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Contribution to the tectonic setting of the Northern Galala Plateau, Gulf of Suez, Egypt

Mohamed M.Mahran[1], Wael D.Hagag[1], Gamal M.El Qot[1], Refaat A.Osman[1], Mahmoud K.Alawy[2] and Zakaria Hamimi[1]
[1]Geology Dept., Faculty of Science, Benha University
[2] Geology Dept., Faculty of Science, Alexandria University
E-mail: omahran206@gmail.com

Abstract

Detailed field investigation of the Northern Galala Plateau (NGP), located between the Cairo-Suez district and Wadi Araba, reveals that the exposed stratigraphic succession in the area are the Abu Darag (oldest), Aheimer, Qiseib, Rieina, Ras El-Abd, Malha, Galala, Thebes and Mokattam (youngest) formations. These formations are traversed by three main extensional faulting trends, which can be arranged from oldest to youngest based on their cross-cutting relations into E-W (to ENE-WSW), NW-SE (to NNW-SSE) and NE-SW (to NNE-SSW). These trends can be affiliated to three main far-field tectonic events, namely the Tethyan rifting, the Clysmic rifting and the Aqaba-Dead Sea transform system, respectively. The main objective of the present work is to highlight the characteristic features of the above-mentioned faulting trends in terms of their kinematic history. Results obtained from this study will add much more contribution to our knowledge, not only on the tectonic evolution of the Gulf of Suez rift (GOSR), but also to the whole Afro-Arabian Rift System.

Keywords: Gulf of Suez Rift, Cairo-Suez structural province, Tethyan Rifting, transtensional regime, Afro-Arabian Rift.

1. Introduction

The Northern Galala Plateau (NGP) lies in the northern part of the Egyptian Eastern Desert. Its eastern scarp forms a narrow coast with the Gulf of Suez (GOS). It is regarded as one of the tilted fault blocks of the intensively faulted GOS area, among other rising and sinking blocks, such as the Gabal Ataqa and Wadi Ghoweiba, respectively. The structural investigation of the area reveals that the area is mainly cut by NW-trending normal faults affiliated to the Oligo-Miocene rifting phase along with some other E- (to ENE-) and NE- (to NNE-) trending fault sets. The stratigraphic sequence is represented by the pre-rift sediments starting with the Paleozoic to the Quaternary **Figure 1**. The whole rock units outcropping in the area were traversed by rift-related NW-trending mafic dykes of the Oligo-Miocene volcanicity.

The Gulf of Suez-Red Sea Rift basin (GOS-RSRB) (N30ºW) was formed due to the divergent movement between the African plate and the Arabian plate [1]. In recent decades, the GOS-RSRB has been the target of many studies from several angles of views, owing to its geological and economic importance. This area has been considered by many authors e.g. [2, 3] to be a key area showing the evolutionary stages of ocean formation. Additionally, the GOS district is a prolific source of oil and gas.

The NGP extends from east to west for approximately 80 km, with the highest point of about 1260 m above sea level. It overlooks to the east on the narrow coast of the GOS and extends westward to join Gabal Mokattam in the Cairo Governorate near the Nile River. It is bounded by Wadi Ghoweiba to the north, separating it from the Cairo-Suez district, Wadi Araba to the south, separating it from the Southern Galala Plateau, the GOS to the east, and the Nile Valley to the west. It occupies an area of approximately 5750 km². The NGP attracted our attention because it exhibits a wide variety of rift-related structures and rift deformation patterns as part of the GOS structural province.

The present study utilized intensive field study and reappraisal of the stratigraphic succession to investigate the structural setting of rift-related structures, dissecting the NGP, and their relation to the tectonic evolution of the GOS-RSRB.

2. Materials and methods

Intensive field study was centered on mapping contacts between different rock units, investigating fault trends and collecting orientational data of the structural elements. The present study is conducted using different methods and software. The processing of remotely sensed data was performed to discriminate the lithostratigraphic units, structures and to construct a detailed geologic map for the study area. In addition, topographic maps and previously published geologic maps and cross-section were utilized during the construction of a geologic map of the study area. Mapping, analysis and interpretation of the structural elements was achieved using several software including ENVI 5, Adobe Illustrator 2020 (v24.2.3.521), GPS, FaultKin, Stereonet and CorelDRAW.

