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ORIGINAL PAPER

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Gravity and Areomagnetic Signatures and their Geological Significance in the Abu Gharadig Basin, Northwestern Desert, Egypt

Abstract: Geological interpretation of Bouguer gravity anomalies and total intensity magnetic anomalies of two profiles from the Abu Gharadig basin suggests a general northward increase in basement depth (about 3 to 6 Km). Gravity modeling using software given by Enmark (1981) and Begg *et al.* (1987) are applied along the gravity profiles, giving reliable results agreeing with the available geologic information on the area. The magnetic profiles are interpreted and analyzed using two methods: non-linear optimization techniques and interactive techniques. A prominent uplift of the basement rocks is observed to the south, which is considered a part of the major basement high in the northern Western Desert of Egypt. In addition, a significant deepening of the basement is found to the north, which represents a part of the major subsidence including the present Mediterranean basin. The abnormal thickness of the sedimentary section of various facies, and the presence of deep-causative intrabasement (acidic or basic bodies) are possibly considered the main causes for 1) the origin of different gravity anomalies (negative and positive respectively); and 2) the origin of different magnetic anomalies (low and high), particularly those in the middle part of the study area.

المدلولات التثاقلية والمغناطيسية وانعكاساتها الجيولوجية على منطقة حوض أبوالغراديق، شمال الصحراء الغربية- مصر

حمزة احمد إبراهيم

المستخلص: التفسير الجيولوجي للبيانات التثاقلية المستمدة من خريطة البوجير وأيضاً للبيانات المغناطيسية المستمدة من خريطة المغناطيسية الكلية لمنطقة أبو الغراديق والمناطق المجاورة يشير إلى زيادة عمق صخور الركيزة المعقدة كلما اتجهنا شمالاً (ناحية البحر الأبيض المتوسط).

وتهدف الدراسة الحالية لمنطقة أبو الغراديق إلى معرفة أصل الشذوذ التثاقلي السالب الكبير (-24 مللي جال) وأيضاً معرفة أصل الشذوذ المغناطيسي الصغير نسبياً(-25 جاما) الموجود إلى الشرق من منخفض القطارة (الجزء الأوسط من منطقة أبوالغراديق) ، وأيضاً تهدف هذه الدراسة إلى التعرف على أصل الشذوذ التثاقلي الموجب الكبير (+13 مللي جال) ومعرفة أصل الشذوذ المغناطيسي الكبير نسبياً (+575 جاما) في منطقة بئر Agnes-1 (ناحية الجنوب) ، وقد تمت هذه الدراسة عن طريق تصميم نماذج رياضية تثاقلية ومغناطيسية على طول البر وفيلات المدروسة حيث أفادت نتائجهم في رسم قطاعين تحت سطحيين إستنادًا على البيانات التثاقلية مرة والبيانات المغناطيسية مرة أخرى.

تشير نتائج الدراسة الحالية بمنطقة أبوالغراديق إلى التغير الواضح في عمق صخور الركيزة المعقدة والتي تتراوح تقريباً من 3 كم جنوباً إلى حوالي 6 كم شمالاً ناحية حوض البحر الأبيض المتوسط .ويعتقد أن السبب الرئيسي للشذوذ التثاقلي السالب وأيضاً للشذوذ المغناطيسي الصغير نسبياً في الجزء الأوسط من منطقة أبوالغراديق (غرب منخفض القطارة) ربما يرجع إلى وجود جسم كبير على عمق كبير من سطح الأرض (<15 كم) هذا بالإضافة إلى سمك الغطاء الرسوبي الكبير المتميز ببيئات ترسيبية متنوعة ، بينما يرجع أصل الشذوذ التثاقلي الموجب وأيضاً الشذوذ المغناطيسي الكبير الموجود بمنطقة بئر Agnes -1 إلى وجود جسم ناري قاعدي ذو امتداد كبير كثافته أعلى من كثافة الصخور النارية المحيطة به هذا بالإضافة إلى سمك الرواسب الصغيرة في هذه المنطقة والمميزة للمناطق الجنوبية عموماً.

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Introduction

The study area represents a great part of the Abu Gharadig basin, which lies to the northeast of the Qattara Depression in the northern Western Desert of Egypt. Recently, this region has been considered a very important province for oil and gas potentialities in Egypt, so many wells have been drilled by different oil companies in different parts of this region (Fig. 1). The north of the Western Desert is dominated by several basins and ridges (Fig.2).

