Pure Appl. Geophys. 170 (2013), 2207–2229

DOI 10.1007/s00024-013-0650-5

Pure and Applied Geophysics

2.5-D Gravity/Magnetic Model Studies in Sahl El Qaa Area, Southwestern Sinai, Egypt

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Abstract—The 2.5-D gravity-magnetic models of the upper crustal structures of Sahl El Qaa Area, Southwestern Sinai were constructed along seven profiles, focusing on the uppermost crustal layers to a depth of 4–5 km. In addition separation filtering process; spectral analysis and trend analysis were used to investigate the Bouguer and total intensity aeromagnetic field maps qualitatively and quantitatively. The study showed that the regional structures consist of tilted blocks in the form of a major NW-synclinal feature with an axis dipping northward. This feature is dissected by the NE trending cross faults forming horsts, grabens and step-fault structures. The tilted blocks are controlled by a major normal fault system and are greatly modified in the dip regime from north to south. They show a regional NW dip regime in northern and southern parts, where the depth to the basement reaches about 2–3 km in the down dip. In the central portion, the basin is dipping steeply to the east, with maximum depths attaining about 4–5 km.

Key words: Sahl El Qaa, Southwestern Sinai, gravity and magnetic data, spectral analysis, 2.5-D model.

1. Introduction

El Qaa Plain is a structural depression trending NNW-SSE, parallel to the main rift system of the Gulf of Suez (Fig. 1). It lies between Latitudes 28° 00′ N AND 28° 50′N and Longitudes 33° 00′E and 34° 00′E, occupies about 3,500 km^2 and covers about 110 × 60 km along the eastern part of the Gulf of Suez. It attains its maximum width to the north and gets narrower southward for the overlapping of the south Sinai basement massif, as well as a number of wells drilled in the El Qaa basin.

Over the last few years, the development of Southern Sinai depends upon increasing the hydrocarbons exploration and groundwater aquifers of the El Qaa plain area. The water resources and oil productions in this area are very limited and need new discoveries in order to cope with the future demands. In respect to this, the delineation and detection of the subsurface situation are of prime importance for reasonable and convenient management. Integrated geophysical surveys such as gravity, magnetic, deep seismic, and well logging are the most suitable tools to help to achieve the exploration purposes.

The aim of the study was directed to model the regional structures of the basement rocks and the overlying rock units, to define the regional subsurface configurations of the study area. Our integrated analyses provide a further investigation of the gravity and magnetic data, constrained by borehole information, relevant previous studies, reports and geophysical analysis carried out in the study area. The present study based mainly on the Bouguer map with a scale of 1:100,000 and a contour interval of 2 mGal, executed and supervised by the General Petroleum Company (G.P.C. 1985) under the auspices of the Egyptian Academy of Science and Technology. Gravity measurements were conducted using Worden gravity meters and have a sensitivity of ±0.01 scale unit. Gravity observations were taken at each kilometer over rectangular loops in the plain area. Gravity stations were tied to the gravity main base station (Lat. 28° 14′ 00″, long. 33° 37′ 00″, elevation +75, absolute value of 979, 148, 48 ± 0.05 mGal.) at El Tor city. The total intensity aeromagnetic map with a scale of 1:250,000 and a contour interval of 10 nano Tesla (nT), was compiled by the Geological Survey of Israel (1980). In addition, all available well logging data including composite logs and density logs were incorporated. The spatial relationship between the gravity and magnetic anomalies were studied in some detail, through performing the 2.5-D forward

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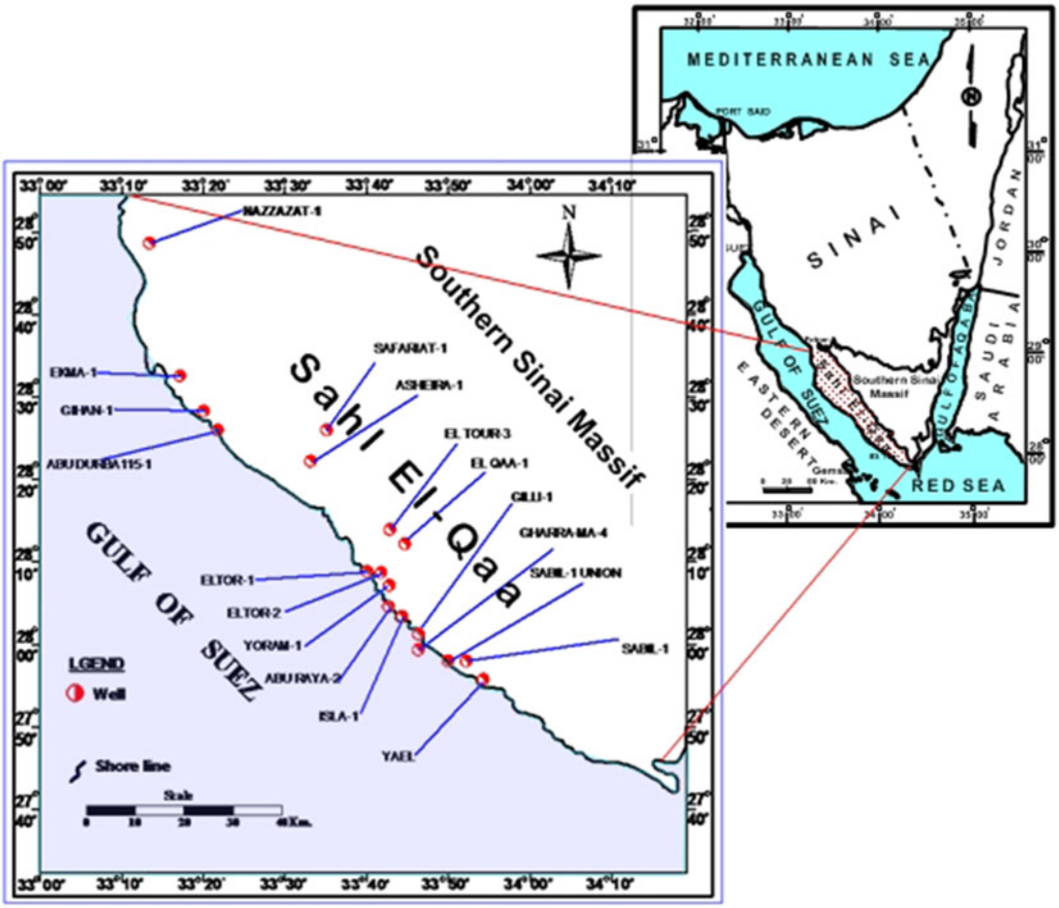

Figure 1
Location of the drilled wells in the study area

modeling. The combination among all the available data allows us for giving an improved geologic picture of the study area.

2. *Geologic Setting*

El Qaa Plain is the most attractive basinal area in the southwestern part of Sinai. The complete stratigraphic sequence of El Qaa plain (Fig. 2) includes rocks ranging in age from Paleozoic to Quaternary, unconformable overlies the pre-Cambrian basement rocks (Bunter 1982).

The topography of El Qaa plain could be divided by El-Refai (1984) into three major units as follows; (i) The eastern topographic high; (ii) The western moderate topographic unit and (iii) The central topographic low.

Geomorphologically, Sahl El Qaa area can be subdivided into three parts;

1. The outskirts of the rugged mountainous area of the South Sinai massif, that forms a small part of the African–Arabian Shield in the east, rise up to 2,662 m a.s.l (Gabal Katherine). These rock units are highly fractured and cut by different sets of dyke-like structures, forming common deep narrow drainage lines, wadis and streams. The high mountainous range in the eastern part plays an important role in the development of this coastal plain.
2. To the west, El Qaa Plain is limited by larger sedimentary hills parallel to the Gulf of Suez, e.g., G. Qabaliat (about 60 km length and 6 km width), G. Ikma, G. Hammam Mousa and G. Abu Sweira north El-Tour (250 m a.s.l). It is also bounded by some basement outcrops such as G. Araba and G. Durba.

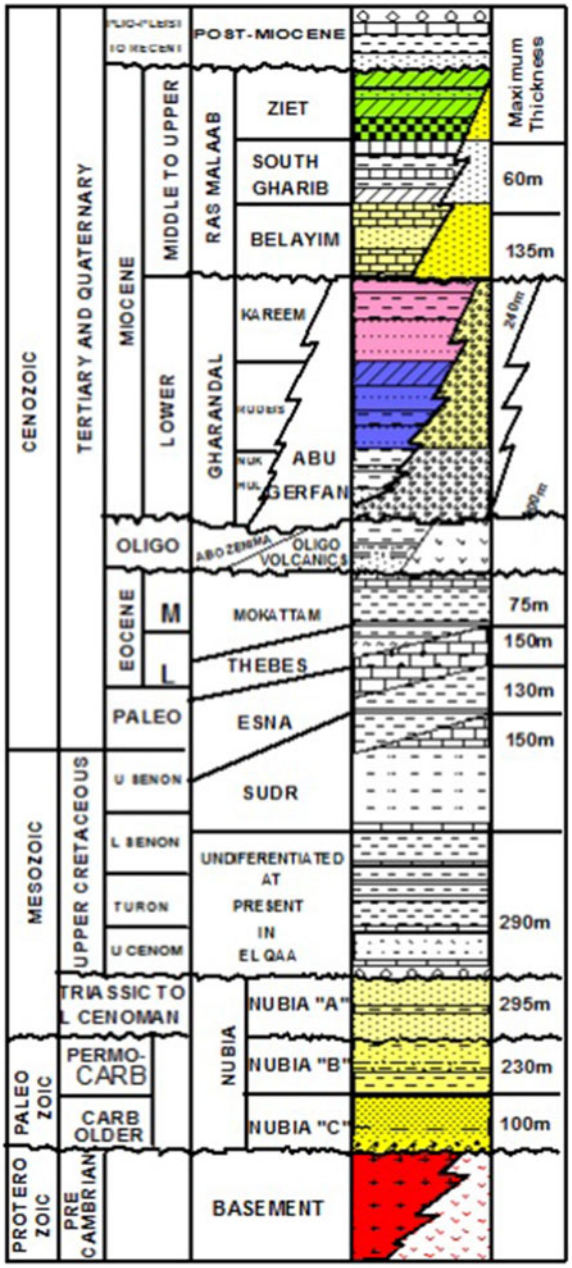

Figure 2
Complete stratigraphic sequence of the study area (after Bunter 1982)

3. The majority of the area consists of wadi deposits, rock fragments, alluvium deposits, sand and gravel, sabkha and playa, ranging from 0 to 200 m a.s.l in elevation. Some basins drain to the Gulf of Suez (Araba), and others drain to El Qaa Plain (Al Abyad, Abura and Wadi Araba El-Saghir Basins).

Many recent geological studies were carried out by many authors such as Gorski and Ghodeif (2000); Sayed *et al* (2004); Leppard and Gawthorpe (2006) and others. They concluded that the geology of this area is covered by Quaternary alluvium, sabkha and costal sand, representing the El Qaa plain deposits. The eastern and northeastern parts of the study area are underlain by different geological units ranging from pre-Cambrian to Pliocene in age. Yousef (2003) divided the upper part of the study area into eight geomorphic units (Fig. 3) as; the pre-Cambrian mountainous unit; sedimentary hills unit, alluvial fans, terraces, dry wadis, playa deposits, sand dunes and sand sheets, and sabkhas.