3. Regional Geology and Lithostratigraphy

The exposed stratigraphic succession in the NGP ranges in age from the Late Paleozoic to the Quaternary. It starts at the base with the Upper Carboniferous to Lower Cretaceous sequence of clastic sediments with minor carbonate interbeds, followed upward by carbonate sequence representing rocks varying in age from the Late Cretaceous to the Eocene. Most of the stratigraphic contacts between these rock units are distinguished by unconformity surfaces. These rock units will be summarized in the next paragraphs.

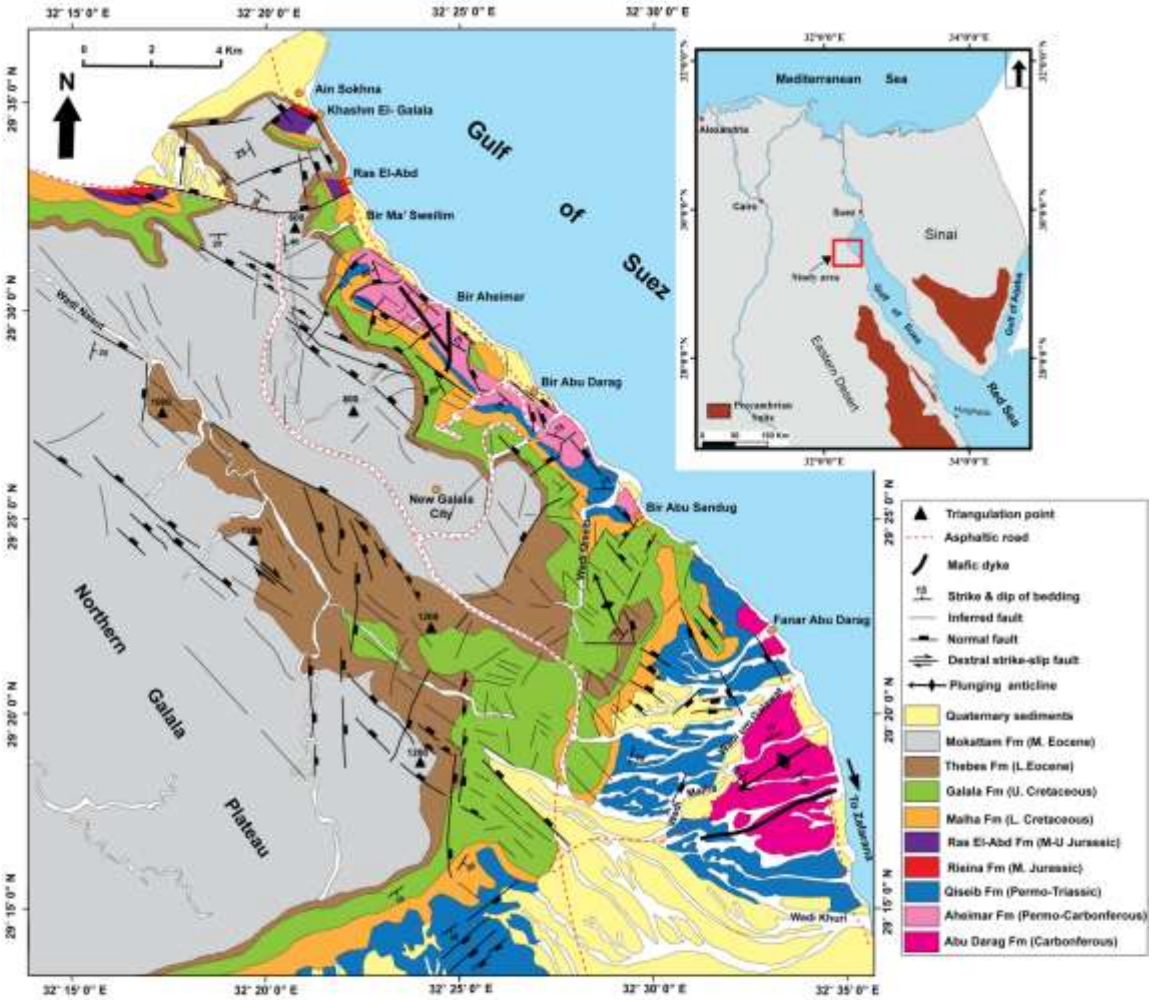

Fig.(1) The Geological map of the NGP modified after [4], [17] and [9]. Inset map shows the location of the study area in the northeastern Egypt.

