Quaternary Deserts and Climatic Change, Alsharhan, Glennie, Whittle & Kendall (eds)
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Sedimentological aspects and hydrocarbon potential of the Quaternary in the Gulf of Suez rifted basin, Egypt

A.S.Alsharhan
Faculty of Science, UAE University, Al Ain, United Arab Emirates

M.G.Salah
Faculty of Sciences, UAE University, Al Ain, United Arab Emirates

ABSTRACT: The Quaternary sediments in the Gulf of Suez rift basin rest on almost five thousand meters of sediment ranging in age from Cambrian to Miocene. In this basin, the Quaternary section consists, in ascending order, of the Warden and Zaafarana formations. The Warden Formation consists of sandstone and shale with some anhydrite and thin carbonate interbeds. The Zaafarana Formation consists mainly of interbedded carbonates and shales with thin sandstone streaks. The distribution of the different Quaternary facies is controlled by the influence of structural topography and eustatic sea-level variations. During the Quaternary deposition, the Gulf of Suez was an area for alluvial sedimentation, and included the alluvial fans which were built out from the bounding rift scarps. The Quaternary sediments were deposited in continental to shallow marine settings with localized restricted lagoonal environments. They lie unconformably over the late Miocene Evaporites (Zeit and South Gharib formations). This unconformity was produced by the renewed uplift of the rifted basins. The latter caused the Red Sea to connect the Indian Ocean with the onset of marine conditions. The Quaternary section of the North African rifted basins the Gulf of Suez, Gulf of Aqaba, Red Sea and Gulf of Aden attracted the attention of oil explorators in the last ten years. This has tested hydrocarbons at different locations in these basins. The Wardan sandstones, as well as, the Zeit Sandstones produced and/or tested hydrocarbons in the Abu Durba Oil Field (Egypt), Suakin Discovery (Sudan) and Abbas Discovery (Yemen). The hydrocarbon trapping mechanisms for the Quaternary reservoirs are structural and stratigraphic.

1 INTRODUCTION

This study concentrates on the Gulf of Suez rift Basin, which is the northern extension of the Red Sea, and extends for almost 320 km with an average width of 50 km (Fig. 1). This basin constitutes a large depression which only lies below sea level in its axial portion (Said 1962). The limits of the Gulf of Suez rift are defined by laterally-persistent fault zones on either side. These fault zones generally trend NW-SE, and the basement rocks are exposed on their upthrown side; they become less well defined to the north (Fig. 1).

For almost ninety years, the geology and the hydrocarbon potential of the Gulf of Suez has been the subject of numerous investigations. The regional structural setting and the geologic history of the Gulf of Suez was a matter of interest for many researchers and continue to be the focus of many current research programs. Among past and recent papers covering different aspects of the evolution, development, sedimentation and hydrocarbon habitat of the area of interest are those by El-Tarabili (1970), El-Ayouti (1980), Abdine (1981), Sultan and Suchultz (1984), Chenet et al. (1984), Montenat et al.(1988), Meshref et al. (1988), Fichera et al. (1992), Salah (1994) and Alsharhan and Salah (1994, 1995).

This prolific oil-producing basin contains more than 50 oil fields, and reservoirs which range in age from the Precambrian basement to the Quaternary. The Abu Durba oil field, discovered in 1937, is the only field in the Gulf of Suez basin that has produced oil from the Quaternary sandstones.

The purpose of this paper is to define the subsurface lithostratigraphic units of the Quaternary section, to interpret its facies variations and their related depositional environment and to assess its hydrocarbon potential (including reservoir, source and seal potential) for the Gulf of Suez oil province.

2 GEOLOGIC SETTINGS

This section focuses on the stratigraphy and structural geometry of the Gulf of Suez rifted basin.

2.1 *Stratigraphy*

The definition of the lithostratigraphic units in the Gulf of Suez and the Red Sea has been written on by many authors, including Hume (1911), Abdallah et al. (1963), Egyptian General Petroleum Corporation (EGPC) Stratigraphic Committee and Sub-Committee (1964, 1974) and Alsharhan and Salah (1994, 1995). The stratigraphic section of the Gulf of Suez ranges in