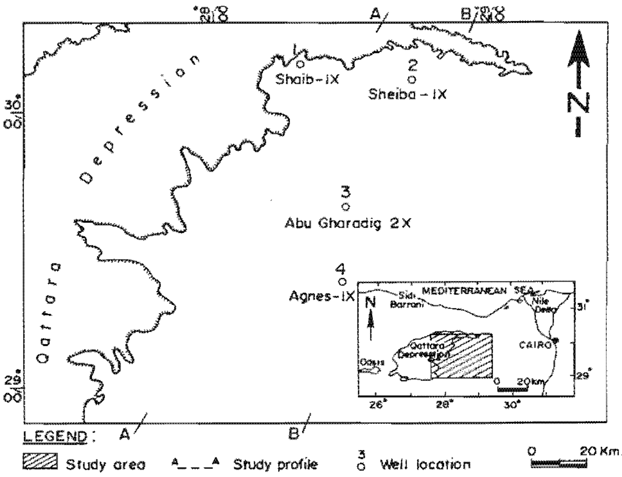

Figure 1. Location map of the study area.

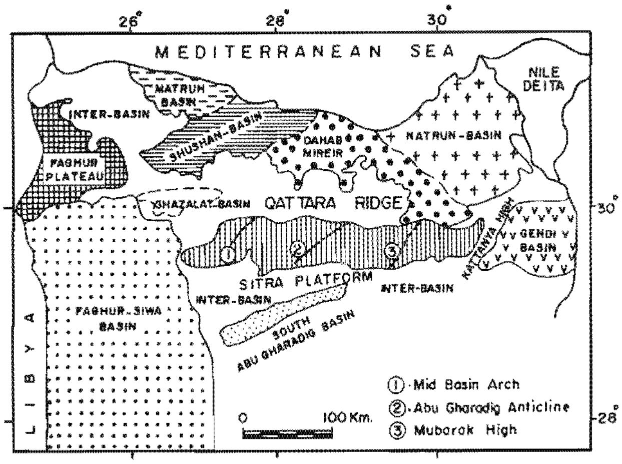

Figure 2. North Western Desert basins delineation map (Modified after Meshref, 1982).

The initial data used in the present study are in the form of Bouguer gravity and aeromagnetic anomaly maps. Both maps were kindly provided by the Egyptian General Petroleum Corporation (E.G.P.C). The study profiles are marked A-A/ and B-B/ on the Bouguer gravity map (Fig. 6) and also on the aeromagnetic map (Fig. 7).

Morphologically, two major surface features generally characterize the study area. Abu Al Izz (1971) classified these features as the following; a) The rocky southern Miocene plateau with its northern portion made up of the middle Miocene Marmarica "limestone" (Tm) and its southern portions consisting of the lower Miocene Moghra "sandstones and gravels" (Tm), b) The Qattara Depression itself with its floor is made up of the lower Miocene Moghra "clastics" (Tm) covered by playas and shallow saline water ponds in its deepest portions and encrustation, silt, loose sands and sand dunes (Qd), as well as, sabakhas (Qsb) in its shallow portions. The Eocene "limestone" (Te) and the Oligocene "clastics" (To), which are the oldest exposed-rock units in the area, are found to crop out in the southern portions of the Miocene plateau and the Qattara Depression (Fig.3).

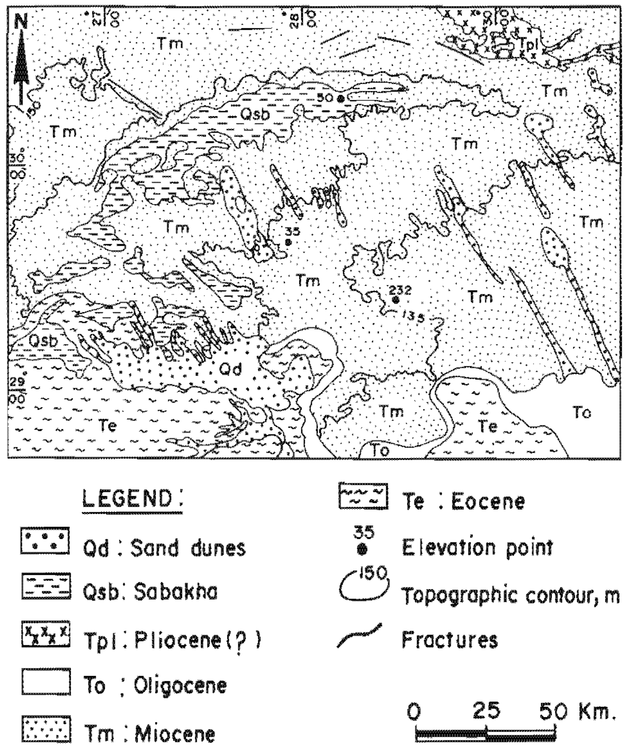

Figure 3. Simplified geological map of the Qattara Depression area (Modified after the Egyptian Geological Survey, 1981).