3.1. The Abu Darag Formation

The Abu Darag Formation (Fm) was first introduced by [4] to describe a 175 m thick section exposed at the Suez-Ras Gharib road near the Abu Darag Lighthouse. It was subdivided into three members; shale series; massive claystones, shales with fossil fragments of crinoids, bivalves, and brachiopods, coarse-grained to gritty sandstones **Figure 2**, marls and crinoidal limestones. The authors assigned the Abu Darag Fm to the Pennsylvanian age. In the study area, this formation forms low residual hills and cuestas. The lower boundary of the Abu Darag Fm is unexposed in the study area, whereas its contact with the overlying Qiseib Fm at the Abu Darag Lighthouse is marked by an unconformity surface. The main environment of the Abu Darag Fm suggests an oscillatory nature of the sea over the basin of deposition, indicating a shallow-marine transgression in the upper unit, although the lower unit is characterized by continental to semi-continental deposits [4].

3.2. The Aheimer Formation

The Aheimer Fm (Late Pennsylvanian to Early Permian) was first introduced by [4] to describe a 250 m thick section at Wadi Aheimer on the eastern cliffs of the NGP. This formation includes three members; the lower member is composed of dark green and gray shales intercalated with some thin pinkish fossiliferous calcareous clays, yellow massive sandstones, and clays rich in brachiopods, corals, crinoids and bryozoans. The middle member consists of yellowish brown massive sandstones, fossiliferous limestones and shales, marls and siltstone interbeds. The upper member is made up of fine to medium-grained, thick-bedded sandstones and fossiliferous claystones and shale interbeds. The lower boundary of the Aheimer Fm is not exposed in the study area, but it is assumed to overlie or interfinger with the Abu Darag Fm, whereas the upper boundary with the Qiseib Fm in the Abu Darag Lighthouse shows seeming conformity [5]. The middle member of the Aheimer Fm was deposited in shallow marine conditions, whereas the upper member shows a marginal intertidal environment with a possibility of changing into a fluviatile environment near the base [4].

Fig.(2) Cross-bedded, coarse-grained sandstones of the Abu Darag Fm exposed in the vicinity of the Abu Darag Lighthouse, 29°18'59.80"N 32°33'30.30"E; looking NE.

3.3. The Qiseib Formation

[6] first introduced the Qiseib Fm for the brick-red shale and sandstone sequence at Wadi Qiseib area. This formation comprises three members; the lower member consists of violet yellow or brown, cross-bedded and nonfossiliferous sandstone, including a shale-siltstone bed and a sandy conglomeratic bed. The middle member is made up of yellow hard dolostone, interbedded with green calcareous shale and siltstone. The upper member consists of reddish brown, thin-bedded, fine-grained, unfossiliferous sandstone. [6] suggested the age of the Qiseib Fm based on the badly preserved fossils in the middle member to the Permo-Triassic. The Qiseib Fm is rich in red to violet ferruginous sandstone and siltstone bands (paleosol horizons). The Qiseib Fm overlies the Aheimer Fm at Wadi Qiseib area with no visible unconformity and also overlies unconformably other Paleozoic rocks such as the Abu Darag Fm in the Abu Darag Lighthouse. The Qiseib Fm underlies unconformably the Lower Cretaceous Malha Fm **Figure 3** [7]. This formation was deposited under continental semi-arid conditions mainly, since the red beds are thought to be an evidence of subaerial exposure. Moreover, a fluviatile environment could be confirmed by the presence of plant remains and lenticular bedding, also the scour surfaces suggest channel deposition [5].