Different geophysical works were carried out in the study area, e.g., Geofizika (1963); Kamel and Fouad (1975); Webster and Riston (1992); Shendy (1984); Rizkalla (1985); Abdelrahman *et al*. (1987); Tealeb and Riad (1987); Meshref and El-Kattan (1989); Ibrahim and Ghoneimi (1992), and others. They showed that most of prevailing structural elements (mainly faults) exhibit a trend that more or less parallels the trend of the Gulf of Suez.

Bill and Abdel Aziz (1982) studied the seismic work accomplished on EL Qaa plain. They mentioned that the plain is a synclinal half-graben structure. The thicknesses of the Miocene and Post-Miocene formations increase towards the northeastern direction.

The analysis of the aeromagnetic map of El Qaa plain by Meshref and El-Kattan (1989), concluded that, the plain represents a structurally controlled basin, which is bounded to both eastern and western sides by two major faults of NW trend.

3. *Potential Field Data*

3.1. *Gravity Data*

Qualitatively, the Bouguer gravity map (Fig. 4) comprises different anomalies of varying wavelengths and amplitudes, which reflect great variations in the depths to their sources, as well as density contrasts. To the east, it shows broad gravity minima (from −30 to −63 mGal) oriented in the NW direction over the down faulted blocks of El Qaa

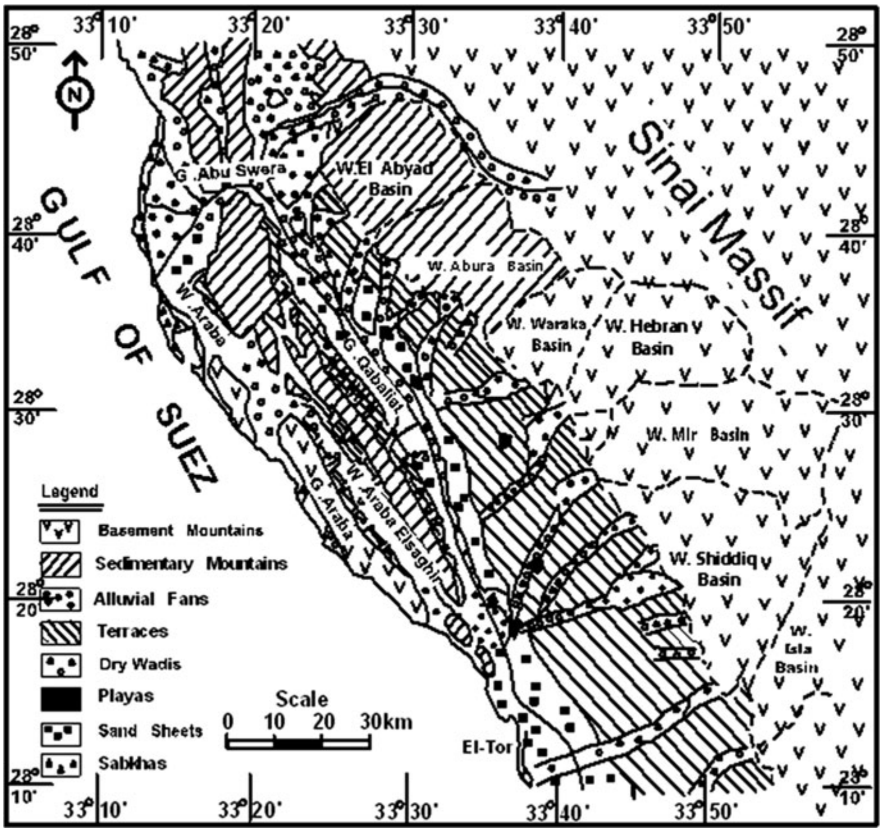

Figure 3
Geomorphological map of the study area (after Yousef 2003)

basin, surrounded by high gravity zones in conformity with uplifted basement blocks. To the west, it shows negative anomalies (from −30 to −52 mGal) associated with the Gulf of Suez province. These two low gravity anomalies are separated by a high anomalous feature, of elongate nature in the NW direction, parallel to the shore line. It is attributed to uplifted basement blocks either cropped out (G. Araba and G. Durba) or cancelled (G. Qurbat and G. Abu Sweira). Linear patterns and steep gradients are most probably related to major fault zones separating the different blocks of the basement rocks. This interpretation is confirmed by the high gravity/magnetic association, that may indicate great variations in the subsurface topography. Generally, the structures on the Bouguer gravity map illustrate that tectonics of the North Red Sea are extensively implied all over the study area and strongly affect the Bouguer anomalies.

3.2. *Magnetic Data*

The total intensity aeromagnetic map (Fig. 5) was reduced to the north magnetic pole (RTP), using a mathematical procedure described first by Baranov (1957); Baranov and Naudy (1964); Bhattacharyya (1965, 1967) and Baranov (1975). Magnetic reduction to the North Pole was processed by alteration inclination of 41°, declination of 2.35° and total field strength of 42,200 nT. Qualitatively, the RTP magnetic map (Fig. 6) shows two types of magnetic anomalies; the first type reflects low frequency and low amplitude, which is associated with the Gulf of Suez province and El Qaa basinal area, while the second one is of high frequency and high amplitudes restricted over some ridges and uplifted basement features.

The magnetic field is overprinted by two dimensional anomalies running almost in the NW and NE directions. A maximum value is 660 nT and lies in the northeastern

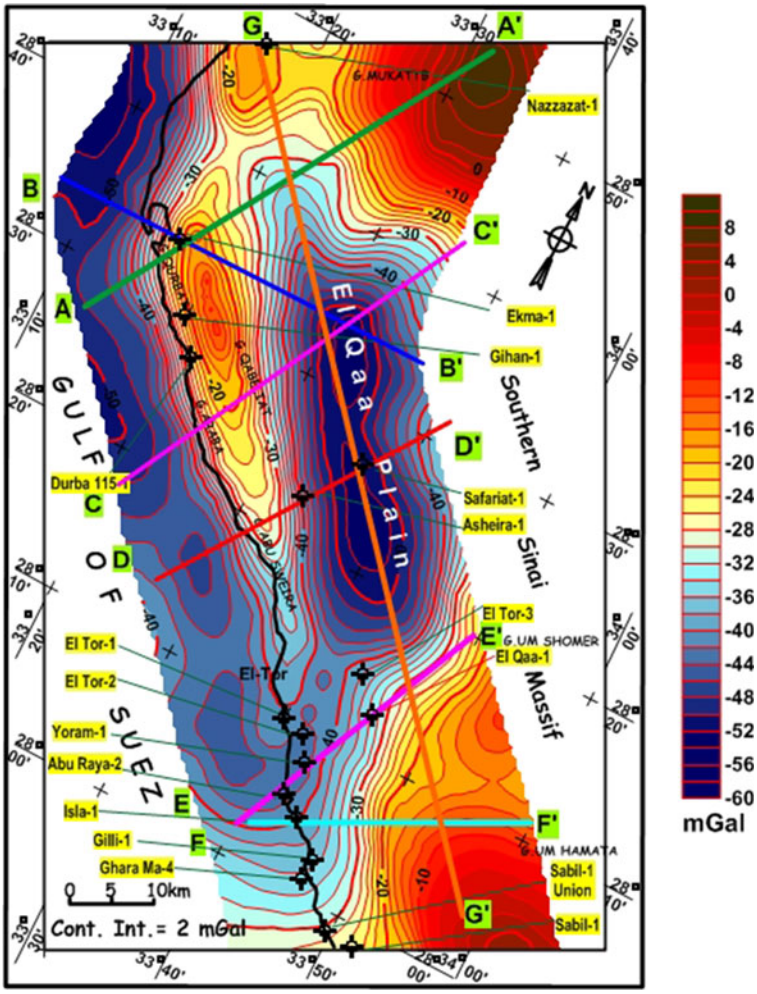

Figure 4
Bouguer gravity map of the study area

portion, while a minimum value of 60 nT is in the southeastern part. The linearity and sharp reliefs may be related to structural elements or linked with boundaries among formations of different magnetization. Close correlation between the gravity and magnetic trending anomalies in Figs. 4, 6 indicates that the tectonic affected the basement rocks and the overlying sedimentary cover.

4. Data Processing

4.1. Regional/Residual Separation

Regional anomalies of high amplitudes and of large area extension are primarily associated with larger and deeper features within the basement and at its surface. Conversely, the local anomalies of low amplitudes extend over some parts of a few kilometers and are superimposed upon the regional anomalies. Generally, the separation of the regional field is thought to be essential, since the area is mostly affected by the Gulf of Suez tectonics. The digitized Bouguer gravity values are subjected to a separation technique using the nine-point method (Nettleton 1976) to isolate the residual anomalies from regional ones. Regional components of first, second, third, fourth, fifth and sixth orders were fitted to the input data. The correlation coefficients among the successive residual maps were calculated (Table 1) to determine the optimum order of the regional surface to be used, which when subtracted

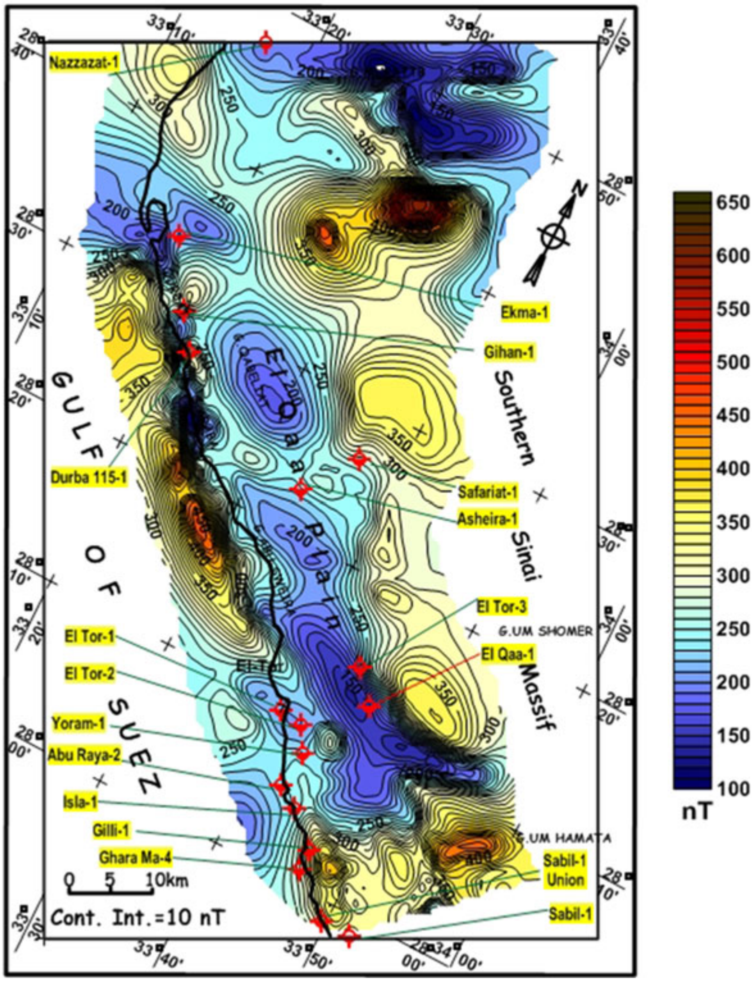

Figure 5
Total intensity aeromagnetic map

from the observed data produces the least distorted residual component of the field (ABDELRAHMAN *et al.* 1989).

