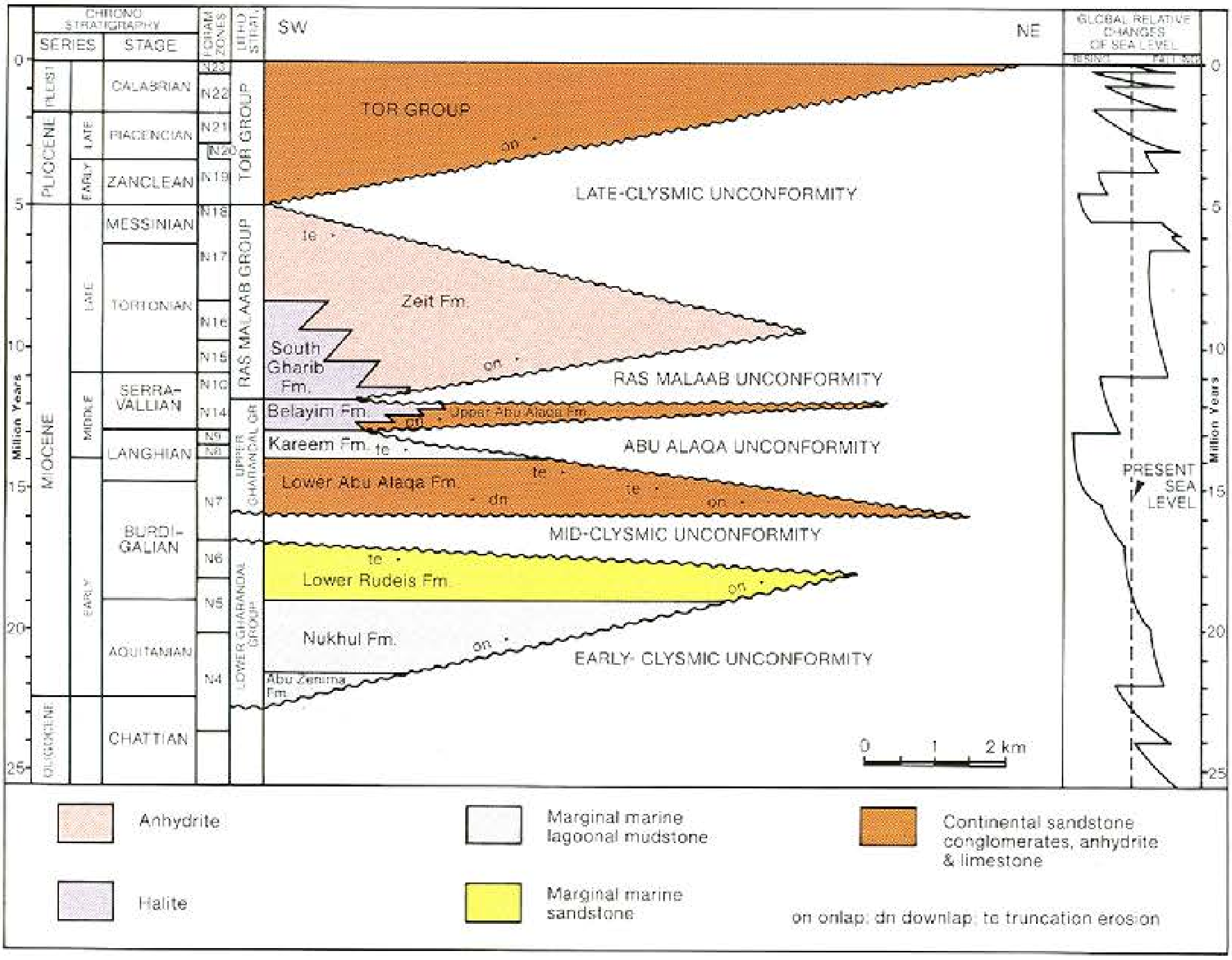


Fig. 1-10. Chrono-stratigraphic chart of the Gulf of Suez.

The **Ras Malaab** Group overlies the Kareem Formation in most of the Gulf area. However, over high pre-Miocene paleotopography the Gharandal Group is partially or completely missing due to non-deposition. On such highs the Middle Miocene evaporitic sequence rests directly on Rudeis, Nukhul or pre-Miocene formations.

Middle Miocene formations are present all along the coastal area of the Suez graben. Their development however is minor, when compared with the thickness of the formations of equivalent age within the graben itself. A marked difference is also noted in its lithological characteristics with predominantly carbonates, anhydrites and gypsum in the graben rim areas, and huge salt development in the graben proper.
Thickest salt is encountered in the southern part of the Gulf of Suez. The wells drilled on the island of Tawila penetrated a section of layered rocksalt over 3200 m thick. Generally a cyclical deposition of salt, anhydrite, fine and coarse clastics can be identified. High energy reefal carbonates are developed along high edges of uplifted pre-Miocene fault blocks.

In spite of the significant thickness of salt, no salt movements nor typical salt induced structures have been recognized with the exception of local flowage leading to the formation of pillows in lows between fault blocks.
Northward, from Ras Gharib towards Suez, salt deposition is replaced gradually by anhydrite and carbonates. Salt formations are almost absent in the coastal belts east and west of the Gulf, from the area of Izz el Urban, and in the NE part of the Gulf no evaporites occur.
The Ras Malaab Group is subdivided into the Belayim, Ras Gharib and Zeit Formations.

The **Belayim** Formation consists in general of anhydrite and salt at the bottom, and is topped by a sequence of sandstone and shales. The sandstones again have excellent reservoir characteristics and contain oil in the Morgan, Belayim Land, Belayim Marine, and Shukeir Fields.

On structural highs where Lower Miocene deposits are absent, reefal build-ups are developed and contain the oil of the Ras Gharib, Bakr and Gemsa Fields.

The overlying **South Gharib** Formation consists of a few very thick salt beds with anhydrite, shale and sandstone stringers in between. The thickness of this formation exceeds 1000 m specially in the central part of the Gulf. Its depositional cycles vary from place to place in number and in thickness of salt and anhydrite layers.

The **Zeit** Formation forming the top of the Ras Malaab Group is represented by numerous alternating thin beds of shale, gypsiferous shales, anhydrites and sandstones. Salt levels are rarer. Minor oil bearing sands have been encountered in the Belayim Land Field. The thickness of this formation varies since it has been exposed to strong erosion that led to the major unconformity between the Miocene and the Plio-Pleistocene strata.

Pliocene-Pleistocene

A blanket of coarse and fine clastics and, in some areas, oolitic limestones cover the unconformity surface of the Miocene formations. This blanket is widespread and its thickness varies from a few meters to about 500 m. Although impregnations of asphalt have been described from many surface seeps and in wells, no commercial quantities of oil have been encountered to date.

With the deposition of the Plio-Pleistocene formation the taphrogenic movements of the Gulf of Suez ended. The Gulf, during the relatively short period of Lower and Middle Miocene had experienced a strong and fast subsidence accompanied by an infill of sediments, which kept pace with the subsidence. The environment must have been super-saline at least during Middle Miocene with hot brines that favoured the deposition of thick salt.

The Globigerina Marls of the Gharandal Group contain a fauna of Mediterranean origin. An opening of the clysmic gulf toward the Mediterranean Sea is therefore to be assumed at least for the Lower to Middle Miocene time. Miocene rocks with a Mediterranean fauna are also described from outcrops in the coastal areas of the Sudan and Erythrea, proving that the Gulf of Suez was connected at that time to the Red Sea to the south, and to the Mediterranean to the north. It was most likely during the Plio-Pleistocene time that the connection with the Mediterranean Sea was disrupted, perhaps by an arm of an ancestral proto-Nile.

HYDROCARBON HABITAT

Source Rocks

Source rocks are generally classified according to the amount and type of organic matter, the degree of maturation and the thermal alteration.

The sedimentary section of the Gulf of Suez contains six intervals which exhibit source rock characteristics. These intervals consist of fine clastics and carbonates and are present in Carboniferous formations (Nubia B), in Upper Cretaceous carbonates (Brown Limestone of the Sudr Formation), in Paleocene-Eocene deposits (Esna Shale) and in Lower and Middle Miocene fine clastics (Kareem, Rudeis and Belayim shales). Their content in organic, oil prone matter ranges between 1.04 to 1.44% which is classified as a "good content".

Based on the results of intensive studies and analyses carried out on numerous well samples only four levels were considered to have the prerequisites to yield oil. These are the **Kareem** and **Rudeis shales** of the Gharandal Group, the **Belayim shales** of the Ras Malaab Evaporites and the **Esna Shale** of the Paleocene-Eocene sequence.

Other potential source rocks appear to be either immature (Belayim shales), or overmature (Brown Limestone of the Sudr Formation, and the Black Shales of Nubia B).

These formations may have yielded oil prior to the pre-Miocene erosional period and the accumulations of these oils may have been dispersed during the taphrogenic phase.

However, some more recent studies suggest that the Brown Limestone of the Senonian Sudr Formation may be predominantly responsible for the oil wealth of the Gulf of Suez.

In any event the origin of the Gulf of Suez oil remains debated.
The maturation level of the source rocks in the Gulf of Suez area appears to be essentially the result of age and burial.

The temperature gradient that affected the thermal alteration of the organic matter had apparently little influence on the various levels as it varies very little over the general Gulf area and averages about 2°F/100 ft.

Reservoirs

Most of the Gulf of Suez oil occurs in sands of Miocene, Cretaceous and Carboniferous age. Commercial oil is also present in Miocene, Eocene and Upper Cretaceous fissured and fractured reefal and shelf limestones. The porosity of the sand reservoirs varies from 9 to 25% regardless of age. Marked variations are observed with permeabilities ranging from 10 to 1000 md. Reservoir thicknesses of effective pay range from 10 to 150 m for Tertiary sands and from 10 to 350 m for the Nubia sands.

Fracture and fissure porosity encountered in the limestone reservoirs is due to the intense structuring that affected the Suez graben area.

Traps, Seals and Migration of Oil

Accumulations of oil are encountered in reservoirs associated with fault block structures. Synsedimentary fault block movements during the Oligocene-Miocene taphrogenic phase produced lateral and vertical facies changes within short distances and short periods of time. These facies changes in turn controlled source, reservoirs and seals.

Coarse clastics were generally deposited in lows of the tilted surface of fault blocks leaning against the fault plane, high energy carbonates developed on the edges of fault blocks.
Reducing conditions prevailed in structural lows and led to the development of source rocks. Time equivalent and overlying shales, and especially the evaporitic sequence of the South Gharib — Zeit Formations of Middle Miocene age, provided the necessary and most efficient seals.

The plasticity of these evaporitic sequences enabled them to mold to the various types and sizes of fault blocks during the differential vertical and horizontal block movements. Most of the important oil fields are found on tilted fault blocks or in reversals produced by warping of formations over fault blocks. A typical example is seen in Fig. 1-11 which shows a cross-section of the Belayim Field.

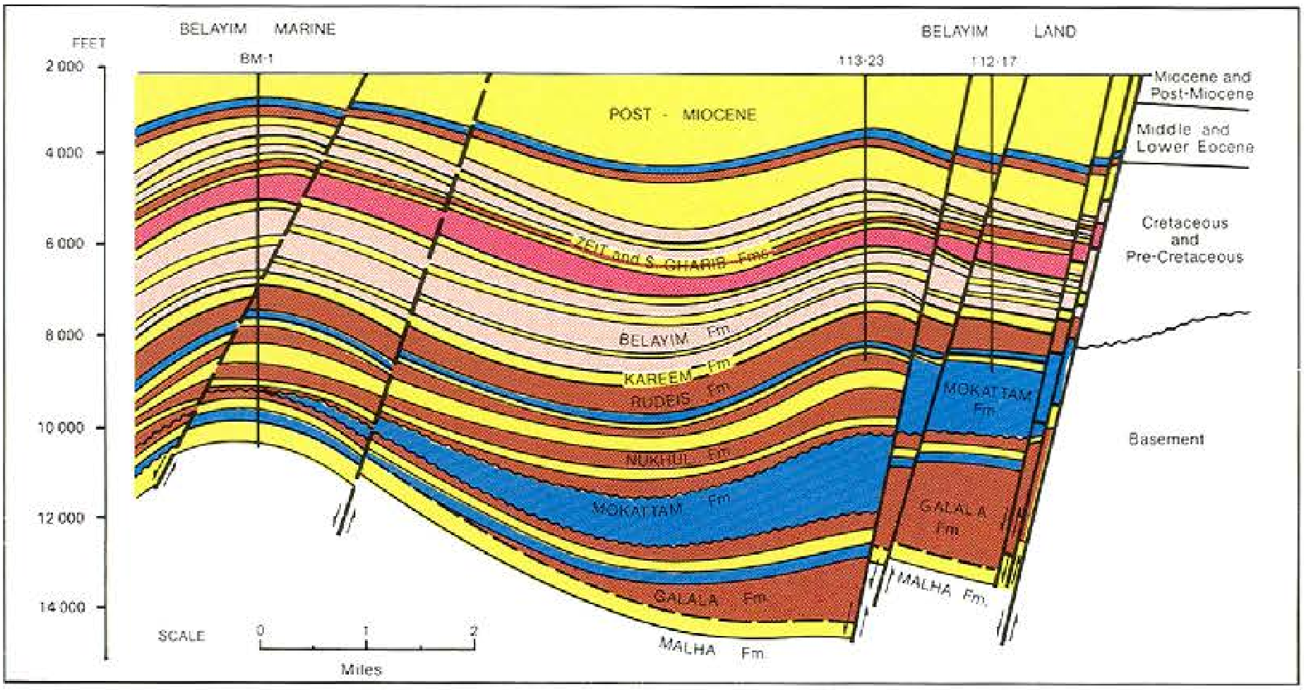


Fig. 1-11. Cross-section through the Belayim Field.

Nature of Hydrocarbons

The crude oils of the various fields and producing formations share a common marine source. The aromatic content of the crudes is relatively low and decreases from the lower pay zones (Cretaceous) upwards, while the sulphur content increases. This trend applies to oil samples from 16 fields.

Suez crude can thus be classified as asphaltic-paraffinic, the content of paraffins and asphaltenes ranging in all pay zones from 2.9 to 4.2% and 2.4 to 12%, respectively.

The content of sulphur ranges from 1.6 to 3.9% and is higher in the upper pays of a field. It is also higher in the fields situated in the northwestern part of the Gulf. The sulphur content decreases with the increase of API gravity.

Low API gravity crudes, such as those from the Asl Field, are considered to derive from immature sources. It could also be related to the escape of the low molecular weight fraction due to leakage of the seal, or to degradation processes.

The Gulf of Suez fields are characterized by a paucity of associated gas or gas caps especially in pre-Miocene pay zones. Only a few fields have high gas/oil ratios or gas caps with condensate content.

Fields

At the time of writing, there are 32 producing fields in the Gulf of Suez area, as seen in Fig. 1-12. Seven of them can be classified as large fields with proven recoverable reserves exceeding 250 million barrels.

These are the Morgan, October, Belayim Land, Belayim Marine, July, Ramadan and Ras Gharib Fields.

Four fields with proven recoverable reserves of over 125 million barrels of oil are the Ras Bakr, Ras Sudr, Shoab Ali and Ras Budran Fields.

The remaining twenty one have reserves ranging from 0.5 to 50 million barrels of oil.

As of January 1, 1983 cumulative production from the Gulf of Suez oil fields amounted to over 2500 million barrels and remaining reserves amounted to almost 3800 million barrels.

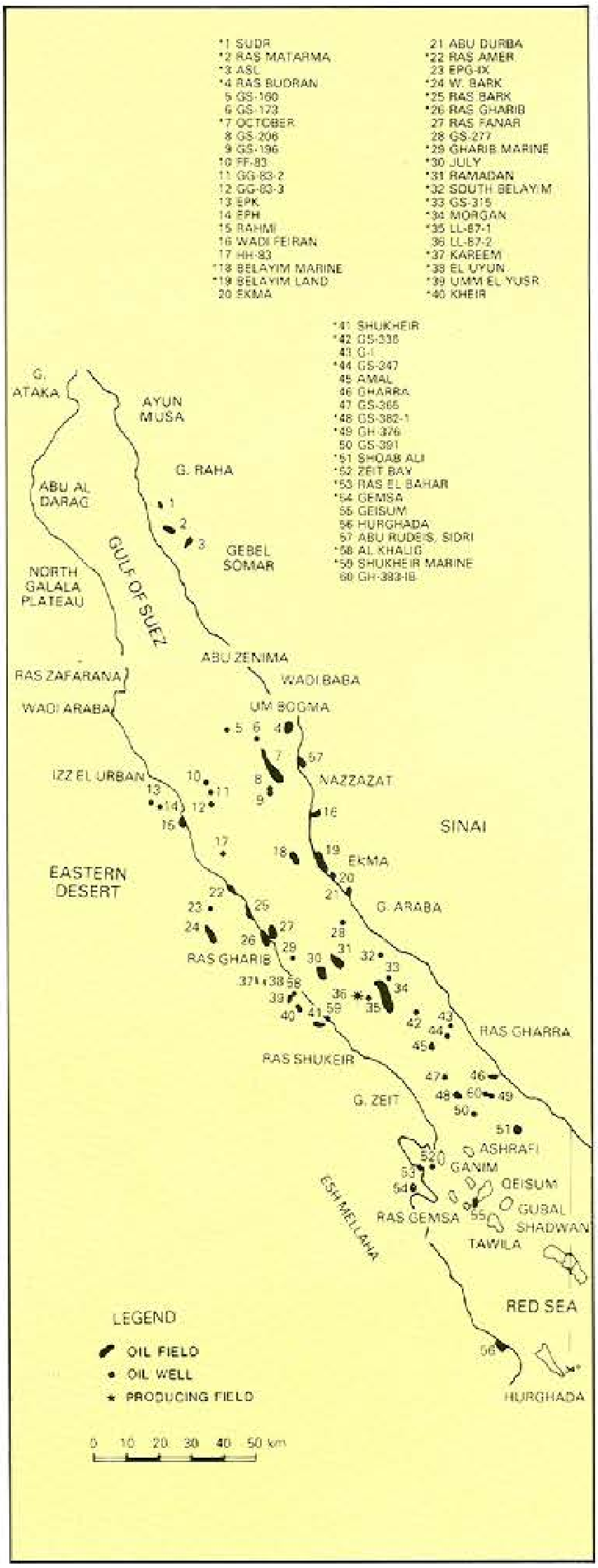


Fig. 1-12. Map locating oil fields in the Gulf of Suez.

1.2 THE WESTERN DESERT

The Western Desert comprises the area west of the Nile river and Delta and covers 700,000 sq km, about two-thirds of the area of Egypt.
It extends 1000 km from the Mediterranean Sea to the Sudanese border in the south and 600 to 800 km from the Nile valley to the Libyan border in the west.

The Mediterranean continental shelf covers roughly 5000 sq km, up to the 200 m isobath west of Alexandria, and its width ranges from 5 to 30 km.

In the deep offshore area, west of the Nile Delta, referred to as the Herodotus Basin (Fig. 1-2) the thick sedimentary fill is likely to exceed 13,000 m.

TECTONIC SETTING

The sedimentary cover of the Western Desert is part of the foreland deposits which fringe the northern continental margin of the Afro-Arabian shield.

From the southernmost area of the Western Desert the exposed pre-Paleozoic basement shows a regional northward slope, with corresponding increasing thickening of the unconformable sedimentary cover, made up of Paleozoic, Mesozoic and Tertiary to recent formations.

In the Mediterranean coastal area, the basement lies 5000 to 8000 m below the surface, according to magnetics.
In the Western Desert, the Egyptian platform may be subdivided, from south to north, into four units, as seen in Fig. 1-13.

Craton and Stable Shelf

Area of shallow to exposed basement rocks, with low structural relief and thin sedimentary cover of mainly Mesozoic fluvio-continental clastics.

Unstable Shelf

Northward thickening sedimentary section underlain by high basement relief due to block faulting and affected by minor compressional folding.

Hinge Zone

Located between the mobile shelf and the miogeosynclinal basinal area. It causes a rapid, basinwards

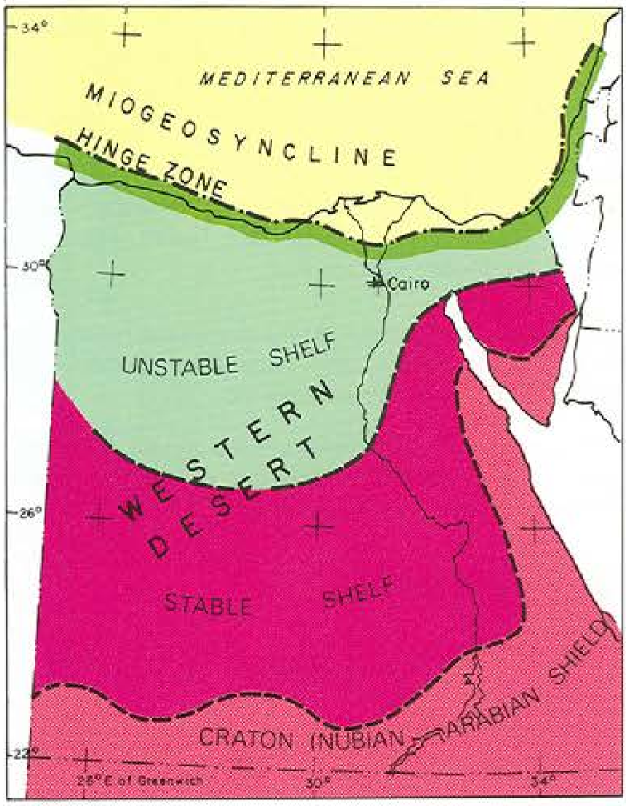


Fig. 1-13. *Sketch of the structural aspects of the Nubian-Arabian shield margin in Northern Egypt.*

thickening of Oligocene to Pliocene sediments, and practically coincides with the present Mediterranean coastal area.

Miogeosyncline

Presently submerged and partially buried under thick Plio-Pleistocene deposits in relation to the Nile Delta.
The structural grain of the basement is dominated by two orthogonal trends induced by successive diastrophic phases.

During Paleozoic time, at least two phases of major deformation produced a N to NW trending system of block faulting and gentle folding with marked unconformities within the Paleozoic section. Although these movements were rejuvenated, a new trend of structures was superimposed and became predominant in the modelling of the basement and distribution of the sediments. With a general easterly trend (ENE to ESE), this new grain resulted from the Alpine orogenic phases which follow one another throughout the Mesozoic time and had their climax during Lower Tertiary.

As already seen in Fig. 1-2, the structures consist mainly of parallel, elongated, tilted fault blocks, that is, horst and half-graben structures, with associated erosion of the upthrown blocks.

Concurrently, from late Jurassic onwards, differential depocenters developed with correspondingly strong changes in thickness and facies, especially during the Upper Cretaceous.

Structures result primarily from vertical movement of basement blocks, and consist of draped over and/or faulted anticlinal features.

Compressional anticlines are subordinate and probably derive from drag folding, related to lateral movement along basement faults.

STRATIGRAPHY

Fig. 1-14 shows a generalized stratigraphic column of the Western Desert.
The sedimentary section of the Western Desert ranges from Lower Paleozoic to Recent. Four major sedimentary cycles occurred, with maximum, southward transgression in Carboniferous, Upper Jurassic, Middle and Late Cretaceous, Middle Miocene and Pliocene time.

Maximum, northward regressive phases occurred during Permo-Triassic and Lower Jurassic, and continued in Lower Cretaceous, and again in late Eocene to Oligocene, with a final phase in late Miocene times.
On the stable paltform in the southern middle part of the Western Desert, the sediments are mainly made up of clastic sequences accumulated in continental or transitional environments. They grade northwards to restricted marine and platform carbonates, which were deposited on the unstable shelf area, corresponding roughly to the northern middle part of the Western Desert.

The predominant orientation of the isopach lines is parallel to the main tectonic trends of the basement, that is NNW-SSE during Paleozoic and ENE-WSW during the Mesozoic and Tertiary times.

In the unstable shelf area, the lithostratigraphic column of the overlying series may be subdivided into three sequences. First the **lower clastic unit,** from Cambrian to Cenomanian, second the **middle carbonates,** from Turonian to Eocene and finally the **upper clastic unit,** from Oligocene to Recent.

Precambrian Crystalline Basement

The basement complex which forms the nucleus of the Nubian-Arabian shield is widely exposed in the Gulf of Suez and Red Sea coastal range and in the southern tip of the Sinai Peninsula. It sparsely outcrops in the southernmost part of the Western Desert. The basement consists mainly of gneisses, migmatites, metasediments (chlorite-schists, slates, phyllites, etc.), ultra-basic and ultra-acidic plutonic intrusions, and granitoids of various ages.

Paleozoic

The Paleozoic depocenters seem to trend generally NNW-SSE, being controlled by the major faults developed in Late Precambrian time.

In the northwestern corner of the Western Desert along the Libyan border a N-S trending synclinorium (Siwa Oasis - Faghur) has been delineated with a Paleozoic section of some 3000 m thickness.

The eroded Nubian-Arabian shield corresponding to the Western Desert area, was invaded from the northwest by the Tethys, a very shallow epicontinental sea.

During the Cambro-Ordovician time, coarse clastic series were deposited in fluvio-continental or in a beach and tidal shoal environments.

Immature arkosic sediments with fresh feldspars indicate high relief, short transportation and rapid burial. They consist of white to varicolored, generally crossbedded, micaceous and hematitic, kaolinitic, fine to coarse-grained sandstone, with interbeddings of lenticular, argillitic red shales. Some dolomitic stringers and authigenic anhydrite are also present.

Glacial tillite has been observed in the uppermost part of the sequence.

The thickness is probably less than 300 m.

The Silurian clastic sequence consists of white to light grey, fine to medium-grained well-sorted sandstone, interbedded with variegated, micaceous shales. It was deposited during a transgressive marine phase, in a depositional environment varying from offshore shelf to subtidal and perideltaic.

