CHAPTER TWO

STRATIGRAPHY AND GEOLOGIC STRUCTURE

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This chapter tackles, generally, the review of the stratigarphy and geologic structure (faults, folds and unconformities) of the Gulf of Suez and Northern Sinai with especial emphasis to detailed core description of the cored intervals from the study areas (Ras Shukeir Coastal Sabkha, Ras Gemsa, Ras Dib, South East Zeit, Shagar and Gubal Island fields with North Sinai and Esh Mallah Fields). The core description includes: Lithology, primary structures, fossil content, accessory minerals etc. Based on the above description the cored intervals can be defined into different facies types and facies associations, finally we can predict the depositional environments for the sediments along the cored intervals. The studied cores are belonging to Ras Malaab Formation (M. Miocene).

1. Stratigarphy of the Gulf of Suez:

A summary of Miocene stratigarphy in Gulf of Sues is given with especial emphasis on the western side of the Gulf of Suez, which comprises the investigated area. The Miocene stratigarphy in gulf region gained its importance due to research for oil where the Gulf of Suez is considered the most important oil province in Egypt. As a result of the increasing exploration activities within the Gulf of Suez, the stratigraphic subdivision of Miocene rock was of prime interests for the oil companies in order to elucidate suitable and well defined mappable time-rock units where the majority of oil production from the Miocene sediments.

The Miocene rocks in Gulf of Suez (both off and onshore sections) were studied by many workers; among of them those of: Frass, 1868; Mitchell, 1887; Blanckenharn, 1901 and 1921; Barron, 1907; Ball, 1916; Hume *et al*, 1920; Moon and Sadek, 1923; Macfadyen, 1930;

Bowman, 1931; Wait and Pody, 1957; Said and Basionni, 1958; Sadek, 1959; Said, 1962; Ghorab, 1964; The Stratigraphic committee of Egyptian petroleum corporation (E.G.P.C.), 1964; Heybrock, 1965 and 1984; Sauay, 1966; Ghorab and Marzouk, 1967; Said and El-Heiny,1967; Hassan and El-Bashlouty, 1970; Rabson, 1970; Gezzery and Marzouk, 1973 and 1974; The national Stratigraphic subcommittee, 1974; Garfunkel and Bartov, 1977; Beleity,1982; El-Zaraka and Wally, 1982; Schlumberger, 1984; Sellwood and Netherwood, 1984; Scott and Govean, 1985; Evans,1988 and others. In addition to the above mentioned workers many trial by petroleum companies were made to classify the Miocene rocks in their concession areas.

Moon and Sadek, 1923, subdivided the Miocene rocks in Gulf into five Units of Gypsum intercalated with fossiliferous limestone (Nullipore rock) which separates Gypsum NO.5 form Gypsum NO.4, Marls separates Gypsum NO.4, Gypsum NO.3 and Gypsum NO.2 (Upper and Lower intergypseous Marls).

Heybrock, 1949, gave a regional picture of Miocene rocks in the Gulf of Suez at different localities. He included under Gharandal and Evaporite Groups, the Miocene rocks of non-marine, coastal, shallow and deep-water facies. Heybrock's work was based mainly on surface exposures from both sides of the Gulf of Suez. Said, 1962, reviewed the work of earlier workers and presented a general section for the Miocene rocks in the Gulf of Suez region as follows.

Upper Miocene	Lithothamnion Limestone
	Evaporite Formation
Middle Miocene	Upper Globigerina Marls and beds of *Aturia*
	Lower Globigerina Marls and *Pectea* beds
Oligo-Miocene	Basal Miocene Conglomerates and Sandstones.

Heybrock, 1965, discussed the marine evaporites on both sides of Gulf of Suez. These evaporites occupy vast elongated depression and theses depressions are related to the Major African and Indian Ocean rift systems. Heybrock recognized two clearly distinct facies in the Miocene rocks: a lower clastic facies (Gharandal Group) and an upper evaporite facies with typical saline deposits (Evaporite Group).