Gravity results as shown in Table 1, the highest correlation coefficient value among successive residuals lies at radii 4 and 5 km (r_{45}), which is considered to be the best fitting for gravity interpretation. As a result of residual and regional gravity maps at a depth interval of 4 km (Figs. 7, 8) reflect all the near-surface and deep-seated anomalies, which extend over shallow and deep sources, respectively. A close correlation between the strong positive anomalies, as well as, the negative ones in Figs. 7 and 8 may reflect that Sahl El Qaa area is of a deep-seated origin.

The magnetic results in Table 1 show that, r_{34} is the optimum order for the residual magnetic separation. Commonly, the residual magnetic map (Fig. 9) seems to be more complicated than the residual gravity map (Fig. 7). This complexity came from litho logic changes in the basement composition or due to variations for its relief or both. Regardless, they comprise many anomalous features of similar types and comparable locations.

In contrast, the regional magnetic anomalies (Fig. 10), which are totally negative across the entire area of El Qaa basin, and the residual magnetic field in Fig. 9 contains some positive anomalies associated with shallow basement blocks (supra-basement features).

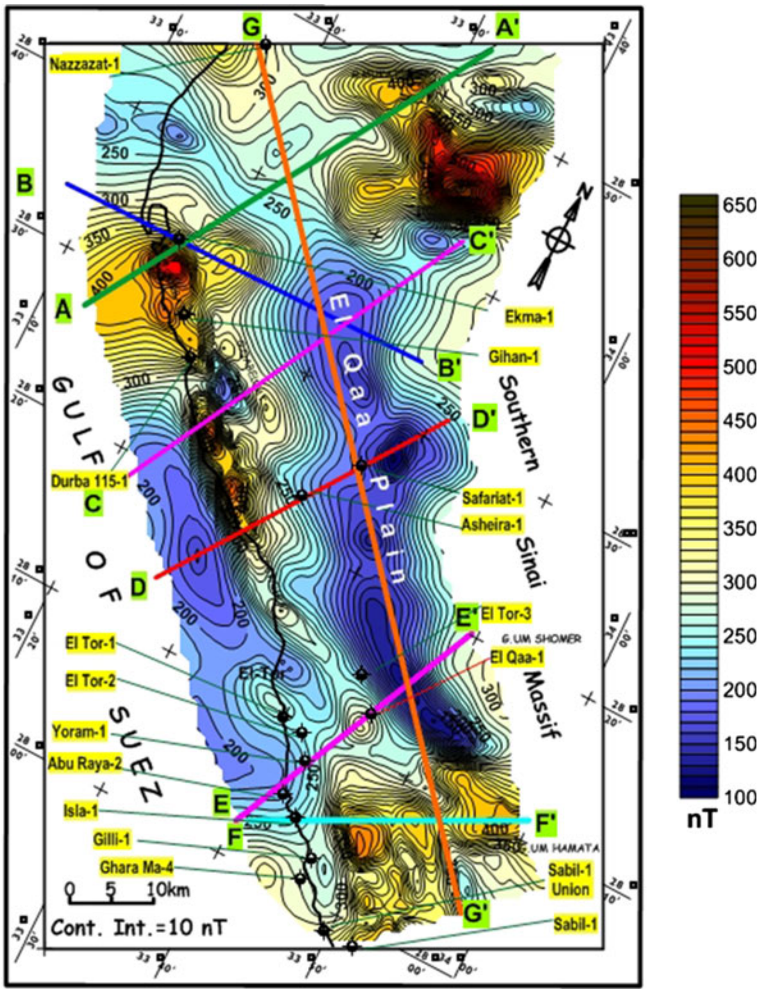

Figure 6
Reduced to pole magnetic map

Table 1

Correlation coefficient results for the residual gravity and magnetic maps

	Gravity	Magnetic
r_{12}	0.83445	0.95712
r_{23}	0.88482	0.97505
$\boldsymbol{r_{34}}$	0.93040	**0.99597**
$\boldsymbol{r_{45}}$	**0.97509**	0.99009
r_{56}	0.95011	0.98068

Furthermore, the strong anomalous features on the residual map (Fig. 9) are clearly expressed on the regional map (Fig. 10) indicating that, the shallower structures are affected by deeper ones. This means that, the rooted and deeper components and associated structures extend upwardly to the shallower ones.

4.2. Trend Analysis

The purpose of using the two-dimensional trend analysis technique is to define statistically the tectonic trends developed in the study area. It may help in the study of the tectonic forces which affect the basement rocks and the overlying sedimentary cover. The trend analysis is a method in which the tectonic setting of the area is determined, where tectonic history of the rocks is in some degree recorded from the magnitude and pattern of the gravity and the magnetic anomalies (Affleck 1963).

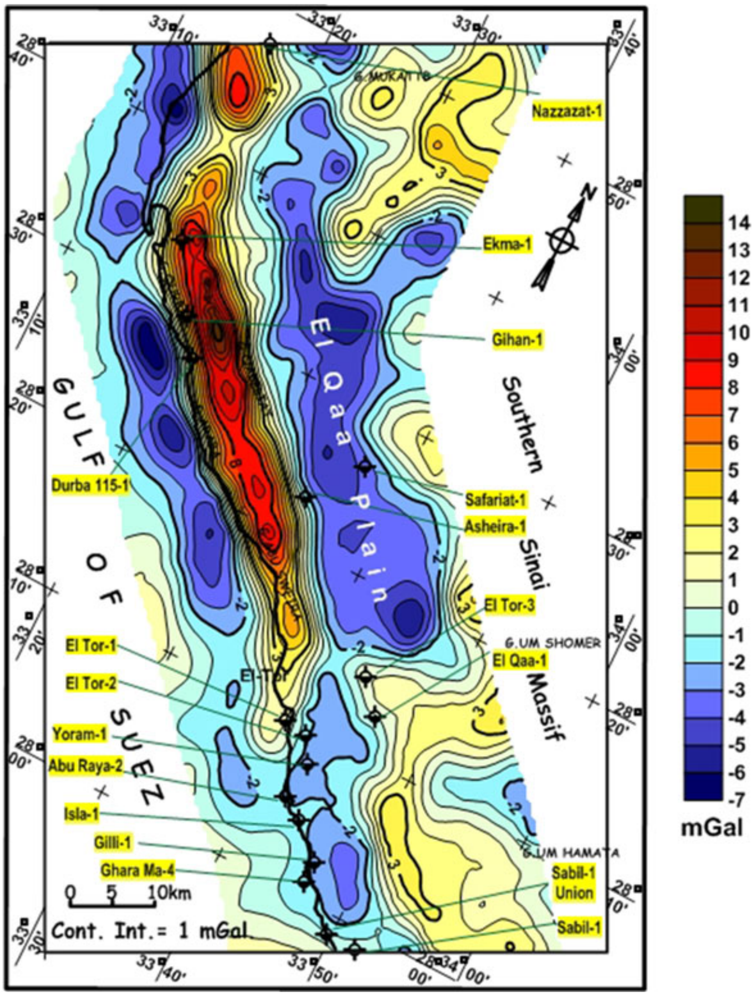

Figure 7
Residual gravity map at depth 4 km

Anomalies usually align themselves along definite axes forming trends. In the present work, trends of anomalies for the RTP and Bouguer gravity maps, as well as the regional and residual filtered maps, were traced out. The length and direction, clockwise from the north of all trends were measured. The total length of the trends within 10° of azimuth was summed up and calculated as a percentage of total length of their trends. A simple and standard method for portraying the two-dimensional patterns is to construct a frequency plot, showing the percentage of trends lying in various direction ranges. The length percentages (L %) of the different anomaly trends and their distribution within the area are represented as frequency curves. The gravitational results (Fig. 11) show four major tectonic trends oriented in the N45°W (Gulf of Suez), N–S (East-Africa), N75°E (Syrian Arc) and E–W (Mediterranean), as arranged in decreasing order of magnitude. The magnetic results (Fig. 12) show three major peaks trending in the N 45° W, N 65° E and E–W directions.

Overview, the most prevailing gravity/magnetic trends are more or less parallel to the trend of the Gulf of Suez. These tectonic trends are familiar trends in the basement rocks of the North Red Sea area and were discussed by many authors; Youssef (1968); Abdel Gawad (1969); Said (1962); El-Shazly (1986); Abu El-AtTa (1988) and others.

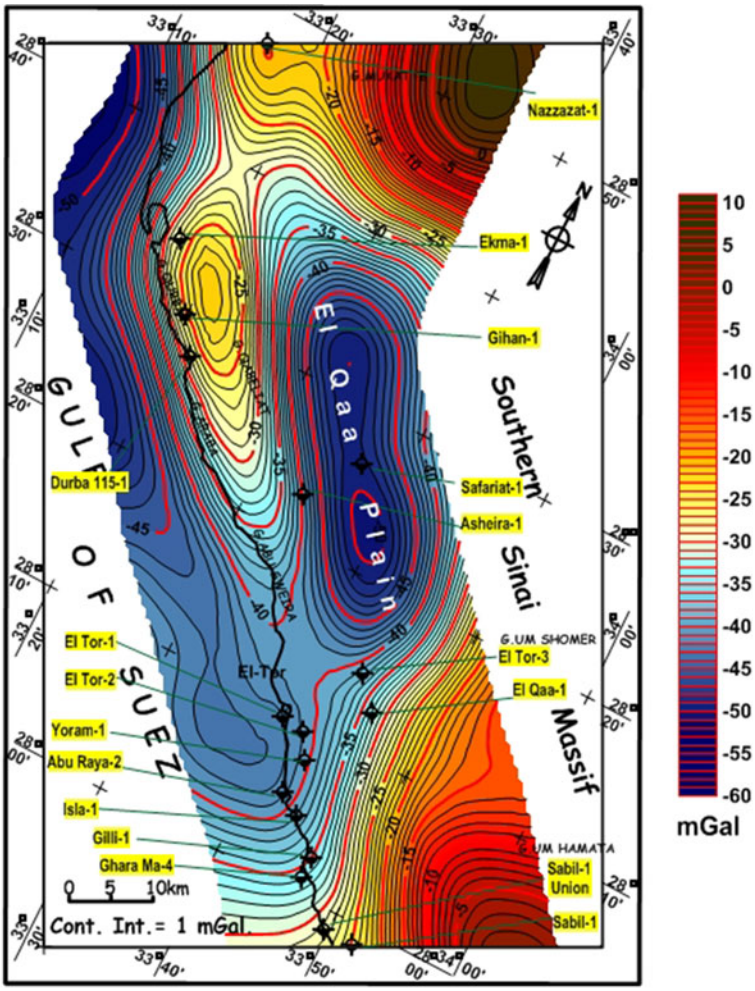

Figure 8
Regional gravity map at depth 4 km

4.3. Spectral Analysis

The two-dimensional spectral analysis (Spector and Grant 1970) has been applied on the magnetic profiles ($P_{A-A'}$–$P_{G-G'}$) shown in Fig. 6. The power spectrum curve was used to estimate the depths for the local sources in the Sahl El Qaa basinal area. The frequencies were used to resolve the RTP magnetic profile into two segments representing deep and shallow depths (Fig. 13). The estimated depths to the basement exhibit values ranging between 0.3 and 5 km, as deduced from the averaged power spectrum. The lower and upper depths in Table 2 were taken as constraints for the depth extremes in the modeling process.