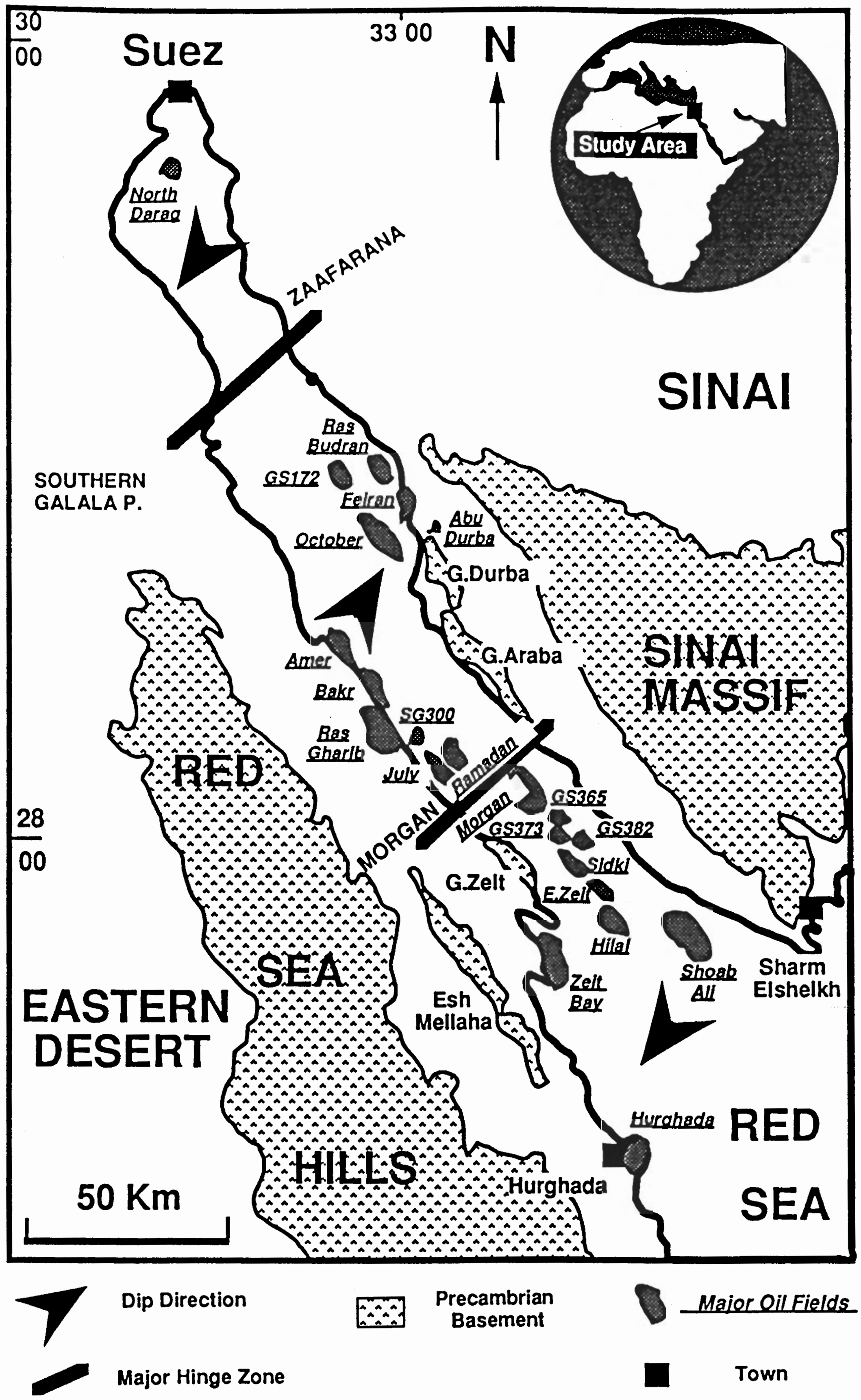

Figure 1. Location map and regional geometry the Gulf of Suez (modified after Moustafa 1976, Salah 1994).

age from Precambrian to Recent and can be classified into two megasequences: pre-rift (pre-Miocene) and syn-rift (Miocene to Recent) (Fig. 2).

2.2 *Structure and tectonic regime*

The Gulf of Suez rift represents a northern extension of the Red Sea. It constitutes a large depression which lies below sea level in its axial portion. The Suez rift trends in a NNW-SSE direction separating the African plate from the Sinai microplate (Fig. 1). The direction of the plate motion during the rift was studied by Abd El-Gawad (1970) who demonstrated that two pairs of shear zones in Arabia and Africa have a lateral displacement that is consistent with that observed along the Gulf of Aqaba Fault Zone. McKenzie et al. (1970) matched the coastline of the Arabian Peninsula with that of African Red Sea capturing the precise direction of plate motion. Both reached the same conclusion, namely that the general movement of the Arabian plate relative to the African plate was toward the northeast. The contrasting widths of the northern portion of the Red Sea rift zone and the southern Gulf of Suez suggest that left-lateral movement along the Gulf of Aqaba strike-slip zone has allowed significantly more crustal extension within the Red Sea than has been achieved within the Gulf of Suez.