The subsurface stratigraphy of the Abu Gharadig basin area and the surrounding parts (Fig. 4) has been studied by many workers (e.g. Abu El-Naga, 1984; Elzarka, 1984; Ibrahim, 1986; Bayoumi and Lotfi, 1989; Said, 1990; Setto, 1995). According to these studies, the following is a summary of the subsurface geologic settings in this important part of north Egypt:

a. The Paleozoic sediments are made up of interbedded sandstone and shales with minor carbonates. They reach a maximum thickness of about 4000 m to the west of the study area.

b. The first transgression of the Mesozoic in this part of Egypt was detected to be in the middle Jurassic.

c. No marine Triassic sediments are recorded.

d. The Cretaceous is divided into a lower clastic unit and an upper one consisting of carbonates.

e. The Cenozoic is characterized by open marine conditions resulting in the deposition of various sedimentary facies ranging in composition from clastics to non-clastics.

f. The clastic sediments are common, but carbonate rocks may dominate in some local deep basins.

g. The sedimentary successions in the Abu Gharadig basin were deposited on a platform environment of uniform sedimentation with little variation in sedimentary facies.

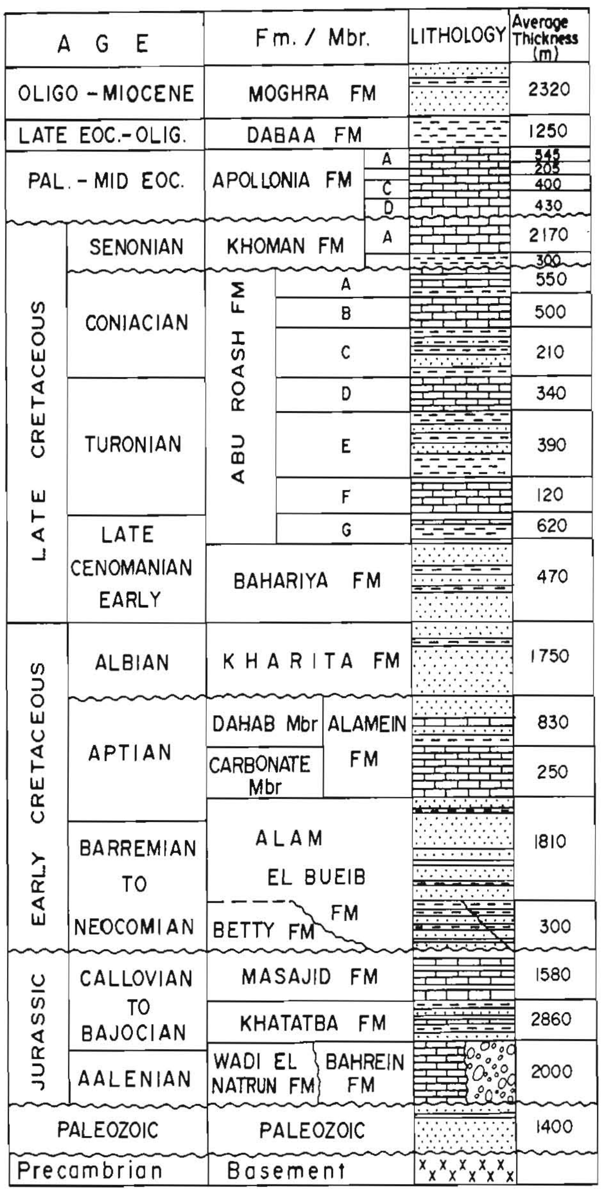

Figure 4. General subsurface stratigraphic column of the Abu Gharadig basin (After Abu El-Naga, 1984)

The investigated area represents a part of the major unstable shelf of north Africa and the Mediterranean (Henson, 1951; Said, 1962) and at the same time it is related to the mobile belt (Weeks, 1952) which is characterized by a complex subsurface structural pattern (Fig.5). Many fault trends; E-W, WNW, ENE, NW and NNE, have been deduced from different geological and geophysical studies which were carried out by many investigators (e.g. Riad, 1977; Meshref, 1982; Setto, 1995). A folding system, as a result of the compression forces, was also recorded in the area.