4.4. 2.5-D Modeling

The modeling technique was achieved using a 2.5-D gravity/magnetic interactive modeling package running on GM-sys software (1998). The Bouguer gravity values along seven profiles (Fig. 4) were traced and used as the observed gravity profiles, in the NE, ENE and NW directions. Comparable profiles were taken through the same locations on the RTP magnetic map, as shown in Fig. 6. The potential fields (gravity/magnetic) were calculated iteratively for the basement structural cross-section until a good fit was reached between the observed and the calculated profiles, taking into consideration that, the bottom surface of the modeled polygons was

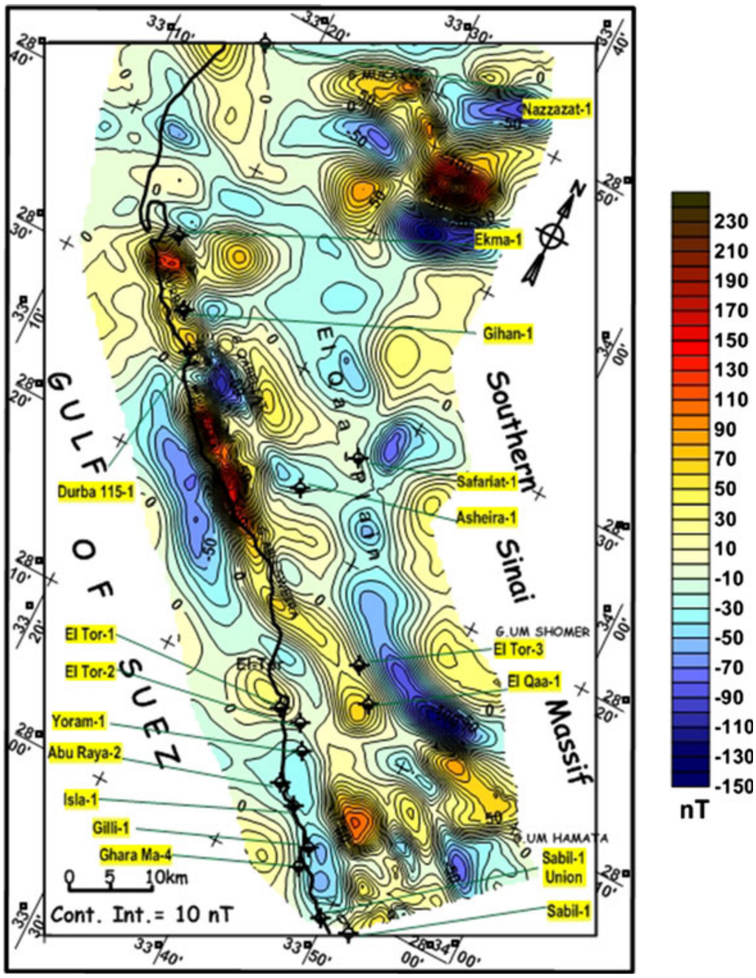

Figure 9
Residual magnetic map at depth 3 km

assumed to be 4–5 km, in order to satisfy the regional effect in the investigated area. Constructing and constraining the models requires the use of all the available information and data from geophysics and geology. However, the well logging data (Table 3) are taken as a reference for adjusting the basement depths. The stratigraphic sequence showed seven layers, rather than sea water, are overlying the basement. These layers are Nubia (Pre Miocene), Lower Rudies, Upper Rudies, Kareem, Belayim, Zeit (Miocene) and Post Zeit (Post Miocene) formations. Thicknesses of the sedimentary formations in the Sahl El Qaa basin were controlled using the composite logs of the available drilled wells in the study area, as well as the seismic information. The sedimentary fill was modeled using several units that have different densities with depth and null magnetic susceptibility. Density information had been taken from the density logs of El Qaa-1, Safariat-1, Ashiera-1, Isla-1, Abu Raya-2 and Sabil-1 wells, using an average of the corresponding density values. Furthermore, the density models were computed taking into consideration that the basement complex is of granitic rocks of mean density equals 2.67×10^3 kg/m^3, intruded by some basic rocks such as gabbro type of 2.82×10^3 kg/m^3. The density of the sea water in the offshore areas was 1.033×10^3 kg/m^3. The average magnetic susceptibilities for the basement rocks around the study area are mainly acidic igneous rocks. The magnetic

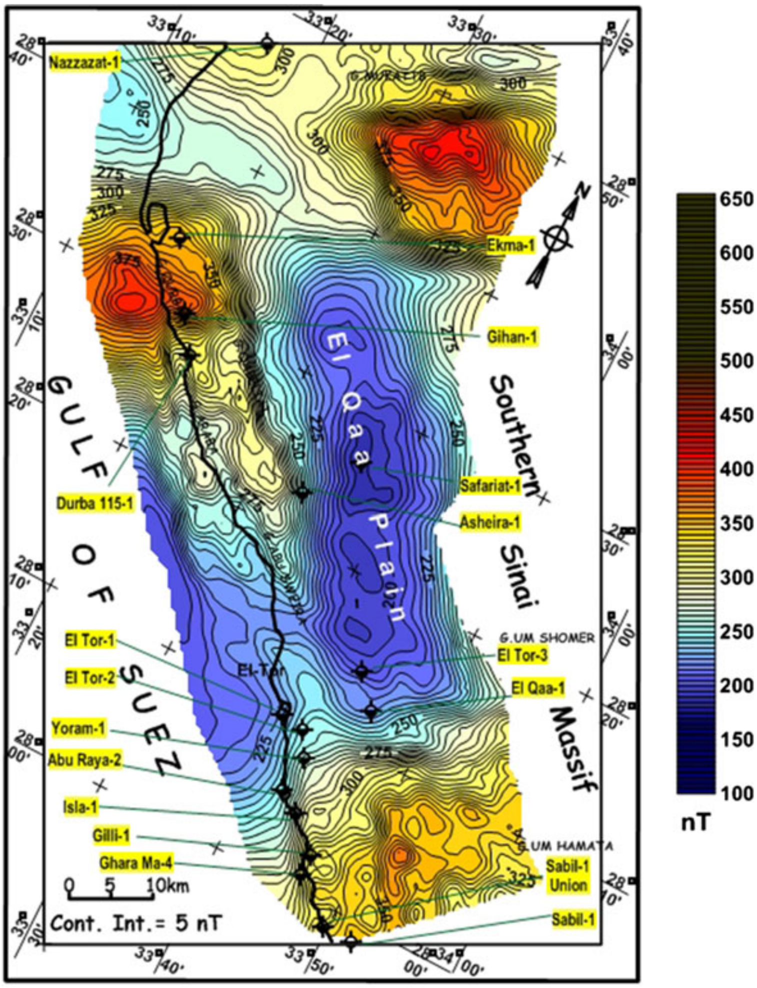

Figure 10
Regional magnetic map at depth 3 km

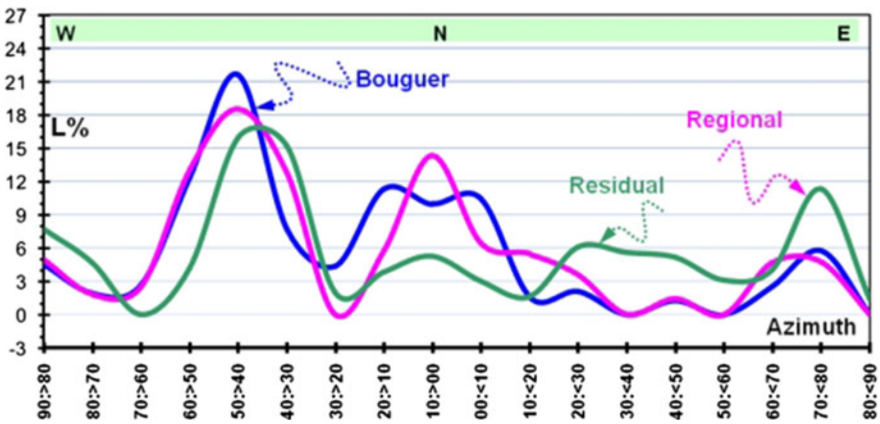

Figure 11
Frequency distribution curves of gravity trends

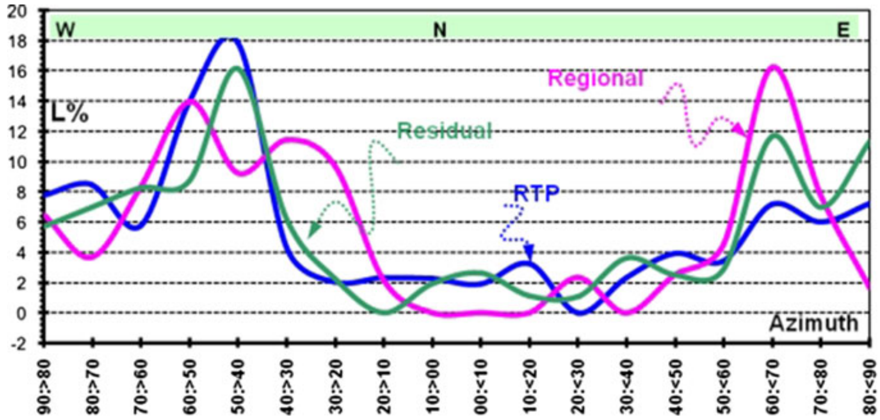

Figure 12
Frequency distribution curves of magnetic trends

susceptibility of 750×10^{-6} cgs units and magnetization of 398×10^{-5} emu/cm^3 were used to construct the 2.5-D magnetic models, based on the El Qaa-1 well which has a depth to basement rocks of 1,219 m (Egpc 1986). Accordingly, the modeled profiles were constructed to incorporate the subsurface information provided by the drilled holes (Table 4) and by the available seismic lines.