The amount of extension was calculated at the northern, central and the southern parts of the Gulf of Suez by Meshref and Khalil (1990). They constructed three representative structural cross sections and calculated 5.1, 14 and 23 km of extension and an increase of 11%, 17% and 33% of the initial width in the northern, central, and southern parts of the Gulf of Suez, respectively. From the previous results it is evident that the northwestern sector of the Red Sea has experienced more extension than the other parts of the Gulf of Suez (Meshref & Khalil 1990).

The limits of the Gulf of Suez rift are defined by laterally persistent fault zones on both sides of the rift system. These fault zones generally trend NW-SE with basement rocks exposed on the upthrown side; they become less well defined to the north. The bounding faults branch into numerous, curving, interconnected extensional faults toward the north; moreover, the displacement across the fault zone progressively decreases to the north. These bounding faults and basement exposures are clear in the study area and standout as topographic markers outlining the rift geometry (Fig. 1).

The fault system geometry of the basin indicates an extensional setting. Generally, the Gulf of Suez is subdivided into three sub-provinces which are in accordance to the dominant structural dip of the sedimentary cover (Moustafa 1976). These sub-provinces are separated by two major transfer faults or hinge zones by most of the geologists working in the Gulf of Suez. To the north is the Zaafarana Hinge Zone and this separates the northern sector of the Gulf of Suez with its general dip to the southwest from the central sector which dips to the northeast. The second hinge zone is the Morgan Hinge Zone and this separates the central sector of the Gulf from the southern sector which dips to the southwest (Fig. 1).

The timing of rifting is dated as late Oligocene to early Miocene. Dating the basaltic igneous activity in the Suez area has placed the rift between 19 to 24 Ma (Fichera et al. 1992). Litho- and bio-facies analysis of the stratigraphic sequence have suggested an age of late Oligocene to early Miocene (Salah 1994). Cochran and Martinez (1988) established the initiation of rifting from the time of the generation of the oceanic crust of the Red Sea and indicated that this started about 23 Ma. Moretti et al. (1986) concluded that the main rifting phase was in early Miocene time.

3 STRATIGRAPHY AND DEPOSITIONAL SETTINGS OF THE QUATERNARY

3.1 *Stratigraphy*

The Quaternary section has been studied by Said, (1962 and 1990), Abd El Salam and El Tablawy (1970), Fawzi and Abd El Aal (1984), Abd El Shafi (1990), and Alsharhan and Salah (1995). This research has been incorporated into present paper. The Quaternary sediments are well developed in the Red Sea, Gulf of Suez and Gulf of Aqaba rift basins and possess different stratigraphic nomenclatures. A comparison of the different stratigraphic names used in the four countries along the Red Sea basin are shown in Figure 3. In the Gulf of Suez rift basin, the Quaternary sediments are characterized by remarkable variations in the both facies and thickness.

The type locality of the Quaternary section was proposed by the Scony Vacume Oil Company (SVOC) at the Ras Shukheir area on the western side of the Gulf of Suez. Fawzi and Abd El Aal (1984) recognized two facies within the Quaternary section: the Gihan facies containing predominant sandstones with thin beds of shale and anhydrite, and the Morgan facies which consists of shale, carbonates and thin anhydrite and interbeds with localized salt beds in the lower part of the section. Abd El Shafi (1990) recognized three lithostratigraphic units in the Quaternary section of the Gulf of Suez (Fig. 4). These units are:

1. Darag Group, which consists of two formations: the Wardan (clastic and evaporite interbeds) and Zaafarana (limestone, sand and shale interbeds); and is well distributed in the northern sector of the Gulf of Suez;
2. Ashrafi Formation, which consists mainly of a thick body of limestone and sandy limestone with streaks of anhydrite, and is developed in the southern Gulf of Suez.
3. El Tor Formation, which consists of medium to very coarse sandstone with thin shale interbeds and is present at the margins of the Gulf of Suez.

The Quaternary section in this study is subdivided into two members. The lower of the two is known as the Wardan Member, and consists of interbedded sandstones, shales and anhydrite; the upper unit was termed the Zaafarana Member, and consists mainly of carbonates and shales with thin beds of sandstone.