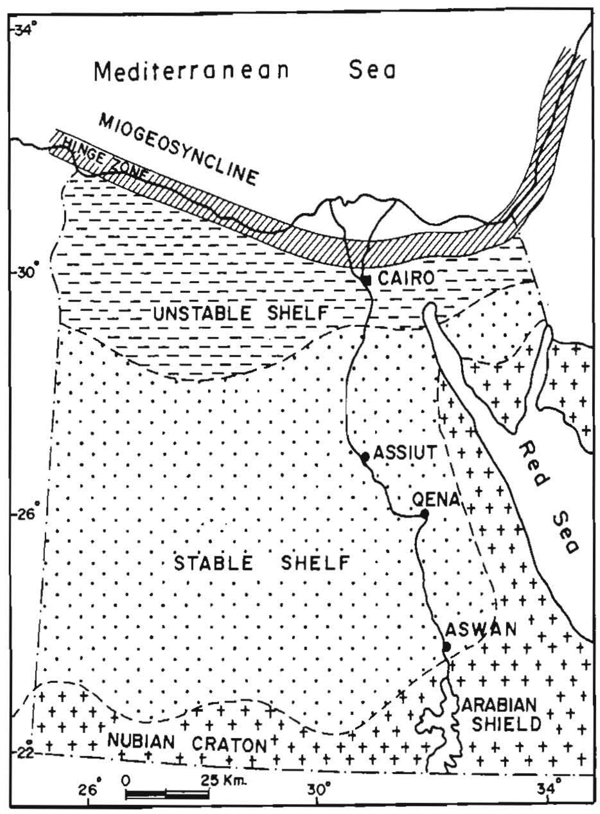

Figure 5. Sketch of the structural aspects of the Nubian-Arabian shield in north Egypt (After Meshref, 1982).

Methods of Analysis

The present study aims at obtaining more information on: a) source of major negative and positive gravity anomalies (especially the anomaly -24 mgal near the northeastern portion of the depression, and also the anomaly +13 mgal near the southern part of the area) (Fig. 6), b) source of the corresponding magnetic anomalies either low or high (especially -25 and +575 gammas) (Fig. 7) and consequently, c) distribution of different uplifted and subsided blocks which may have important reflections on the distribution of hydrocarbon reservoirs in the area. The techniques applied include:

1. Calculation of residual anomalies by applying the adopted least-square approach suggested by Abdelrahman *et al.* (1985).

2. $2^1/_2$ - dimensional modeling for the Bouguer gravity residual anomalies by using the software given by Begg *et al.* (1987) and Enmark (1981) respectively.

3. Half-width modeling for both major gravity and magnetic anomalies to estimate the preliminary depths to different causative buried bodies.

4. Basement-depth determination by applying non-linear optimization techniques and also interactive techniques for the magnetic profiles.

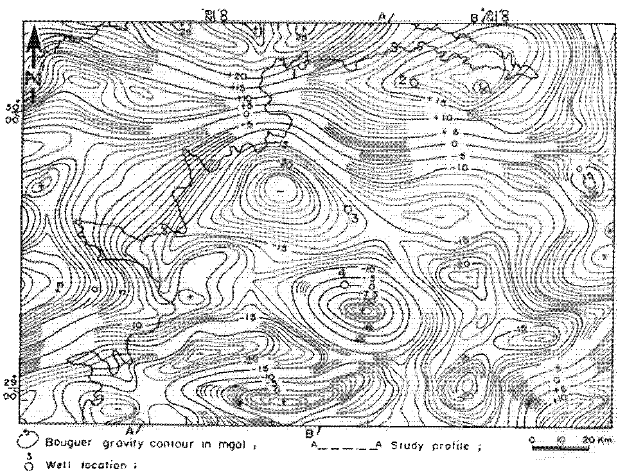

Figure 6. Bouguer gravity anomaly map of the Abu Gharadig basin area (Compiled by the E.G.P.C., 1982).

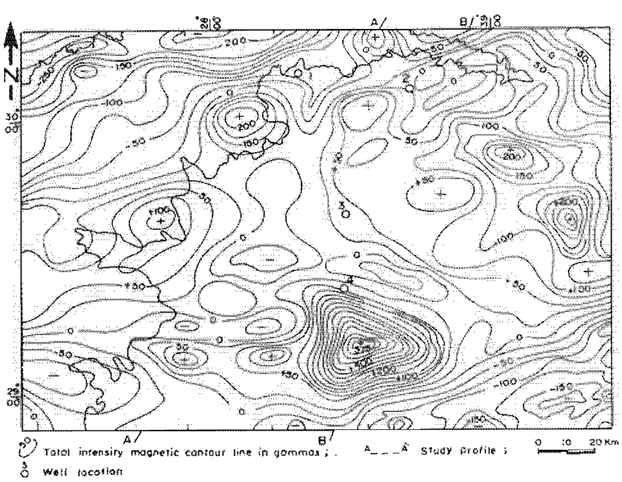

Figure 7. Total intensity aeromagnetic anomaly map of the Abu Gharadig basin area (After Aeroservice, 1964).