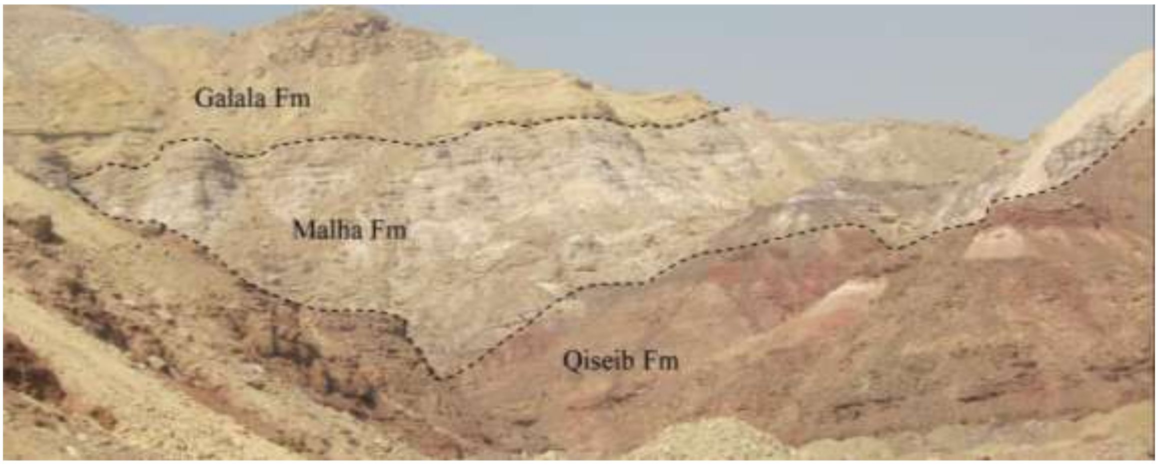

Fig.(3) Permo-Triassic Qiseib Fm underlying the Cretaceous Malha and Galala formations (fms), near the Abu Darag Lighthouse, 29°24'1.70"N 32°32'6.80"E; looking W.

3.4. The Rieina Formation

The Rieina Fm was first introduced by [8] to describe a nearly 70 m thick Jurassic section at Khashm El-Galala area. It also outcrops at Ras El-Abd area, yet at a smaller thickness. It is made up of varicolored friable cross-bedded sandstones. These sediments form a cyclic pattern starts as coarse-grained at the base, medium-grained and fine-grained sandstone and siltstone at the top, each cycle ranges in thickness from 2 to 8 m, with no marine fossils detected [9]. The Rieina Fm is estimated to be of Bajocian age [8]. The lower boundary of the Rieina Fm is unexposed in the studied sections, but it is assumed to be unconformably overlying the Permo-Triassic Qiseib Fm. The upper boundary of the Rieina Fm is marked by a thick paleosol section, followed by a nearly 50 cm thick of *Thalassinoides* burrows-bearing bed. This indicates an unconformable relation with the overlying Ras El-Abd Fm **Figure 4**. The lithofacies and microfacies of the Rieina Fm indicate that the deposition occurred in a fluvial system.