Thicknesses range from 25 to 400 m.

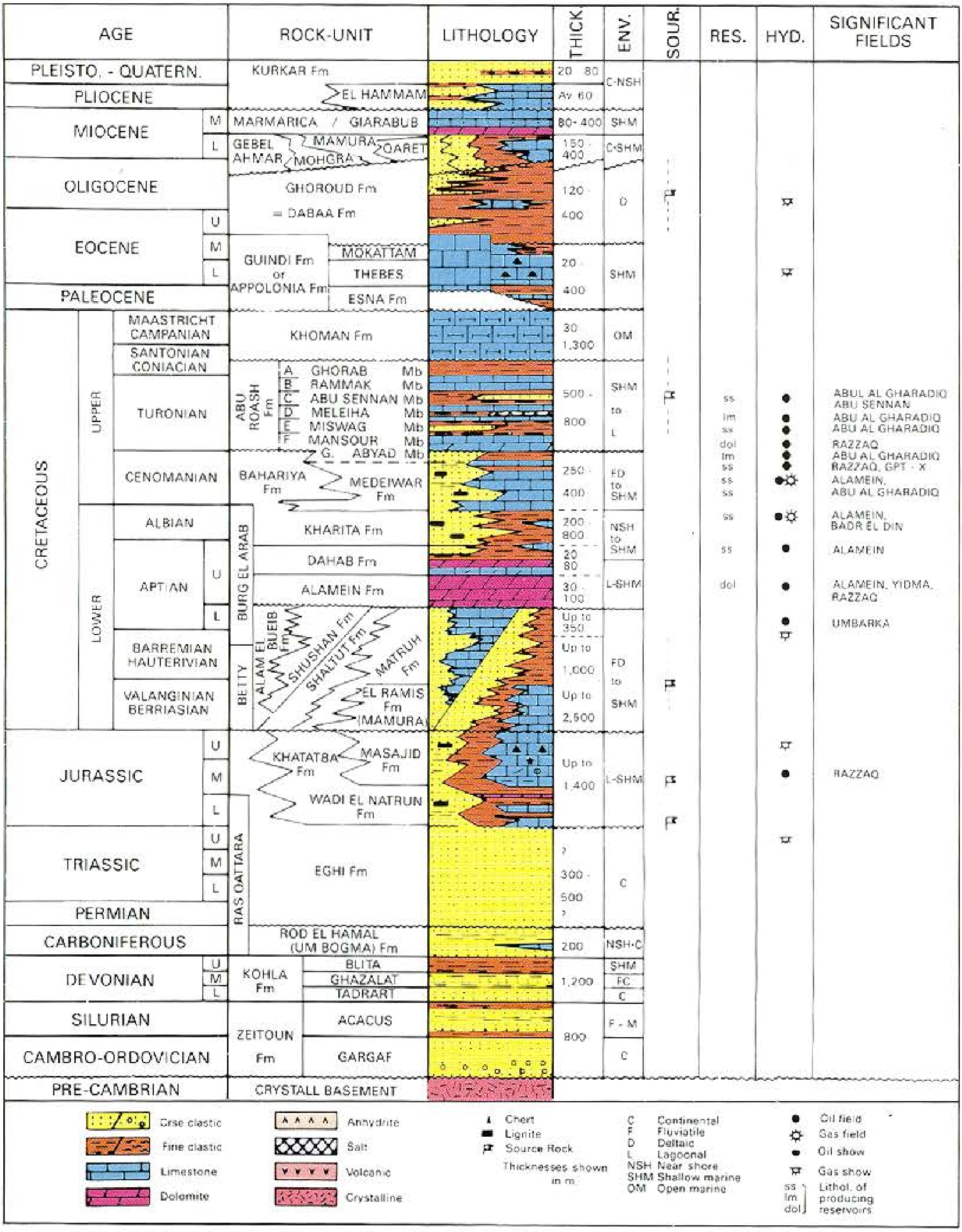


Fig. 1-14. Generalized litho-stratigraphic column of the northern part of the Western Desert.

The Devonian series in the south of the Western Desert are described as alternating marine shales and delta-prodelta sandy complexes, with a basal regressive sandy sequence (**Tadrart** Formation). This was followed by a fluvio-deltaic shaly sequence (**Ghazalat** Formation) and transgressive, shallow marine deposits (**Blita** Formation), composed of grey to greenish, silty shales, with interbedded sandstones, including coal seams and stringers of dolomite and dolomitic limestone.

Thickness is in the order of 350 m.

In the southwestern corner of the Western Desert, the Lower and Upper Devonian sandy deposits (120 m thick), are practically devoid of any shaly sequence. These formations correspond to braided stream, tidal flat and tidal channel deposits. In the northwestern corner of the Western Desert (Siwa Oasis area), the thickness of the Devonian section is more than 1000 m, and the shale sequences of shallow marine origin are well developed.

North of parallel 27°N, in the Desouky subbasin, the maximum estimated thickness of the pre-Carboniferous Paleozoic section is about 2500 m.

A diastrophic phase occurred between the Silurian and Devonian, accompanied by local basaltic flows. The Carboniferous deposits are generally considered transgressive in relation to the underlying Paleozoic series, especially in the Gulf of Suez and Sinai areas. In the south of the Western Desert, however, there are indications that the Carboniferous could be locally regressive.

Fluvial to deltaic sediments are intercalated with coastal plain sequences. They consist mainly of fine to coarse, or even conglomeratic sandstone, grading into siltstone, with interbedding of shales, with rare limestone stringers.
Their total thickness averages 600 to 700 m.

In the northwestern corner of the Western Desert (Siwa Oasis - Faghur area), more than 1000 m of alternating sandstone and shales, with limestone near the top, represent the Carboniferous section. In the vicinity of the Uweinat basement high, in the southernmost corner of the Western Desert, the Carboniferous consists of crossbedded sandstones deposited in a tidal flat, and a shelf-shoreface transition environment, with a strong tidal current oriented in a N-S direction. This indicates a possible connection with the Tethys to the north, through the Siwa-Faghur embayment.

Paleozoic-Mesozoic Transition

In late Carboniferous, regional upwarping related to the Hercynian orogeny affected the whole Western Desert and led to terrestrial conditions which prevailed during the Permo-Triassic time. They are represented by the widespread, unconformable **Eghi** Formation.

This poorly documented formation consists of light-coloured sandstone with some coaly or lignitic seams.

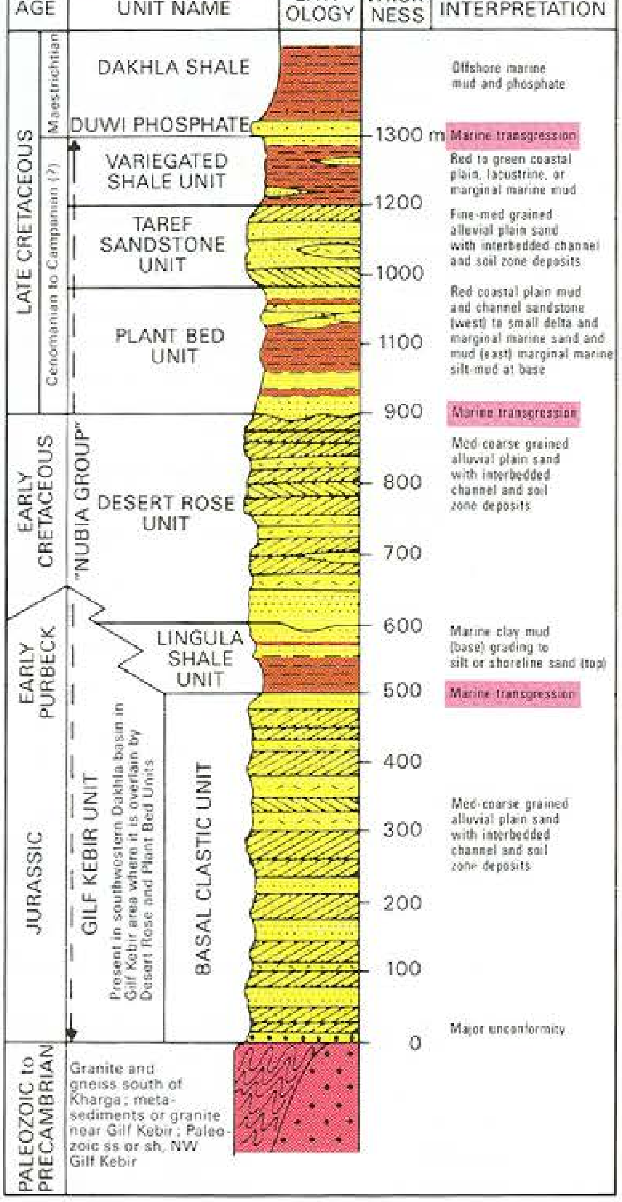


Fig. 1-15. *Generalized stratigraphic column of the Nubia strata from the south of the Western Desert.*

Some intercalations of dolomite and shales are present, as well as dolerite intrusions of Triassic age.

In the southern half of the Western Desert, the Eghi Formation extends stratigraphically upwards and represents the continental equivalent of the Jurassic marine section present in the north of the Western Desert. The upper part of the Eghi Formation represents the Lower Nubia strata.

Mesozoic

Throughout Mesozoic time, a continental depositional environment prevailed over the whole of the Western Desert south of parallel 28°N. There, Precambrian basement and/or Paleozoic clastic series are unconformably overlain by the Nubia strata, whose age ranges from Jurassic to Late Cretaceous. Their aggregate thickness is around 1500 m, (see Fig. 1-15).

These strata may be subdivided into three sedimentary cycles, each consisting of a basal, well-developed sandy unit, deposited in alluvial-plain environments, followed by a transgressive shaly, marginal marine-type sequence (E. Klitzsch et al., 1979). The three transgressive phases occurred in Latest Jurassic, Middle and Latest Cretaceous respectively, possibly corresponding to a worldwide eustatic rise in sea level. The Maestrichtian transgression extended widely southwards beyond parallel 24°N.

The fluvio-continental sediments of the Nubia Group gradually change northwards to the marginal, and even open marine facies seen in Fig. 1-15.

The Lower Jurassic, present in the northwestern corner of the Western Desert (**Wadi Natrun** Formation), consists of lagoonal deposits, that is alternating dense limestone, green shales and dolomite, with subordinate interbeds of sandstone and anhydrite.

The Middle to Late Jurassic is represented by the **Khatatba** Formation, a thick carbonaceous shale sequence, with interbedded porous sandstone (oil bearing in the Razzaq Field), coal seams and limestone streaks. Basinwards, it grades into the time equivalent **Masajid** Formation, made up of platform carbonates, including oolitic, reefal and dolomitic limestones, with cherty intervals. Maximum development of carbonates occurs towards the Nile Delta area.

A widespread unconformity is recorded at the Jurassic-Cretaceous boundary. A strong generalized diastrophic phase of late Kimmeridgian, responsible for block faulting and rifting along the North African continental margin, affected the north of the Western Desert.
A sedimentary gap of the uppermost Jurassic section and even erosion of earlier Jurassic sequences occurred, particularly on the structurally highest parts of the tilted faulted blocks. These generally E to NE trending highs, crossed by rejuvenated NNW-SSE Paleozoic faults, played a determinant part in the facies and thickness distribution throughout Cretaceous time.

As a consequence of these block-tilting tectonics, a complex pattern of graben shaped depocenters developed over the unstable shelf area.

The most prominent of them are the SW Qattara-Abu Gharadiq troughs (Fig. 1-18). Large amounts of fluvio-deltaic material from the emergent land to the south were trapped there during Lower Cretaceous time.

During Upper Cretaceous, combined eustatic rise in the sea level and downwarping of the continental margin moved the front of the sandy clastic depositions south of parallel 29°30'. Simultaneously, shallow marine carbonates invaded the unstable shelf area to the north.

Periodically reactivated tilting of basement fault blocks led to remarkable erosions over the highs and originated alternating sequences of shales and limestone all around, with local unconformities, onlapping wedges and significant thickening of the series towards the adjacent subsiding areas.

The most intensive deformation occurred during Late Senonian - Early Tertiary time, giving rise to the bulk of the structures drilled so far, and which consist mainly of faulted anticlines.

There is a profusion of local names for designating the Cretaceous rock units. For part of them, the time equivalence has not yet been accurately established, and correlations from one area to another are still ill-defined.

Practically all of the producing horizons of the Western Desert are Cretaceous in age. They either pertain to the Neocomian to Albian sands and carbonates or to the Cenomanian-Turonian carbonates and sands.

Fig. 1-16 shows a lithostratigraphic correlation of the Cretaceous in the Western Desert, and Fig. 1-17 shows a corresponding N-S correlation.

The Lower Cretaceous clastic series correspond to a transgressive cycle, with fluvio-continental sediments at the beginning (Neocomian) and at the end (Upper Albian - Lower Cenomanian) with a transitional near-shore to deltaic depositional environment during Lower Aptian and Albian. A maximum transgressional phase occurred during Middle and Upper Aptian, with the deposition of the Alamein carbonates in a restricted marine to lagoonal environment. This transgression extended southwards to latitude 29°30'N.

The Lower Cretaceous hinge line between the shelf and the basinal area coincides roughly with the present coastline.

Some reefal carbonate build-ups (**El Ramis** or **Mamura** Formation) developed at the edge of the shelf as a survival of the Upper Jurassic **Masajid** Formation.

Interfingering of the overlying sandy sequences with the basinal shales (**Matruh** Formation) takes place all along this hinge line, with a sand/shale ratio dropping from 1/1 to 1/10 within a few kilometers. The hinge line is locally deflected southwards due to foundering of the basement and resulting N-S trending grabens. In the Mersa-Matruh area, such a subsided channel or embayment was filled by 3000 m of Lower Cretaceous sediments, of which more than 2000 m of Neocomian and Aptian shales are considered mature, oil-prone source rock, as seen in Fig. 1-18a.

The transgressive carbonate sequence of Aptian, as seen in Fig. 1-18b, includes tight, micro-crystalline limestone, dolomitic limestone and dolomite of the **Alamein** Formation, with some stringers of anhydrite. The widespread Alamein dolomite, a good regional seismic marker, is one of the main producing horizons of the Western Desert, but its porosity and permeability varies considerably from place to place.

The upper clastic and regressive series are referred to as the Albian **Kharita** Formation and Lower Cenomanian **Bahariya** Formation. They were respectively deposited in shallow marine and fluvio-deltaic environments. They consist of consolidated sandstone with occasional coal seams and minor intercalations of shales, with the marly facies restricted to the present coastal area (**Medeiwar** Formation). Fig. 1-18c shows an isopach and lithofacies map of the Lower Cenomanian and Albian.

Oil and gas is produced from the Bahariya sandstones in the Alamein and Abu Gharadiq Fields.

Upper Cretaceous time was characterized by active deformation and faulting of the basement, accompanied by a prominent southward transgression of the sea. Sediments laid down during the great depositional cycle extending from Upper Cenomanian to Middle Eocene are collectively known as the Middle Calcareous Division. Fig. 1-18 (d and e) shows isopach and lithofacies maps of the Upper Cenomanian to Santonian.

In the Upper Cretaceous section, the thickness of which may exceed 2300 m, two main rock units have been recognized. These are the **Abu Roash** Group and the Khoman Formation.

The Abu Roash Group (up to 1000 m thick in the Abu Gharadiq depocenter) contains a large part of the discovered oil reserves.

The Abu Roash Group has been subdivided into seven rock units (A to G), which cover the Upper Cenomanian to Coniacian (Santonian) time interval. They correspond to alternatively transgressive and regressive phases, characterized respectively by:

- Shallow to deeper marine carbonates on the highs, the limestones were dolomitized and have both vugular and fracture porosity. In conjunction, there is substantial sand development.
- Shallower deposits, consisting of alternating shales and sandstone.

During the Turonian, **Meleiha** Formation, an evaporitic sequence was deposited in some areas, especially in the northern zone (Matruh).

Isopach and facies maps of the Abu Roash Group indicate gradual thinning northwards associated with an increasing sand/shale ratio, which suggests the existence of an E-W trending high, located off the present coastline.

The **Khoman** Formation, of Upper Santonian to Maestrichtian age, unconformably overlies the Abu Roash Group, particularly in the structurally highest areas. It exhibits a marked change in facies, showing two main lithologic units.

The lower unit is mostly shale with highly argillaceous limestone. The upper unit consists of fine-grained, white chalky limestone with chert bands. This section is characterized by low permeability and lacks adequate reservoir qualities.

In the Abu Gharadiq depocenter, its total thickness exceeds 1250 m, but it is completely missing on the central ridge. Fig. 1-18f shows an isopach map of the Maestrichtian/Campanian.

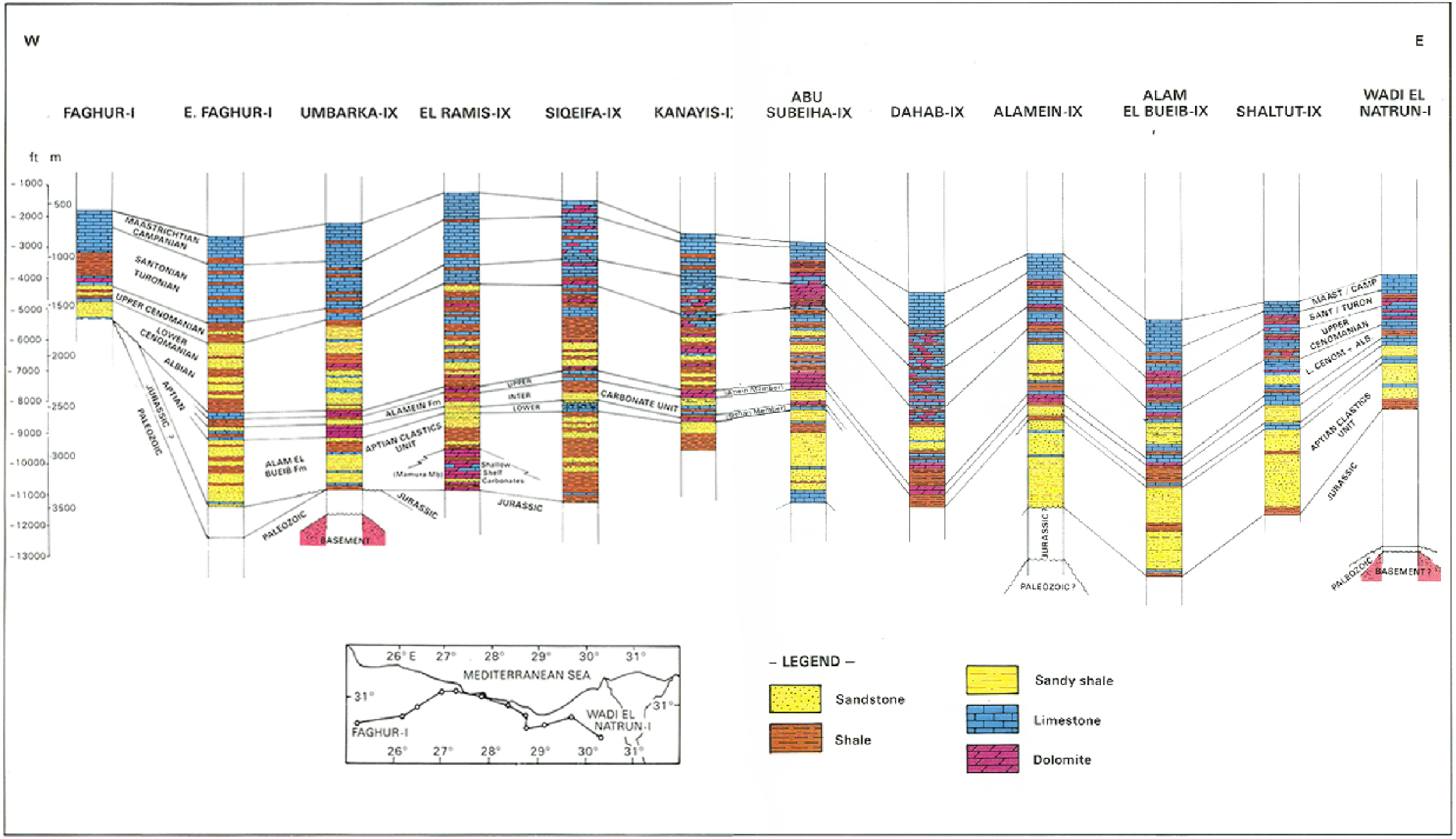


Fig. 1-16. E-W litho-stratigraphic correlation showing ~~f~~*acies changes of Cretaceous rocks in the Western Desert.*

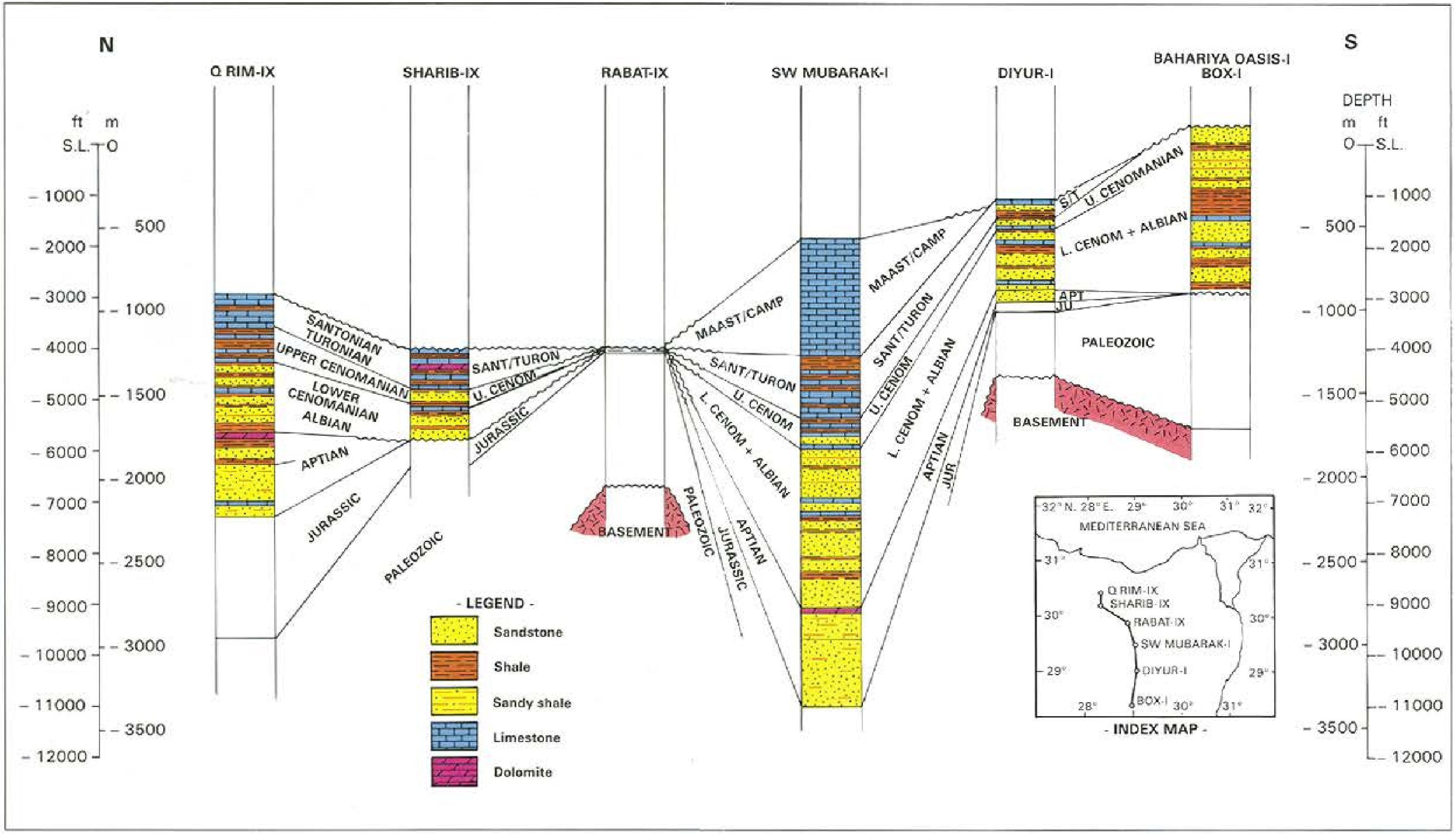


Fig. 1-17. N-S litho-stratigraphic correlation showing facies changes of Cretaceous rocks in the Western Desert.