In the past, many techniques for rapid geopotential field modeling have been developed (e.g. Talwani *et al.*, 1959; Bott, 1960; Morgan and Grant, 1963; Tanner, 1967). In principle, all these methods depend upon idealizing a body by a two-dimensional mass distribution. The mass distribution is either divided into a large number of vertical strips (Bott, 1960; Tanner, 1967), or is fitted by an n-sided polygon (Talwani *et al.*, 1959; Morgan and Grant, 1963; Enmark, 1981) to determine its structural configuration by the method of successive approximation.

In this study, the gravity profiles in question are modeled using a $2^1/_2$ D-modeling, based on the formulas of Enmark (1981), which is slightly changed from the well known 2-D formulas given by Talwani *et al.* (1959). An optimization procedure (generalized matrix inversion) that computes the best model in the least-square sense is applied. Also, a software gravity program given by Begg *et al.* (1987) is applied in certain cases, especially for anomalies of approximate symmetrical forms (e.g. -24 mgal along the profile A-A$^/$) to estimate the approximate depths below the major anomalies in question. According to drilling data at some wells, e.g. Sheiba-1X, Sharib-1X and Agnes -1X, the basement rocks vary from acidic (granite and granodiorite) to basic and ultrabasic (basalt and dolerite). So, the author built the modeling process according to that subsurface lithologic information, which assisted in putting the maximum and minimum values of the density contrasts.

Local/regional anomaly separation for gravity (Figs. 8 a & b) and magnetic (Figs. 8 c & d) anomalies was carried out using the adopted least-square approach given by Abdelrahman *et al.* (1985). This method is simple and accurate, and yielded anomaly residuals useful for the preliminary determination of the basement depths.

The approximate depth to the center of the buried causative bodies along each gravity and magnetic profile was estimated by using the half-width technique and assuming that the causative bodies are spherical.

The total intensity aeromagnetic map of the study area (Fig. 7) was used to determine the depth to the different buried intrusive bodies and the structural configuration of the basement surface along the study profiles A-A$^/$ and B-B$^/$. This gives valuable information on the thickness and the general geologic setting of the overlying sediments, which in turn permits better estimates for the basement depths together with those obtained from the gravity data along the same profiles.

For a proper interpretation of the geomagnetic field, several considerations in the present study are taken into account:

1. Where the basement rocks are covered by sediments, most if not all of the observed magnetic anomalies can be attributed to the basement rocks because their polarization is much greater than that of normal sediments (Nettleton, 1940; Sharma, 1976).

2. Magnetic anomalies can be produced by lithologic changes within the basement, variations in thickness of the magnetic bodies, topographic relief, structural features such as faults and folds and changes in magnetic susceptibilities.

3. The magnitude of a magnetic anomaly is not only a function of the vertical extent of the causative body (Nettleton, 1976) in contrast to the case for gravity. Thus, the magnetic anomaly of a small body at a shallow depth can have the same amplitude as that of a large body at a greater depth as long as the ratios R^3/Z^3 (R, the radius; Z the depth to the center of the spherical-causative body) are the same. Only the horizontal dimension of the anomaly will be changed.

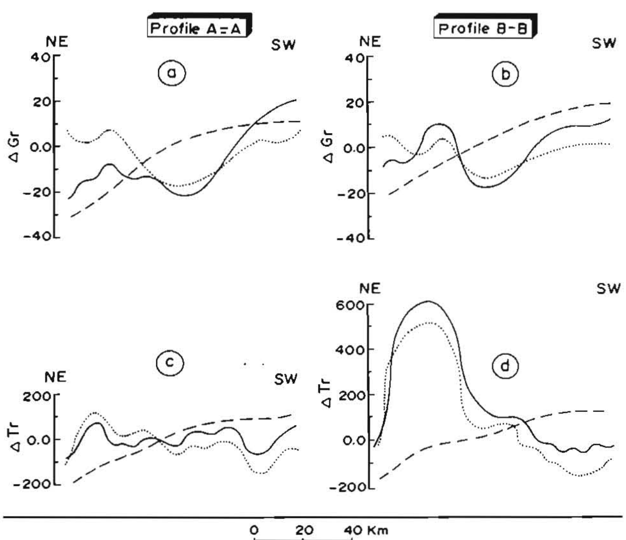

Figure 8. Profiles showing Bouguer gravity anomalies (a & b) and total magnetic intensity anomalies (c & d) with their computed components (residual and regional) in the study area.