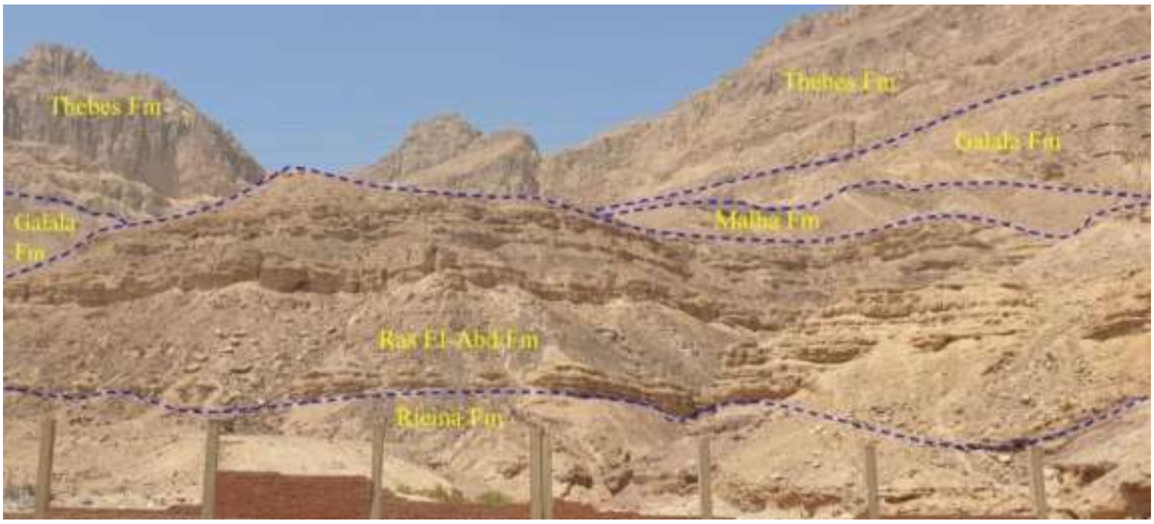

Fig.(4) Jurassic sequence exposed at the Ras El-Abd area underlying the Cretaceous and Eocene rocks, 29°33'7.66"N 32°21'32.11"E; looking W.

3.5. The Ras El-Abd Formation

The Ras El-Abd Fm was first introduced by [8] to define a 150 m thick Jurassic section at Khashm El-Galala area. The formation decreases at Ras El-Abd area reaching nearly 100 m thick. It consists mainly of shale, limestone and dolostone with marls and sandstones interbeds. According to [10], the formation is characterized by the presence of three main shell beds, represented by a molluscan shell bed, the lower rhynchonellid bed and the upper rhynchonellid bed. [11] proposed a Bathonian age for the shale-limestone member of the Ras El-Abd Fm. Based on the microfacies association identified by [9], the carbonate deposits dominated in the Ras El-Abd Fm were considered to be deposited in a restricted shallow marine environment created during a transgression–regression cycle.

3.6. The Malha Formation

The type section of the Malha Fm is located 2.5 km north to north-east of the Abu Darag Lighthouse. At this locality, the Malha Fm reaches 106 m thick. It is composed of fine to coarse-grained, cross-bedded sandstones cemented by kaolin, ill-sorted gravelitic sandstones with kaolin beds in variable thicknesses, fine to medium-grained, false-bedded sandstones with kaolin lenses, kaolinitic sandstone, clayey sandstone and clays [6]. The beds are varicolored, mainly white in addition to some orange, limonitic yellow, yellow and green colors. In the study area, the Malha Fm exhibits an unconformable relation with the underlying Ras El-Abd and Qiseib fms as well as versus the overlying Galala Fm. [6] assigned an age of latest Aptian-Albian to this formation which is considered to be deposited under terrestrial or fluviatile to marine conditions [12]. The facial and faunal contents indicate the up and down oscillatory movements of the sea over the basin of deposition [6].

3.7. The Galala Formation

The term Galala Fm was first introduced by [4]. It was subdivided by [13] into two informal members; a lower marly and shaly member followed by an upper limestone member. [14] studied the Galala Fm at the Abu Darag Lighthouse and described it as 122 m thick, composed mainly of fossiliferous marl, dolomitic limestone, with a few shale and siltstone interbeds. The two informal members were described as follows; the lower member (marly shaly member) attains a thickness of 78 m and is composed mainly of marl with a few limestone, shale, siltstone, claystone, and sandstone interbeds. The upper member (carbonate member) is a succession of 44 m thick, consists of dolomitic limestone, chalky limestone, sandy limestone, dolostone with marl interbeds. The Galala Fm is a highly fossiliferous unit. The recorded macrofossils by [14] include bivalves, gastropods, cephalopods and echinoids. From the collected macrofauna, the Galala Fm is considered to be of a Cenomanian – early Turonian age. The litho- and biofacies of the Galala Fm designate the Tethyan sea transgression over the NGP during the Cenomanian. They also reflect that the deposition occurred in warm, shallow, slightly oscillating shelf environment with normal salinity [15].