Hosny *et al,* 1986, subdivided the regional Miocene stratigarphy in the Gulf of Suez area into two main Stratigraphic provinces based on facies changes. Lower Miocene deposits characterize the first Stratigraphic province and there is no sharp boundary between the Lower and Upper Miocene rock. The second Stratigraphic province is subdivided into sub provinces; the sub-province 2A represent anhydrite facies and sub-province 2B represent continuous section of sand-shale facies.

The work of Gezzery and Marzouk, 1974, which is concerned with the Stratigraphic analysis of Gulf of Suez had been modified using modern facies concept by Garfunkel and Bartov, 1977; Hgras and Slocki, 1982; Fawzy and Abdl Aal, 1984; Khalil and Saudi, 1984 and Richardson *et al* 1986. Generally, the Miocene section in Gulf of Suez region (Fig.3) represented by a lower clastic Group (Gharandal Group) and an upper evaporite Group (Ras Malaab Group). The Gharandal Group is characterized by the dominance of sandstone, shale, marl and limestone. The Ras Malaab Group consists mainly of anhydrite and salt with numerous intercalations of shale and marls. The Miocene section is overlain unconformably by a very thick Pliocene and Pleistocene succession of gravel and sand with intercalation of marl and shale (Hassan and El Bashlouty, 1970).

2. Stratigarphy of North Sinai:

Said, 1990, mentioned that the Miocene sequence in north Sinai is known only from the subsurface, where as in central and southern Sinai. Miocene rocks are restricted to the eastern bank of Gulf of Sues. Concerning the Miocene rocks in north Sinai, detailed palaeobathymetric, nannoplankton biostratigraphy and facies analyses of exploratory boreholes indicated that the beginning of Messinian (Upper Miocene), Said, 1990. It's evident that the Miocene succession in the Gulf basin is characterized by a remarkable lateral change in thickness and facies as a result of the Miocene block faulting (Sadek, 1958; Garfunkel and Bartov, 1977).

3. Stratigarphy of the Study Areas:

3.1. Ras Shukeir Coastal Sabkha:

The Stratigraphic sequence and facies association of supratidal, coastal Ras Shukeir sabkha is based on the study and examination of shallow deep cores covering a profile C1-C3-C4-C5-C6 and trench (Fig. 23). A complete detailed cores description with facies association are given and illustrated in Figs (25, B, C, D, and E) and trench (Fig. 34). All Stratigraphic sequence of cores intervals are represented by a clastic sequence with absence of anhydrite and presence of disseminated gypsum and halite crystals. A disseminated and very thin laminated organic matter are occurred and detected. Lithologically the sediment of Ras Shukeir sabkha composed of fine-grained terrigenous materials with disseminated interstitial gypsum crystals at shallow depth and salt interbedded mostly with friable clay and silt. Anhydrite is absent and these sediments are capped with salt crust formed mainly of gypsum and Anhydrite. The organic material occurred as disseminated and very thin parallel laminae.

3.2. Ras Gemsa Field (Area):

Gemsa area consists of gypsum, algal dolomite and Biocalcite of the Miocene Zeit Formation. Rock in drill holes at Gemsa consists of salt, reefal dolomites, Basal Miocene sands and Precambrian granite. The reefal dolomites are referred to as the main dolomite and host the hydrocarbon reservoir. The evaporite section is covered by Pliocene-Pleistocene gravel and

Quaternary alluvium. At the base of the Evaporite reefal dolomite is present in contact with basal Miocene sands resting up on Precambrian

Zeit Formation:

The upper Miocene Zeit Formation is composed of Gypsum and Anhydrite in beds one to two meters thick with thin shale interbeds at top of evaporite beds. These rocks were deposits on shallow hypersaline lagoons grading upwards to intertidal condition so that the rocks grade from massive, coarse crystalline gypsum (lagoon) to planar stromatolytic zones and shale. Interbedded with gypsum units are microcrystalline dolomites, which increase in number and thickness from west side of Great Gemsa to east side.