Key: ΔGr : Residual gravity field in mgals; Δ Tr : Residual magnetic field intensity in gammas; — : Observed field anomaly; .... : Residual field anomaly; - - - - - : Regional field

Results and Discussion

1. Description of gravity and magnetic fields:

The Bouguer gravity anomaly map of the study area (Fig. 6) shows a general northward increasing trend starting from north of Sharib area (+27 mgal, at the most northeastern portion of the Qattara Depression, and a minimum value -24 mgal at the central part of Abu Gharadig basin). This trend continues into the Mediterranean Sea. The most salient negative gravity anomaly (-24 mgal) has nearly an E-W trending, oval-shaped anomaly and it is almost coinciding with the central portion of the Abu Gharadig basin.

It is noticed that most of the northern parts of the study area are nearly dominated by positive gravity anomalies. The southern parts are characterized by alternation of positive and negative anomalies, while the central part is dominated by negative ones (Fig. 6). The major linear gravity anomalies have E-W, WNW, ENE, NW and NE directions. They have a gentle gradient, suggesting a large-scale subsidence for the basement rocks especially to the north, which may have led to the formation of the Mediterranean basin.

In contrast to profile A-A/ profile B-B/ (Fig. 6) does not intersect the center of the large negative gravity anomaly. To the north, along the study profiles, Bouguer gravity values increase rapidly, suggesting rocks of higher densities.

The magnetic intensity pattern and its trends in the study area are very complicated (Fig. 7). The middle part of the study area is occupied by parts of a magnetic high trending nearly N-S. To the south, alternating high and low magnetic belts of smaller aerial extent and larger magnetic gradients are observed. Moreover, the southern parts of the study area are characterized by a number of magnetic anomalies, especially to the southeast. Their magnetic zones have the highest amplitudes within the study area (>100 g) and exhibit very steep gradients.

Both the gravity (Fig. 6) and aeromagnetic (Fig. 7) anomaly maps of the area under study emphasize the existence of a major E-W trending fault system (F_1) (Fig. 9). This major fault system is controlling the Abu Gharadig basin from the north and running along with the steep gravity gradient (Fig. 6), separating the trending high anomaly belt, occupying the northern portion of the basinal block, from the major gravity minimum in the central basinal block. However, the trace of such a fault zone appears to be camouflaged on the magnetic map due to the effect of the igneous intrusions (basaltic and doleritic), recorded in some wells (Sharib-1X and Agnes-1X), within the Paleozoic section in the locality where such a fault exists and seems to be genetically associated with it. Also, the careful inspection of both gravity and magnetic anomalies in the investigated area indicates another E-W trending fault system (F_2) (Fig. 9) separating the upthrown block of the southern high from the downthrown block of the Abu Gharadig basin. All these indications emphasize that the basin is a structurally controlled one (Bayoumi and Lotfi, 1989). It is bounded from the north and south by two major normal-fault systems (Fig. 9).

Moreover, most of the local gravity and magnetic anomalies observed in the area are probably due to granitic/granodioritic basement complex below the basin floor or probably due to basic and ultrabasic intrusions within the Paleozoic section, such as those recorded at Sharib -1X and Agnes -1X wells, or both.

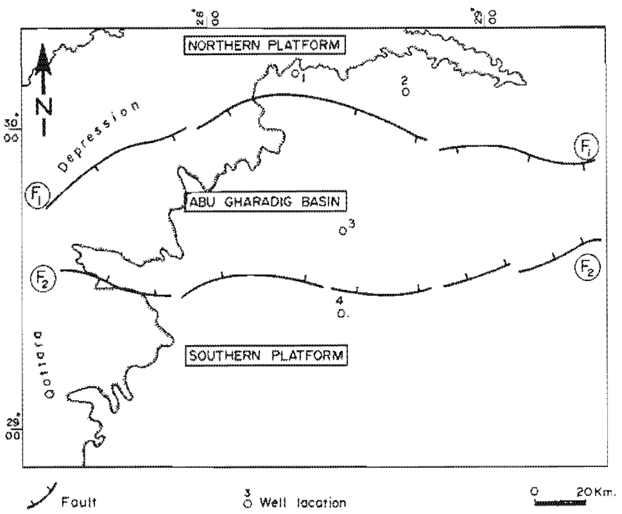

Figure 9. A map showing the major fault systems delineated in the Abu Gharadig basin.

2. Interpretation of selected gravity and magnetic profiles:

The gravity anomalies along the study profiles are modeled in terms of: a) underlying basement, and b) discrete intrusive bodies. A good fit between the observed and calculated gravity values in terms of underlying basement can be reached by using minimum and maximum density contrasts of -0.15 and -0.35 gm/cm^3 respectively, after several trials. The depths to the buried causative body, i.e. basement rocks along each study gravity profile (Figs. 10 a & c), shows a general increase to the north followed by a decrease, in contrast to the geological findings. The obtained results agree with those reported in the literature (Schlumberger Middle East S.A., 1984) and also with those recorded by Bayoumi and Lotfy (1989). The maximum depths to the basement rocks obtained below the gravity profiles A-A$^/$ and B-B$^/$ are about 5.5 and 4 km respectively. A good fit between the observed and calculated gravity values in terms of discreet intrusive bodies can be reached by using minimum and maximum density contrasts of quite different values (-11 and -32 mgals respectively) (Figs. 10 b & d).