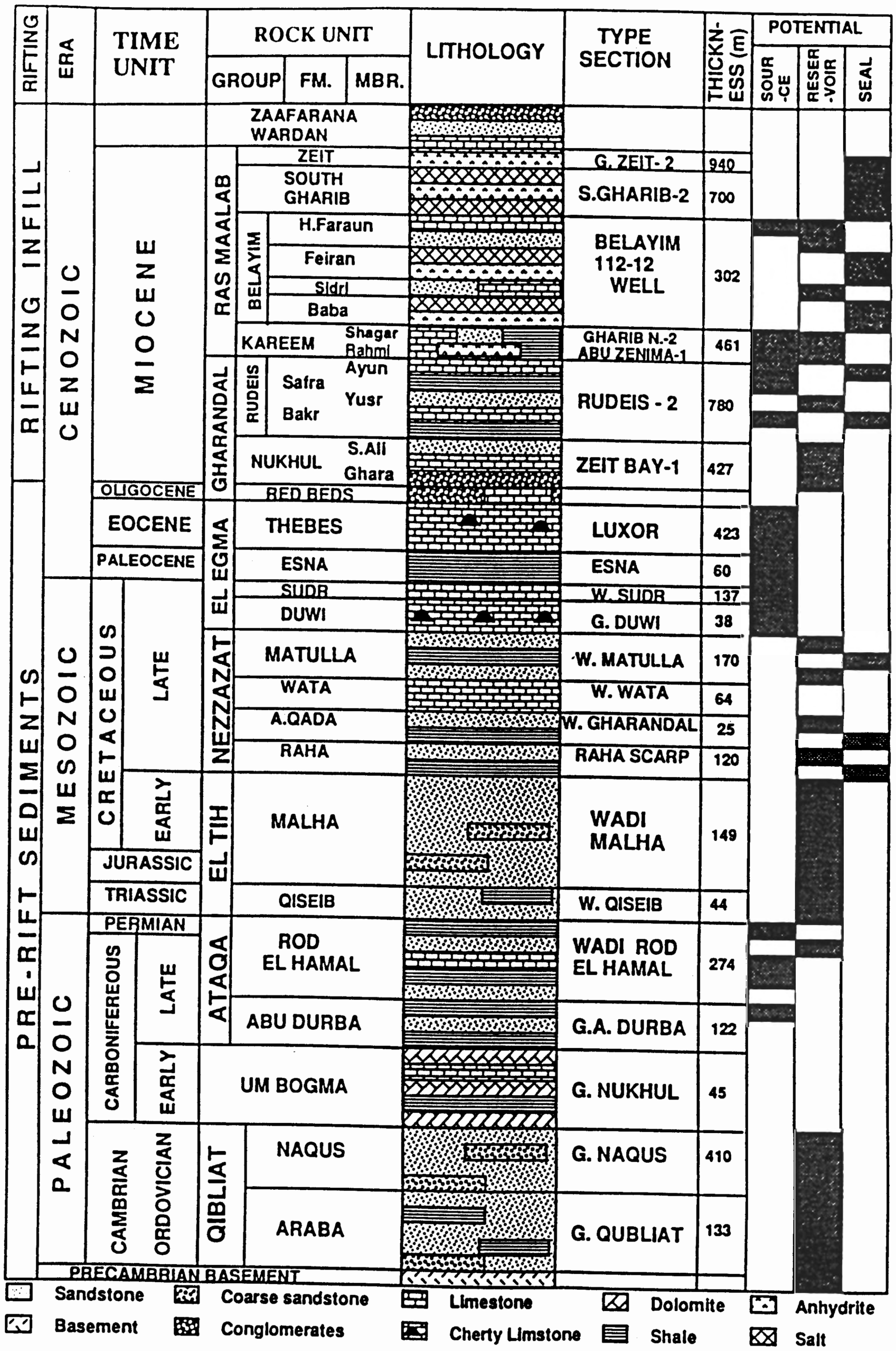

Figure 2. Stratigraphic column of the Gulf of Suez (modified after Salah 1994, Alsharhan and Salah 1995).