The detailed lithological description and facies associations of the core intervals from drilled wells (Gs-89-02, 03, 04, 05 and 06) are given and illustrated in lithological logs (Figs. 4,5,6,7 and 8).

3.3. South East Zeit Area (Field):

Outcropping rock at South East Zeit consists of Miocene Evaporites through to be part of the Zeit Formation and Plio-Pleistocene gravels. The subsurface Stratigraphic succession as indicated by drilled well is consists of from the base to top: Precambrian volcanic, Lower Miocene Evaporite followed by Plio-Pleistocene gravel and Quaternary Alluvium

Thickness and units intersected in hole GS-89-07 is:

Unit	Interval
Quaternary Alluvium and Plio-Pleistocene	0-33 m

Miocene Evaporites	33-173 m
Lower Miocene (2) clastic	173-204 m
Pre-Cambrian volcanic porphyry	204-266 m

The detailed lithological description and facies associations of the core interval from drilled wells (Gs-89-07) are given and illustrated in lithological logs (Fig.9).

3.4. Ras Dib Area (Field)

The Stratigarphy of Ras Dib is detected from outcropping rocks at vicinity of this area, which consists of consists of Gypsum, biocalcite and reefal dolomites of Miocene Zeit Formation. Plio-Pleistocene gravel deposits Plio-Pleistocene beach terraces and Quaternary alluvium at top.

-Younger deposits

Younger rocks in Ras Dip area consist of Pio-Pleistocene gravel deposits, Plio-Pleistocene beach terraces and corals and a quaternary alluvium. The gravel deposits are the oldest of these units and are mooted on Ras Dib area and the E side of Gebel El Zeit by beach Terrace deposits and corals Quaternary alluvium blankets the entire older unit.

-Zeit Formation

Most of outcropping rock at Ras Dib consists of Gypsum and Anhydrite of Zeit Formation. The Gypsum and Anhydrite contain interbedded shales and Sandstones and considered to have been deposited in shallow hypersaline lagoon.

-Lower Miocene

Evaporites rest on Miocene Gharandal group clastic in holes 8, 12, and 14. These rocks composed of shale and marl, while holes 9&11 have a shale section overlying conglomerates.

Hole 10 has no shale and Evaporites rest directly on conglomerates. The implies uplift prior to the deposition of Evaporites and removal the shales overlying the conglomerates, this interpretation seen to be supported, by the structure contours on the top of the Lower Miocene which shows development on anticline with crest in the vicinity of hole 10.

-Pre-Miocene

These rocks consist of Nubian and companion Sandstones. The Precambrian is composed of red granite.

Subsurface lithologies of Ras Dib area consist of clastic rock in lower Miocene Gharandal group and cretaceous Nubian Sandstones. The detailed lithological description and facies associations of the core interval from drilled wells (Gs-89-08, 9,10,11,12,13 and 14) are given and illustrated in lithological logs, (Figs.10, 11,12,13,14,15 and 16).

3.5. Shagar Area (Field):

The outcropping rocks at Shagar area indicate that the stratigarphy of this area consists of from the bottom to top Evaporites and Sandstones of the Miocene south Gharib formation, Miocene–Pleistocene gravels and Sandstones and Quaternary Colluviums and Alluvium.

-Miocene South Gharib Formation

The outcrop at Shagar prospect area consists of the upper Evaporite units and Sandstone of the Middle clastic unit.

The Evaporites occur in beds about 3 m thick with the tops of the Evaporite beds marked Shale bed smaller than 1 m thick. Two prominent shale markers about 3m thick occur near the base and about midway through the upper Evaporites zones, at contact between the upper Evaporites and middle Sandstones member, a Gypsum conglomerate zones is developed which consists of Cables of Gypsum in sandy matrix. These zones represent an unconformity surface between the two units. In same places in Wadi Garf this contact zone is altered to biocalcite and contains dead oil. The Sandstones member consists of coarse grain Sandstones with minor shale beds. The lower Evaporite member of South Gharib Formation occurs only in the subsurface and is 90 m. The unit consists of anhydrite with minor clastic zones. The South Gharib Formation rests on Belayim Formation.