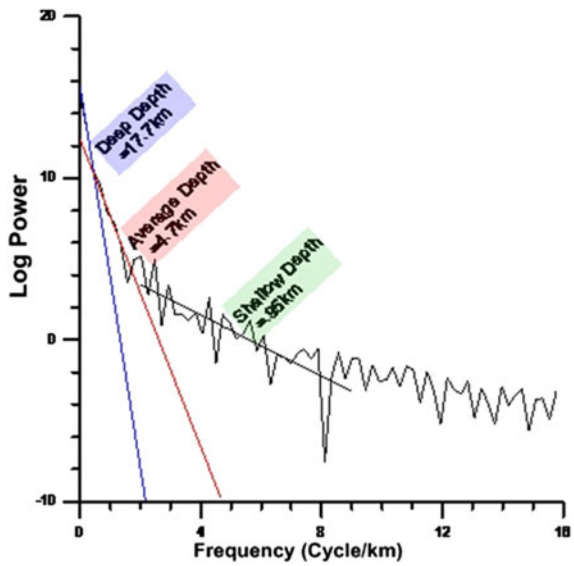

Figure 13
Energy spectra of magnetic data and the average depths calculated along profile (P2)

4.4.1 Profile A–A′

The model A–A′ (Fig. 14) passes through the northern part of the study area. It is taken in the northeastern direction, at a right angle to the northwest Clysmic trend, along the transect that begins at the Gulf of Suez and ends at the western side of the Sinai massif. The structures contain eight basement blocks, separated by normal fault patterns, forming alternated horsts and grabens, which the latter were defined by high and low gravity/magnetic anomalies, respectively. The low gravity anomalies are rather matched with the deep basement features, while the strong magnetic amplitudes are associated with the uplifted basement blocks. Generally, the model shows that the basement surface is gently dipping to the west, with a maximum depth of about 2.65 km at the centre. The depths to the basement and the

Table 2

Spectral analysis results along Sahl El Qaa magnetic profiles

Profiles	$P_{A–A'}$	$P_{B–B'}$	$P_{C–C'}$	$P_{D–D'}$	$P_{E–E'}$	$P_{F–F'}$	$P_{G–G'}$
Shallow basement (km)	**0.33**	**0.96**	**1.03**	**1.35**	**0.75**	**0.29**	**0.49**
Deep basement (km)	**3.04**	**4.71**	**5.02**	**3.31**	**2.03**	**2.96**	**3.55**

Table 3

Total depths of the drilled wells in the study area

Well name	Long.	Lat.	Depth (km)	Base of well
Abu Durba 115-1	28° 28′ 17″	33° 19′ 53.7″	2.09	Basement
Abu Raya-2	28° 08′ 47.7″	33° 40′ 11.6″	2.65	Upper-Cret
Ashiera-1	28° 26′ 11″	33° 32′ 53″	1.633	L Senonian
Ekma- 1	28° 34′ 23.8″	33° 15′ 42″	2.17	Basement
El Qaa-1	28° 14′ 26.3″	33° 41′ 32.8″	1.229	Basement
El Tour-1	28° 10′ 47.1″	33° 37′ 47.5″	1.011	Upper-Cret
El Tour-2	28° 10′ 45″	33° 39′ 15″	1.314	Nubia
El Tour-3	28° 16′ 30″	33° 40′ 30″	1.406	Nubia
Ghara Ma-4	27° 59′ 33.8″	33° 44′ 03″	3.074	Basement
Gihan-1	28° 30′ 38.2″	33° 17′ 04.7″	2.9	Basement
Gilli-1	28° 03′ 06″	33° 46′ 15″	2.217	Nubia
Gs 287-1	28° 25′ 12″	33° 21′ 36″	2.49	Basement
Isla-1	28° 07′ 27.8″	33° 42′ 32.8″	2.88	Nubia
Nazzazzat-1	28° 47′ 12.3″	33° 12′ 56.5″	0.8	Basement
Sabil-1	28° 00′ 48.9″	33° 50′ 43.9″	1.192	Nubia
Safariat-1	28° 29′ 26.1″	33° 35′ 33.1″	2.803	Upper-Cret
Yael-2	27° 55′ 36″	33° 52′ 42″	1.91	Basement
Yoram-1	28° 09′ 23.8″	33° 40′ 20″	2.16	Basement

overlying sedimentary cover were constrained using the Ekma-1 well (drilled depth is 2.17 km). The mass densities of the proposed polygons are adjusted to range from 2.57 to 2.73×10^3 kg/m^3, while the magnetic susceptibility values are varied from 900 to $3{,}050 \times 10^{-6}$ cgs. This narrow range is quite sufficient to made a good fitness between the observed and calculated profiles.

4.4.2 Profile B–B′

The profile B–B′ (Fig. 15) extends for about 48 kmin length, cutting across two low features; the Gulf of Suez province to the west and El Qaa plain basin to the east. They are separated by a set of uplifted basement blocks either cropped out (G. Qurbat) or canceled (Qabeliat horst) of high gravity and magnetic magnitudes. The basement surface exhibits a number of major fault zones of significant displacements that determine the configuration of the basin and its boundaries. Within the confines of these fault systems, the basement is dissected into some tilted blocks of various sizes. Qualitatively, the model shows good fitness between the observed and theoretical profiles, that exhibits positive correlation with the basement reliefs. The strong anomalies are associated with the uplifts or horst structures; whereas the low ones are restricted over the major basinal parts. Generally, the basement attitude shows eastward regional dip regime, with a maximum depth of about 4.35 km at the middle (P5). They reveal a narrow density range between 2.63 and 2.70×10^3 kg/m^3, and reflect considerable variations in the basement composition, where the apparent susceptibilities vary from 900 to $3{,}300 \times 10^{-6}$ cgs.

4.4.3 Profile C–C′

The model C–C′ with a length of 61 km (Fig. 16), cuts across the middle part of the study area in the NE–SW direction. It shows two anticline uplifts of high magnetic and gravity anomalies, alternating with two major basins of large negative magnetic and gravity anomalies. The observed and calculated anomalies were fitted using six polygons representing six basement blocks with different tilts, compositions, sizes and depths. These fittings confirm the subsurface structures in the lower part. The high gravity and sharp magnetic reliefs are restricted over G. Araba, where the basement cropped out parallel to the shoreline, as well as the shallow basement of the Sinai Massif, while the broad gravity and magnetic lows are principally associated with El Qaa and the gulf basinal areas. It exhibits a

Table 4

Input parameters of available drilled Wells in the study area

Well	Formation	Group	Top (m.)	Bottom (m.)	Av. density	Age	Lithology
Sabil-1	Post-Zeit	TOUR	30	525		Post-Miocene	Sandstone and clay
	Kareem-Belayim-upper Rudies Equiv	ABU ALAQA	525	624.809	2.103	Mid-Miocene	Sandstone and clay
	Lower Rudies	GHARANDAL	624	779	2.264	Early-Miocene	Sandstone and clay and marl
	Rre Miocene (Nubia)	NUBIA	992	1192		L.Cretaceous	Sandstone and clay
ISLA-1	Post Zeit	TOUR	15.239	992.98		Post-Miocene	Sandstone and clay
	Zeit	ABU ALAQA	992.98	1110.64	2.307	Late-Miocene	Sandstone and clay and anhydrite
	Belayim	ABU ALAQA	110.64	1348.06	2.329	Mid-Miocene	Sandstone and clay and anhydrite
	Kareem	ABU ALAQA	1348.06	1417.25	2.353	Mid-Miocene	Sandstone, clay and dolomite
	Upper-Rudies	ABU ALAQA	1417.25	1698.26	2.353	Early-Miocene	Sandstone, clay, dolomite and anhydrite
	Lower-Rudies	ABU ALAQA	1698.26	2234.07	2.34	Early-Miocene	Sandstone, clay and dolomite
	Rre Miocene (Nubia)	NUBIA	2755.25	2879.61	2.353	L.Cretaceous	Sandstone, clay and conglomerate
Abu-Raya-2	Post Zeit	TOUR	40	690		Post-Miocene	Sandstone and clay
	Zeit	ABU ALAQA	690	830	2.414	Late-Miocene	Sandstone and clay and anhydrite
	Belayim	ABU ALAQA	830	1026	2.352	Mid-Miocene	Sandstone and clay and anhydrite
	Kareem	ABU ALAQA	1026	1150	2.341	Mid-Miocene	Sandstone, clay and dolomite
	Upper-Rudies	ABU ALAQA	1150	1368	2.339	Early-Miocene	Sandstone, clay, dolomite and anhydrite
	Lower-Rudies	GHARANDAL	1450	2170	2.283	Early-Miocene	Sandstone, clay and dolomite
	Rre Miocene (Raha)		2170			U.Cretaceous	Sandstone, clay and dolomite
El-Qaa-1	Post Zeit	TOUR	50	309		Post-Miocene	Sandstone and clay
	Zeit	ABU ALAQA	309	352		Late-Miocene	Sandstone and clay and anhydrite
	Belayim	ABU ALAQA	352	375	2.362	Mid-Miocene	Sandstone and clay and anhydrite
	Kareem	ABU ALAQA	375	458	2.241	Mid-Miocene	Sandstone, clay and dolomite
	Upper-Rudies	ABU ALAQA	458	560	2.289	Early-Miocene	Sandstone, clay, dolomite and anhydrite
	Lower-Rudies	GHARANDAL	560	694	2.206	Early-Miocene	Sandstone, clay and dolomite
	Nubia	NUBIA	909	1219	2.353	L.Cretaceous	Sandstone, clay and conglomerate
Safariat-1	Post Zeit	TOUR	259.067	633.953		Post-Miocene	Sandstone, clay and limestone
	Zeit	ABU ALAQA	633.953	755.2575	2.43	Late-Miocene	Sandstone, clay, dolomite and anhydrite
	Belayim	ABU ALAQA	755.2575	999.695	2.4	Mid-Miocene	Sandstone, clay, dolomite and limestone
	Kareem	ABU ALAQA	999.695	1167.327	2.306	Mid-Miocene	Sandstone, clay and dolomite
	Upper-Rudies	ABU ALAQA	1167.327	1642.792	2.372	Early-Miocene	Sandstone, clay, and limestone dolomite
	Lower-Rudies	GHARANDAL	1642.792	2208.168	2.52	Early-Miocene	Sandstone, clay, dolomite and limestone
	Pre Miocene (Matulla)		2208.168			U.Cretaceous	Sandstone, clay, dolomite and limestone
Ashiera-1	Post Zeit	TOUR	304.785	374.386		Post-Miocene	Sandstone, clay and limestone
	Zeit	ABU ALAQA	374.386	448.034		Late-Miocene	Sandstone, clay, and limestone dolomite
	Belayim	ABU ALAQA	448.034	551.052		Mid-Miocene	Sandstone, clay, anhydrite and limestone
	Kareem	ABU ALAQA	551.052	668.089		Mid-Miocene	Sandstone, clay and dolomite
	Upper-Rudies	ABU ALAQA	668.089	883.887		Early-Miocene	Sandstone, clay, and limestone dolomite
	Lower-Rudies	GHARANDAL	883.887	1338.007		Early-Miocene	Sandstone, clay, dolomite and limestone
	Pre Miocene (Sudr)		1338.007			U.Cretaceous	Sandstone, clay, dolomite and limestone