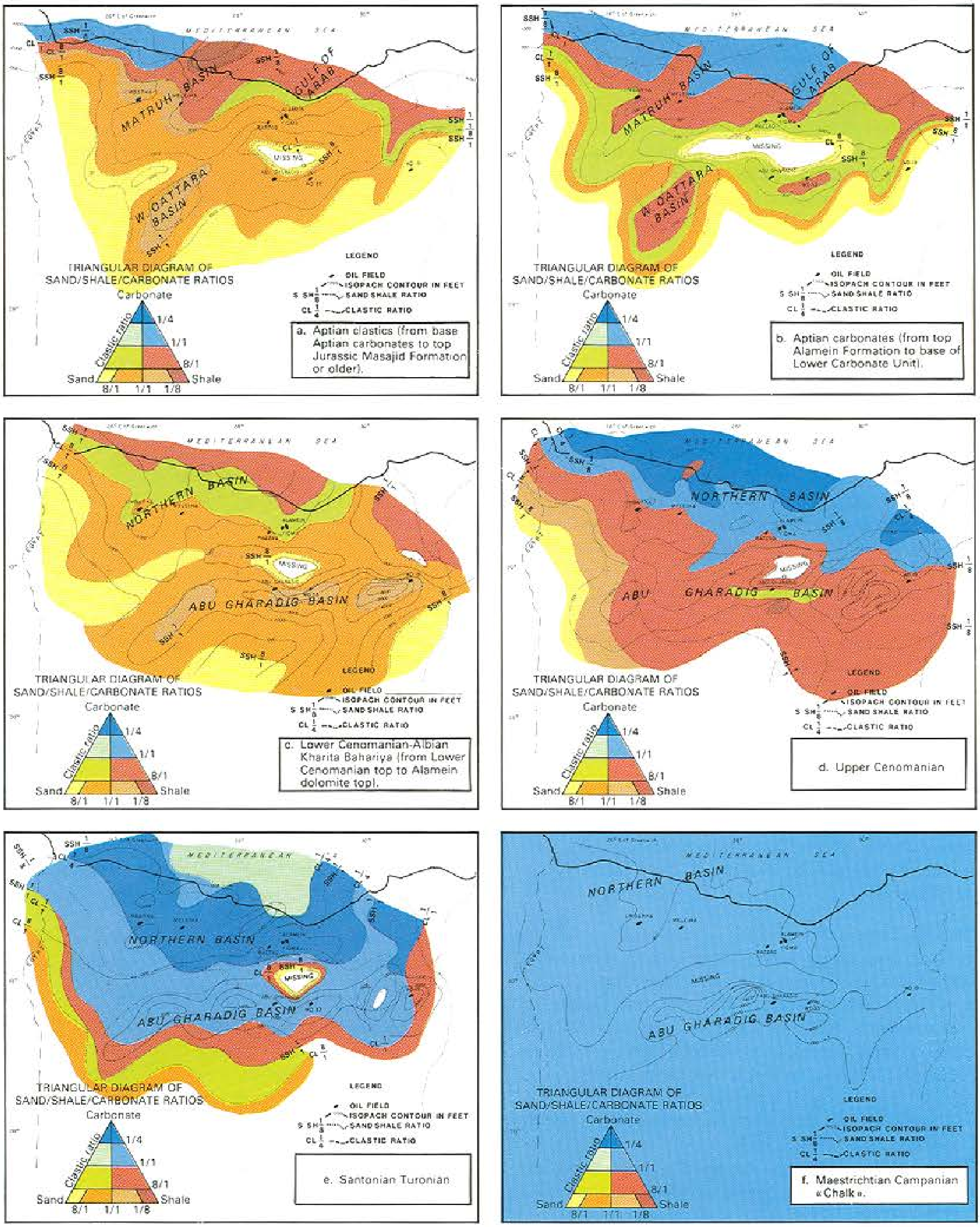


Fig. 1-18. Lithofacies maps of the Western Desert.

From the Abu Gharadiq depocenter, the Upper Cretaceous and Tertiary sediments rapidly thin southwards. In the Bahariya Oasis, the Upper Senonian transgression is represented by the **Ain Giffara** Formation of Campano-Maestrichtian age and consists of a basal marine sequence, 10 m thick, of dolomitic and phosphatic sandstone. It is overlain by the white Khoman chalk, Maestrichtian to Danian in age. These marine facies extend to the most southeastern area of the Western Desert.

Cenozoic

The transitional period between Late Cretaceous and Early Tertiary corresponds to the Alpine orogenic phase during which the ENE-WSW Syrian Arc system of deformation was most active.

At the end of Cretaceous time, sedimentation was continuous in the structurally low and subsiding areas, but depositional gaps and erosional truncations were common on the pre-existing highs, which were reactivated, especially during the Paleocene.

The extension of the **Esna** Formation, mainly Paleocene in age, is thus of limited area. It consists of light, chalky, occasionally reefal limestone, alternating with a variable content of fossiliferous and occasionally gypsiferous shales.

The overlying Lower to Middle Eocene **Thebes** Formation extends as far south as latitude 23°N. In the subsurface, it may be missing on the crest of major structural highs, but exceeds a thickness of 1000 m in the Fayoum trough. It is composed of white chalky, cherty limestone, dolomitic in places, becoming sandy to the south and shaling out northwards.

The **Mokattam** Formation is assigned to Middle Eocene and comprises light-coloured nummulitic and argillaceous limestone, with interbedded marls. It is regressive in relation to the Thebes Formation and markedly more terrigenous, with development of thick sand lenses. In the subsurface, it thins on highs and thickens in the active depocenters.

The facies distribution from Paleocene to top Middle Eocene is seen in Fig. 1-19.
Bituminous limestones reportedly outcrop in the north Bahariya area. Eocene oil bleeding limestone was cored in Burg el Arab and oil was tested from Eocene limestone in SW Mubarak. Some Eocene production was obtained from the WD 19-1 well.

The depositional environment of the Eocene carbonate series widely varied from tidal flat and platform conditions to a marginal and basinal environment, with occasional turbiditic fans.

The Mokattam Formation terminates the "Middle Calcareous Division". It was followed by the "Upper Clastics Division", a basically regressive cycle, which extends up to the Messinian (Uppermost Miocene).

This period was characterized by downwarping and intense basinwards step-faulting of the continental margin which generated the south Mediterranean basin. Concurrently, rifting of great magnitude formed the complex graben systems of the Red Sea, the Gulfs of Suez and Aqaba, and developed the dense NNW-SSE wrench-faulting system which crossed the "alpine" structures trending E to NE.

Since early Oligocene, in relation to the broad domal arching which affected all the Gulf of Suez and Red Sea areas prior to the rifting, the Western Desert hinterland emerged with consequent denudation and supply of clastic material.

The shoreline withdrew to between parallels 29 to 30°N. To the north, the scene was dominated by marked constructive delta systems, with northward progradation of the shelf and deposition of the thick, mainly pro-deltaic **Dabaa** Formation composed of argillaceous, carbonaceous shales with some interbeddings of glauconitic, sandy limestone.

Fig. 1-20 shows the facies distribution in Late Eocene to Middle Miocene time.

The maximum thickness of the Dabaa Formation in the present coastal area is around 650 m.

In Oligocene time, basalt-dolerite dykes and flows took place as a result of tensional movements in the rift zone.

The Miocene covers most of the Western Desert north of latitude 29°. Deltaic deposition (**Moghra** Formation) continued in the same pattern as in Oligocene, but clastic material was increasingly shifted eastwards by persistent longshore currents.

The northwestern shelf area, protected from the influx of clastic material, was covered from early Miocene by platform carbonate deposits (**Marmarica** Formation) which progressively extended to the east over abandoned deltas and paralic sediments.

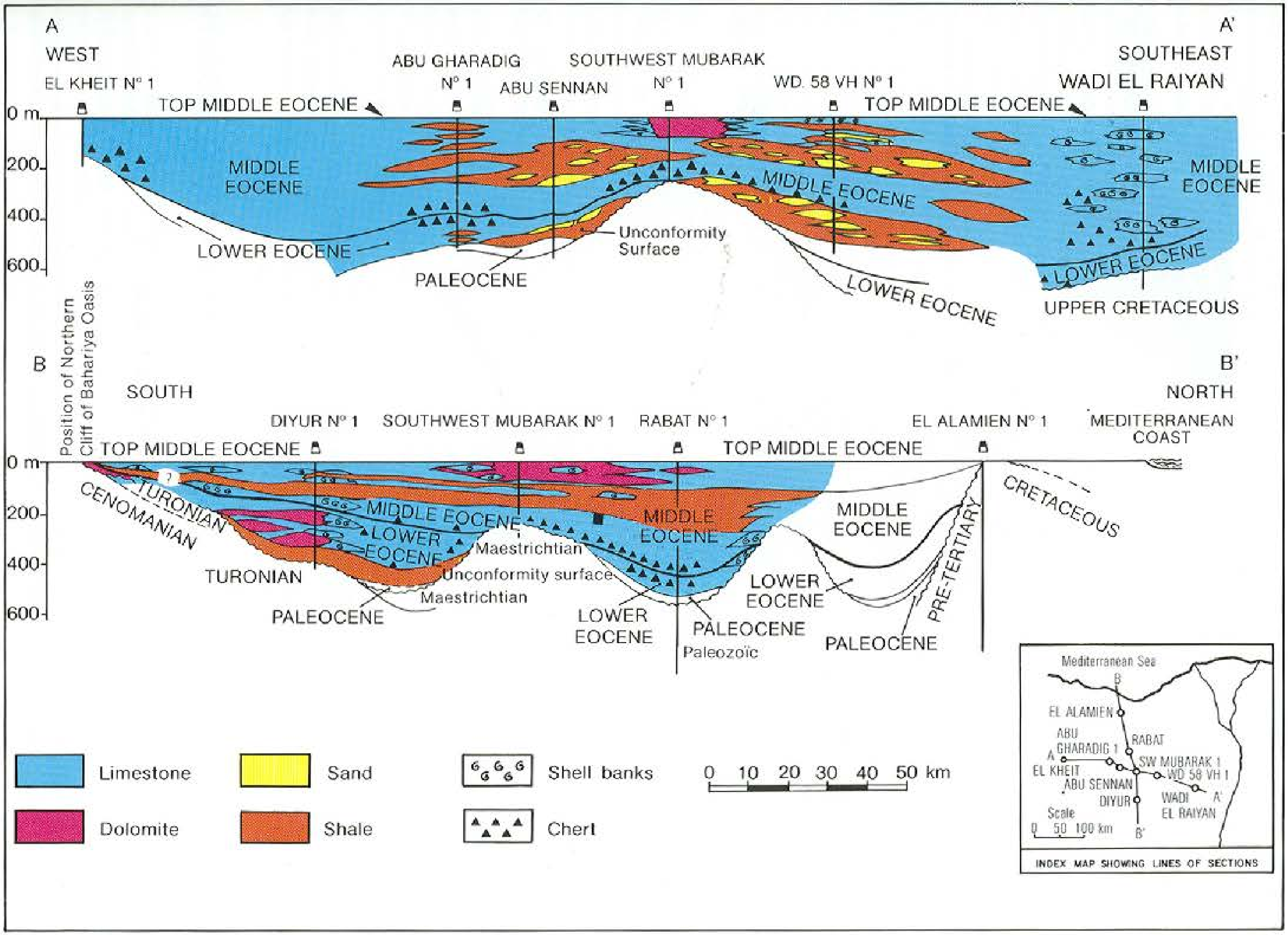


Fig. 1-19. Geologic cross-section showing facies distribution in Eocene time, levelled on top Middle Eocene.

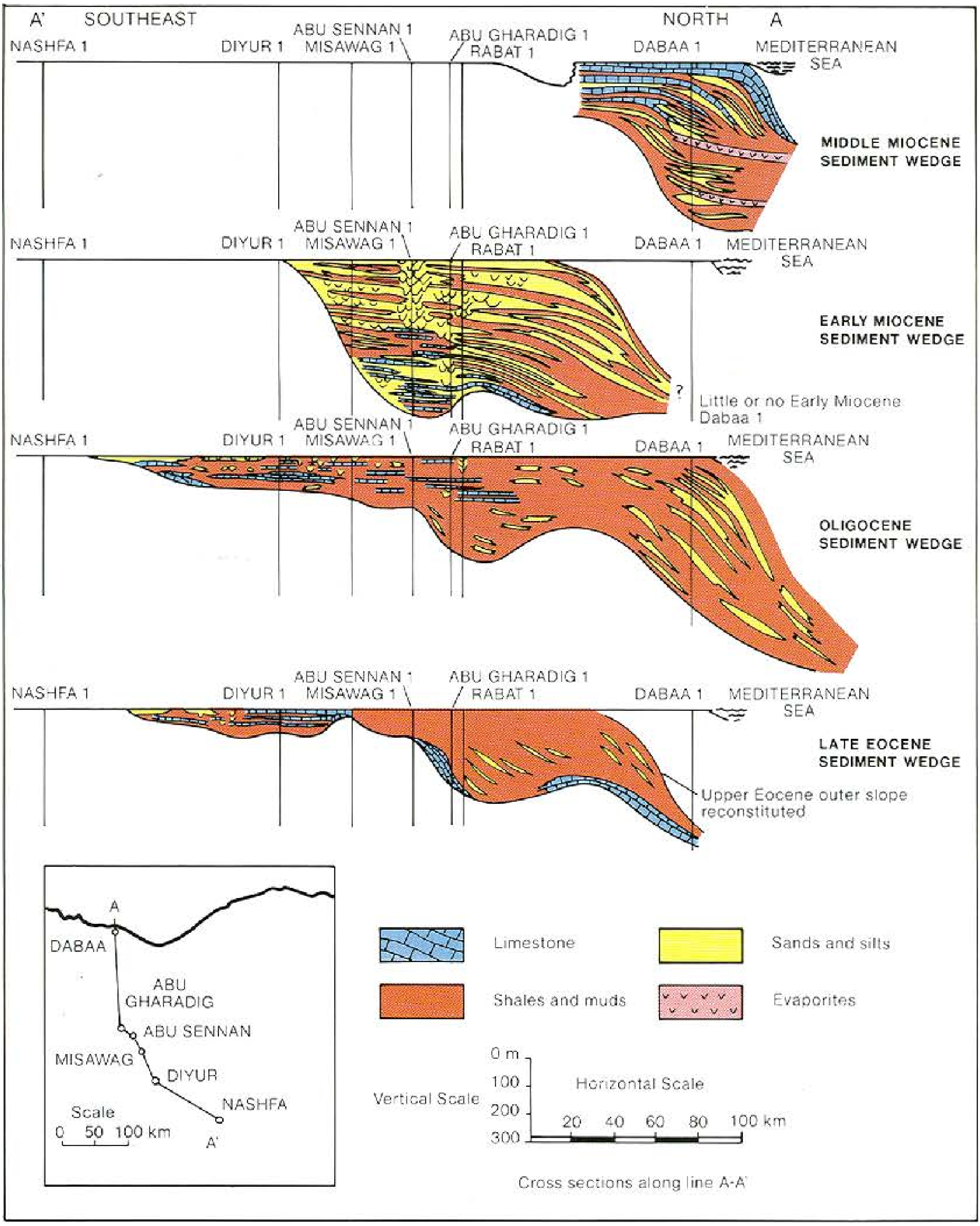


Fig. 1-20. Stratigraphic cross-section showing facies distribution in Tertiary time (Late Eocene to Middle Miocene).

Tectonic deformation resulted in a change of orientation of the hydrographic net, and the bulk of the clastic material was drained by the proto-Nile, which started building its delta near the site it presently occupies.

The Lower Miocene Moghra Formation consists of light-coloured sandstone, interbedded with soft shales, deposited in a deltaic or paralic environment, grading into the predominantly shaly **Mamura** Formation. The **Gebel Ahmar** Formation is the continental, variegated, sandy and conglomeratic equivalent of the Moghra deposits.

The Middle Miocene shoreline was located between latitudes 29°30' and 30°N, except for a narrow fringe of sandy deposits along the present shore and east of longitude 29°. The shelf was covered by the white, fossiliferous occasionally reefal limestone of the Marmarica Formation, with a narrow fringe of sandy near-shore deposits. East of longitude 29°, clastics are predominant, and the Marmarica limestone changes laterally to the peri-deltaic deposits of the Nile.

Upper Miocene was a period of uplift, accompanied by a gradual regression of the sea which led to the "Messinian salinity crisis", well known in this eastern part of the Mediterranean basin where thick evaporite sequences were laid down at this time. In the Western Desert, no marine sediments of this age have been identified so far, even in the coastal area.

In Plio-Quaternary time, marine, near-shore deposits were restricted to the northernmost fringe of the Western Desert, along the coastal area. They consist of sandstone, sandy fossiliferous limestone and detrital limestone bars.

Offshore they probably grade rapidly into marly to shaly sequences. Inland, sands of Plio-Pleistocene age were deposited under continental conditions.

HYDROCARBON HABITAT

In the Western Desert, hydrocarbon production is concentrated almost exclusively in Aptian and Cenomanian-Turonian carbonate and clastic reservoirs, with the exception of the Razzaq Field which also produces from the Upper Jurassic.
In Umbarka well 3, oil impregnation has been found in sandstone of questionable Paleozoic age.

There exist virtually no source rock analyses of the still poorly investigated Paleozoic, so that no objective inference can be made as to its hydrocarbon potential.
Nevertheless, the facies observed in the Devonian and Carboniferous along the Libyan border to the north show some promise.

Good oil and gas shows have been reported from Eocene carbonates (Abu Gharadiq, Matruh areas), but theoretically, burial and thermal conditions to which Eocene and younger Tertiary sediments were submitted in the Western Desert, were not adequate for hydrocarbon generation. Thus, these shows could result from migrated hydrocarbons.

Source Rocks

In the Mesozoic clastic series, the organic material is mainly derived from land plants (carbonaceous shales, lignite and coal seams). Source rocks in these sequences are thus predominantly gas-prone according to Tissot and Welte classification (J.R. Parker, 1982). They have been recognized, in low concentration, throughout all the clastic sequences, but are locally more concentrated in the Middle Jurassic Khatatba Formation.

More oil-prone source rocks do exist locally, where liptinic material (pollen, spores, algae, cuticles) are concentrated.

They are present in the Khatatba Formation as well as in the Lower Alam el Bueib (Barremo-Aptian) and Kharita (Albian) Formations.

Typical oil source rocks are present in non-calcareous shale sequences and are likely to be associated with the transgressive front of the Upper Jurassic and Upper Cretaceous carbonates. They have been recognized in the Upper Jurassic Masajid Formation, in the Neocomian Matruh shales and in the Abu Roash Formation (Cenomanian-Turonian).

The thermal gradient in the Western Desert is rather low, ranging from 1.23 to 1.78°F/100 ft.

Reservoirs

Potential reservoirs, especially sandstones, are widely represented throughout the Mesozoic section. The main carbonate-producing reservoir is the Aptian Alamein dolomite or dolomitic limestone, which shows relatively low primary porosity, but very good secondary vugular or fracture porosity, up to 25 %.

Porosity in the Alamein Field ranges from 7.5 to 23 %, and permeabilities vary from 30 to 2250 md. Flowing potential of wells reaches 8000 B/D.

In Yidma Field, porosity of the Alamein dolomite averages 8 %.

In the East Razzaq Field, the Abu Roash G Member produces from a dolomitic horizon with porosity up to 30 %.

Other oil-bearing carbonates are the limestones or dolomitic limestones, locally cavernous and fractured, of the Middle Abu Roash Formation (D Member in the Abu Gharadiq Field).

Sandstones of highly variable porosity and permeability have been found to be oil and/or gas-bearing at different stratigraphic levels; in the Paleozoic (?), in the Upper Jurassic Khatatba Formation, and intercalated in the Aptian Alamein Formation, in the Albian Kharita and Cenomanian Bahariya Formations, as well as in the Members C, E and G of the Turonian Abu Roash Formation.

The fields discovered to date are generally associated with paleo-highs where the carbonates and clastic reservoir characteristics have been favourably influenced by both the high energy depositional environment and the fracturing due to the periodic structural adjustments.

Traps, Seals and Migration of Oil

The oil and gas fields discovered to date are generally capped by shale sequences intercalated in the carbonate and clastic sections.

Local development of evaporitic sequences, including anhydrite and tight primary dolomite, may provide adequate seals, as in the case of the basal Member G of the Abu Roash Formation, in the Alamein Field.

Based on the burial and thermal history of the source rocks, potential hydrocarbon-generating areas have been delineated as seen in Fig. 1-21. They give a clear indication of the areal relationship between the postulated oil and gas kitchens and the discovered fields (J.R. Parker, 1982).

Oil of a similar type produced in the Alamein, Razzaq, Yidma, Umbarka, and Meleiha Fields probably migrated from Middle Jurassic and Lower Cretaceous source rocks.

Gas found in the Abu Gharadiq basin probably comes from source rocks contained in the same stratigraphic horizons.

Oil of the Abu Gharadiq and WD-33 Fields, whose characteristics differ from those pertaining to northern oil, was probably "cooked" in situ, that is, in the Abu Roash Formation.

Migration occurred vertically or over short distances from the surrounding graben-like depocenters towards the adjacent faulted uplifts.

Traps are of the combined stratigraphic structural type, consisting mainly of faulted anticlinal features induced by generally vertical basement movement.

Due to periodic rejuvenation of these horst-type structures, unconformities and gaps, onlapping wedges and erosional pinch-outs are frequently associated with the culminating areas and form multiple stratigraphic traps.

Nature of Hydrocarbons

Oil produced from the Western Desert fields ranges from 34 to 44° API gravity. Crude is paraffinic, with a low sulfur content of about 1 %.

Wet gas produced from Abu Gharadiq Field has a liquid/gas ratio of 88 bbls/MMCFG.

Fields

The first commercial discovery was made in 1966 with the Alamein Field.

To date, there are eighteen oil and/or gas fields and discoveries, with eight fields on stream, for a total of 180 exploratory wells.

Production level in 1982 was around 30,000 B/D. The size of the fields range from 3.5 million bbls of recoverable oil in WD-19, to 60 million barrels of oil in the Alamein as well as in the Abu Gharadiq Fields.

Figs 1-22 and 1-23 show the structural aspect of the Alamein and Razzaq Fields.

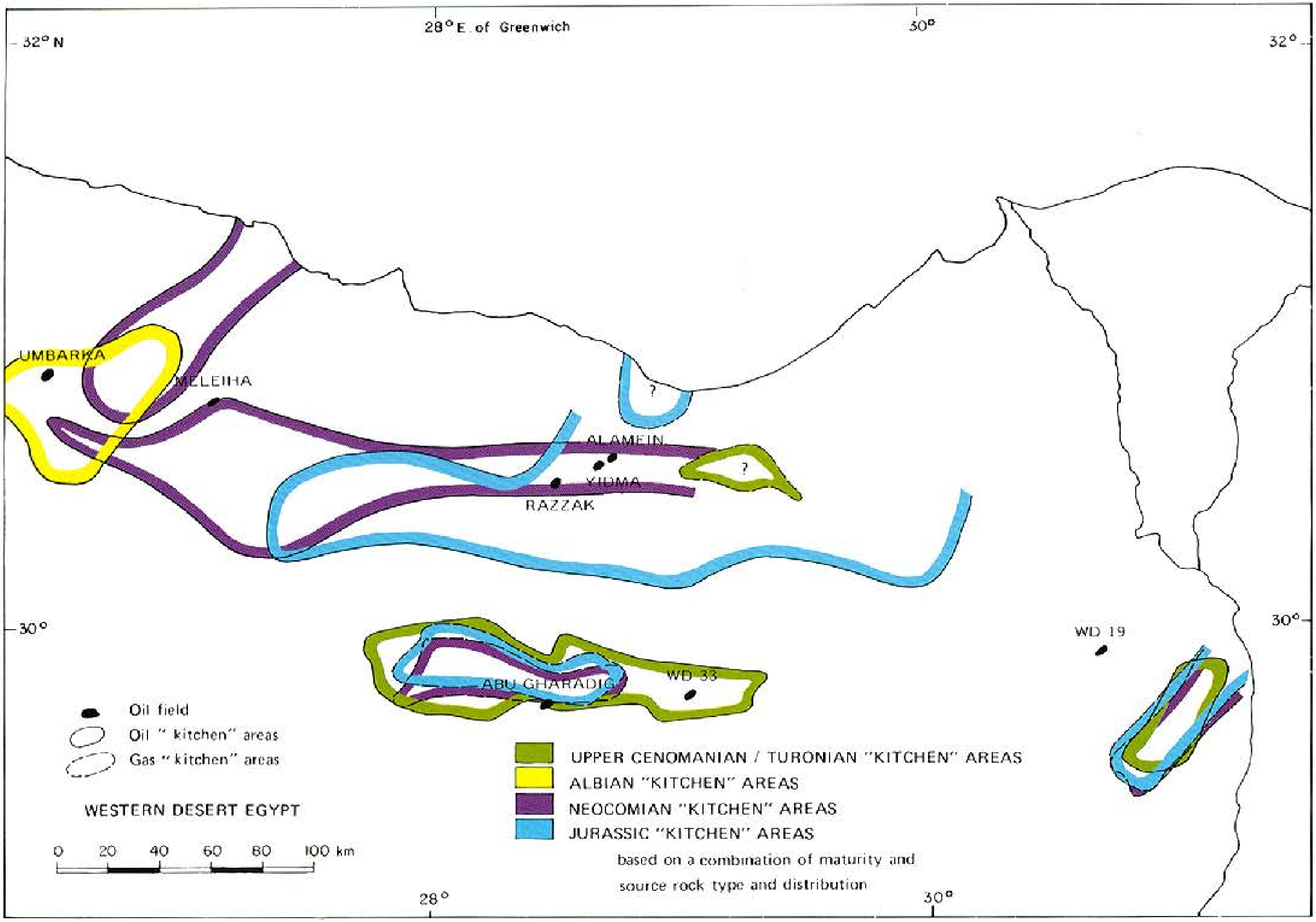


Fig. 1-21. *Distribution of the oil and gas "kitchen" areas in the north of the Western Desert.*

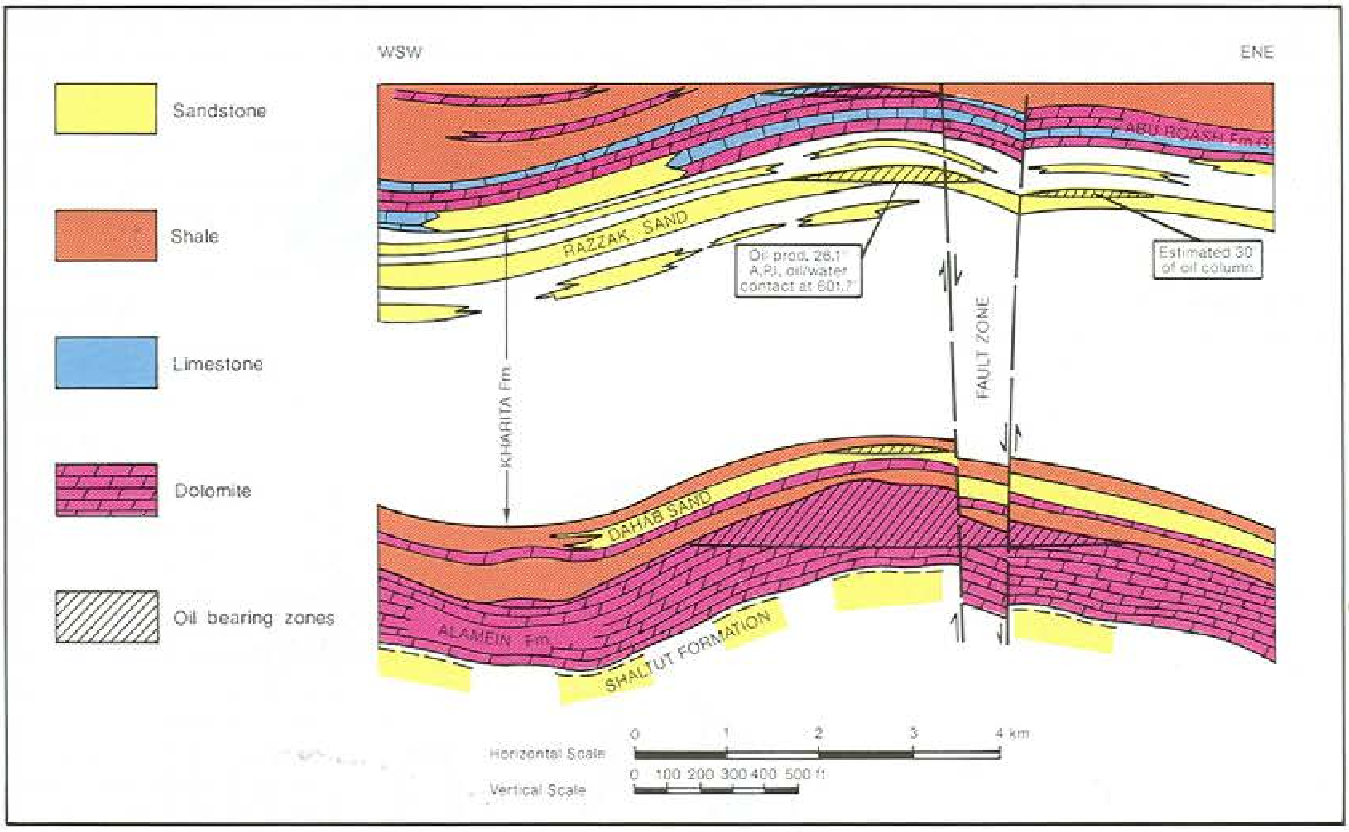


Fig. 1-22. Schematic cross-section of the producing interval of the Alamein Field.