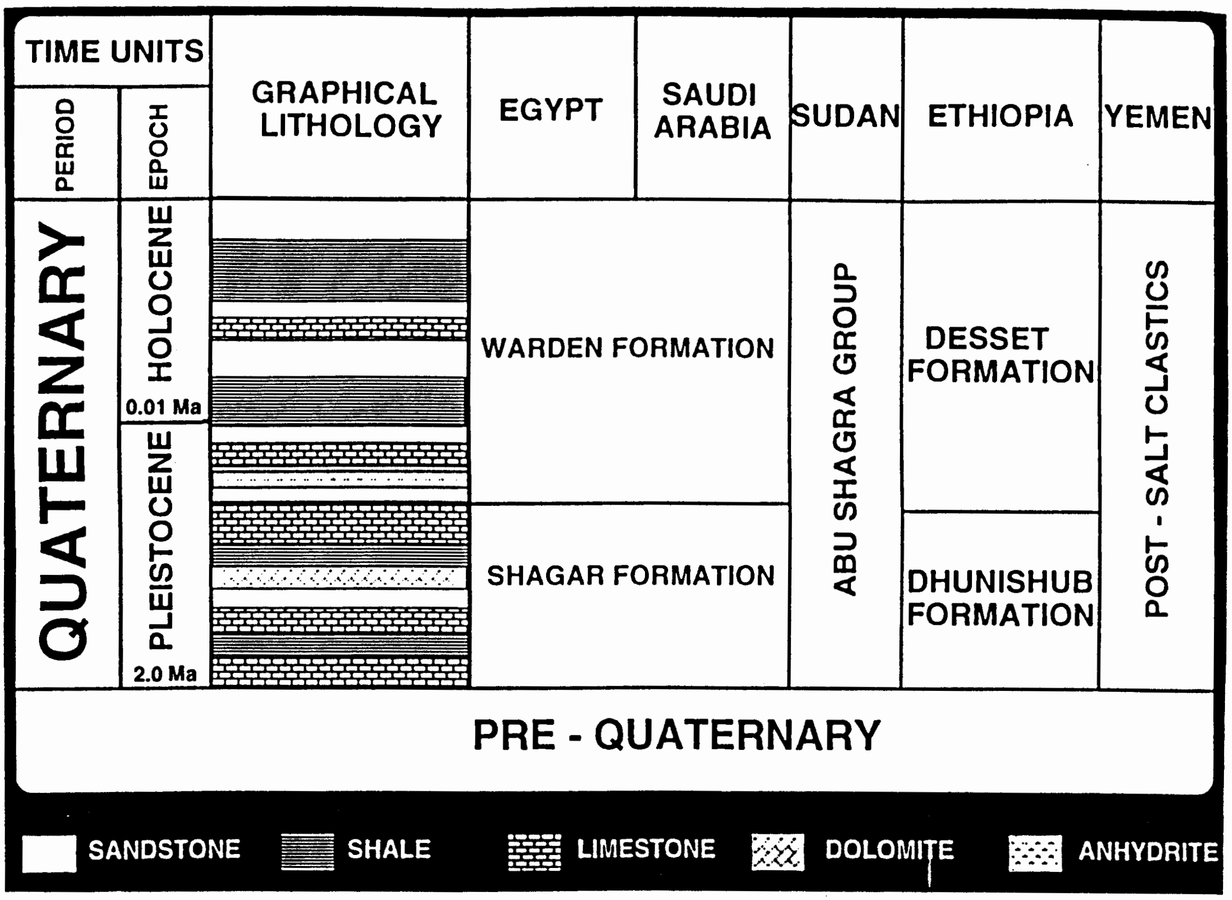

Figure 3. Comparison of the stratigraphic nomenclatures on both sides of the Red Sea rift basin.

The main depocentres in the Gulf of Suez basin are the Abu Zenima, Ras Shukheir and Wadi Gharandal sub-basins, in which the Quaternary section exceeds 1,000 ft in thickness (Fig. 5). The fossil content of the Quaternary section includes ostracods, foraminifera, nanoplanktons and shell fragment (Abd El Shafi 1990)

The Quaternary sediments unconformably overlie the late Miocene Evaporites (Zeit and South Gharib formations) and lies below the evaporites of the Belayim Formation. Its lower boundary is picked at the presence of the first thick anhydrite bed, and is marked by a sharp decrease in both sonic and gamma-ray log readings (Fig. 6).

3.2 *Environments of deposition*

The Quaternary Section consists of interbedded shales, sandstones, carbonates and anhydrites and comprises three different depositional settings:

1. Alluvial fans (known as El Tor Formation by Abd El Shafi (1990). The alluvial fans are localized deposits developed in areas of high relief where there was an abundant supply of sediments, in this poorly vegetated, arid to semi-arid region where rainfall was infrequent but violent and erosion was rapid. These sandstones are coarse- to very coarse-grained. In the Gulf of Suez area, alluvial fans were laid down on both margins of this Miocene rift (Fig. 7). During the Quaternary deposition, the Gulf of Suez was a particularly suitable area for alluvial sedimentation, in which the alluvial fans were built out from the bounding rift scarps. These fans are recorded at the southern and central onshore portions of the basin, around the margins of the basin and close to the exposed Precambrian Basement from which they were derived as in the West Hurghada, Gebel El-Zeit, Ras Shukheir and Zaafarana areas on the western side of the Gulf of Suez, and Belayim, Ras Ghara and El Qaa areas on the eastern side;
2. Deltaic fans: The fan delta sequence is interpreted as a sequence of fan delta deposits built out onto a relatively shallow shelf area upon which the deposition of carbonate was prevalent. This type of sequence is dominant in the southern and central Gulf of Suez (Hareed, East Zeit, Esh Mellaha Ashrafi and Morgan areas), where the fans prograded toward the southeast and southwes. direction, respectively being controlled structurally. The fan delta developed as a series of overlapping lobes with sediments being supplied via channels. In Esh Mellaha area, the deltaic fans over millions of years follow the same composition, trend and extension of the on-shelf delta with a slight shift seaward as indicated by Salah and Alsharhan (1995) in their study of the middle Miocene

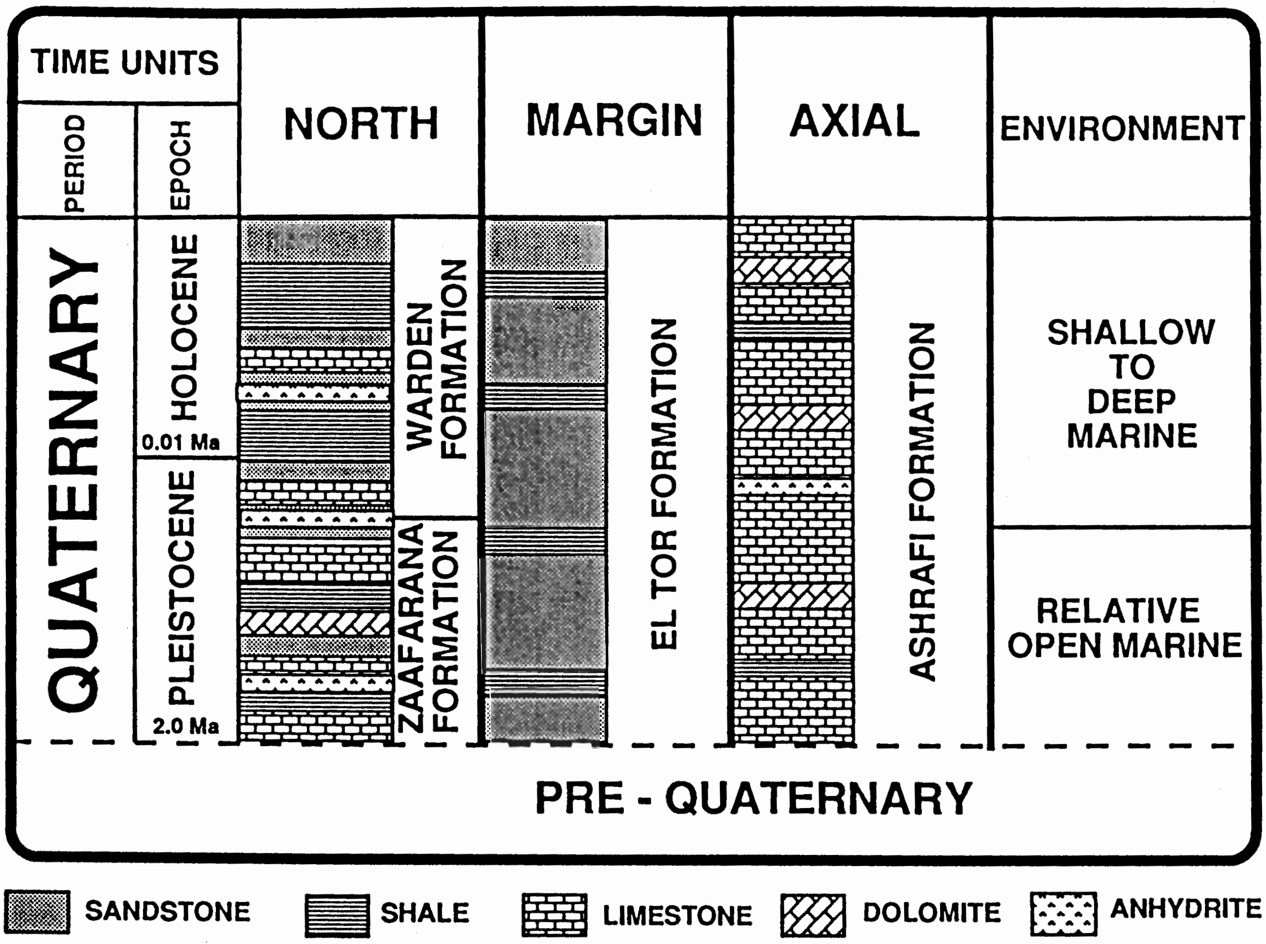

Figure 4. Lithology and depositional environment of the Quaternary sediments along the Gulf of Suez (modified after Abd El Shafy 1990).