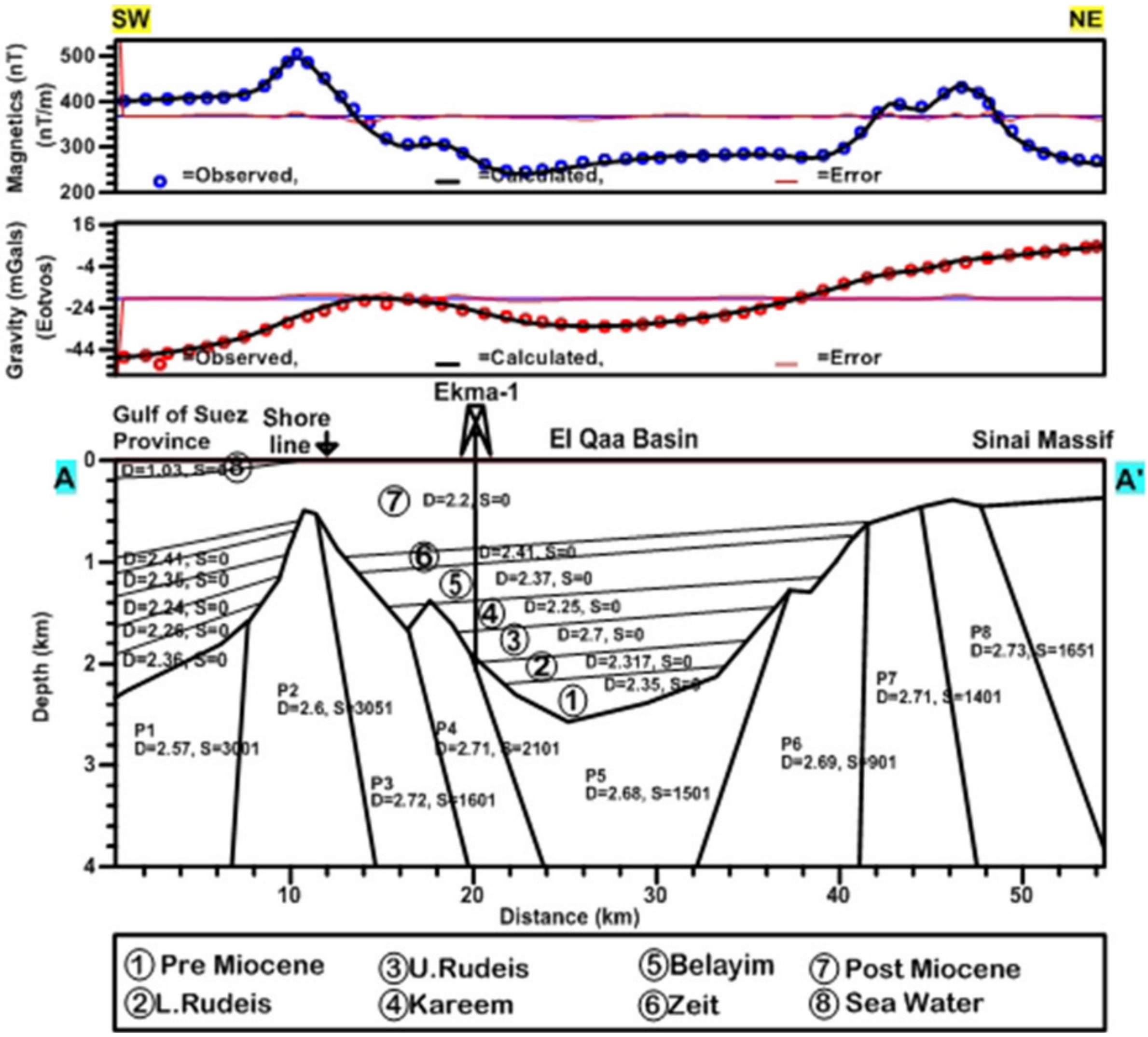

Figure 14
2.5-D gravity and magnetic modelling along profile A–A′

thick sedimentary section in the central part attaining about 4.5 km, wedged to the east and west, and surrounded by shallow igneous and metamorphic pre-Cambrian rocks. The general trend of the basement surface's attitudes is dipping towards the eastern side. The proposed polygons show normal density (from 2.61 to 2.75 × 10^3 kg/m^3) and susceptibility (from 650 to 2,150 × 10^{-6} cgs) indicating that, the topography on the top of basement rocks plays the main role of such gravity/magnetic associations.

4.4.4 Profile D–D′

The profile D–D′ (Fig. 17) locates at the southern part of the profile C–C′, passes laterally in the central portion across the deep basinal area. It shows two anticline uplifts of high magnetic and gravity anomalies, alternating with two major basins of large negative magnetic and gravity anomalies. The basement relief is controlled by several normal faults at varying depths and different throws, causing complex structures of alternating high and low lands. In

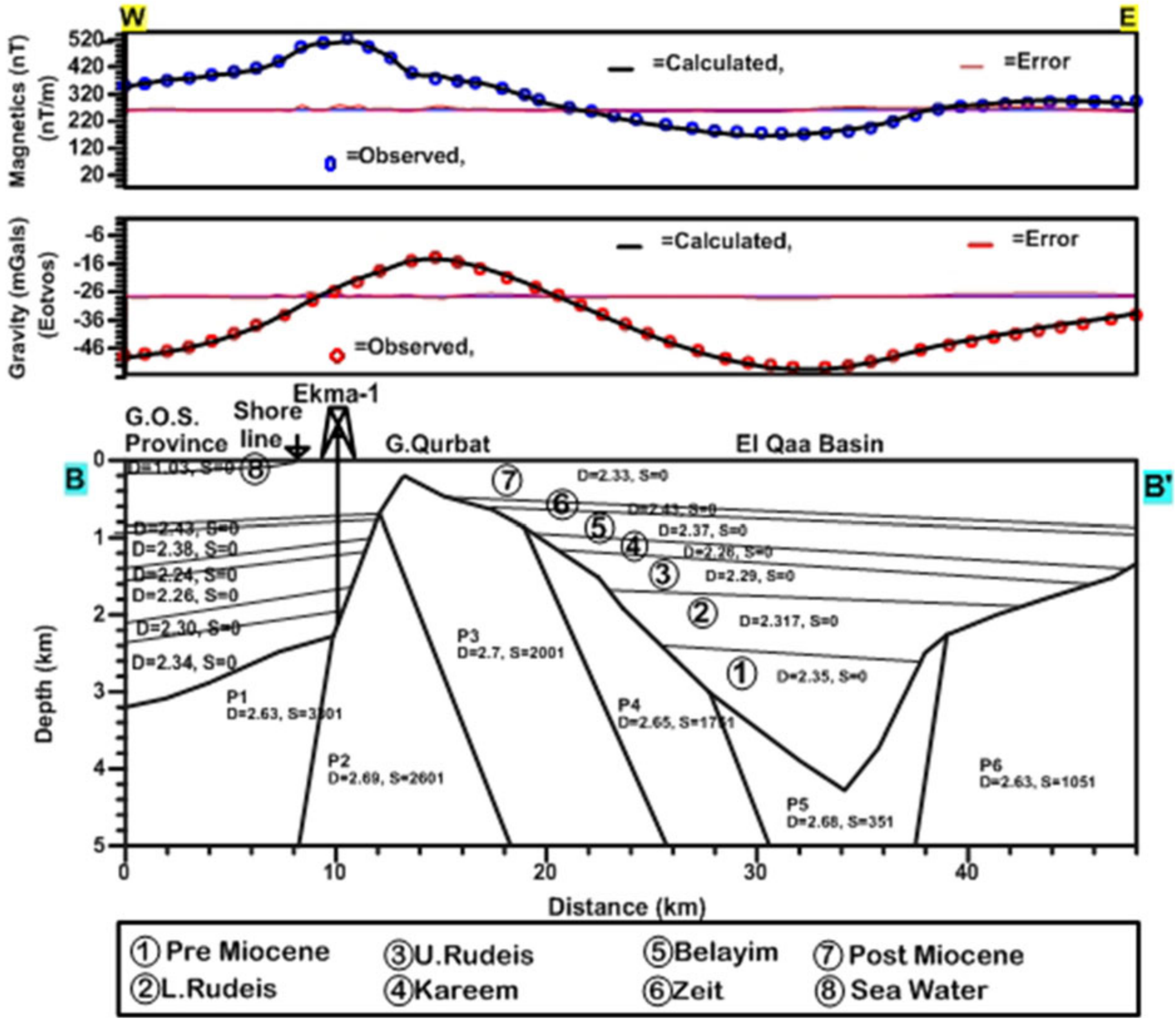

Figure 15
2.5D gravity and magnetic modelling along profile B–B′

general, the basement surface's attitude plunges to the east and west, with thickening in the overlying sedimentary cover away from the coastal area. Maximum depth to the basement complex (4.65 km) is evidenced in the middle part of El Qaa basin at polygon No.7. Commonly, the physical parameters show no pronounced changes, whereas the subsurface topography exhibits great variations from east to west. The basement outcrop along the shoreline (Gabal Araba) plunges through two contrasting dips toward the eastern end western depressions. The drilled holes along this trend (Safariat-1 well and Asheira-1 well) were used to construct and constrain the basement depths and the overlying sedimentary formations.

4.4.5 Profile E–E′

The profile E–E′ (Fig. 18) runs in the NE–SW direction along the southern part of El Qaa-1 plain. The model reveals a great structural variation along the southern portion of El Qaa basin. The basinal part of Sahl El Qaa became shallower in depth, narrower in width, and separated from the Gulf of Suez basin by a small uplift. As well, the basement surface shows a westward regional dip regime with eastward