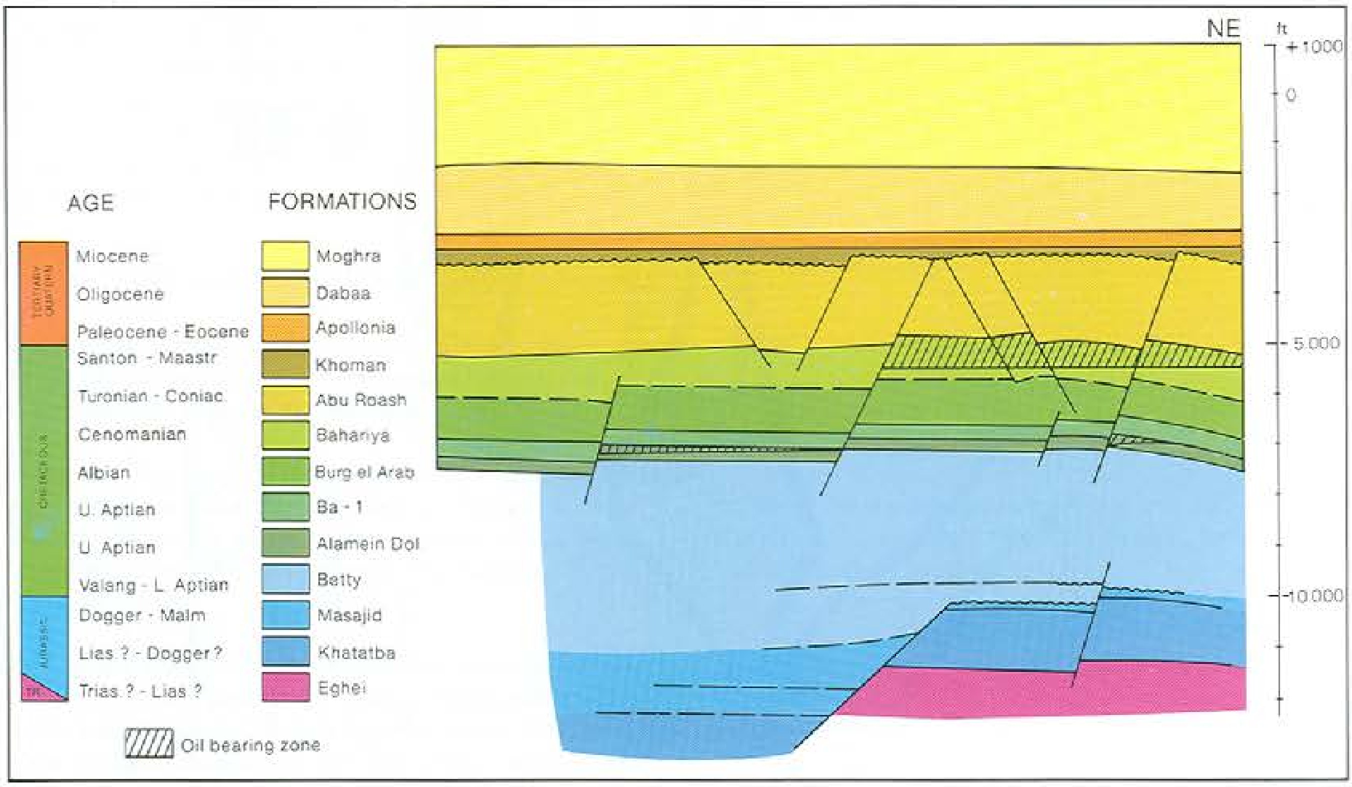


Fig. 1-23. Schematic structural cross-section of the Razzaq Field.

1.3. THE NILE DELTA

The present Nile Delta covers an onshore area of about 25,000 sq km and about an equal amount offshore to the 200 m isobath.

The southern apex of the Delta is at 30°N, some 30 km north of Cairo, where the Nile river splits into the western or Rosetta (Rashid) branch, and the eastern or Damietta (Dumyat) branch. The Delta is a lobate build-up whose formation begun in Miocene time. The ancient distributaries disappeared due to intensive irrigation constructions in the onshore Delta plain and were eventually reduced to the two branches mentioned above.

The construction of the Aswan dam in the upper reaches of the Nile river produced a significant reduction of outflow and concurrent sedimentary load, resulting in severe erosion of the Delta front with a consequent retreat of the Delta of several meters per year.

The Nile Delta appears to be more strongly developed on its eastern flank, due to longshore currents sweeping large amounts of fluvial deposits eastward.

In the offshore area, the delta front is expressed by a northward bulge of the various isobaths. It extends far beyond the 200 m isobath into the deep water area.

Expanses of fluviatile deposits and of delta build-ups are present as relics in several parts of northern Egypt. The oldest of these Tertiary deposits is present in the region of Faiyum, north of Birquet-Qarun at an elevation of about 350 m above sea level and dates back to Late Eocene-Early Oligocene. The deposits which have a thickness of 310 to 400 m exhibit deltaic and associated beach and offshore depositional sedimentary features and contain the well known fossil vertebrates. However, no signs have been observed and recorded which could indicate the place of origin and course of this Eo-Oligocene river which meandered across the plateaus of northern Egypt and built up the deltas.

In the Western Desert, river deposits consisting of sands and gravels overlie the Eo-Oligocene formations. They are spread over the plateau between Minia and the Bahariya Oasis. These formations are of Early Miocene age and were deposited by rivers which opened into the delta of the Moghra Oasis at the eastern tip of the Qattara depression.

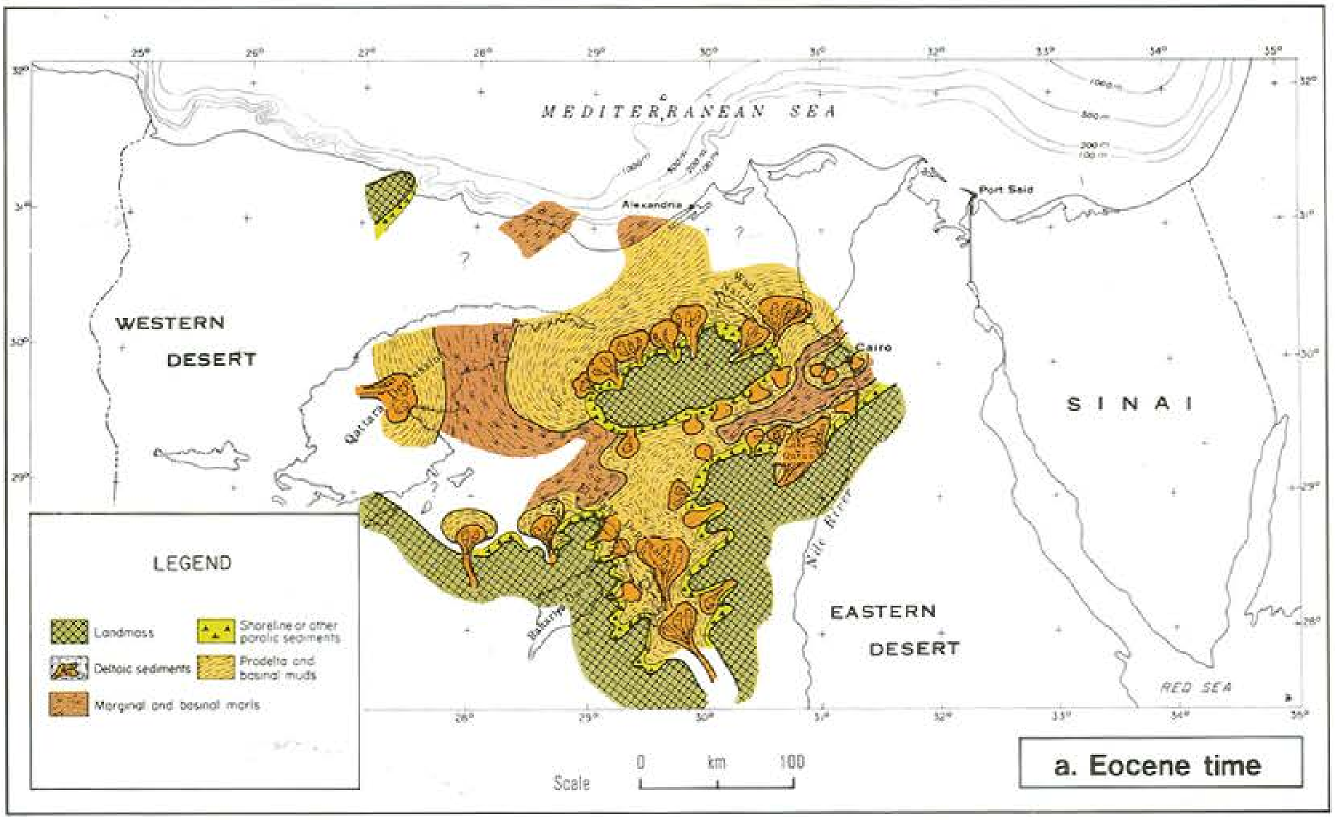
Again, the presence of land and semi-aquatic fossil vertebrates found in the area of Moghra indicate that these deposits formed a prograding delta.

Salem (1976) considered that the Eo-Oligocene and Early Miocene clastics represent deposits of an ancestral Nile which flowed in a northwesterly direction across the present-day El Bahr depression and into the Mediterranean Sea; and that an eastward shift of the Nile and its delta took place during Early to Middle Miocene time. This drastic change of course from west to east was probably the result of crustal movements that affected northern Egypt. Fig. 1-24 shows a tentative model of the course and depositional conditions of this ancestral Nile and its delta.

Said (1981) reached quite different conclusions based upon large amounts of data obtained from a number of water and oil wells drilled in the Nile valley and in the onshore and offshore delta area, also from geophysical records and seismic data.

According to Said, the River Nile owes its origin to a major tectonic event which affected the Mediterranean Sea in Late Miocene time. Crustal movements obstructed the connection between the Atlantic Ocean and the Mediterranean in the area of the Straits of Gibraltar. The interrupted inflow from the Atlantic led to a gradual dessication of the Mediterranean Sea, with subsequent developments of extensive and thick salt and evaporite deposits (Rosetta Formation). The lowering of the sea level due to the dessication is also evidenced by the steeply sloping river beds which at that time formed the drainage of the surrounding land masses into the lowered sea level.

Moreover, the enormous volume of evaporated water provoked a marked climatological change with frequent pluvial periods. Torrential streams cut deep gullies along the high mountain ranges of the Eastern Desert and flowed into the Eo-Nile which had developed as a subsequent river. It flowed in a deeply incised canyon, similar both in shape and dimension to the Grand Canyon of the Colorado River. According to Said, the Eo-Nile canyon had a length of some 1,300 km and a gradient of around 1: 400. Its bottom reached a depth of −170 m at Aswan, of −800 m at Asyut, halfway between Aswan and Cairo, of −2,500 m in the recently discovered channel north of Cairo and of over −4,000 m in the northern Delta Embayment, as seen in Fig. 1-25. It appears that in the slightly elevated south Delta Block this ancestral river cut through Oligocene basalts and clastics.



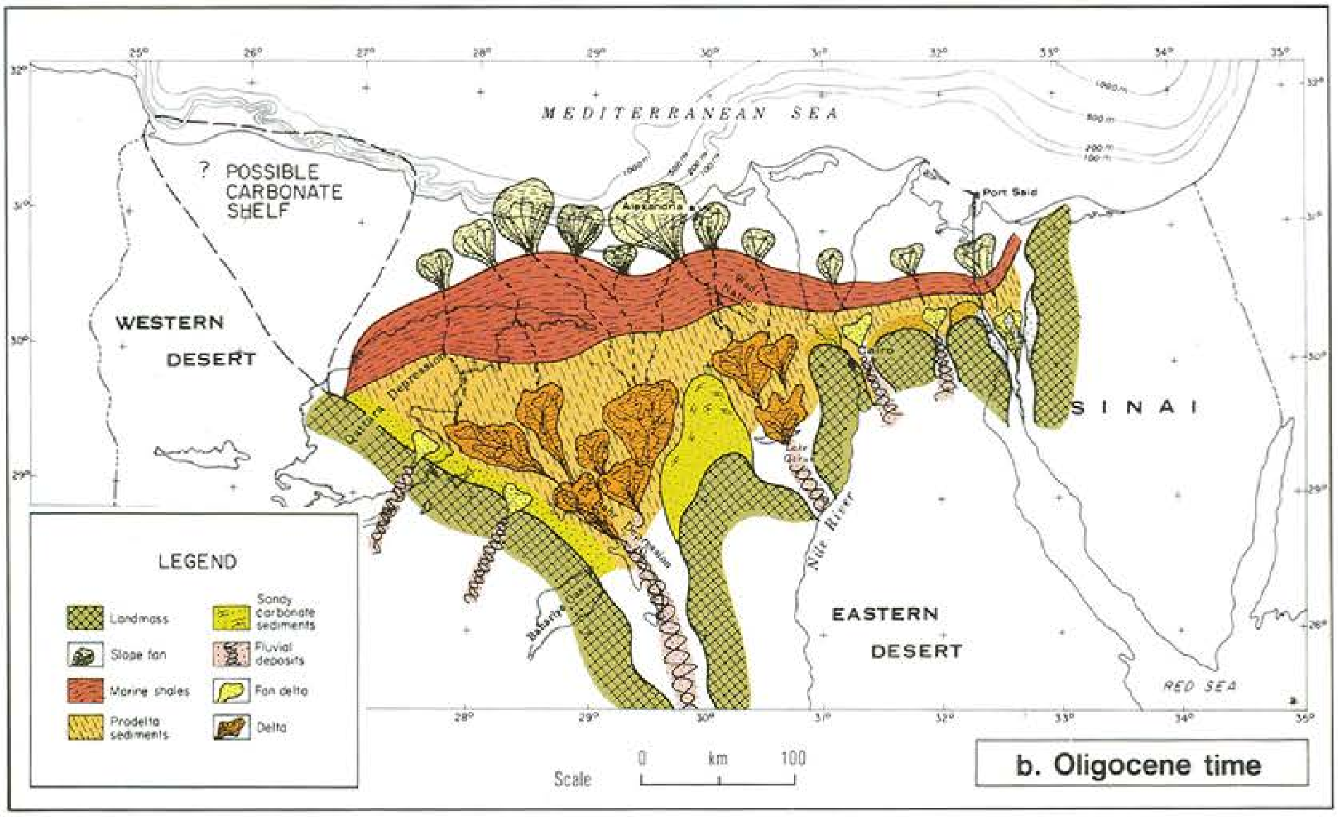


***Fig. 1-24.** Tentative depositional models for the Nile Delta.*

It then cut through Eocene and Cretaceous formations and scoured the Jurassic formations. It is most likely that these latter formations formed the bottom of the Late Miocene Eo-Nile canyon. The Eo-Nile, after cascading over the hinge zone into the north Delta Embayment spread out its sedimentary load in a series of coalescing fans. The thickness of the Late Miocene sediments range between 100 and 2,000 m.

With the beginning of the Pliocene, a renewed opening of the Mediterranean in the Straits of Gibraltar allowed a new inflow from the Atlantic. The advancing and rising sea eventually reached the area of northern Egypt, drowned the delta of the Eo-Nile and transgressed into the Nile valley depression, forming a narrow and long gulf extending south of Aswan. The Pliocene Sea also covered large parts of the land around the modern Delta, but overlapped the present-day Mediterranean littoral with only small fringes.

Thus it appears that the Nile Delta began to be formed by the Eo-Nile and subsequently by a number of large rivers from Pliocene through Pleistocene to Recent times. The Nile as it is known today appears to be a humble "descendent" of much larger and fast flowing rivers which flowed through the Nile valley and built up the huge delta. Compared to the Eo-Nile its gradient between Aswan and Cairo is only 1:13,000.

TECTONIC SETTING

The structural setting of the general area covered by the delta has been outlined with reasonable certainty by geophysics and well data. A pronounced flexure affecting pre-Miocene formations extends E-W accross the mid-delta area. This is the flexure seen in Fig. 1-13 in the section on the Western Desert. Seismic reflectors attributed to Lower Tertiary and Upper Cretaceous formations dip very steeply to the northwards, N of this line.

South of the flexure, asymmetric folds referred to as the Syrian Arc fold system extend along an arcuate trend from the northern Sinai and north of the Gulf of Suez across the southern part of the Delta into the Western Desert. This fold bundle is related to the Laramide phase of the Alpine orogeny and was formed in Early Miocene time.

North of the hinge line, marked large normal faults affect the Delta area. These gravity induced "down-to-basin" displacements occur along listric fault planes and involve very thick Neogene formations which are generally developed in an open marine bathyal facies.
Fig. 1-26 shows a schematic section of the down-to-basin faulting as interpreted from seismic sections in the central and western part of the Delta. Tilted fault blocks, 4 to 8 km wide, are recognized in these two areas.

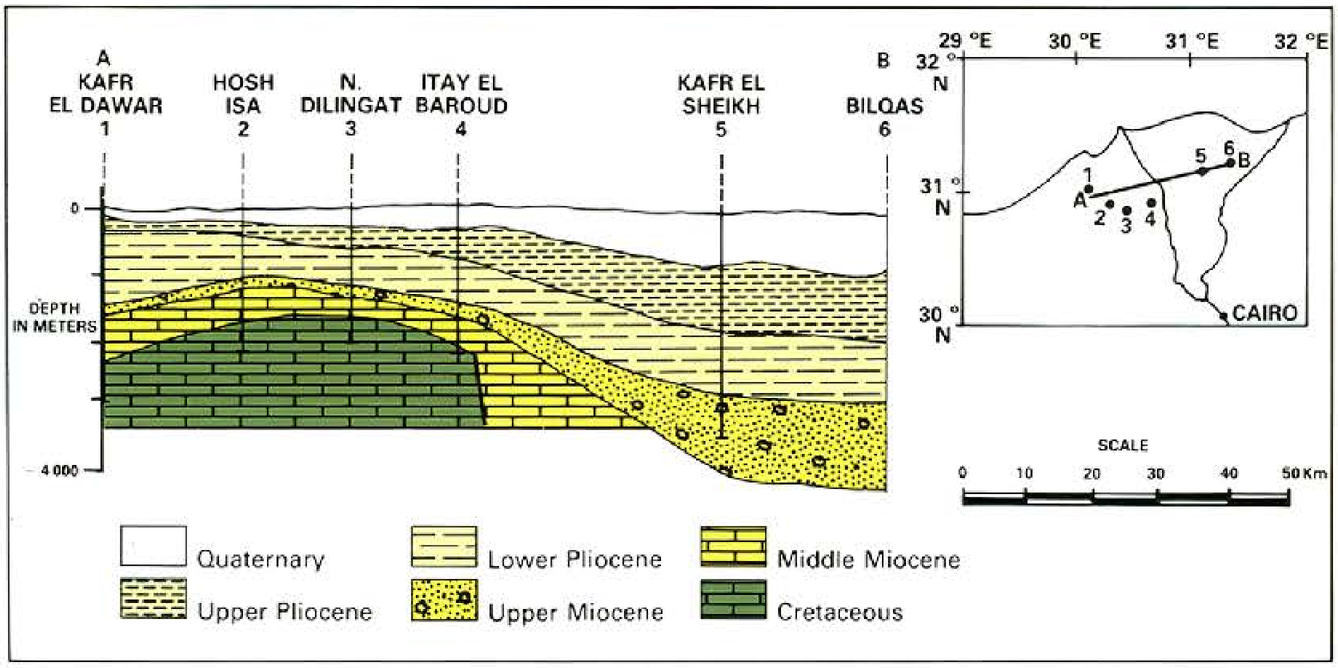


Fig. 1-25. *Cross-section in the Nile Delta (after Said 1981).*

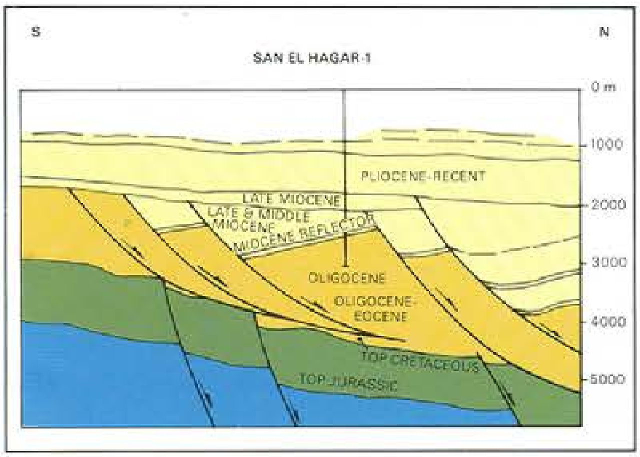


Fig. 1-26. Inferred growth fault structures with fault blocks in the westcentral part of the Nile Delta.

Rifting and transform faulting which led to the opening of the Red Sea, affected to a lesser extent the northern part of the Gulf of Suez. These movements produced a gentle N-S uplift in the central part of the Delta in contrast to the predominant E-W trend of the Mediterranean continental margin.

The Nile Delta as it is now, can be classified as a wave dominated feature with a tendency to extend into the eastern Mediterranean due to W-E longshore currents.

However, for its main build-up it had been a river dominated delta as proved by the prograding deposition of the clastic formations towards the north, northwest and northeast, as seen in Fig. 1-27, and the N-S scours that affected the Oligocene surface, see Fig. 1-28.

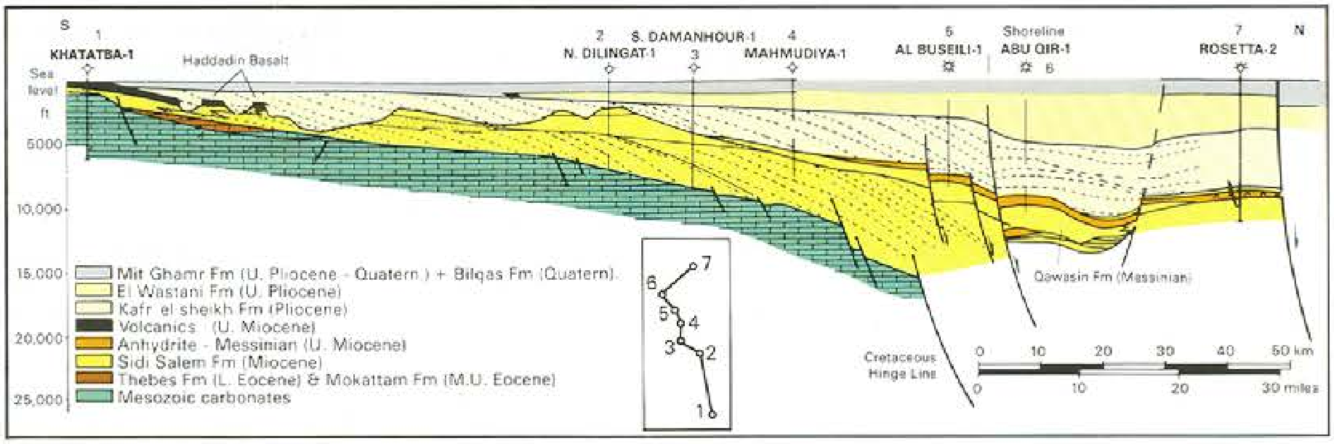


Fig. 1-27. Geological section through the western flank of the Nile Delta.