The Belayim formation consists of member from top to bottom. These are Hammam Faraon, Feraan, sidri and member. The Hammam Faraon and sidri member are clastic zones, which are recognizable marker in other part of Gulf of Suez basin while the Feraan and Baba member are anhydrite. The Hammam Faraon in the Shagar is 55m thick, the Feraan and batsu member Evaporites. The Sidri member is 10 m thick and Baba is 20-m thick whole 15a was lost near the base of Hammam Faraon member and did not reach the lower member of Belayim.

-Plio-Pleistocene Gravels

South Gharib Formation is overlain by Plio-Pleistocene gravel deposits with cables and boulders of volcanic rocks in a coarse sand matrix . along the East Side of the area fault scarps are present in these gravels indicating very faulting . The Plio-Pleistocene gravel is deposited with the source area of the cable to the west in the Red Sea hills.

-Quaternary collovium and alluvium

All the older units are marked by Qui-Call and an alluvium deposit consists of large gravel , sand and Wadi fill material. The detailed lithological description and facies associations of the core interval from drilled wells (Gs-90-15A and 16) are given and illustrated in lithological logs (Figs. 17and 18).

3.6. Gubal Island Area:

The outcrops at Gubal Kebir consist of recent reefs and carbonate sand, Plio-Pleistocene reefs and limestone with shale fragments and Miocene gypsum with clay.

The oil and gas tests on Gubal intersected the following stratigraphic sequences from the base upwards, as follows:

Pre-Miocene rock; Pre-Miocene rocks represented by fresh pink granitic grit.

Miocene Rock:

A) Miocene clastic: represented by igneous grit sand and gravel with boulders,

B) Miocene carbonate:

represented by dolomitic reefal limestone impregnated with small quantities of heavy oil A marked horizon of water with H_2S is associated with the top of this limestone therefore some sulfur shown in this intervals

C) Miocene Evaporites:

represented by Gypsum or Anhydrite, which is occasionally slightly calcareous and intercalated with shale bands. They outcrop at the site of the hole GS-90-17 and were encountered in all EPC drill holes.

Post-Miocene (Plio-Pleistocene) rocks:

Represented by shale, marls with a lateral variation of grits in Gubal #4 and by grey oolitic limestone to shell fragments and scattered clastic intervals in Gubal Island. This unit may be either Pliocene or Pleistocene and crop-out over most of Gubal Kebir and covers of Gubal

The detailed lithological description and facies associations of the core interval from drilled wells (Gs-90-17and 18) are given below and illustrated in lithological logs (Figs.19 and 20).

3.7: Esh El-Malaha and North Sinai:

Only tentatively available core samples from well (DH-3R and DH-7) were selected. Lithologically, these samples are consists of coarse crystalline gypsum, anhydrite with halite

4. Geologic Structures:

The Gulf of Suez is the northwest branch of the Red Sea separating Africa from Sinai Peninsula (Fig.21). Rifting commenced in the latest Oligocene to earliest Miocene, (Sellwood and Netherwood, 1984; Scott and Govean, 1985). Basaltic igneous activity occurred in late Oligocene or early Miocene, just before the deposition of the earliest Miocene sediments (Sidner, 1973; Moneisy and Krevzer, 1974). This igneous activity is generally interpreted as related as related to initial faulting in the Suez rift (Lyberis, 1988). The rocks of the Gulf of Suez are characterized by rapid central changes in thickness and facies in response to Miocene block faulting (Sadek, 1959; Garfunkel and Bartov, 1977).

The areas of study lie in the western side of Gulf except the north Sinai (Mediterranean Sea), hence, it necessary to give a brief and simplified review concerning the regional structure of Gulf to facilitate the understanding the structure of these study areas.

Most workers studied the Gulf of Suez rift to elucidate its origin and its evolution. Among the most important of them are given in the following:

Shukri, 1954, mentioned that the faults trending NW-SE, E-W (Tethyan). NE-SW (East Africa) and WNW-ESE were considered the major controlling normal faults in the Gulf of Suez.