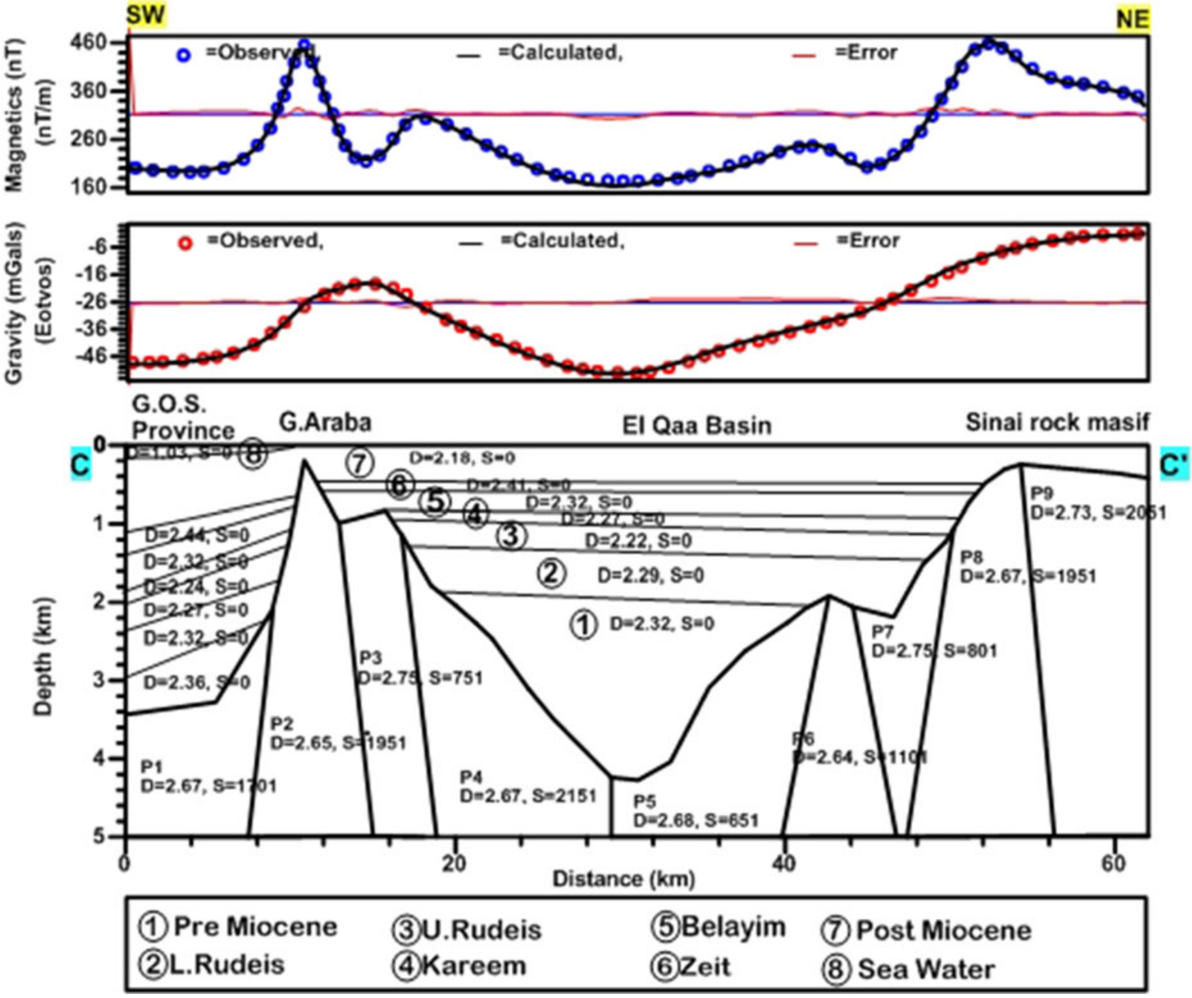

Figure 16
2.5D gravity and magnetic modelling along profile C–C′

thinning of the overlying sedimentary cover. The depths to the basement rocks range from less than 1 km in the east to more than 2.5 km below sea level in the west, in agreement with the well log data of Abu Raya-2 and El Qaa-1 wells. The magnetic analysis along this trend is of interest from one point of view, since it is related to the lithology rather than topography. The positive magnetic anomaly is associated with block (P4) of high magnetic susceptibility (basic intrusion); meanwhile the magnetic low anomaly is correlated with a shallower block (P7) of low susceptibility (acidic dyke). The existence of such acidic and basic rocks within the study area may clarify the strong rifting effect and tectonics of the Northern Red Sea.

4.4.6 Profile F–F′

The profile F–F′ (Fig. 19) lies in the extreme southern portion of the study area and extends about 33 km in the E–W direction. The structures determined along this trend reveal normal and parallel down-faulted blocks of shallow basement. Commonly, the model provides evidence that the basement blocks throw down in a step-like form, dip steeply toward the west and exhibit a westward regional dip regime. The

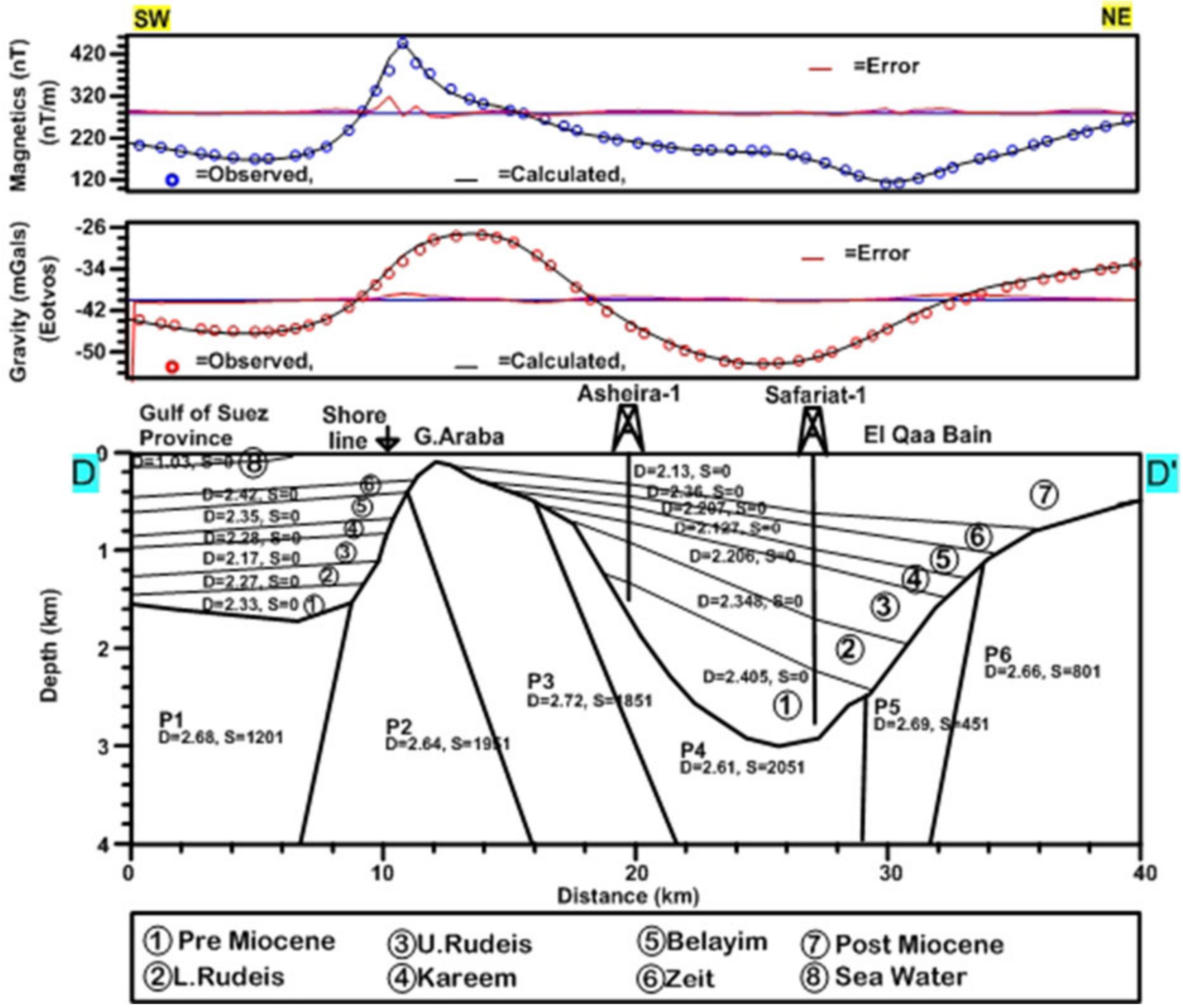

Figure 17
2.5D gravity and mgnetic modelling along profile D–D′

thickness of the sedimentary sequence increases from a few meters in the eastern part of the study area to 2.7 km in the western portion. Isla-1 well (2.88 km) is used as a start point to obtain good fitting between the calculated and the observed curves. The profile reflects an acidic basement complex nature, except for some basic rocks associated with the strong magnetic amplitudes. The mass density shows no pronounced changes and demonstrates normal distribution ranging from 2.67 to 2.76 g/cc.

4.4.7 Profile G–G′

The profile G–G′ (Fig. 20) cuts vertically across the major axis of El Qaa basin, trending in the NW–SE direction, for about 105 km long. The structures show a number of normal fault patterns of different throws, tilts and directions, break through the basement surface, forming a broad and deep basinal area, surrounded from the north and south by two structural high parts. The basement floor is characterized by a rough surface and highlights many horsts, grabens and step-fault structures. Maximum thickness of the sediments is recoded at the middle part (4–5 km), while a minimum one could be traced outward (1–2 km). The calculated gravity/magnetic values for the modeled anomalies show a remarkable match with the observed values. The gravity/magnetic profiles show positive correlations with the topography of the basement relief. They demonstrate few

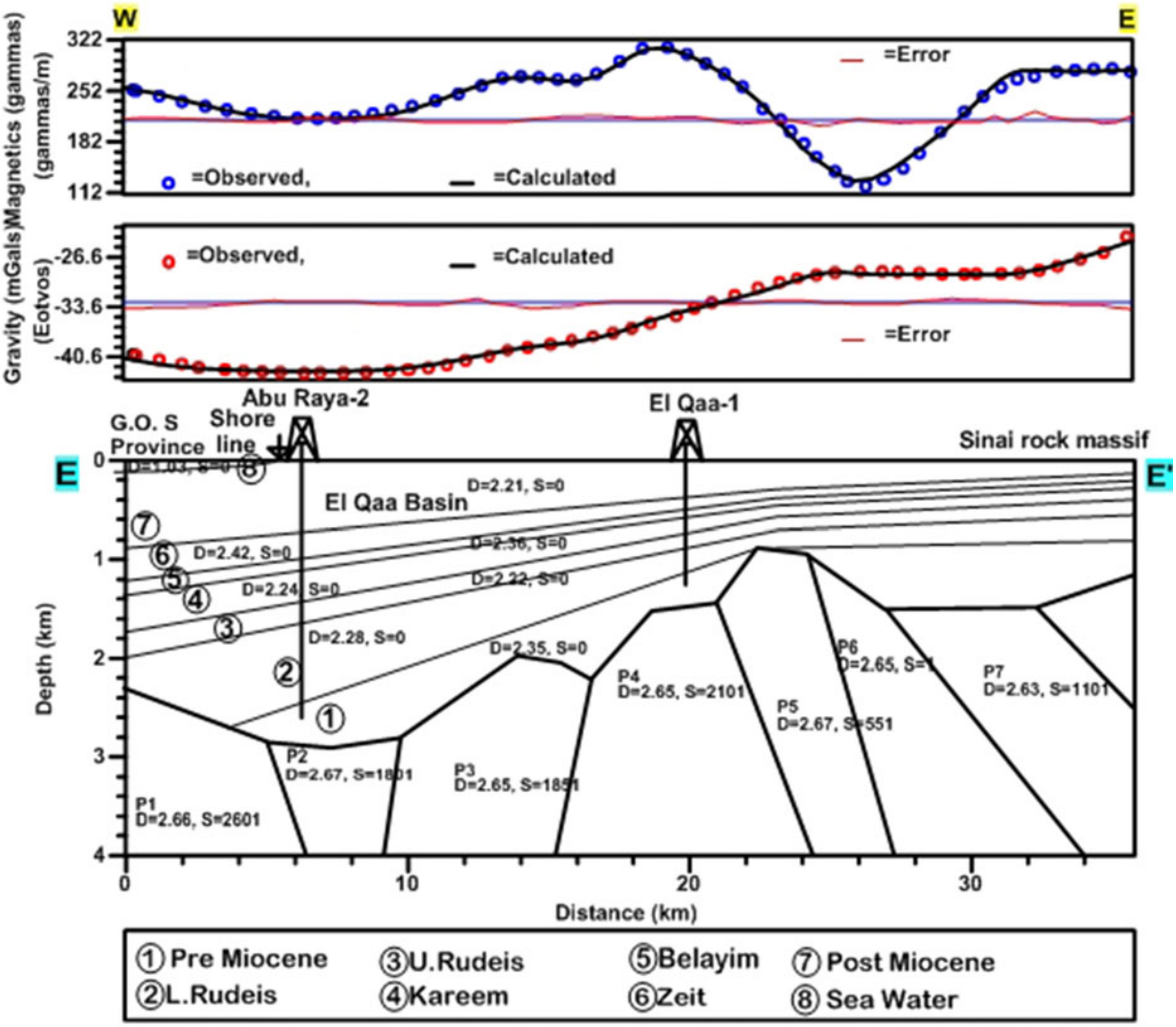

Figure 18
2.5D gravity and mgnetic modelling along profile E–E′

exceptions over some blocks, where their origins are mostly due to sharp density/susceptibility contrast. The modeled profile provides evidence that the structural setup of the basement affects the thickness variations of the overlying sedimentary section. The calculated depths were taken from the density log of the Safariat-1well.