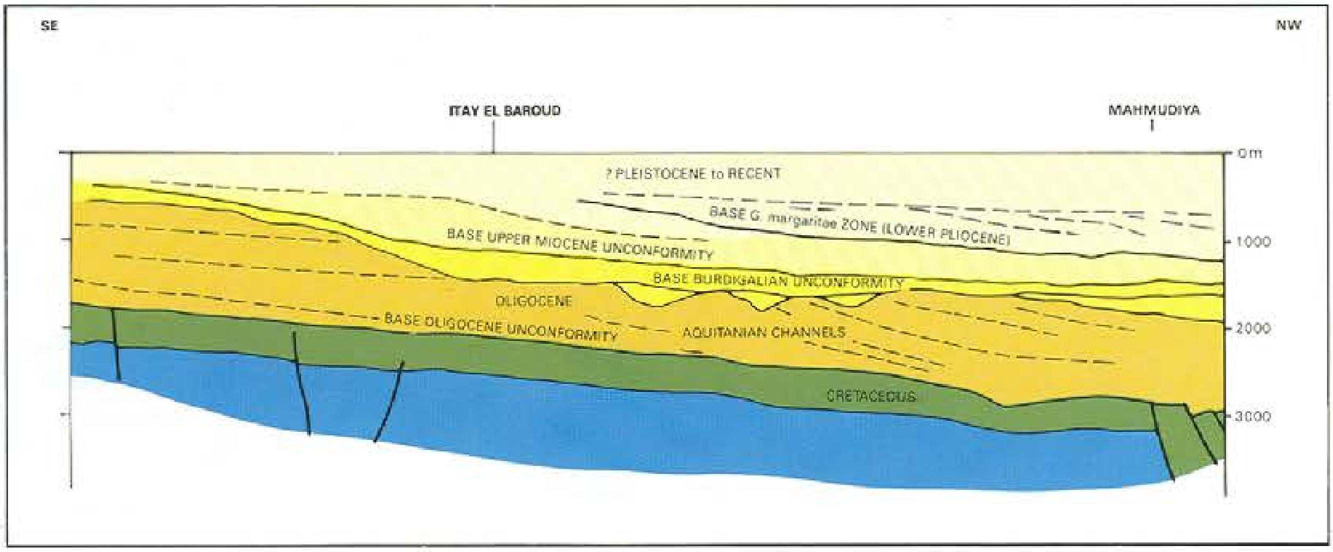


Fig. 1-28. Interpreted seismic section across the west flank of the Nile Delta, showing Aquitanian channel fills.

STRATIGRAPHY

A generalized stratigraphic column of the Nile Delta area is seen in Fig. 1-29.
The sedimentary sequence of the Nile Delta with hydrocarbon potential is limited, for the time being, to the Neogene formations trapped against listric fault planes or over tilted fault blocks. However, pre-Miocene formations which form the base of these Neogene sequences may also be considered as having hydrocarbon potential. They are, however, confined to the platform and its edge along the hinge line where they could be developed as high energy deposits such as reefal build-ups. North of the hinge line they may be adversely affected by the normal down-to-basin step faulting.

Paleozoic formations have not been encountered to date, and if indeed they are present, would be at inacessible depths.

Mesozoic

The pre-Miocene formations which were penetrated near the hinge line, included the series from Upper Jurassic to Oligocene. They consist of typical close to shore shelf and lagoonal deposits.
The stratigraphically lowest Mesozoic formation encountered in the Delta is of Upper Jurassic age. An overall regressive shoreline environment is observed for the Upper Mesozoic sequence, with significant unconformities at the top and bottom of the sequence. Best porosity is developed at the top of the Cretaceous in a saccharoid, vuggy dolomite. However, dolomitic and anhydritic cement obstructs the pores. No high energy nor reefal build-ups have been encountered, although these had been the objectives of exploration.
Upper Jurassic comprises mainly limestones with shaly interbeds, all with poor porosity.

Neocomian is represented by dark grey shales with occasional thin sandstone and limestone. Massive beds of limestones occur on top and at the bottom of this interval.

The Barremian consists of limestones and interbedded sandstone and thick grey shales. Dead oil is reported from sandstones and limestones.

The Aptian is subdivided in upper shales and limestones, tight massive limestones and lower shales, and limestones with thin interbeds of sandstones. Porosities and permeabilities are low.

The Albian is represented by limestones and grey shales with rare dolomites. The limestones are chalky but have a porosity of up to 12 % decreasing, however, downsection.
Cenomanian to Senonian is represented by a series of limestones and dolomites with occasional good porosity but low permeabilities.

Cenozoic

Middle Lower Eocene consists of a thin series of marly limestones.
Oligocene is a very thick series of predominantly shales with some sandstone interbeds.
The predominantly carbonate deposits of the Mesozoic and Lowermost Tertiary are overlain by a huge section of Oligocene and Neogene clastics.
Comparisons of the sections penetrated in the Delta area suggest the sedimentary build-up to be very similar over the entire Delta. The section is a massive clastic sequence of fine and coarse clastics with rare intervals of anhydrite and carbonates. Rizzini et al. (IEOC 1976), who introduced the Neogene stratigraphic breakdown, also recognized a Miocene, a Pliocene and a Holocene depositional cycle. This stratigraphic subdivision is generally adopted although there may be some differences of opinion in regard to age definitions. Fig. 1-30 shows this tentative stratigraphic model of the Delta build-up and Fig. 1-31 expresses the different age attributions for the same formations, depending on age definitions based on faunal associations.
The biostratigraphic units recognized by Rizzini et al (1976) are Langhian (Lower Miocene), Serravallian and Tortonian (Middle Miocene), Messinian (Upper Miocene), Lower, Middle and Upper Pliocene, and Pleistocene.

Miocene

The Miocene cycle consists of formations ranging in age from Lower to Upper Miocene. The depositional cycle is subdivided into rock units which are the Sidi Salem Formation, the Qawasim Formation and the Rosetta Formation. The cycle starts with an open marine deposit and ends with a starved evaporitic sequence. These units overlie pre-Sidi Salem formations which can be regarded as time equivalents of the Moghra series of the Western Desert and are considered of Oligocene age.
The thickest section of the **pre-Sidi Salem** Formation, some 300 m, was encountered in the Al Tabia IX well located near the coast NE of Alexandria. It is a typical open marine to fluvio-marine deposit with predominant shales and rare limestone stringers.

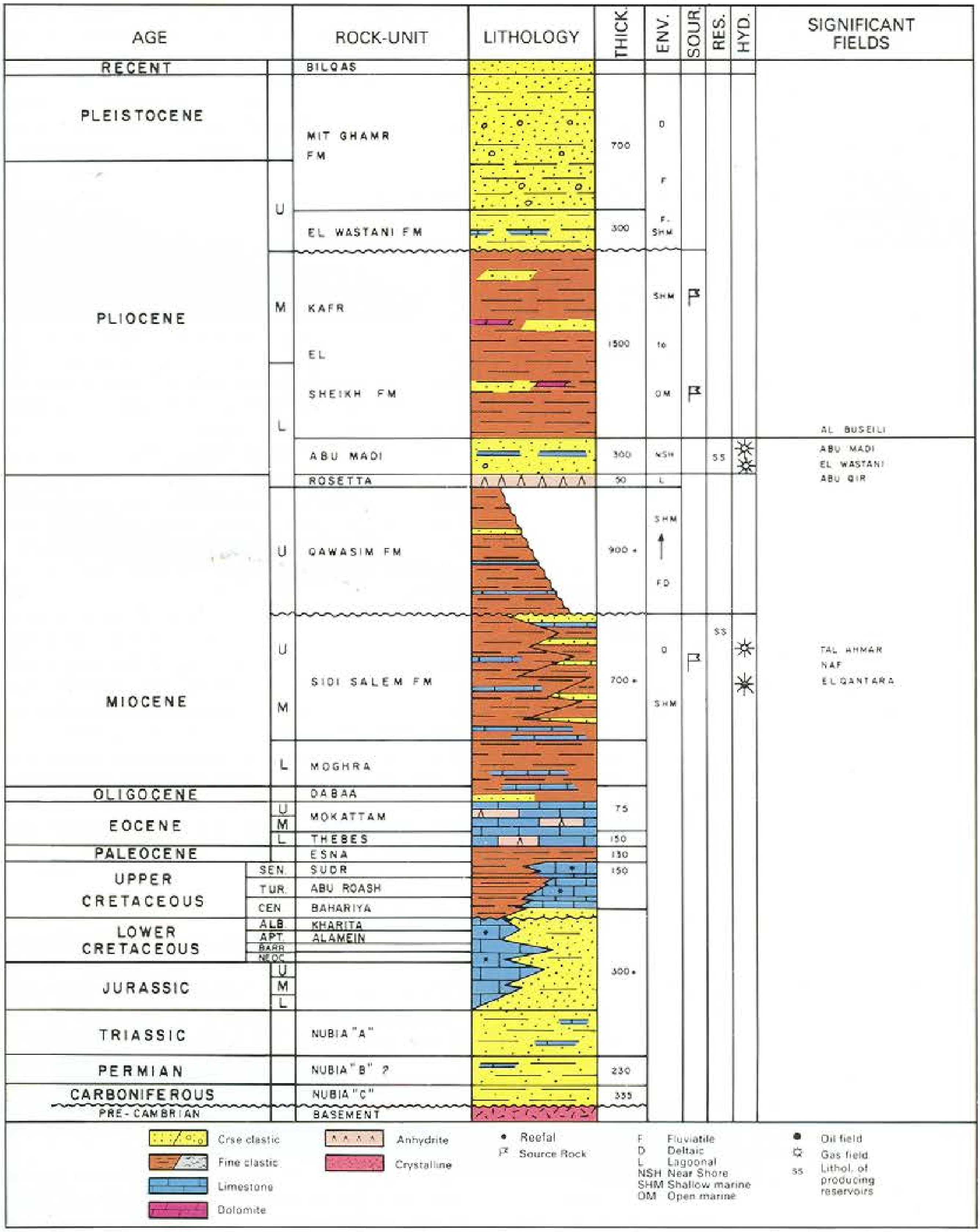


Fig. 1-29. *Generalized litho-stratigraphic column of the Nile Delta with inferred old Tertiary and pre-Tertiary sequences.*

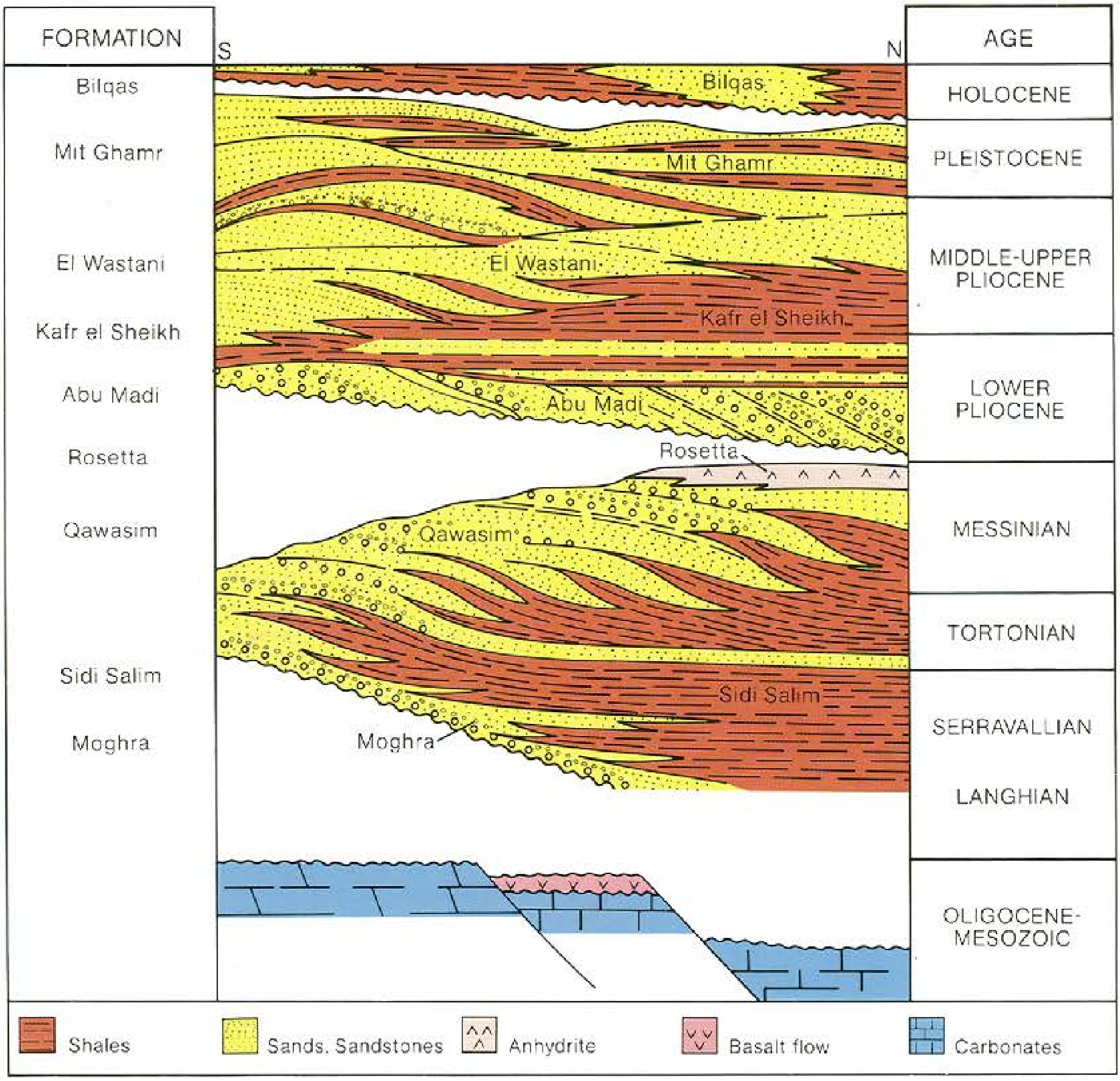


Fig. 1-30. *Stratigraphic model of the Neogene-Quaternary in the Nile Delta.*

The age of the **Sidi Salem** Formation, ranges from Langhian to Tortonian. The lower limit is not known in the central part of the Delta, but was encountered in the western offshore area (Abu Qir). The type section of this unit is represented by the bottom sequence of the Sidi Salem well 1 from 3592 to 4038 m. The well is located south of Lake Burullus. The Sidi Salem Formation is composed of predominant shales with few interbedded dolomitic marls and rare sandstones. The upper limit is formed by the base of the thick conglomeratic series of the Qawasim Formation. Offshore it is overlain directly either by the Rosetta Anhydrite or by the Lower Pliocene clays of the Kafr el Sheikh Formation.

Extensive facies changes, both lateral and up-dip occur within the Sidi Salem Formation in particular and in the Miocene sequence in general. Fig. 1-32 shows the relationship between the various Neogene units.

The **Qawasim** Formation overlies the Sidi Salem Formation and comprises a thick sandy and conglomeratic series of Tortonian to Messinian age. The type section of this series is composed of an irregular sequence of thick sandstones and very thick conglomerates containing often well rounded pebbles. The series is present in the interval from 2800 to 3733 m in Qawasim 1 well, located some 14 km east of the Sidi Salem well 1. The formation contains a rare Messinian fauna. It could be regarded as a lateral facies of the Sidi Salem Formation rather than an independent, stratigraphically higher rock unit.

In any case, the development of this series marks a change in the depositional environment from fluvio-deltaic to marine. The thick sandstone beds as well as the conglomeratic layers have generally a lenticular shape and are prone to slumping. Sedimentary structures typical of high energy deposits alternate with structures of quiet and restricted water circulation.

The **Rosetta** Formation is represented by large layers of anhydrite with interbedded thin claystones. The formation has been encountered in well Rosetta 2 in the interval from 678 to 2718 m. The well is located offshore, NE of the mouth of the Rosetta Nile branch. The presence of the Rosetta Anhydrite seems to be limited only to the northern and offshore part of the Delta. It has not been encountered in wells drilled on the west flank of the Delta (Abu Qir) but was present again offshore to the north of Alexandria.

A Messinian age has been attributed to the Rosetta Anhydrite because of its position below the marine shales of defined Lower Pliocene age. The formation indicates a general starvation of the sea that affected the whole Mediterranean area and led to the deposition of evaporites. The absence of the Rosetta Anhydrite in certain areas of the Delta may be due to local shoaling, where brine concentration would not be possible, or to emergence.

Pliocene

The Pliocene cycle is subdivided into the Abu Madi Formation, the Kafr el Sheikh Formation and the El Wastani Formation.

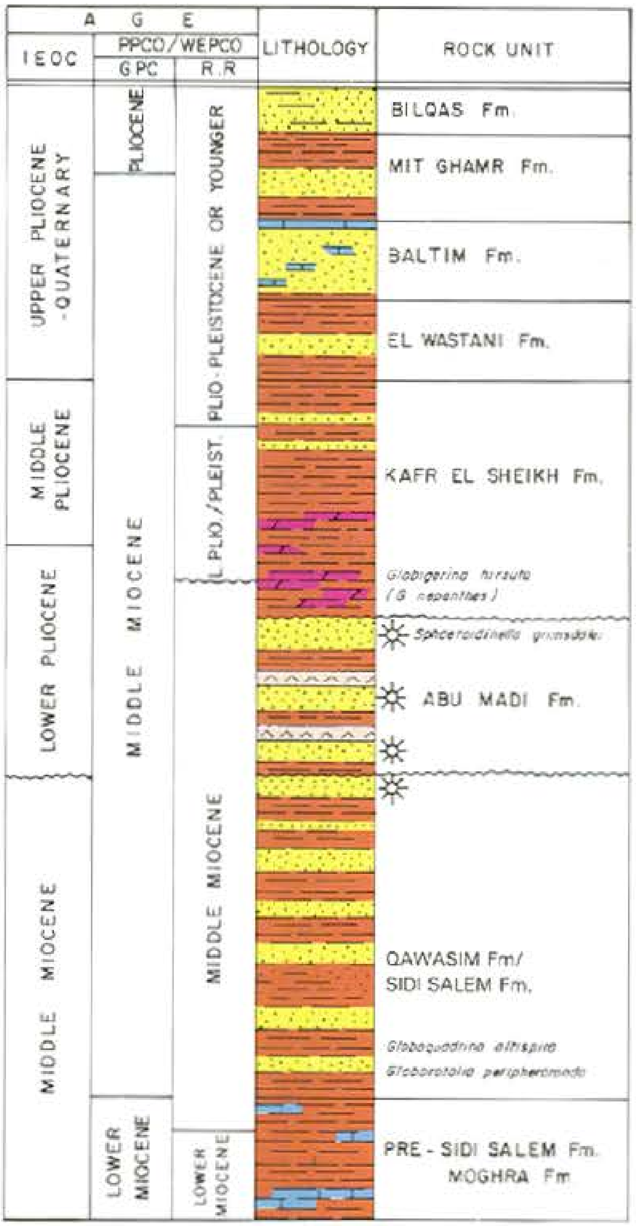


Fig. 1-31. *Abu Qir stratigraphic column showing different age attributions.*

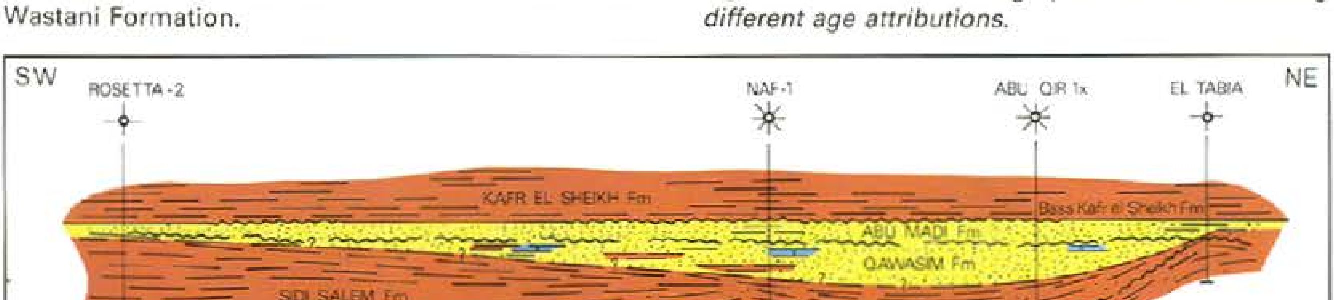


Fig. 1-32. *Facies relationship of Neogene formations on the west flank of the Nile Delta.*

The **Abu Madi** Formation is represented by a series of thick bodies of sands, in part pebbly, with interbedded thin shales. The formation is crossbedded and overlies the Rosetta Anhydrite and/or the Qawasim Formation, with a marked unconformity. It is a marine deposit of Lower Pliocene age. The shale content increases upsection and the contact with the overlying Kafr el Sheikh Formation is gradational. The formation was deposited in a deltaic environment and grades upsection into a shallow marine environment. The type section, is present in the Abu Madi well 1 in the interval from 3007 to 3229 m. The Abu Madi Formation is the gas producing horizon of the Nile Delta gas fields.
The **Kafr el Sheikh** Formation ranges in age from Lower to Middle Pliocene. The sequence consists of soft clays with interbedded, poorly consolidated sands with a clayey matrix. The clays are composed in equal proportions of kaolinite and montmorillonite with very little illite. The development of this series appears to be rather constant over the entire Delta area.
Its lithology and faunal content points to an outer shelf depositional environment. Its top is defined by the overlying El Wastani sheet sands which have a typical littoral fauna. The section has been penetrated in the Kafr el Sheikh well, located some 40 km SSW of the Abu Madi gas field, in the southcentral part of the onshore Delta area. Its thickness is 1458 m.

The **El Wastani** Formation is 120 m thick in El Wastani well 1. The unit consists of thick quartzose sands with argillaceous interbeds. Its upper limit is ill-defined and its age is Upper Pliocene. The depositional environment of the formation is transitional between the outer shelf facies of the underlying Kafr el Sheikh Formation and the overlying Holocene Mit Ghamr Formation. It exhibits well developed foresets due to progradation.

Holocene

The **Mit Ghamr** Formation was encountered between 20 and 484 m in the Mit Ghamr well located in the southern part of the Delta on the east side of the Damietta branch. The depositional environment of this formation is probably shallow marine to fluvial. It is a typical fill-up of a basin with shelly sands, coquina beds, clays and peat. Its age is Uppermost Pliocene to Quaternary.
The **Bilqas** Formation is the top cover of the Delta area and consists of sands and clays. Plant remains and peat deposits are frequent. The deposition occurred most likely in lagoons and brackish swamps, interrupted by beach sands.

HYDROCARBON HABITAT

Encouraging discoveries of major gas fields have been made in the onshore and offshore areas of the Nile Delta. The Delta seems gas prone, essentially methane, with a fair content of gas condensate; very few wells have produced oil and gas. The main producing formation is the Abu Madi sandstone of Lower Pliocene age.

Source Rocks

The presence of organic rich shales within the Sidi Salem and the Kafr el Sheikh Formations is well known. However the type of source rocks, the degree of maturation and the thermal alteration of the organic content is not well understood.

Reservoirs

The Abu Madi sandstones have proved to be the most suitable reservoirs of the Nile Delta and most of the fields produce gas from these sands. The North Alexandria Field NAF has 21% average porosity for the Abu Madi sand. Additional reservoirs are represented by the sands of the Sidi Salem Formation (Tal al Ahmar, El Temsah).

Traps and Hydrocarbon Migration

Lenticular sands are present on gentle anticlines. However, other types of traps, typical of deltas in general can be visualized. Fig. 1-28 shows channels scoured in Oligocene formations and filled with Lower Miocene formations. Evidence of growth faults is seen on seismic sections.
The generation of gas and its condensate is thought to have occurred in relatively recent time, that is after the deposition of the Pliocene sequence. The pathway from the source rock to the reservoir was probably short.

Nature of Hydrocarbons

Gas of the producing fields in the Delta consists of methane (87 to 93%) with a tail of higher hydrocarbons. The gas condensates vary from 42 to 59°API. In pre-Miocene formations, shows of dead oil were reported in Lower Cretaceous carbonates and sandstones, some gas and fluorescence was noted in Eocene marly limestones.

1.4 SINAI

Sinai covers about 61,000 sq km. Basement rocks form the high-relief mountainous tip of the peninsula, culminating at 2675 m (Gebel Musa). The central part of Sinai is covered by the subhorizontal Mesozoic and Tertiary sediments which form the high plateaus of Egma and El-Tih. These are drained towards the Mediterranean Sea by the multiple affluents of the Wadi el Arish. From latitude 30° to the north, alternating faulted domes, anticlines and synclines known as the Syrian Arc, form a contrasting topography of low alluvial plains and high hill masses.

Due to a series of down-to-basin faults, Neogene in age, the northern fringe of the Syrian Arc sinks seawards. It is hidden under the Quaternary coastal plain and the continental shelf deposits.

To date, the prospective area is confined to the northern coastal plain along the Mediterranean, and its offshore extension, as well as the western coastal plain along the Gulf of Suez with its offshore extension.

TECTONIC SETTING

The Precambrian igneous and metamorphosed rocks of the Nubian-Arabian shield are exposed in the southern part of the Sinai Peninsula. Their peneplaned paleosurface dips gently northwards with consequent thickening of the overlying sediments, whose ages range from Cambrian to Recent.

On the Mediterranean coast, the total thickness of sediments exceeds 6000 m.

From the south, where the strata are practically horizontal, the structure of the sedimentary cover becomes progressively more complex towards the north. The northern third of Sinai exhibits a series of close, parallel anticlinal trends, which pertain to the Syrian Arc system.