Said, 1962, mentioned that there are marginal faulted zones bordering the Gulf of Suez depression on both sides the eastern and western sides. These zones are marked by high vertical escarpment on the up thrown sides. Folds are also present, but play a minor role in the structure of the region.

El-Tarabili, 1964, mentioned that the so-called folding described by many workers, is in fact due to dragging of strata along the boundaries of the faulted blocks. Abdel Gawad, 1969, mentioned that there are four trends of fracture systems in the Gulf of Suez region, which are also widespread through out the Red Sea area. These structure systems are: 1- NW-SW trend that is parallel to the Gulf of Suez, i.e. Erthryan trend. 2- NE-SW trend, which is perpendicular to the Gulf of Suez, i.e. Syrian trend and 3- Two fracture systems diagonal to the Gulf of Suez and controlling the coastlines (N-S and WNW-ESE trends).

Garfunkel and Bartov, 1977, studied the structure of the Gulf of Suez area and their interpretations can be summarized as follows:

1. The Gulf of Suez is a Cenozoic structure which slices through the continuous Arabo-African plate
2. Pro-rifting tectonics was described as long wavelength oscillations. There is no evidence that structure similar to the present Suez rift excited before the late Miocene. Rifting was well underway in the Oligocene to early Miocene as shown by basaltic activities and faulting, which led to local erosion and deposition of coarse terrestrial conglomerates.
3. The rift structure is dominated by normal fault and tilted blocks. The overall effect of deformation was starching normal to rift trend.

Mostafa, 1976, mentioned that the configuration of Gulf of Suez is controlled by complex pattern of faulting dominantly in the Gulf direction with a complementary direction along the Aqaba trend.

Abdalllah *et al*, 1983, grouped the fault block of Gulf of Suez into three major provinces of contrasting dip direction. These are: 1- North Wadi Araba province with southeast dip. 2- The central Belayim province with northeast dip. 3- The southern Amal province with south-southwest dip. Bayoumi (1983), discussed, the tectonic origin and evolution of the Gulf of Suez from gravity data. His result can be summarized in the following:

1. Almost all the linear structures in the Gulf of Suez are strike-slip faults of different trend.
2. These major fractures systems are identified as three left lateral trending N35W, N60E and N15 and three right lateral trending N45W, NNE-SSW and N8SE
3. The Gulf of Suez seems to have been subjected to three phases of tectonism associated with five cycles of deformation.

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Chent *et al*, 1984, assumed that the evolution of the Suez rift began in the Oligocene time with duke intrusion but without neither uplift nor significant faulting. The major faulting starts to take place during lower Miocene (23-25 m.y) at least in the southern part of rift with the formation of tilted blocks horsts and grabens bounded inclined normal faults. Progressive tilting of blocks and uplift of rift shoulder characterize the extension, which is still active today, since upper Burdigalain (17 m.y).

Schlumberger, 1984, subdivided the Gulf of Suez into four tectonic provinces. Each province exhibits its own geological characteristics giving rise to specific gravity anomaly, seismic results and coastal configuration. These provinces as follows:

1. The north province is located to the north of a line that runs through Ras Zafarana on the western coast and Gebel Somar in the northern Sinai. This province is formed by single fault scrap on each side of graben.
2. The north central province which has its southern limit given by a line extending from Shukeir on western coast to Wadi Baba on eastern side coast.
3. The southern central province, which appears to have undergone less faulting and main fractures, are Esh El-Mellalhah, Gebel Zeit and Gebel Araba with their flanks.
4. The southern most provinces, which situated to the south of the line running from Gemsa to Ras Gharra and open to Red Sea.

Meshref, 1990, suggested a rifting model for Gulf of Suez showing sense of major faulting that extend and bounded the Gulf of Suez on both sides (Fig.22). He also mentioned that the Gulf of Suez rift comprises a northwest trending intracratonic basin that separated from Red Sea by the Aqaba transform fault. There is a great similarity between this model and the dogleg model proposed by Harding, 1984.