5. Conclusions

In view of the foregoing discussions, a comparative study between the gravity and magnetic interpretations indicates that:

1. The qualitative interpretation of the RTP magnetic map has defined a number of low and high magnetic zones that are well expressed in the Bouguer gravity map. Close association between the high gravity and high magnetic anomalies indicates that most of the magnetic sources are also dense.
2. Close correlation between the major residual and regional anomalies indicates that most shallow features are actually initiated and existed in the deep-seated ones. This may confirm that the structural low of Sahl El Qaa is believed to be of deep-seated origin.

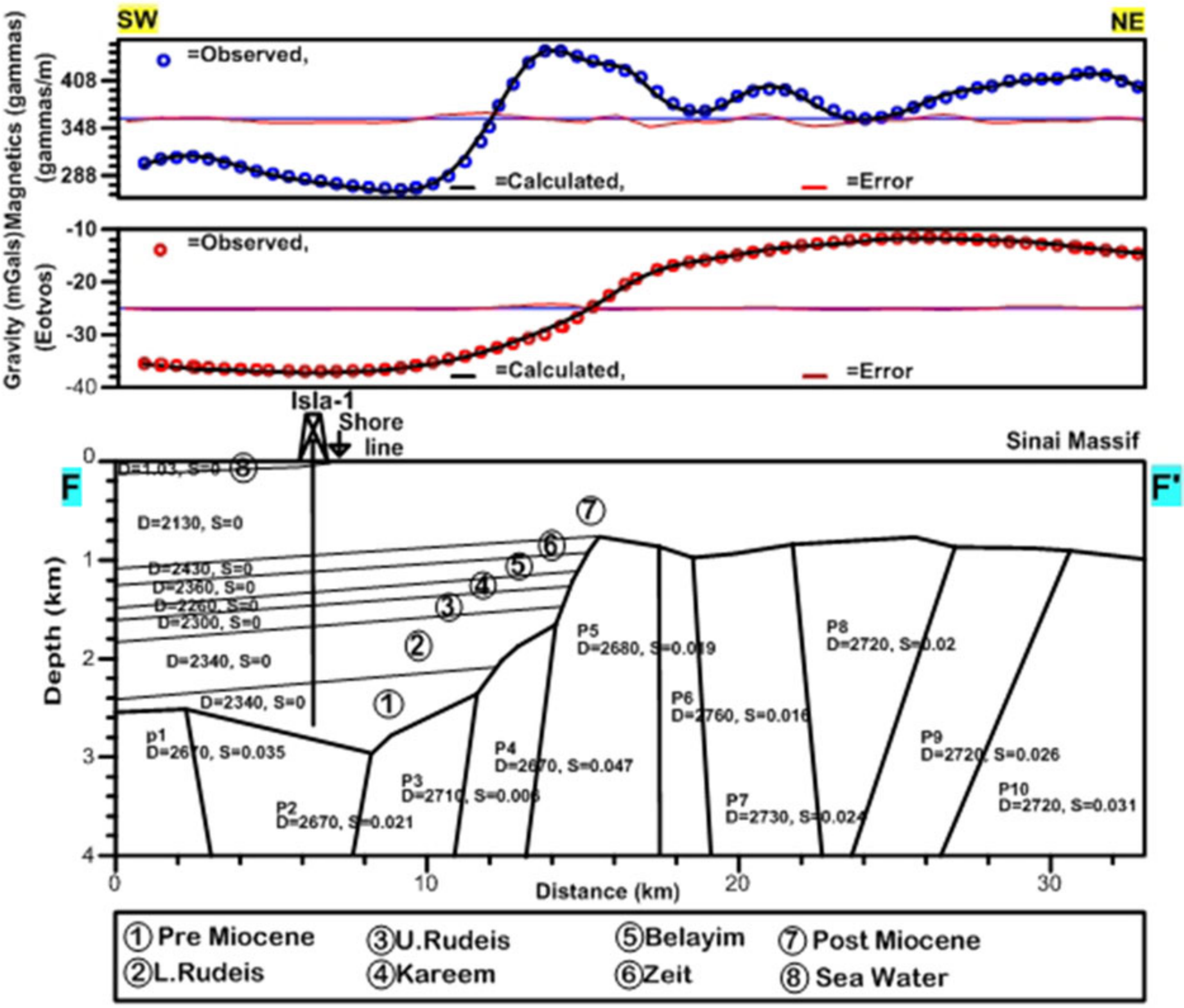

Figure 19
2.5-D gravity and magnetic modelling along profile F–F′

3. The statistical results show the presence of four major tectonic trends affecting the study area, these are N 55° W (Najd), N 25°–45° W (Suez, Red Sea or Clysmic), N 50°–70° E (Syrian Arc) and E–W (Tethyan). Besides, two minor tectonic trends; N–S (East African) and N 5°–15° E (Aqaba). They indicate that the tectonics of the Gulf of Suez and Northern Red Sea, and associated fault systems control the origin of the Sahl El Qaa basin.
4. The depths to the basement rocks are calculated using the spectral analysis technique along seven magnetic profiles covering almost all of the Sahl El Qaa basin. The depths to the basement range from 0.33 to 4.71 km as deduced from the radially averaged power spectrum.
5. The synthesized models illustrate that;

   (a) El Qaa plain is nearly a closed basinal area bounded from the four sides by major normal faults of great throw and magnitude. It is separated from the Gulf of Suez by uplift along the shoreline of Gebel Abu Durba, Gebel Araba and Gebel Qabeliat of the NW regional trend. It also bounded from the eastern side by the sharp topographic relief of the Southern Sinai rock massif.

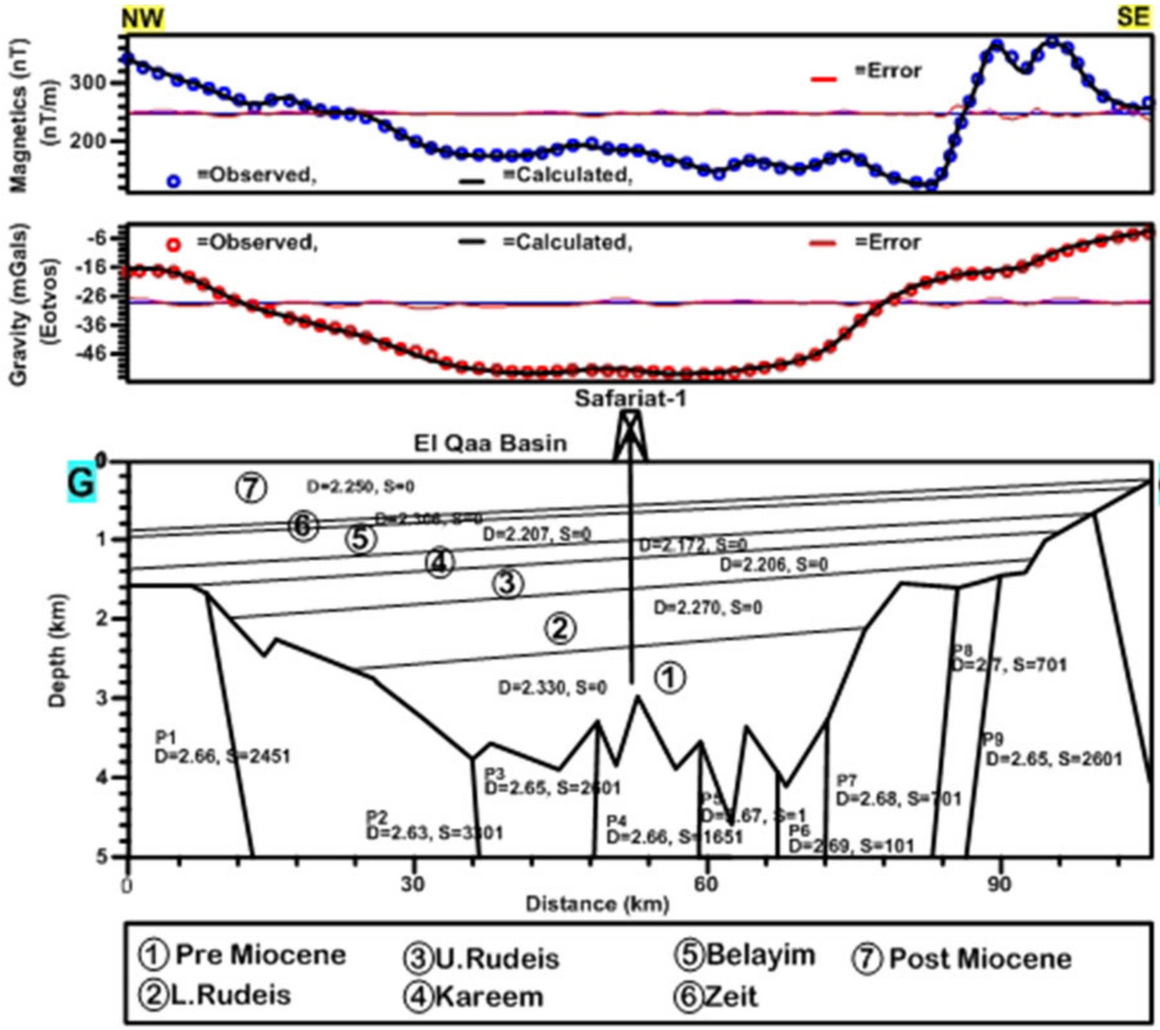

Figure 20
2.5-D gravity and magnetic modelling along profile G–G′

(b) The basement rocks in the study area are divided mainly into some fault blocks of relatively simple and thick sedimentary cover. This simple sequence concealed beneath it a more complicated basement structures made up of swells and troughs. The forms of the basins or sub-basins are structurally related to the lateral/vertical displacements in the underlying basement. It is believed that the tectonic uplift in the study area played an important role in the origin of the El Qaa basin.

(c) The block distributions are greatly differing in the directions and dip regimes. This may lead to the subdivision of the area into three segments of contrasting dip attitudes. The extreme northern part clearly reveals a gentle westward dip; the central part is characterized by a steep east and by northeast dips; while the southern portion is abruptly dipping in one direction toward the west.

(d) Most probable sites of thick sedimentation lie in the middle part, since the basement is loaded by a thick sedimentary section that may exceed 4.7 km in certain places. In the southern part, it ranges from 1 to 2.5 km, while in the extreme northern portion; the thickness varies from 2 to 3 km.

(e) The basement rocks in the study area seem to be of intermediate rock types, intruded by some shallow and deep-seated acidic and basic intrusions. The horst structures show higher basicity in the rock composition than others, since it topped on more basic basement rocks.

Acknowledgments

The author would like to express his deep gratitude to Prof. Dr. A. S. Abu El-Atta. Prof, of Geophysics, Faculty of Science, Ain Shams University, for his keen revision of the manuscript and valuable discussion.

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(Received February 1, 2012, revised January 6, 2013, accepted January 31, 2013, Published online February 27, 2013)