Located in the fork of the Suez graben and the Aqaba-Dead Sea rift, Sinai is flanked by the two corresponding shear fault systems related to the opening of the Red Sea. Along the Gulf of Aqaba, a N15°E sinistral strike-slip movement has been observed, with a horizontal shift of around 110 km.

Simultaneously, right-lateral shear faulting, trending N35°W, developed along the Gulf of Suez, with a horizontal displacement of the western bank estimated at 60 km minimum.

The angle of 50° between the shear fault systems is in accordance with the theoretical ellipse of stresses, and implies a main compressional force directed N10°W.
This force is considered to be responsible for the major faults which cross the Central Sinai, with a general E-W trend, showing vertical displacement up to 1000 m and horizontal offsets which may reach 2.5 km.

In North Sinai, the Syrian Arc folding system exhibits an orientation towards N65° to 85°E which correlates with the NNW trend of the main compressional stress mentioned above. It consists of asymmetrical anticlines with a gently dipping northwestern flank and a steep, in places overturned, or even overthrust southeastern flank.

In the northeast, as shown on Fig. 1-33, the fold belt, (150 km wide), is progressively bent to the north.

Beyond the Egyptian border, it is squeezed between the left-lateral strike-slip fault zone of the Aqaba-Dead Sea rift and the major transform fault called the Pelusium line, a transcontinental megashear suture. There, the anticlines appear to be drag folds. The mechanism and timing of the North Sinai folding is complex and still debated. It results from a changing field of stresses, both in time and direction. It is related to the northward translation of the African plate, to the anti-clockwise rotation of the Arabian sub-plate, and to shear movements along the sides of the triangular Sinai sub-plate.

Some authors consider that the folding started as early as late Paleozoic, when the embryonic Gulf of Suez graben was formed. It underwent periods of reactivation throughout the Mesozoic producing local unconformities restricted to the structural crests. They believe that the crustal deformation climaxed in Oligocene time.

Other authors believe that the Syrian Arc system of folds was mainly formed during early Tertiary and that an incipient deformation could have taken place in Senonian or even Turonian time.

In either case, by the end of Campanian, major anticlinal features showed already vertical closures up to 100 to 200 m.

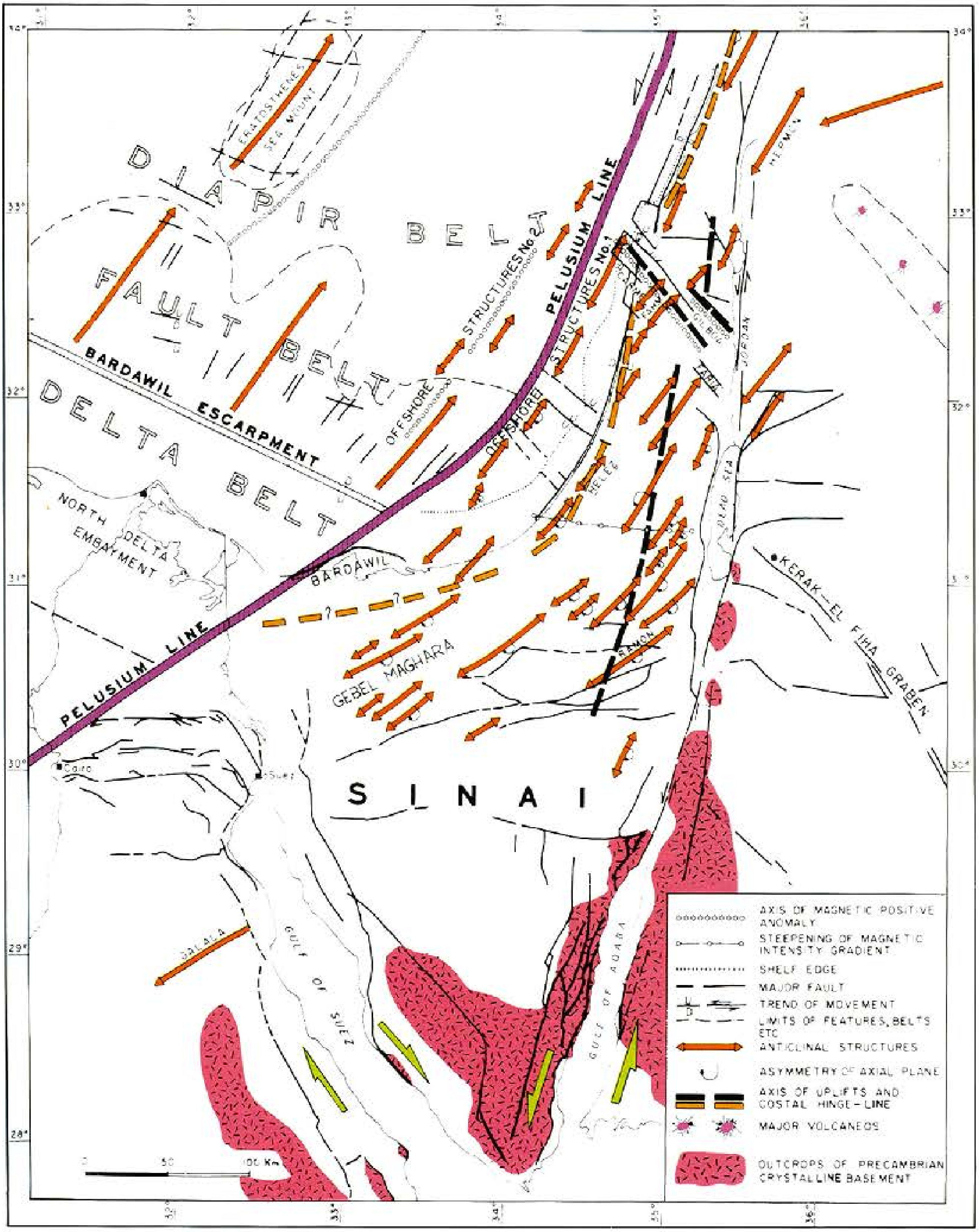


Fig. 1-33. Sketch of major regional tectonic elements of Sinai area.

Detailed structural and stratigraphic studies carried out on well exposed anticlinal cores along the Central Sinai E-W shear zone, have shown the complex evolution of the structures. The folding has been synsedimentary and practically continuous since Upper Cretaceous. The lateral movement along the strike-slip faults has played an important part in the folding process.
Horizontal and vertical movements of major amplitude have been evidenced in post-Pliocene time.

STRATIGRAPHY

Located between the Nubian-Arabian shield in the southeast and the eastern Mediterranean basin, Sinai is covered by sediments predominantly deposited in a shallow platform environment. They range from Cambrian to Recent. A generalized stratigraphic column is seen in Fig. 1-34.

Paleozoic

In the northern Sinai, the Paleozoic section does not outcrop, but it is well exposed in southern Sinai, especially in the Um Bogma area (latitude 29°N), east of Abu Zenima. There, the aggregate 300 m of Carboniferous beds and possibly earlier Paleozoic strata (Cambrian ?) consist mainly of red or variegated sandstone, deposited in shallow marine, lagoonal and transitional environments, see Fig. 1-35. Some 130 km to the NNE, in central Sinai, the Abu Hamth exploratory well penetrated about 680 m of Paleozoic sediments, predominantly made of sandstones and shales.

Mesozoic

Triassic

About 185 m of Triassic sediments are exposed in the core of the Arif el Naga anticline which correspond to the Anisian, Ladinian and Lower Carnian stages and consist of three main lithologic units, from top to bottom as follows:

- A lagoonal to restricted marine sequence, with gypsum, dolomite, micritic limestone and dolomitic marls (50 m).
- An open, shallow marine series of massive, well-bedded, fossiliferous limestone (65 m).
- A clastic sequence of marine sandstone with interbeddings of fossiliferous limestone (70 m).

This sequence is illustrated in Fig. 1-36.
40 km to the northeast, beyond the Egyptian border in the Makhtesh Ramon anticline, the upper anhydritic series is 175 m thick.

Lateral changes in facies and thickness of the Triassic deposits towards the northern Sinai are not known, and they do not seem to extend southward beyond latitude 30°N.

This section, below the cover of the evaporitic layers, could offer some hydrocarbon potential. The Zuq Tamrur 1 well tested oil from Triassic sandstone.

Jurassic

According to surface and subsurface data, a major facies change occurred during the Jurassic and Cretaceous along a narrow hinge zone, the location of which pratically coincides with that of the present coastline of the northern Sinai.

Throughout Jurassic and Cretaceous times, reefal and associated high energy carbonates were deposited along this fault-related hinge zone. It separated the shallow shelf-platform sediments in the southeast from the continental slope deposits in the northwest, as shown on Fig. 1-37; this figure also shows several significant seismic horizons.

The 2200 m thick Jurassic section exposed in the Gebel Maghara anticline is the most complete and thickest Jurassic series outcropping in Egypt. It illustrates the transitional zone between the outer shelf edge carbonate series and the predominantly coarse clastic, and shale sequences of the inner shelf, as seen in Fig. 1-38.

There, Lower and Middle Jurassic series were deposited in shallow shelf or paralic environments, with alternating sandstone and mudstone. The Middle Jurassic clastic interval contains coal seams deposited in fresh or brackish water lagoons, sheltered by the fringing reefs. A eustatic rise in the sea level during the Upper Jurassic induced a southeastward shift of the fringing reefs and associated high-energy carbonates, as evidenced by the **Masajid** Formation in the Gebel Maghara section (Fig. 1-39).

Due to the generalized diastrophic phase of late Kimmeridgian, the scenario in the northernmost Sinai was the same as described for the northern Western Desert.

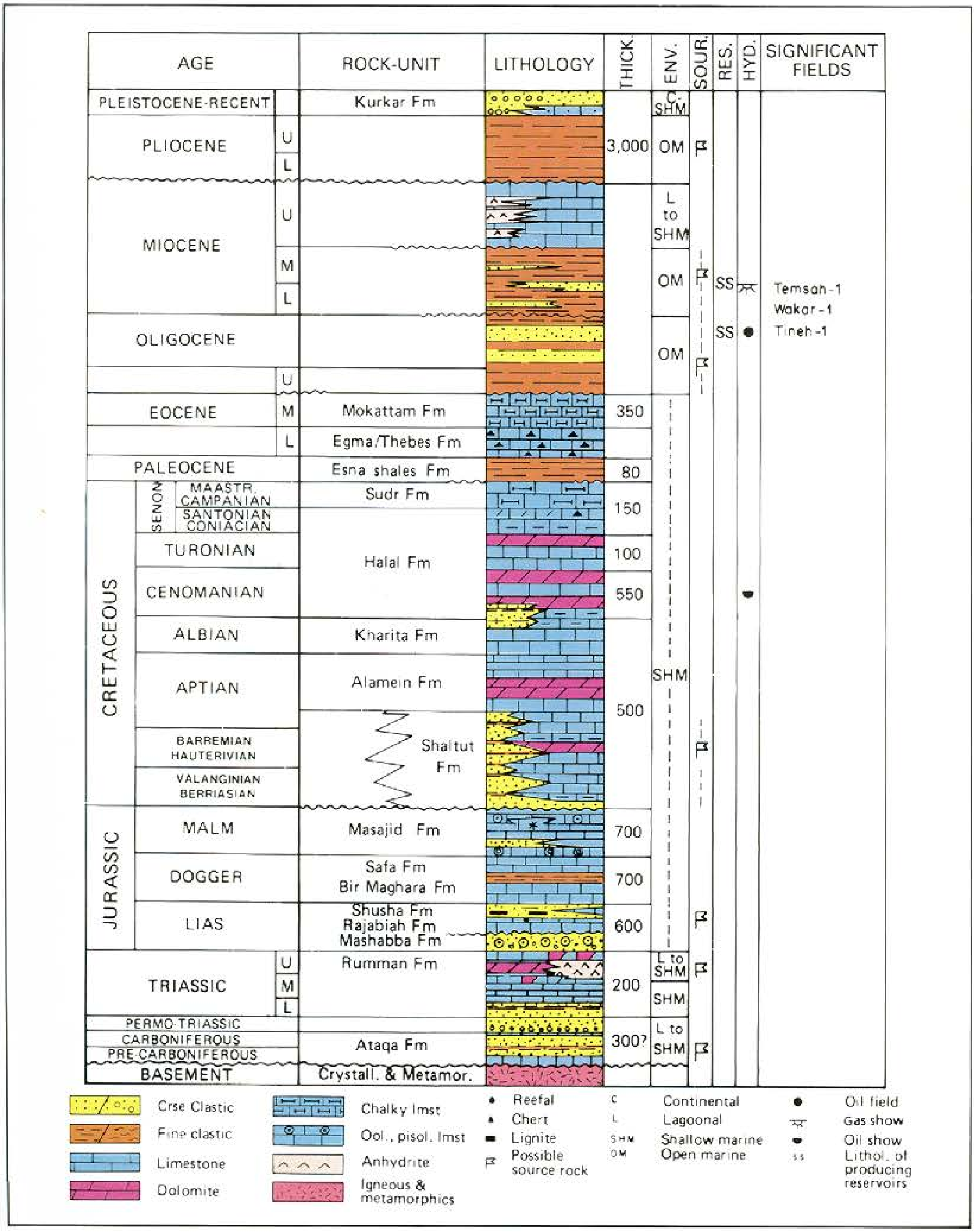


Fig. 1-34. Generalized litho-stratigraphic column of North Sinai.

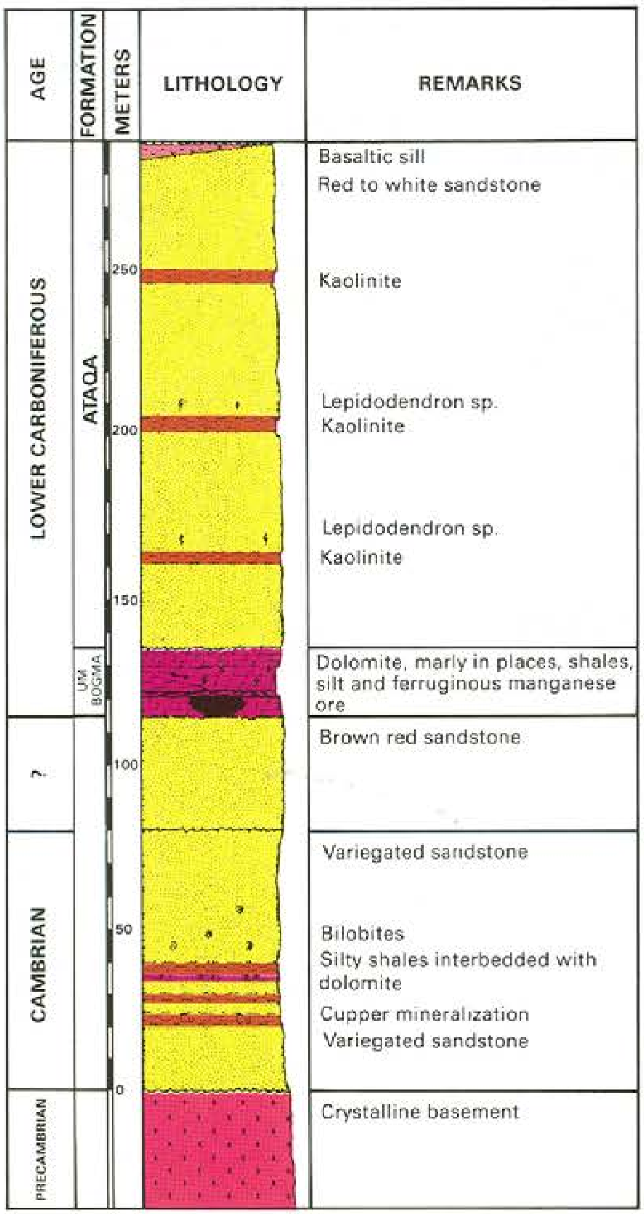


Fig. 1-35. Litho-stratigraphic section of the Paleozoic at Um Bogma, Sinai.

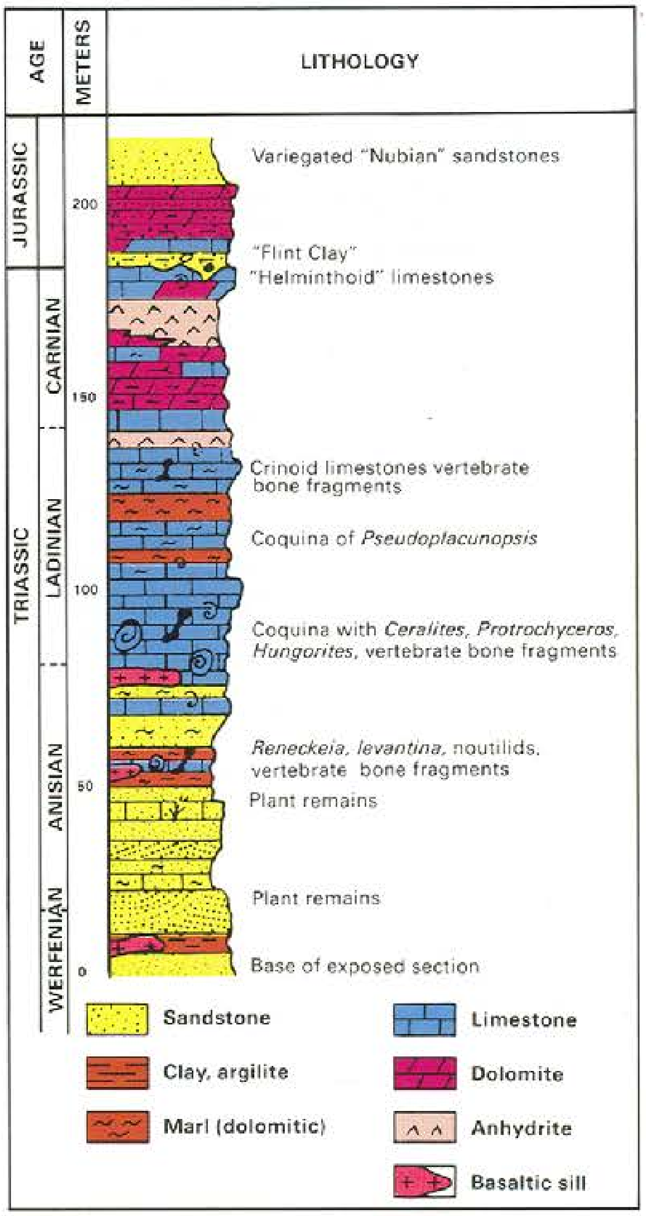


Fig. 1-36. Litho-stratigraphic section of the Triassic at Arif el Naga, Sinai.

General uplifting and correlative withdrawal of the sea was responsible for the non-deposition or erosion of the uppermost Jurassic section.

Cretaceous

A regional stratigraphic gap and unconformity underlies the basal fluvio-continental deposits of the Lower Cretaceous represented by the Nubia strata. They correspond to the major northward pulse of land-derived sediments in northern Sinai.
Following this general regression, the carbonate depositional environment was then re-established. It progressively onlapped the basal Nubia sandstone series in a southward direction.
During the Middle Cretaceous, from Albian to Turonian, rudistid fringing reefs developed all along the pre-existing hinge zone, as in the Jurassic.

They formed a narrow belt of carbonate build-ups several hundred meters thick, interfingered with shallow shelf platform carbonates and continental slope deposits. Back-reef deposits on huge shoals, covered practically the whole Sinai. Dolostones are largely predominant and alternate with bioclastic and oolitic limestones, and with soft marls

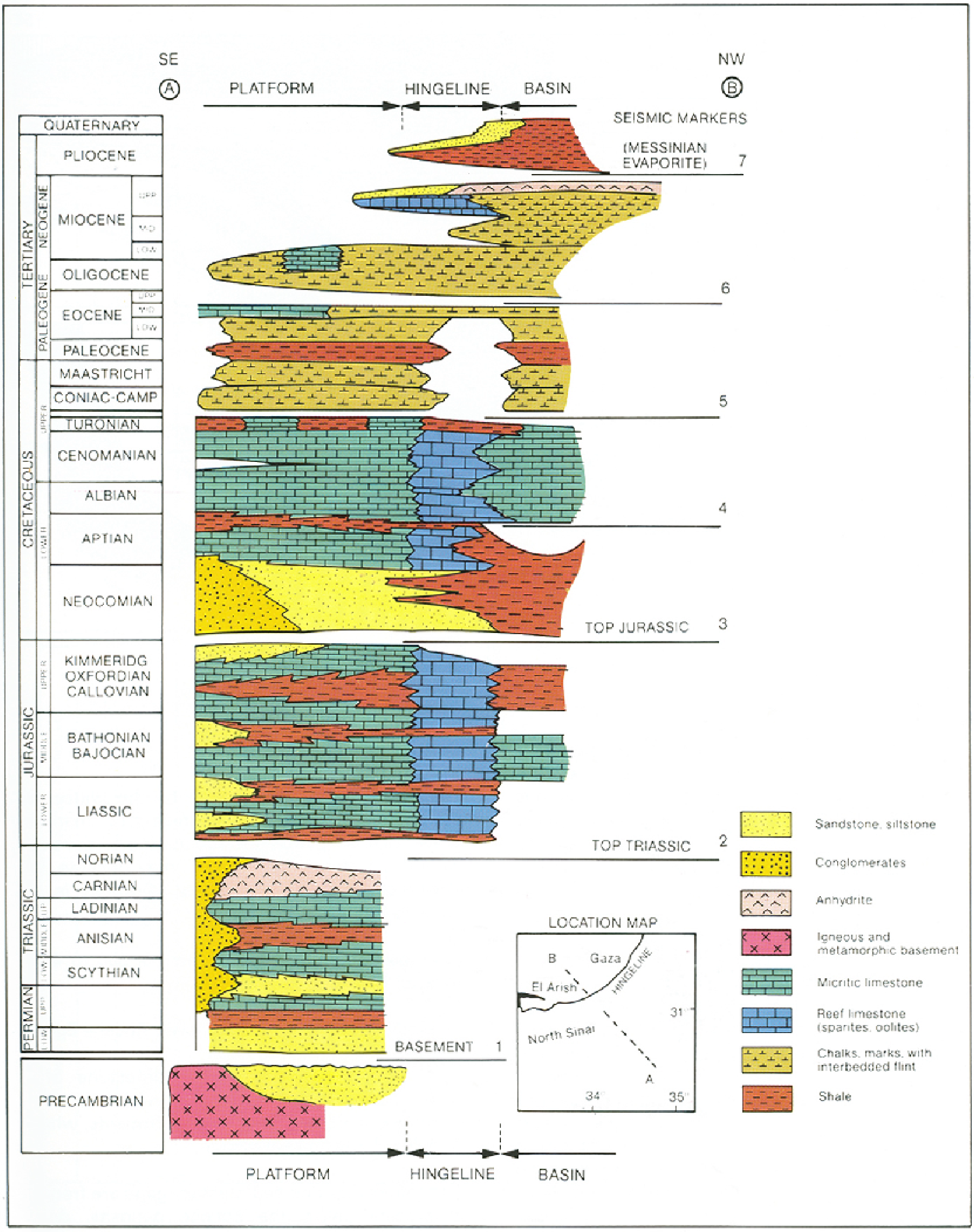


Fig. 1-37. Lithofacies distribution across the hingebelt from the platform to the basin in North Sinai.

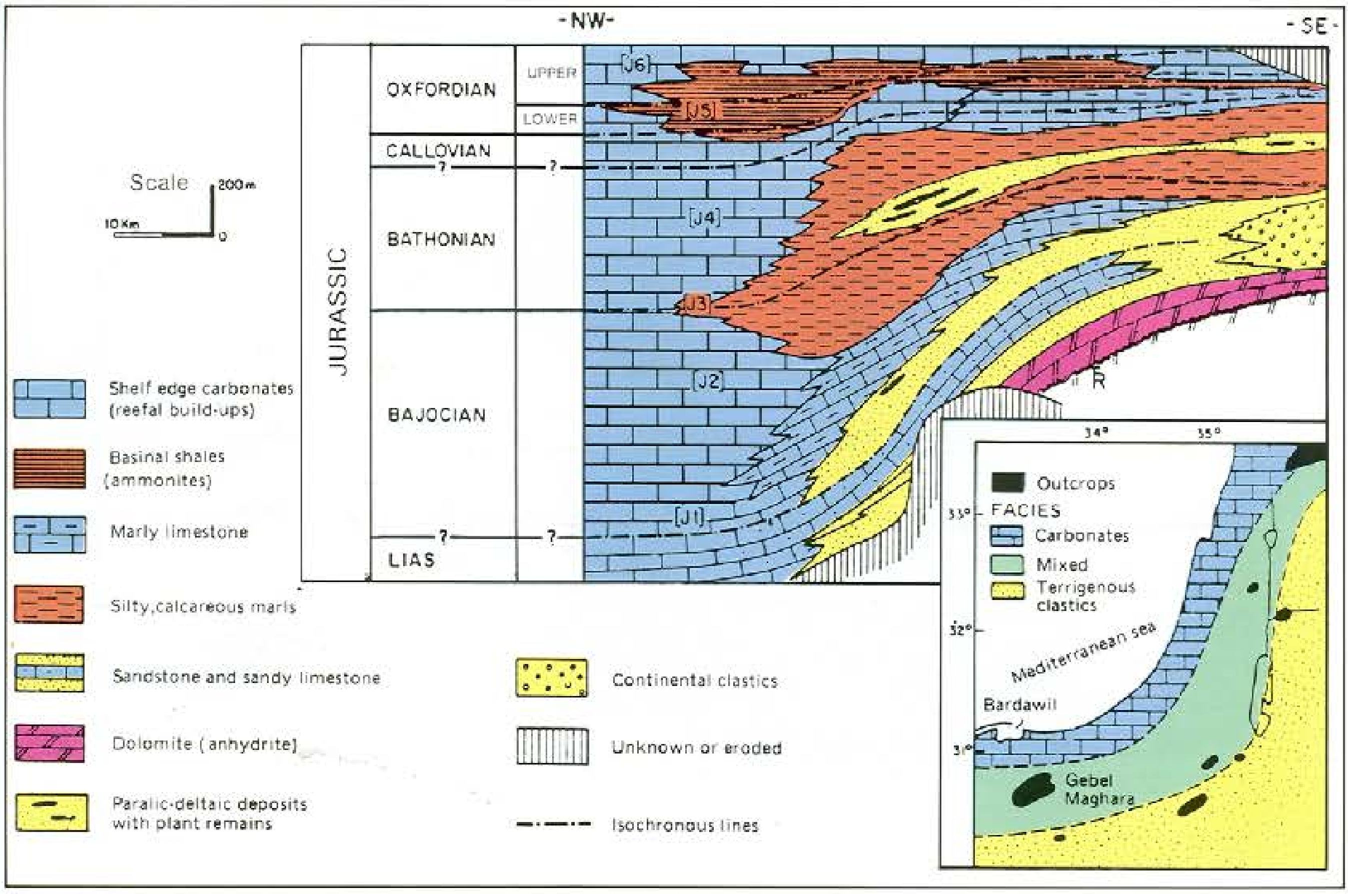


***Fig. 1-38.** Schematic facies distribution ofJurassic in North Sinai.*

and shales, as illustrated in Fig. 1-39 which shows the entire exposed column in Gebel Maghara.