3.8. The Thebes Formation

The Thebes Fm was first introduced by [12] to describe an extensive carbonate platform developed along the southern margin of the Tethyan ocean. The type section of the Thebes Fm is Gabal Gurnah, on the west bank of the Nile River near Luxor, where it reaches 340 m in thickness [16]. [17] classified this formation at the NGP into three members. The lower member is composed of white limestone and marl to marly limestone of yellowish white color. The middle member consists of white creamy limestone, with bands of chalky to marly limestone, rich in chert bands and nodules. The upper member comprises massive white chalky limestone and massive, hard to moderately hard limestone. At Gabal Um Reseis and the surrounding wadis, [17] recorded macrofossils of bivalves, gastropods, bryozoa and echinoids in addition to seven larger foraminiferal species. The foraminiferal taxa recorded are assigned to the late Ypresian age. An extensive marine transgression of the Tethys during the Ypresian covered many parts of Egypt, including the GOS area. The study area is capped by the lower Eocene rocks, representing various depositional conditions [17]. [18] proposed that the Thebes Fm is deposited mainly in a regressive phase.

3.10. The Mokattam Formation

The Mokattam Fm was first described by [19], merely he did not designate a type section for this unit. Many authors considered Gabal Mokattam to the east of Cairo to be the type section of the Mokattam Fm. [20] classified this formation into four members (from base to top) as follows: the Lower Building Stone Member, the *Nummulites gizehensis* Member, the Upper Building Stone Member and the Giushi Member. In the study area, the Mokattam Fm covers the majority of the NGP surface, extending west to join the Gabal Mokattam near Cairo. It is described at Wadi Naaut as 60 m thick of gray hard limestone and dolostone interbeds [21]. [22] recognized planktonic foraminifera and calcareous nannoplankton fossils from the basal part of the Mokattam Fm at Gabal Mokattam and Beni Suef area. The recognized faunal assemblages refer to the late Lutetian age. In the study area, the Mokattam Fm overlies the Thebes Fm which is distinguished in the western GOS region by a reefal nummulitic facies [12].

3.10. The Quaternary sediments

The Quaternary sediments in the study area are represented by raised beach sediments, terrace gravels and peidmont gravels.

4. Rift-related structures

The NGP is highly dissected with rift-related extensional faults, with little evidence of horizontal movement. Based on cross-cutting (overprinting) relations, along with reviewing previous publications that have been carried out in the GOS and its adjacent areas, the following main fault trends are discriminated:

Fig.(5) Field photo showing an E-W major fault scarp bordering the NGP, 29°32'52.75"N 32°17'58.10"E; looking W.

4.1. The E-W (to ENE-WSW) faulting trend

The E-W (to ENE-WSW) faulting trend can be traced easily on the Google Earth and Landsat images. This trend is detected in the NGP with frequently eye-catching structures. A major E-W (ENE-WSW) trending fault marks the northern border of the NGP **Figure 5**, separating the Northern Galala region from the Cairo-Suez District, which is also traversed by numerous E-W trending faults [23]. This master fault (often called the Northern Galala Fault; NGF) extends more than 19 km long in the study area, dipping mainly to the NNE. It starts from the west striking WNW-ESE then it curves into a complete E-W direction and ends in the east striking ENE-WSW. The NGF zone is marked by fault breccia and gouge reflecting a long-lasting movement. Along the fault scarp, remarkable oblique-slip slickenlines are encountered, indicating a combination of dip- and strike-slip- components (i.e., this trend was formed in a transtensional regime). The NGF is associated with other faults, horsts and grabens with nearly the same trend, yet at a smaller-scale.

4.2. The NW-SE (to NNW-SSE) faulting trend

The GOS NW-SE (to NNW-SSE) rift-parallel faults are broadly cutting most of the rock units in the study area and observed at macroscopic- and mesoscopic- scales **Figure 6**. This trend is the most prominent in the form of normal faults, grabens, conjugate faults and joints. A major NW-SE fault is extending for more than 8 km can be traced from the Google Earth maps, cutting the Eocene rock units in the area between Wadi Naaut and the new Galala road to the northwest of the New Galala city. Most of the NW-SE (to NNW-SSE)- trending faults observed at the NGP are synthetic to the Abu Darag rift border fault [24], dipping towards the NE and ENE. Antithetic faults dipping to the SW are sporadic structures.