Kareem Formation. The marginal areas of the main fan lobe deposition consist of interbedded sandstone, mudstone and limestone sequences, while a stacked sandstone sequence dominated in areas of active fan lobe deposition;

3. Sub-marine fans: These are located beyond the shelf edge, and received the bulk of their sediments from turbidity currents and forming cone-shaped bodies of sediments that delineated this rapidly subsiding basin. The sub-marine fans provide thick, extensive and porous sandstone reservoirs. The fans appear to have been fed from a single point source and fines seawards (i.e. as the distance from the source area increases).

Eustatic sea-level variations during the early deposition of the Quaternary section resulted in periodic anhydrite/carbonate precipitation in the marginal areas (Fig. 5). Anhydrites precipitated during the deposition of the Wardan (lower) Member, mainly in marginal, semi-restricted lagoonal settings. The predominance of fossiliferous carbonates with interbedded glauconitic shales in the Zaafarana (upper) Member indicates a marine setting.

4 HYDROCARBON POTENTIAL

The Quaternary sandstones are important as potential reservoir and source rocks, as discussed below.

4.1 *Reservoir potential*

The Quaternary sandstones form one of the reservoir lithologies in the Gulf of Suez and the Red Sea rifted basins, and produce and/or test oil or gas from few oil fields, e.g. Abu Durba (Egypt), Suakin Discovery (Sudan) and Abbas Discovery (Yemen). Their average net pay thicknesses in Abu Durba oil field is 15 m; porosities range from 16% to 33%, and permeabilities from 20 md to 730 md. This good reservoir quality is a result of being buried under shallow depths (less than 1000 m). The overall reservoir quality depends on the shale content and the importance of diagenetic processes including silica dissolution and precipitation. Most of the clastic sediments in the southern and central parts of the Gulf of Suez are derived from eroded basement rocks adjacent to the flanks of the Gulf. Erosion of horsts within the Quaternary basin partly contributed to sand

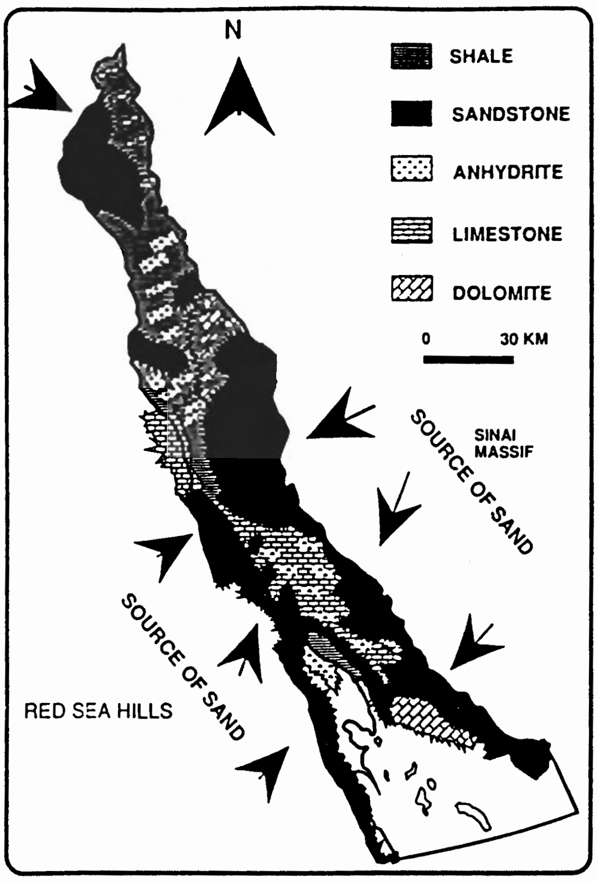

Figure 5. Distribution of the Quaternary lithofacies along the Gulf of Suez.