At the same time, the contribution of terrigenous material derived from the mainland was negligible in northern Sinai. The hard, cliff-forming carbonates of the Upper Turonian consist of well-bedded, massive limestone and dolomite, with chert layers. Total thickness of the Middle Cretaceous carbonates is around 600 to 800 m.

During the Upper Cretaceous, the Sinai shelf platform was uniformly covered by a chalky marly sequence, with predominant foraminiferal and nannoplankton chalk and with minor intercalations of bioclastic limestone and dolomite. The most conspicuous rocks in the sequence are cherts, in massive beds, associated with phosphate. The lower unit, of Coniacian age, is largely argillaceous with soft marls, rich in ammonites. Thickness changes in the Senonian series are due to local morphotectonic features. They average 100 to 150 m. Unconformities, erosional or depositional gaps, from Upper Senonian to Tertiary, are observed in the transitional zone, on the anticlinal crests.

Cenozoic

The Paleocene is represented by the widespread **Esna Shale** Formation. Greenish-grey marl and shale, rich in pyrite, are ubiquitously developed within this formation, which may include local cherty chalk intercalations. Its thickness is very variable but less than 100 m.

The Eocene "plateau limestone", is 300 to 400 m thick and is made up of two units:

- Limestone with flint of the lower Eocene **Egma** or **Thebes** Formations.
- Chalky or hard nummulitic limestone of the Middle Eocene **Mokattam** Formation which becomes marly upwards and northwards, where it fills the synclinal lowlands.

Unconformities and sedimentary gaps are frequently present below the Eocene deposits, due to synsedimentary tectonics, in particular to the folding of the Syrian Arc.

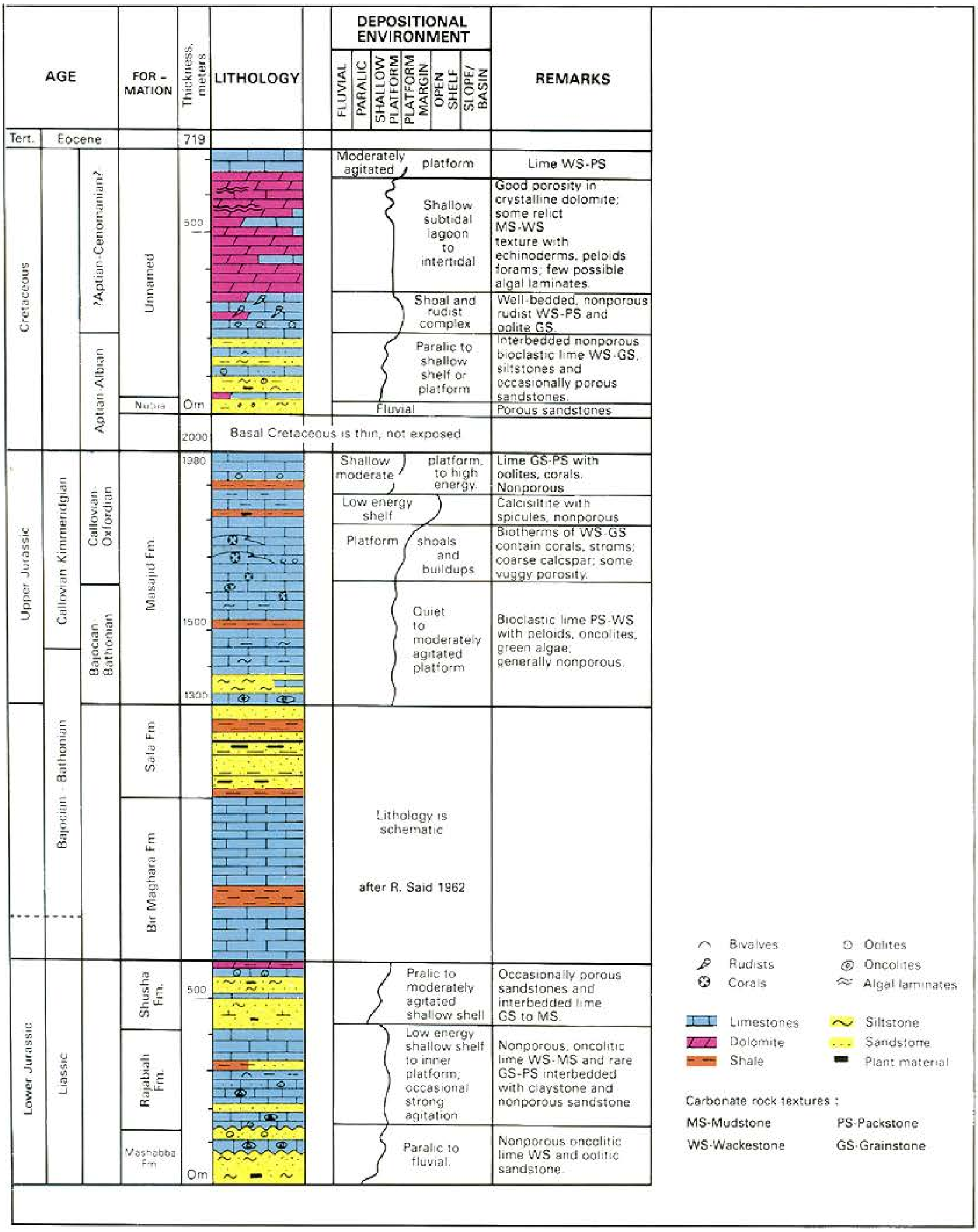


Fig. 1-39. Generalized litho-stratigraphic column of Jurassic and Cretaceous rocks exposed at Gebel Maghara.

The Upper Eocene is not exposed onshore, but a shaly-marly sequence was encountered in offshore well Gal 1.
When the regional doming and rifting of the Gulf of Suez and Aqaba climaxed, in the Oligocene, northern Sinai probably emerged.

A shaly section of Oligocene age was found in the well Gal 1 , and the recent Tineh 1 oil discovery was made in marine Oligocene sandy reservoirs offshore Port Said.
In Early and Middle Miocene time, transgression from the Tethys began, which invaded the Suez graben.
It was followed by the Late Miocene generalized regression which culminated with the deposition, in the Mediterranean basin of the Messinian evaporites, well developed offshore Sinai.

Onshore Sinai, the Miocene deposits are more or less restricted to the eastern bank of the Gulf of Suez.

A thin marine Miocene section is known in northernmost Sinai and extends to the East. Offshore, in the shelf area, Miocene and Plio-Quaternary sediments are well represented, but their structure, thickness and lithostratigraphy is not well known. Thus, the areal distribution of the Miocene platform carbonates and of the coeval sand/shale, mainly supplied by the Nile Delta, cannot be delineated properly.

The Uppermost Miocene evaporites and the correlative halokinetic structures of the overlying sediments seem to be confined to the deep offshore, beyond the NW-SE Bardawil fault scarp and the Pelusium fault zone. An example of these structures is seen in the interpreted seismic section in Fig. 1-40.

The Plio-Quaternary section, represented onshore by thin continental to shore deposits (beach and bar sandstones, shell breccia, bioclastic sandy limestone, conglomerates, dunes) grades offshore to very thick basinal sediments.

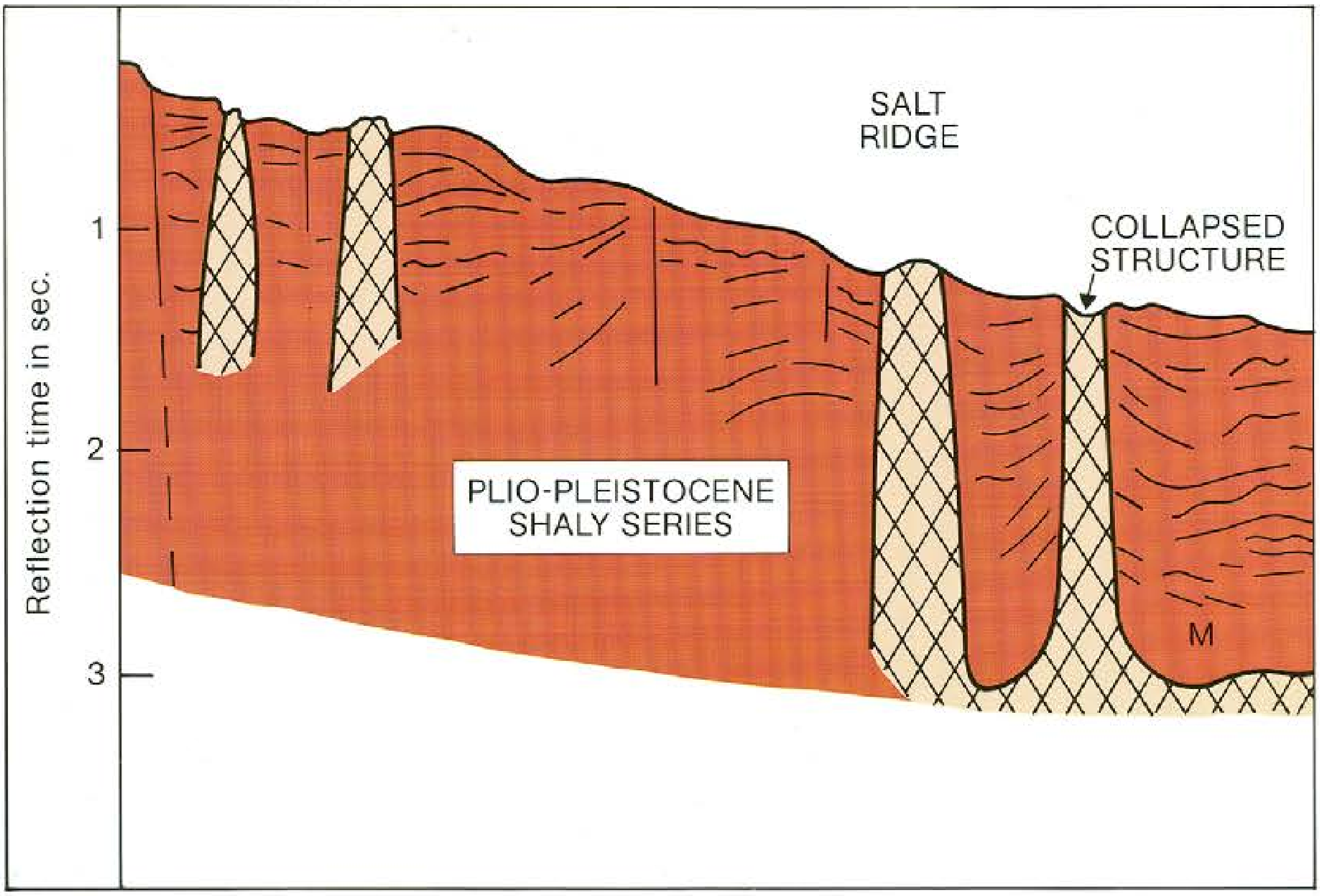


Fig. 1-40. *Diagrammatic interpreted seismic section showing halokinetic structures (Messinian salt) located in the central part of the continental margin off North Sinai.*

Overlying the regressive evaporitic deposits of the Messinian, the Pliocene is composed of a basal transgressive sandy sequence, grading upwards to a thick shale and clay section, with interbedded turbiditic fans.

At the edge of the continental shelf, thickness of the Plio-Quaternary is around 3000 m.

HYDROCARBON HABITAT

The North Sinai area can not yet be called an oil or gas province since the exploration work to date is insufficient for an adequate assessment of its hydrocarbon potential.

Future exploration is expected to focus on two main targets:

— The deltaic and perideltaic sediments of Cenozoic age, supplied by the Nile or proto-Nile and shifted eastwards along the North Sinai platform by the longshore currents.

— The Upper Jurassic and Middle Cretaceous reef belt, located in the present coastal area.

Additional targets are the Lower Cretaceous sandstone (Nubia strata) and the Triassic clastics and carbonates in the onshore area.

Source Rocks

Organic rich shales, interbedded in the Triassic carbonates beyond the Egyptian border, proved to be oil source rocks and could extend into North Sinai.

Carbonaceous shales and coal seams of the Middle Jurassic sequences are potential gas-prone source rocks.

Neocomian basinal shales, the time equivalent of the Nubia sandstone, are considered to be the source for the oil produced in the Heletz-Brur Field, and are likely to be present in the North Sinai shelf area.

North of the hinge line, other shales and marls with source rock characteristics undoubtedly exist as time equivalents of the thick Jurassic and Cretaceous carbonates or are interbedded with them.

Cenozoic source rocks may be similar to those of the Nile Delta province. Upper Oligocene shales are considered a source for gas, and Lower Oligocene series a source for oil.

Reservoirs

Potential reservoir rocks are widely distributed throughout the geological section:

— Sandstone in Carboniferous (?), Lower Triassic, Lower and Middle Jurassic, Lower Cretaceous and Tertiary deltaic or perideltaic deposits.

— Carbonates of the Middle Triassic, bioclastic or reefal limestones of Upper Jurassic and Middle Cretaceous, as well as their dolomitic time equivalents.

Seals and Traps

Apart from the possible evaporitic beds of the Upper Triassic, cap rocks of Mesozoic age are represented by scattered and generally thin shaly or marly intervals.

In the Tertiary section, very thick source shale sequences provide an excellent seal to the imbedded, sandy reservoirs.

Major traps in pre-Tertiary series consist of faulted anticlines pertaining to the Syrian Arc and associated erosional or depositional wedges.

In the hinge zone, step-faulted blocks may form prospective features. Offshore, in the Tertiary series, traps are of the combined structural-stratigraphic type and frequently fault-associated.

Field and Hydrocarbon Shows

The only field which produced in northern Sinai is the Sadot gas field, with ultimate recoverable reserves of 35 million CFG, located in Cenomanian dolomite and limestone. Weak oil shows were found in Cenomanian dolomite, in the Makhl 1 well, and in the Aptian dolomite, encountered in the Sneh 1 well.

In the Tineh 1 offshore well, Oligocene sands yielded 5000 B/D of 30° to 35°API gravity.

The Lower Miocene sand is gas and condensate bearing in Rommana 1 exploratory well.

1.5 THE EGYPTIAN RED SEA AREA

The coastal area of the Egyptian Red Sea is in essence the southern extension of the Eastern Desert. It is formed by the high coastal range made up of Precambrian rocks of the Nubian shield. The elevation of this range averages 1500 m with several high peaks such as Gebel Shayieb (2181 m) and Gebel Hamata (1977 m). The coastal range flanks towards the Red Sea a relatively narrow belt of heavily broken-up limestone plateaus.

The islands at the junction with the Gulf are part of the Red Sea. The most important are Shadwan, Tawila and Ashrafi. With exception of Shadwan which is hilly, the others are flat lying islands with a sedimentary cover or reefal build-ups.

The shelf is relatively narrow and its edge strongly indented. Fig. 1-41 shows the present day configuration of the Red Sea. The shelf averages 10 km in width and only in the Foul Bay and south of the Murray island does it exceed 50 km.

The drop-off into the slope and the central trough area is fast. The shelf surface amounts to about 20,000 sq km. The "potential" surface of the onshore coastal belt is roughly 6000 sq km of its entire extension of about 550 km.

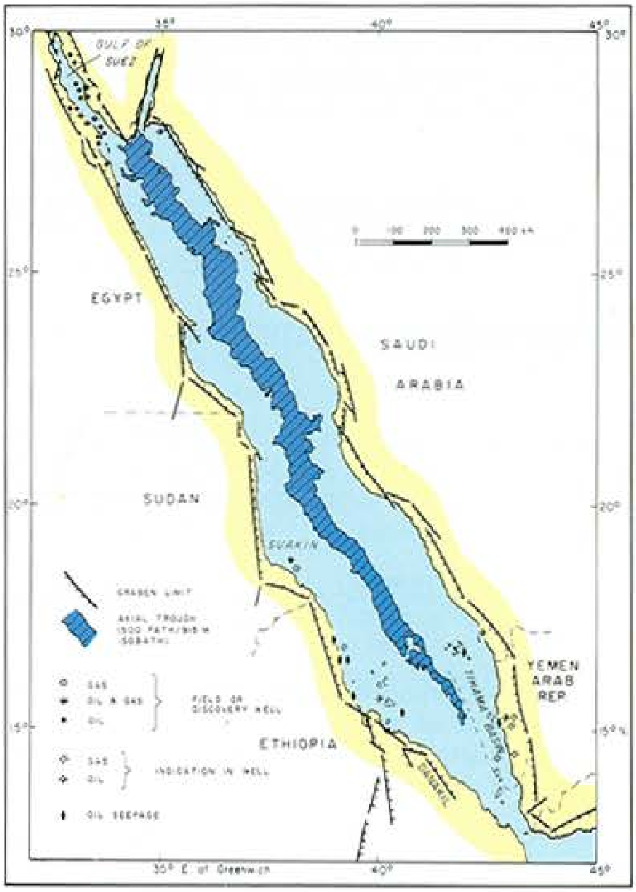


Fig. 1-41. Present day configuration of the Red Sea graben, with location of hydrocarbon occurences.

Offshore, salt induced structures seem to be rather frequent. Gliding phenomena along growth fault type structures are believed to exist in the Sudan and Ethiopian part of the Red Sea, see Fig. 1-42, and a structural stratigraphic section along the coast is seen in Fig. 1-43.

Regional gravity mapping indicates three subbasin trends, the near-shore, central and outer shelf subbasins (see Fig. 1-44).

Near-Shore Subbasins

A series of subbasins have been outlined from north to south. These are the Zeit-Abu Shaar, Hurghada, Safaga, Quseir, Marsa-Alam, Abu Ghussun, Ras Benas and the Foul Bay. Some of these basins deserve attention in exploration for hydrocarbons because of their thick basin fill.

According to Tewfik and Ayyad, the section in the Safaga and Quseir subbasins reached some 5000 m in thickness. It may include Tertiary and pre-Tertiary

TECTONIC SETTING

Structural Development

The formations exposed along the Red Sea coast exhibit an eastward dip into the graben center. The dip angle varies from 35° near the coastal hills to subhorizontal near the coast.

Faults trending NW-SE are the main structural elements of the area. Cross faults at right angles to the Red Sea trend occur and extend into the Red Sea graben.

Folding, attributed in part to the plasticity of the thick gypsiferous formation, in part to drape-over of formations on fault blocks or perhaps due to compressional forces caused by the transform movements, have been recognized.

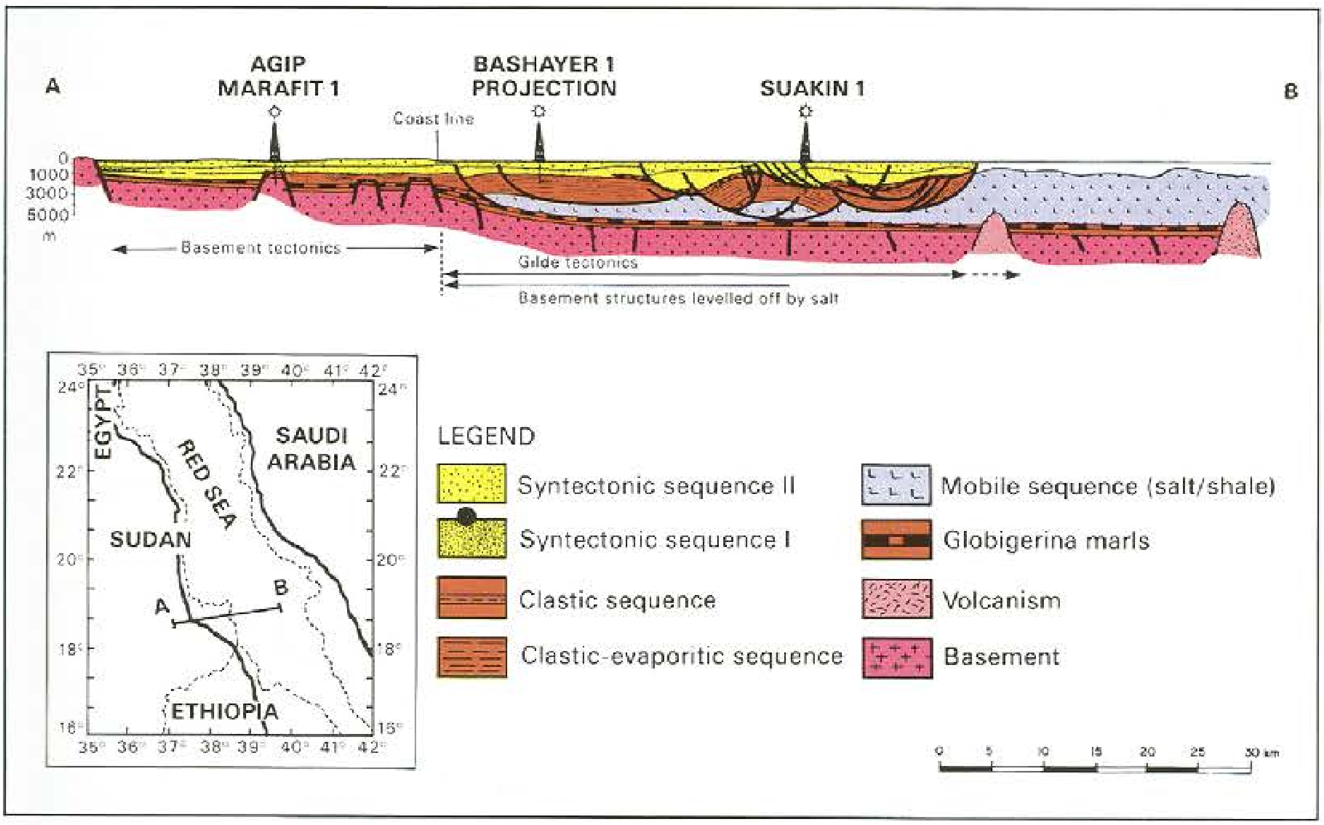


Fig. 1-42. Schematic cross-section of the Sudan part of the Red Sea.

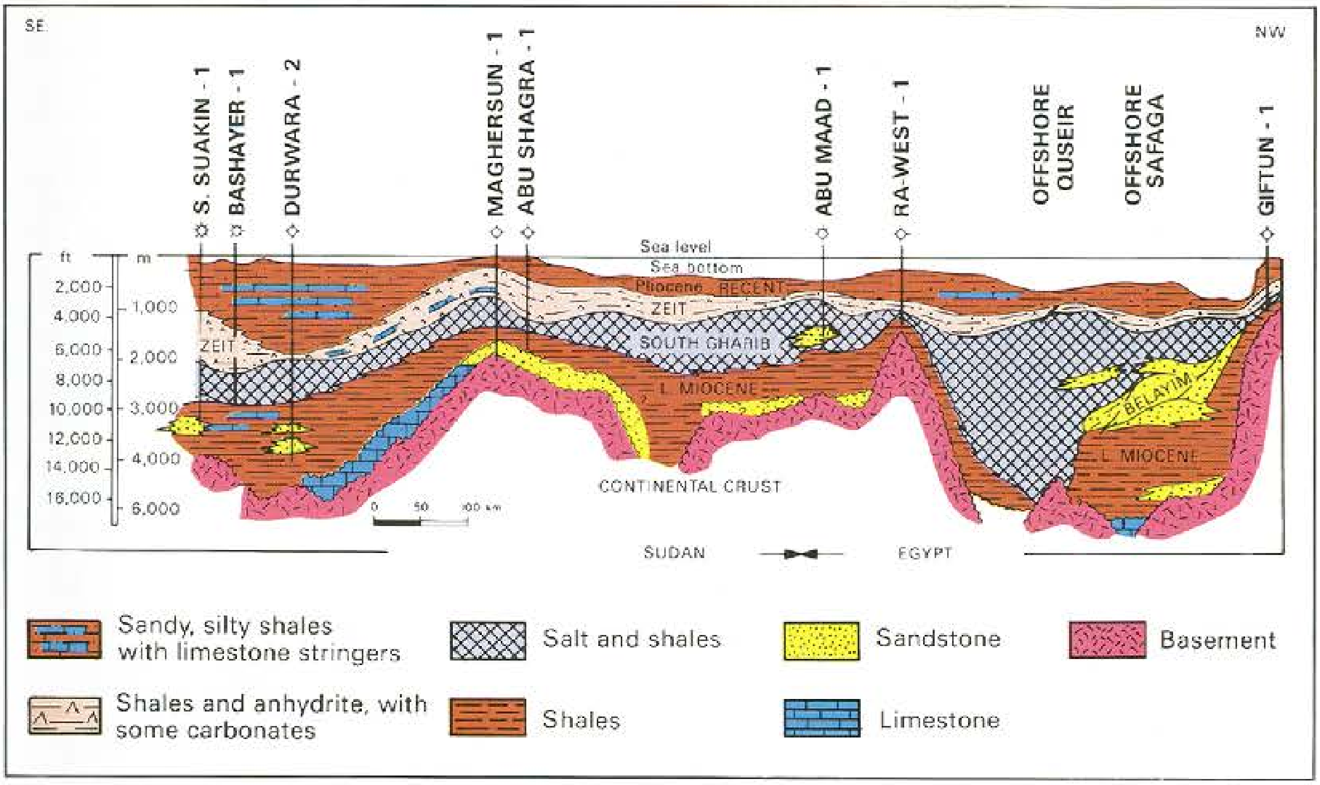


Fig. 1-43. Structural stratigraphic section along the west coast of the Red Sea straddling the Egypt-Sudan border.