Fig.(6) NW-SE striking fault in the Abu Darag Fm with off-setting up to 50 cm, 29°19'59.50"N 32°35'18.90"E; looking NW.

4.3. The NNE-SSW (to NE-SW) faulting trend

The NNE-SSW faulting trend is registered at various locations at the concerned area. It is recorded in the form of normal faults, grabens and joints cutting some rock units in the area. The NE-SW faults cross-cut the rift-parallel faults at a nearly normal angle and therefore can be considered as rift-normal (rift-cross) faults. These faults are either developed due to reactivation of pre-rift fabrics [25] or formed as a result of the effect of the younger Gulf of Aqaba opening.

5. Discussion

Overprinting (cross-cutting) relations were used to determine the relative ages of the structural elements, hence the tectonic movements acted upon the study area. It is one of the best geological principles used to understand the deformation pattern and the tectonic history of any area. It can be stated with reasonable confidence that the main tectonic events affected the Northern Egypt during the Mesozoic and

Cenozoic Eras can be arranged from the oldest to the youngest into:

1) Tethyan Rifting (Jurassic-Early Cretaceous)
2) Closure of Neotethys and basin inversion (Late Cretaceous)
3) Red Sea-GOS rifting (Oligocene-Miocene)
4) Gulf of Aqaba transform fault (middle Miocene-Recent)

Cross-cutting relations are clearly seen in the study area between various structural elements representing various tectonic events. The major E-W Tethyan Rifting-related faults and the Syrian Arc component of the Wadi Araba anticline [24] are cut by the GOS rift itself at the northern and southern borders of the NGP, respectively. This notifies that the GOS-RSRB is younger than both the Tethyan Rifting and the closure of the Neotethys. It is suggested that the closure of the Neotethys took place post-dating its rifting. The NW-SE faults representing the GOS-RSRB are overprinted by the NE-SW faults; this cross-cutting relation is recorded in some locations in the study area.

Conclusions

- From the Carboniferous to the Early Cretaceous, the NGP as part of the Middle East-North Africa (MENA) region was part of abroad shelf system. The Abu Darag, Aheimer, Qiseib, Rieina, Ras El-Abd and Malha fms were deposited in approximately similar environments as the dominant clastic sequences represent continental, fluvial and shallow marine transgression environments separated by some unconformity surfaces indicating subaerial exposures.
- The Tethyan sea transgression over the northern Egypt during the Cenomanian led to the deposition of a shale-carbonate sequence in the study area. The Galala Fm (Cenomanian-lower Turonian) is believed to be the transitional rock unit separating the mainly clastic Paleozoic, Jurassic and Lower Cretaceous succession below from the mainly carbonate Upper Cretaceous and Cenozoic succession above. The shale-carbonate rocks of the Galala Fm are deposited in shallow marine environment followed by the Santonian basin inversion event.
- The lower Eocene Thebes Fm indicates the onset of a major flooding event represented by the deposition of the limestone and dolostone beds.
- The investigated structural fabric elements in the study area follow three main faulting trends or fault sets. The most dominant fault set recorded in the study area is trending NW-SE (to NNW-SSE), with some significant faults trending E-W (to ENE-WSW) and some others trending NNE-SSW (to NE-SW).
- The E-W (to ENE-WSW) normal faults and grabens are believed to be Tethyan rifting-related, formed during the Jurassic-Early Cretaceous times due to the divergent movement between the Afro-Arabian plate and the Eurasian plate. Some of the E-W (to ENE-WSW) fault planes exhibit slip lineations indicating transtensional regime with both dip- and strike-slip components.
- The NW-SE (to NNW-SSE) normal faults and grabens are affiliated to the Oligo-Miocene GOS-RSRB event. The movement that was later aborted in the middle Miocene by the Aqaba-Levant sinistral transform related to the drift of Arabia away from Africa towards Eurasia in a NNE direction. The later was the most-likely responsible for the NNE-trending faults detected in the study area.

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