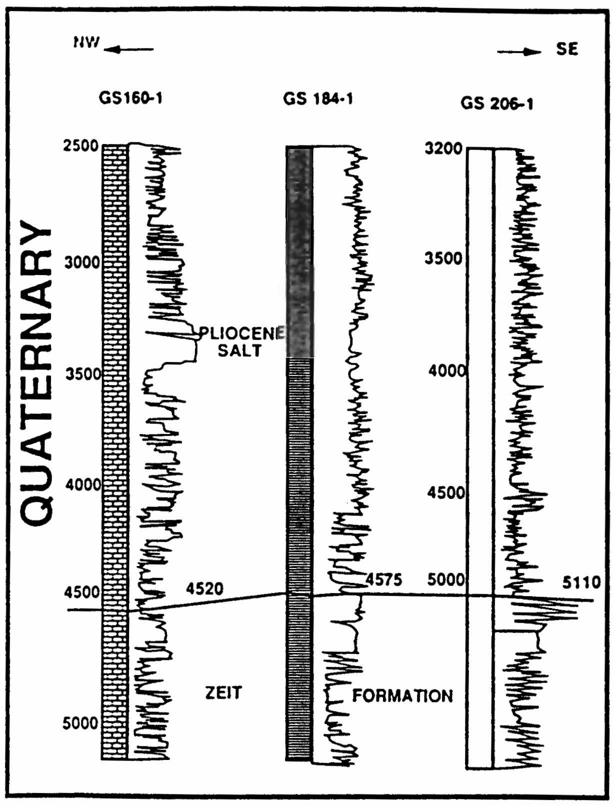

Figure 6. Generalized stratigraphic boundaries and log responses of the Quaternary section.

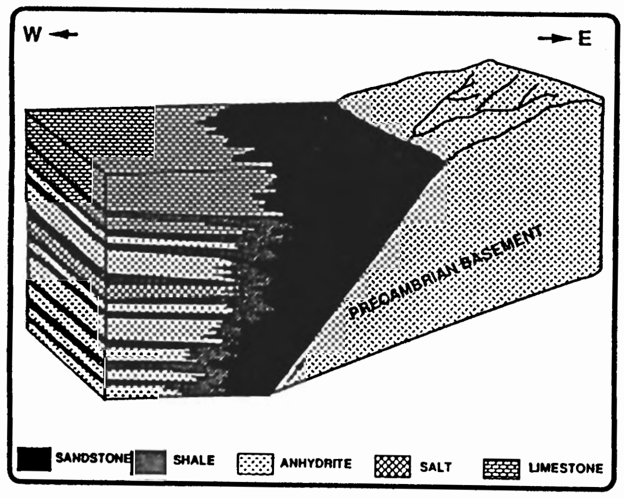

Figure 7. Depositional settings of the Quaternary section along the Gulf of Suez.

accumulation. However, some of these highs acted as a barrier, thus preventing the advance of prograding fans. Most sand bodies are developed adjacent to these highs and in some places they are seen to overstep the highs.

4.2 *Source potential*

The source potential of the Quaternary sediments has been studied by Barakat, 1982 and, Salah, 1992, 1994.

Based on the geochemical analyses of the total organic carbon content (TOC) and the results of pyrolysis (S2) run by these authors and others on the Quaternary shales and carbonates, covering most of the Red Sea and the southern sector of the Gulf of Suez, the organic-rich shaly intervals are considered to have fair source potential; TOC and S2 values average 1.0% and 4 kg/ton, respectively.

The hydrogen index of the Quaternary shales and carbonates ranges between 50 and 350 indicating that a gas-prone source rock is present, (Types III of Tissot 1984).

The Gulf of Suez rifted basin is characterized by the heterogeneity of crustal thickness, and several hot spots occurred and gave rise to localized source kitchens even within shallow depths, especially in the southernmost Gulf of Suez and northern Red Sea (Salah 1992). The average geothermal gradient of the northern and central sectors of the Gulf of Suez basin is 1.55° F/100 m, while it averages 1.75° F/100 m in the southern part (Alsharhan & Salah 1994,1995).

5 CONCLUSIONS

The Quaternary Section in the Gulf of Suez basin, unconformably overlies the late Miocene evaporites, is divided into the Wardan and overlying Zaafarana Members. It was deposited in fluvial, deltaic and marine settings with local lagoons.

These syn-rift sandstones are considered to be one of the reservoir lithologies in the Gulf of Suez oil province, and produce oil from Abu Durba oil field. They have an average porosity of 26%. Shales within the formation have fair source potential and organic material is gas-prone.

ACKNOWLEDGMENT

The authors express their appreciation for the editorial help of C.G.St.C. Kendall, K.W. Glennie, A.E.M. Nairn and G.L. Whittle.

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