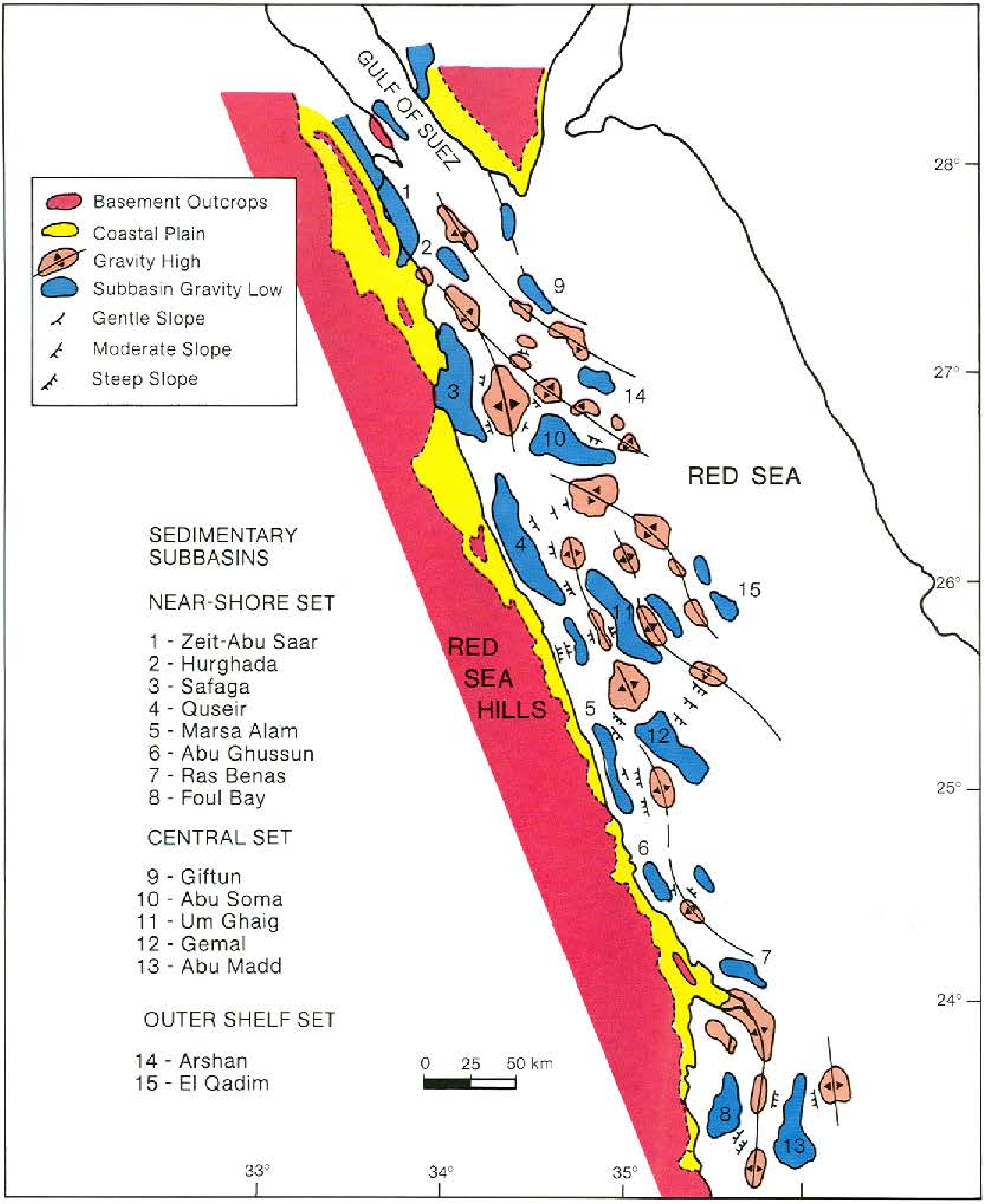


Fig. 1-44. Regional gravity map showing major structural and subbasin trends in the Red Sea area.

formations. The section in Foul Bay appears to be much thinner and composed essentially of Miocene and younger sediments.

Central Subbasins

Located in the central part of the shelf, the Central Subbasins are the Gilftun, Abu Soma, Un Gheig, Gemal and Abu Madd basins.
Little is known about their configuration and fill. Only Abu Madd exhibits a fill of about 6000 m according to magnetic estimates. It is also the only basin from which shows of natural gas were reported during exploratory drilling.

Outer Shelf Subbasins

These subbasins are generally expressed as gravity lows in deep water areas. They are relatively small and their fill is assumed to be formed essentially by the evaporites and more recent sediments. The Arshan and El Qadim outer shelf basins are typical gravity lows.

Tectonic History

The development of the Red Sea has been, and still is the object of intensive studies especially in relationship to plate tectonics and seafloor spreading. Arching and thinning of the continental crust of the Nubian-Arabian shield with subsequent rifting and break-apart during Oligocene-Miocene time have led to the formation of the Red Sea in its present shape, with its marked block faulting on the flanks, and strong subsidence in its center part.

Concommitant transform faulting point to the relative movements of the Nubian plate westward, and the Arabian plate eastward, and are expressed in the zigzag development of the coast line. The left lateral movements observed along the Gulf of Aqaba widened the Red Sea relative to the Gulf of Suez. A second rift west of the earlier (Miocene) rift developed during Pliocene time in the southern part of the Red Sea area, in the Danakil depression. It moved the Afar minor plate eastward and caused the narrowing of the Strait of Bab el Mandeb.

As a consequence of the rifting and transform faulting, oceanic magma poured out in the Danakil depression. In the northern part of the Red Sea it neared the sea bottom in the central part of the graben, as indicated by the high heat flows and elevated gravity values.

During early Paleozoic time most of the Red Sea was occupied by the emerged Precambrian rocks of the Nubian-Arabian shield. Only during a relatively short period in Lower Carboniferous time was the northern area invaded. This was through a narrow embayment by the ancient Tethys, as witnessed by the Carboniferous black shales encountered in wells of the Hurghada oil field.

A gradual emersion of the region and subsequent erosion of Precambrian rocks during Jurassic and Early Cretaceous time led to the formation of the comprehensive continental deposits of the "Nubian series". It was only during Late Cretaceous that a new transgression of the Tethyan Sea took place. This transgression reached much further to the south, since Uppermost Cretaceous to Paleocene shales and sandstones deposited in a shallow marine to brackish environment, are described from wells drilled offshore in the Sudan (Carella and Scarpa, 1962).
Arching of the Precambrian basement in the Red Sea area began probably during Middle to Late Eocene time. Marine Early Eocene deposits are described as far south as Quseir. With the arching the Cretaceous and Lower Tertiary shore lines regressed northwards.

Uplift and crustal thinning with subsequent collapse of the Nubian-Arabian shield occurred during Late Eocene and Oligocene. The Red Sea with its tensional faults along its margins was formed. The high coastal ranges rose, probably due to compensating adjustments for the collapsed part of the shield. Prior to the collapse, the Cretaceous and Lower Tertiary wedges may have been eroded in part.
In Early Miocene, the Tethys transgressed again southwards and invaded structural lows depositing littoral, shallow marine and evaporitic formations. The pre-Miocene bottom of the graben presented a very irregular topography with local lows or basins now filled with deposits exceeding 5000 m thickness.

STRATIGRAPHY

The onshore sedimentary sequence seems to be irregularly distributed and relatively thin. Offshore, magnetic estimates indicate up to 6000 m near the St. John island. However, such estimates may lead to erroneous conclusions since the magnetic susceptibility of basement rocks are close or equal to some types of sedimentary rocks.

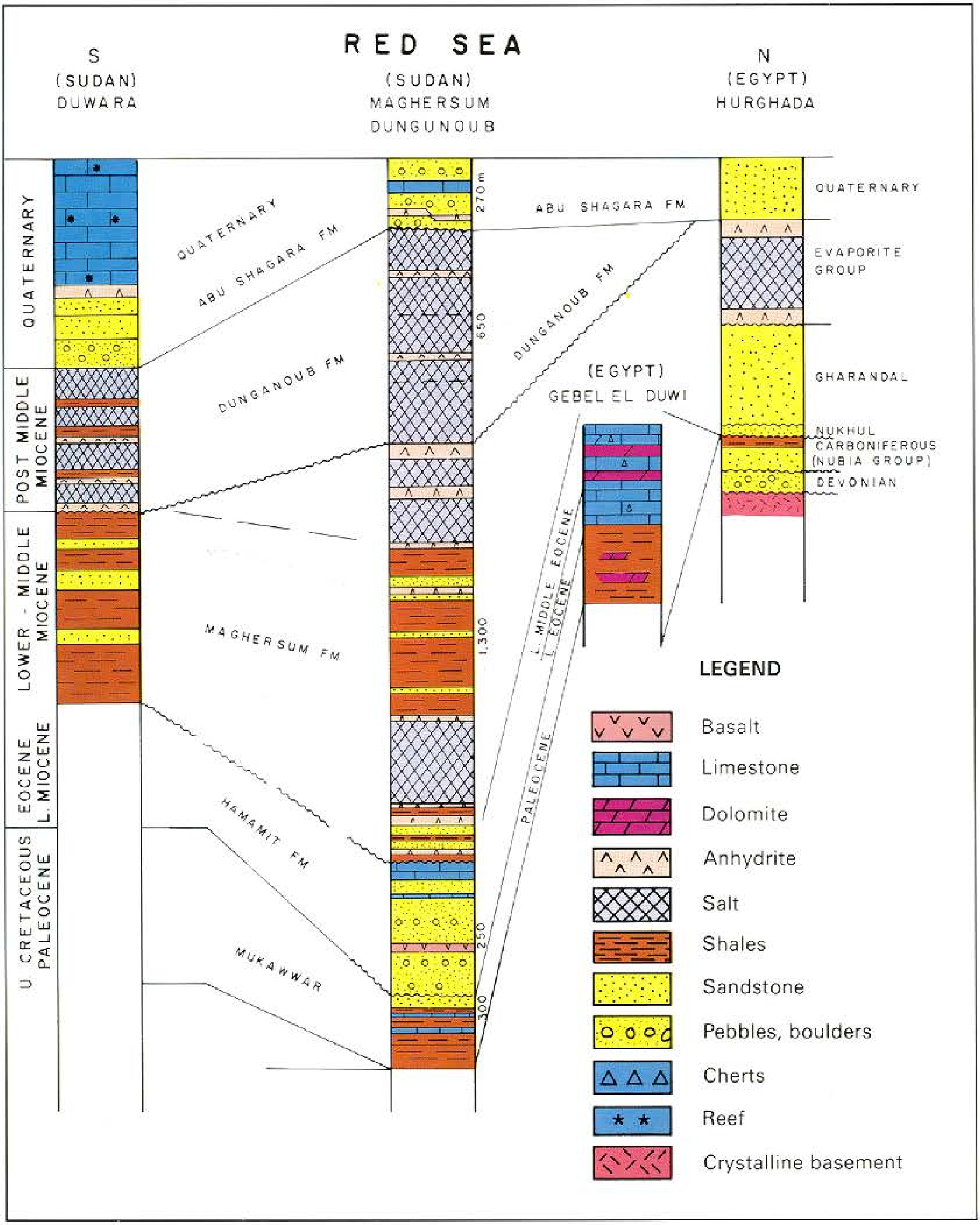


Fig. 1-45. Litho-stratigraphic correlation along the west coast of the Red Sea.

Some of the wells drilled offshore hit basement at a shallow depth, others remained in Miocene formations at great depth (N. Tewfik and M. Ayyad, 1982).

Paleozoic

The only known Paleozoic formations in the Red Sea area are the producing horizons in the Hurghada Field. These are included in the stratigraphic correlation seen in Fig. 1-45.

Mesozoic

The stratigraphic sequence of the Egyptian part of the Red Sea is generally subdivided into pre-rift and post-rift sections. The pre-rift series embrace formations of Cretaceous to Eocene age. Best exposures in development and continuity are described from the Gebel Duwi and Arshan in the Quseir area, as illustrated in Fig. 1-46.

The thickness of the exposed section amounts to about 1500 m. Cretaceous and older formations are represented by the Nubia sandstone sequence of predominantly continental to fluvio-marine origin.

Its thickness is irregular and ranges from 0 to 300 m. The variation is probably due to the irregular topography of the underlying Precambrian surface. The sequence is overlain in Gebel Duwi by marine Senonian.

The Upper Cretaceous begins with a sequence of shales, green to varicolored with minor intercalations of limestones, silts and sandstones. The contact with the underlying Nubian series is gradational. This sequence may be of Cenomanian to Turonian age. It is overlain by Upper Senonian marls, followed upsection by cherty to phosphatic limestones of the **Duwi** Formation of Santonian to Campanian age.

The top of the Cretaceous series is represented by about 130 m thick grey shales and marls of Campanian to Maestrichtian age.

Cenozoic

The Lower Tertiary is composed of a series of chalks, marls, shales and limestones. The sequence points to a continuous deposition from Upper Cretaceous to Lower Tertiary.

Subsequent to the formation of the Red Sea graben in Late Eocene-Oligocene time an erosional period took place. Pre-Miocene deposits were eroded and Miocene formations were eventually deposited over an erosional surface. Early Miocene and younger formations are exposed along the coastal belt from Hurghada to Ras Benas. They were also encountered in considerable thickness in offshore wells.

The Miocene sequence is generally subdivided into three rock units.

— The lower part is represented by the **Boulder Beds** and the **Red Beds** which overlie unconformably the pre-Miocene erosional surface, from Eocene in the north, to Precambrian in the south. Onshore, they consist of reddish siltstones with gravels and pebbles.

  The basal Boulder Beds include granite boulders. The thickness of the series is about 200 m. It thins towards the coastal hills and dips eastwards. An Oligocene to Lower Miocene age is attributed to the series which offshore grades into marine shales and sandstones considered to be time equivalents of the Rudeis and Kareem Formations (Globigerina Marls) of the Gulf of Suez.

— The overlying Carbonate unit, exposed in Wadi Ghussun and on the Ras Benas Peninsula consists of massive, in part reefal, dolomitic and anhydritic limestone with a thickness of about 230 m. It is of Middle Miocene age and may correlate with the Belayim Formation of the Gulf. Channel fills within the Carbonate unit are observed at Wadi Ghussun.

— The Evaporite unit is composed onshore of massive and bedded gypsum, extending along the shore from Quseir to Ras Benas. Some 500 m thickness has been measured.

  Offshore, over 3000 m of rocksalt have been drilled.
  Both the gypsum and rocksalt sequence are considered to be the time and rock equivalent of the South Gharib and Zeit Formations of the Gulf.

Pliocene to Recent formations cover a narrow belt on the coastal plain. They are composed of sands, limestones and conglomeratic deposits and may reach a thickness of about 500 m. In offshore wells Pliocene to Pleistocene formations up to 1000 m thick have been penetrated.

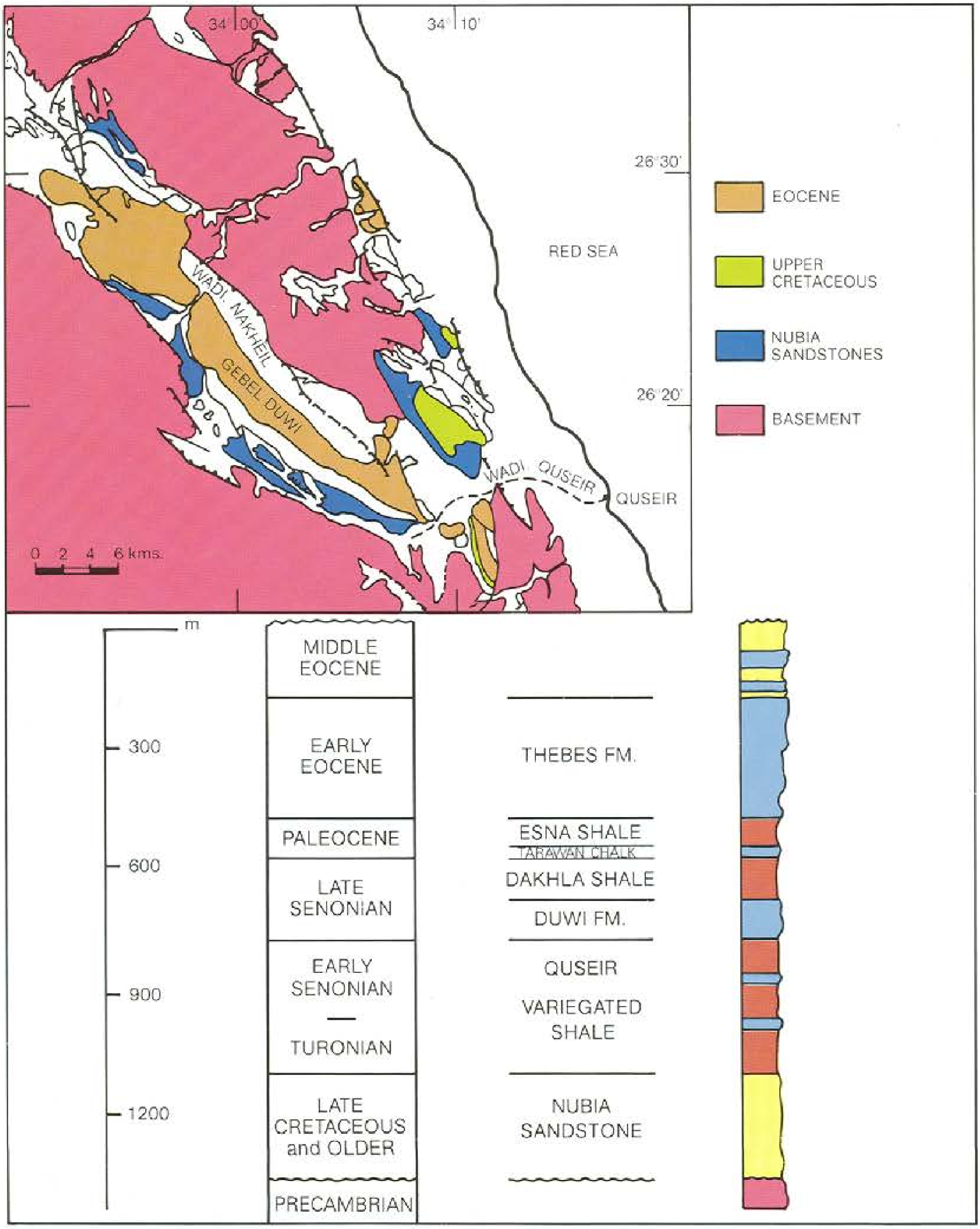


Fig. 1-46. Pre-rifting intracratonic stratigraphy in the Wadi Quseir area.

HYDROCARBON HABITAT

Information on hydrocarbon habitat parameters is scarce for the Red Sea in general, and for the Egyptian part of the Red Sea in particular. Parameters that could possibly be extrapolated have to be derived from the Gemsa and Hurghada Fields near the Red Sea - Gulf of Suez junction, or from wells drilled in the Sudan and Ethiopian waters.

Source Rocks

Shales and marls with source rock characteristics may be present imbedded within the sands and in the thick salt sequences. However, very little data is available.

Reservoirs

Good reservoirs are represented by the Nubian sands which are producing in the Hurghada Field. To outline pre-Miocene structures with Nubian sands is difficult, because of complex faulting and because of thick salt (and volcanics?) that hamper seismic penetration and reflection.

Miocene sands most likely offer the best reservoirs. They are in part imbedded in thick salt, in part developed as channel or beach sands overlying Lower Miocene carbonates, and preserved on tilted fault block surfaces, or draped over fault blocks.

Amber 1 drilled in Ethiopian waters encountered high pressure gas in Miocene sands imbedded in salt. Commercial gas has been encountered in Miocene sands in the shut-in wells Suakin 1 and Bashayer 1 in southern Sudanese waters, and Safaga well encountered oil and gas shows in Miocene channel sands.

Another type of reservoir are the Middle Miocene reefal build-ups. Such rocks exhibit a porosity of 14% in Ra West 1 well. All these reservoirs find their producing equivalents in the Gulf of Suez.

Traps and Seals

Traps are represented by a variety of structural features. Horsts flanking the subbasins and tilted fault blocks are developed along the marginal homocline dipping gently seaward.

Sands preserved on tilted surfaces of fault blocks and carbonate development of the edges of such fault blocks have been outlined and in part tested.

Wedges of sands on the flanks or draped over salt induced structures have been described. All these reservoirs are efficiently sealed by the overlying thick salt deposition.

Temperature measurements of the floor of the Red Sea made by the Challenger Deep Sea Project indicate abnormally high values, and a sharp increase toward the central axis of the Red Sea graben, see Fig. 1-47.

In the rift zone of the southern Red Sea the geothermal gradient reaches values of 14.7°F/100 ft, decreasing towards the north. Another high temperature gradient anomaly is situated east of Quseir where 12 °F/100 ft were measured. The presence of abnormal geothermal gradients in the Red Sea has undoubtedly an important influence upon the generation of hydrocarbons. The gradient increases towards the basin center and towards the south.

Fig. 1-48 illustrates the temperature ranges from 150° to 290°F for oil generation, in depths between 3000 and 14,000 ft, and for gas up to 350°F in depths between 8500 and 16,000 ft.

In essence the southern Red Sea appears to be a gas prone province, whereas gas and oil can be expected in the northern part.

Volcanic extrusives are rarely reported from outcrops along the coastal belt or from wells. They appear to be concentrated in the central trough area.

In any case, whatever the extent and distribution of these formations, submarine volcanic activity is responsible for the high geothermal gradients in the Red Sea.

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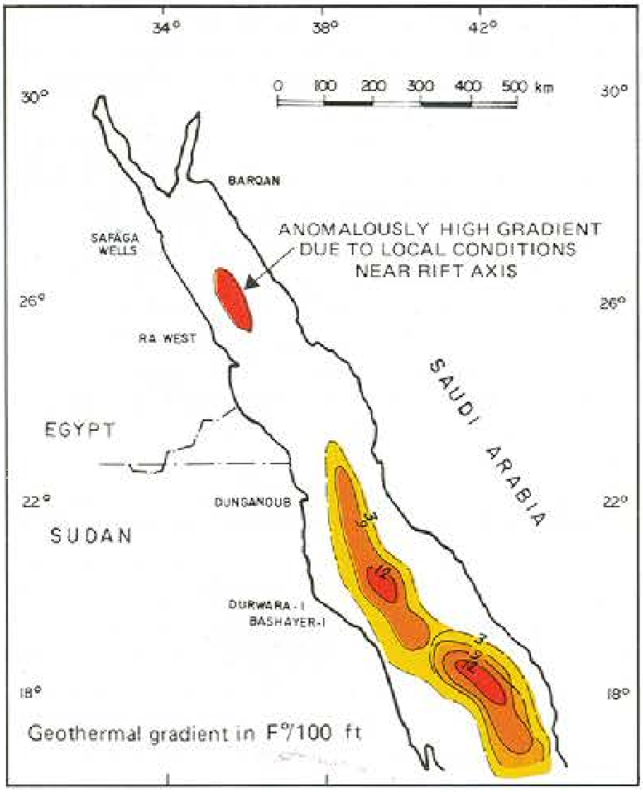

Fig. 1-47. Contours of geothermal gradients showing high values in the center of the Red Sea.

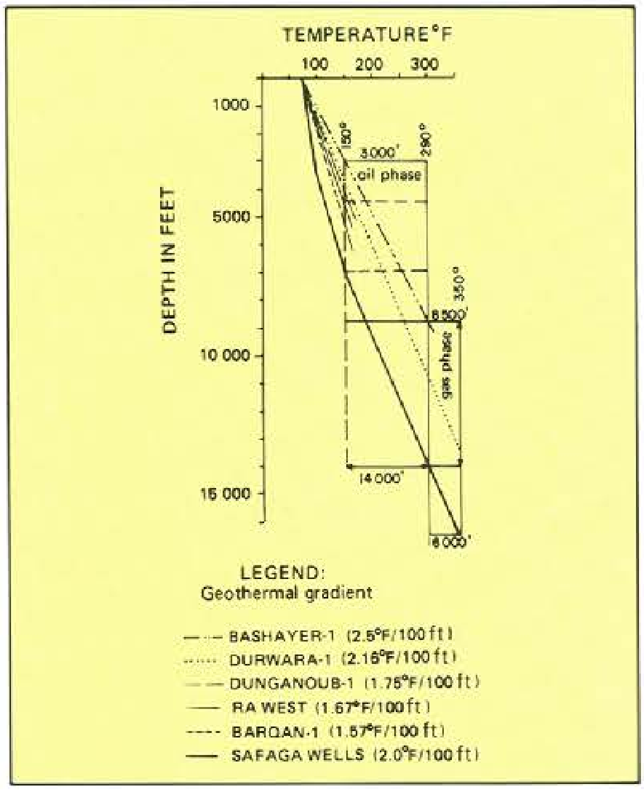

Fig. 1-48. Geothermal gradients from some representative wells in the Red Sea.

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