The depths to the major causative intrabasement bodies buried in the central part of Abu Gharadig basin area are calculated along the gravity profiles (A-A$^/$ and B-B$^/$) and their values are about 27 and 15 Km respectively.

Figures 11 a & c show the possible models that can account for the study magnetic profiles A-A$^/$ and B-B$^/$ in terms of the basement topography. Although the models give good fit between the observed and computed anomalies, it is thought not to be completely feasible. The average sediment thicknesses of about 4 km (Fig. 11a) and 3.2-km (Fig. 11c) are in close agreement with known estimates of the sediment thickness in the Abu Gharadig area (Schlumberger Middle East S.A., 1984). But the models could not account fully for the edges of the trough and involve a magnetization of 3 A/m and 2.5 A/m respectively, values which are too high. Models were obtained (Figs. 11 a & c) having reduced magnetization of 1.60 and 1.70 A/m respectively. Also, the models were obtained (Figs. 11 b & d) having reduced magnetization of 1.3 and 1.4 A/m respectively. In all cases the sediment thickness is not compatible with the known geology of the study area (Said, 1990). Furthermore, attempts to obtain good fits at the edges of the trough led to decrease of the basement depth in areas not in agreement with the known geology.

The conclusion drawn from these sections (Fig. 11) is that variation in the basement topography could contribute to the observed anomalies, but such changes cannot themselves fully account for the observed anomalies. The anomalies are, therefore, thought to be mainly due to highly magnetic bodies occupying much of the entire width of the basin. The observed profiles A-A$^/$ and B-B$^/$ across the basin are, therefore, interpreted in terms of discreet intrusive bodies and the result of this interpretation is presented in Figures 11 b & d.

The different residual gravity anomalies (Figs. 9 c & d) and residual magnetic anomalies (Figs. 9 b & d) of varying amplitudes in the south may suggest structures and density contrasts within the basement due to differential uplift. The central and northern parts of these profiles show an alternation of anomalies with longer wavelengths, implying local and widely separated structural and lithologic variations within the stratigraphic sedimentary sections in the Abu Gharadig area.

The calculated depths to the top of the buried causative body (basement rocks) obtained by the application of both gravity and magnetic data show a spatial variability. The depth values, obtained from gravity and magnetic data, are lying between 5.5 to 5.3 and 3.8 to 3.6 Km respectively along the study profiles A-A/ and B-B/. The careful investigation of the obtained results reveals the presence of a major uplift in the southern part of the examined area, which could be a part of the major southern basement high bordering Abu Gharadig basin from the south. Likewise, a basement trough may be postulated for the central part of the area towards the Mediterranean Sea (Figs.10 and 11).

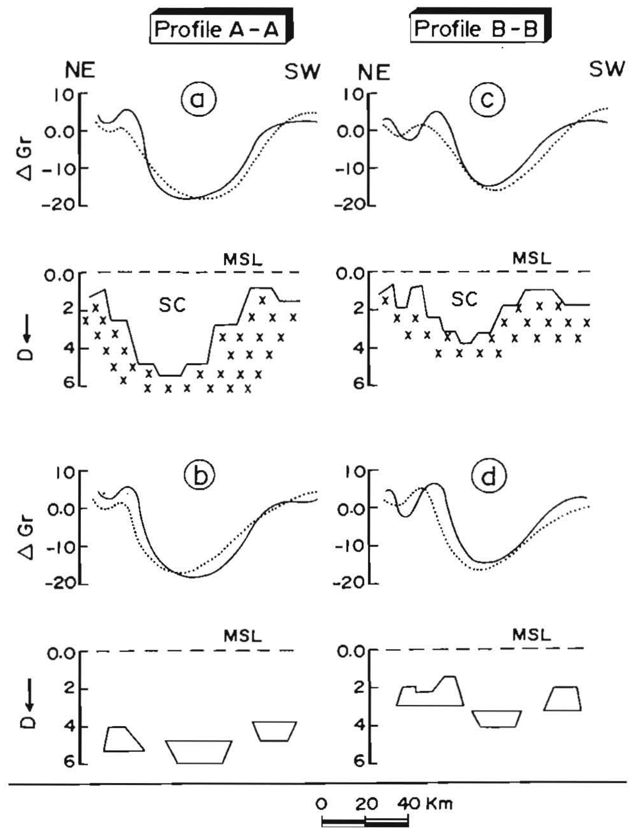

Figure 10. Possible models along the interpreted Bouguer gravity profiles in terms of underlying basement (a & c) and discreet intrusive bodies (b & d).