4.1. Structure of Ras Gemsa:

The regional structure of the Ras Gemsa area is shown on figs. 21and 22. The principal structure feature is a horst block tilted to the west and plunging to the NE. The axial crest of this block occurs just east of Big Gemsa peninsula and extends a south from Gig Gemsa for 11 km

.the axial trace on shore is determined from mapping and offshore from the bouger gravity mapping .The faults bounding this block is cut by east-west trending fault with dip and strike slip motion. The south sides of these faults are up-thrown and the fault show left lateral displacement .One of these faults show left-lateral displacement. One of these faults is present near GS-89-15 is considered to control the alteration and mineralization present in the hole and nearby AEO holes. (P.3)

A central graben zone separates big and little Gemsa. The southern projection of one big Gemsa the rocks dip to the north. On the NE side of big Gemsa the rock appear to dip to the south. It is felt that varying attitudes are not due to faulting. An attempt has been made to depict these relationships in a diagrammatic cross block is interpreted to occur east of the big Gemsa peninsula. The area has been intensively brecciated. Free part holes #1 and 2 tests the western edge of this dissolution zone, which is interpreted to attend to the east into shallow offshore marine areas.

4.2. Structure of Southeast Zeit:

South Zeit located on small fault block that flanks the Zeit up lift. The area is separated from the Zeit up lift by a fault. This fault is probably the reason for oil stain or seep 1.5 km north of the area. Southeast Zeit uplift trends southeast in to the Gulf of Suez and is faulted bounded on north and south side.

4.3. Structure of Ras Dib:

The Ras Dib Area lies on northern end of Gebel El Zeit tilted fault block. This block plunge to N about 7 .The block is bounded on the west by fault which displace the Plio-Pleistocene gravels and is marked by a scarp in these gravels .The area west of this graben and contains thick Miocene age salt deposits .The eastern limited of the Gebel El Zeit from gravity lies about 1km offshore. This location on the gravity contours where the isobath contours drop off steeply.

The Gebel El Zeit block appears to have some motion on its bounding faults during post Lower Miocene the Gebel El Zeit block was quiescent during the deposition of the Plio-Pleistocene reefs now 10m above the modern shore line and since scarps are present in gravels on western edge of Gebel El Zeit up left.

4.4. Structure Shagar Area:

The Shagar area is located near the south end of a large block referred by Freeport Company as the Shagar-Kareem block of after geographic location on south and north end of the block. Major shear zones the block plugs bound the north and south ends of Shagar and Kareem block to north. The Shagar area lies in a major zone termed the Garf Shear. Apparent strike slip separation on the shear at the Plio-Pleistocene and South Gharib contact is 600 m of right lateral motion on the north side of the shear. Subsidiary fault split from the Wadi Garf shear zone and numerous faults are in normal outcrop pattern of an eastward Homo-cline numerous small domes are present. The faulting shatters the Evaporites section, which should provide good ground preparation for sulfur mineralization.

4.5. Structure Gubal Island:

The island of Gubal Kebir is large done like mass, the central part of Gubal Kebir, where the Gypsum outcrops at GS-90-17, is structurally high. An anticlinal igneous core, probably faulted on its steep northeast flank, underlies Gubal Island. The Miocene evaporites lie on dolomite reefal limestones. There are a series of NW-SE fault between EPC #2 and EPC #5 with the east side down. The aggregate displacement across this horizon is large even through the displacement on the individual faults is not great. These faults are probably subsidiary fault to the large displacement NW-SE fault located offshore A gypsum outcrop with sulfur shows, located out 380m south –southeast of EPC # % has probably squeezed through a NW-SE fault.

Most of the oil shows are the east side of the island, which is considered to be faulted, so the small amount of heavy oil, now found in the beds is due to seepage up the fault on the eastern side of the structure.

4.6. Structure of Ras Shukeir Area:

The field observation and aerial photo indicate that the fault play the important role in this area where it facilitate the recharge of area by Sea water, These fault trending N-S, NW-SE and NNW-SSE as suggested by Meshref, 1990 (Fig. 22).