Key: ΔGr : Gravity residual in mgals; —: Observed anomaly; .... : Calculated anomaly; ▽: Intrusive body; MSL : Mean sea level; D : Depth in Km; SC : Sedimentary cover; xxxxx : Basement rocks

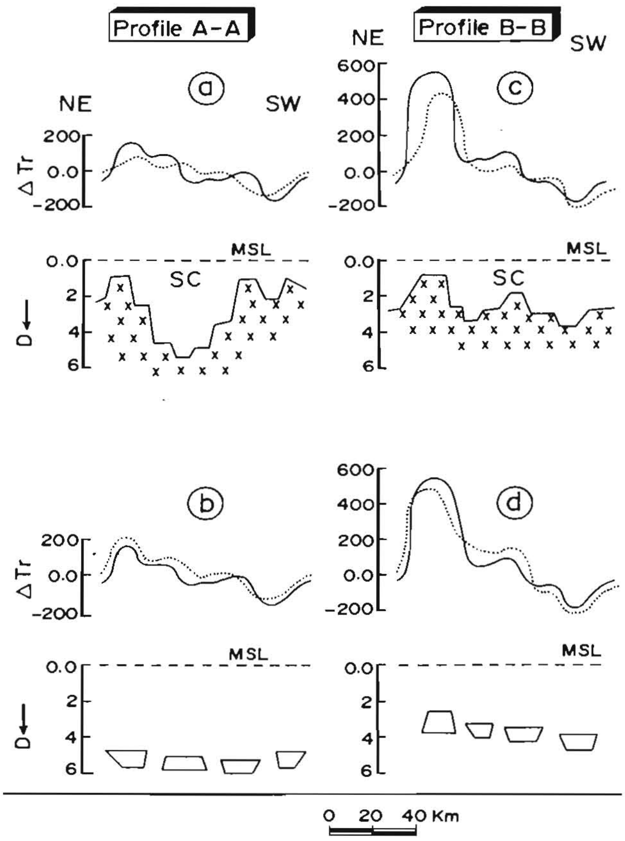

Figure 11. Possible models along the total magnetic intensity profiles in terms of underlying basement (a & c) and discreet intrusive bodies (b & d).

Key: ΔTr: Magnetic residual in gammas; — : Observed anomaly; ...... : Calculated anomaly; ▽: Intrusive body ; MSL : Mean sea level; D : Depth in Km; SC : Sedimentary cover; xxxxx : Basement rocks

Conclusions

From the foregoing results and discussion, the following conclusions can be reached:

1. The average depth values to the top of the basement rocks (about 3.5 to 5.5 km) along the study profiles (gravity and magnetic) in the Abu Gharadig area agree with the expected depths which control the distribution of the geological findings.

2. The distribution of numerous gravity anomalies and magnetic anomalies shows a general northward increase of the basement depth. Prominent basement uplift is lying to the south and represents a part of the major uplift in the north Western Desert of Egypt. Also, the determined northward deepening of the basement is considered a part of the regional northward subsidence, which includes the Mediterranean basin.

3. The results of the interpretation of magnetic data described above suggest that the magnetic anomalies over the Abu Gharadig basin can best be explained by the existence of intrusive bodies beneath the basin with a variation of the basement playing a minor contributory role. These bodies may exist within the basement or within the sedimentary succession of the basin or both.

4. The intrusive bodies may extend to greater depths than is shown in Figures 10 & 11, without affecting the conclusions drawn. The model intrusive bodies are probably of basic composition, on account of their magnetization characteristics.

5. The origin of the major-negative gravity anomaly (-24 mgal) and the relatively low magnetic intensity (< 100 g) in the central area of the Abu Gharadig basin may be due to: a) presence of different sedimentary facies of abnormal thickness, and b) occurrence of a deep intrabasement causative body (> 15 Km).

6. The existence of sizable bodies as modeled here has obvious tectonic implications for the evolution of the Abu Gharadig basin. It is thought that the evolution of the Abu Gharadig basin (starting during late Jurassic) involved the rise of deep-seated basaltic and doleritic mantle blug, related to the early phase of the Alpine Orogeny (Bayoumi and Lotfy, 1989). This resulted in a restricted crustal extension, accompanied by a slow-mild subsidence of the basinal block, along an E-W trending fracture (F_1) in the north Western Desert of Egypt.

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