Journal of African Earth Sciences 82 (2013) 1–14

Contents lists available at SciVerse ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Sedimentary cover in the South Western Desert of Egypt as deduced from Bouguer gravity and drill-hole data

M.M. Senosy [a,*], M.M. Youssef [a], M. Abdel Zaher [b]

[a] Geology Department, Faculty of Science, Assiut University, Egypt
[b] National Research Institute of Astronomy and Geophysics (NRIAG), Egypt

ARTICLE INFO

Article history:
Received 26 January 2013
Accepted 5 February 2013
Available online 20 February 2013

Keywords:
Bouguer gravity
Subsurface structures
Groundwater occurrences

ABSTRACT

The Western Desert, Egypt includes the major groundwater aquifer in the country. It is apart from the Major Sahara Nubian Aquifer which is present in Sudan, Chad, Egypt and Libya. Thickness of this aquifer is changed laterally from south to north and also from west to east. The changes may structurally or litheologicalley control. The present study is focused on using of Bouguer gravity anomaly mapped at a scale of 1:500,000 and the lithological logs of about 120 deep wells used to determine the thickness of the sedimentary sequence containing the main Nubian sandstone water aquifer in important area of Egypt. The area is located in the southern part of the Western Desert bounded by the latitudes 22°00′–26°30′N, and longitudes 28°30′–33°00′E. The predominant structures affecting the basement rocks and the sedimentary cover were traced and analyzed. The gravity stripping approach was applied to eliminate the gravity effects caused by sedimentary sequence and to separate density anomalies within the sedimentary fill from the influence of rocks at deeper levels in the crystalline crust.

The study indicated that the surface of the basement rocks is highly rugged and mostly controlled by structures which have a direct effect on thickness variation of the sedimentary cover all over the area. Regionally the area is characterized by two major intracratonic basins (the Dahkla Basin and the Nile valley Basin) separated by a NE–SW trending swell of the Kharga uplift and bounded at the south by the Oweinat–Bir Safsaf–Aswan uplift. These major tectonic units are controlled by fault structures trending in N–S, E–W, NE–SW, NW–SE, which cut the basement rocks and extend upward in the sedimentary cover. The maximum thickness of sandstone formations is recorded at west Oweinat, west Kurkur, southwest of Aswan, Gramashin, Dakhla oasis and some localities west of Sohag and Qena towns. At these localities the thickness ranges between 600 and 900 m. As this formation is the main water aquifer in the study area, therefore these localities are characterized by the presence of big amount of ground water. Accordingly, these areas must take the priority in the sustainable development programs of southern Egypt.

1. Introduction

The study area is representing the southern part of the Western Desert of Egypt (Fig. 1) which lies between the latitudes 22°00′ and 26°30′N, and the longitudes 16°30′ and 33°00′E. The area is an arid region with no marked drainage lines except from some gullies draining toward the Nile valley. The area is characterized by parallel belts of sand dunes running generally in NNW direction, which seem locally to be controlled by parallel tectonic structures. The study area also includes the famous series of oases including Dakhla, Kharga, and Baris oases, which represent important geomorphological features and their location is most probably structurally controlled.

The Western Desert in general is a huge platform with mean elevation of 500 m above sea level consisting of thick layered sedimentary rocks. The geological units as adopted from a geological map of the area with a scale of 1:500,000 (EGPC and Conoco Coral, 1987) are shown in Fig. 2.

The area under study has received less geological investigation than other parts of Egypt. The geology of the northern part of the area including Kharga oasis and its surrounding parts had been subjected to many investigations such as Said (1962), Kiltzsch (1984), Hendriks et al. (1984), Hendriks (1986), Kiltzsch and Wycisk (1987) and Abdel Zaher et al. (2008).

Sandstone with a slight northward regional slope and dip makes up the largest part of the exposed and subsurface strata. Carbonate strata are confined to the resistant limestone cap of the Egyptian plateau. Within the cut of the sheets, outcrops of crystalline rocks only occur east of Bir Tarfawi (Bernau et al., 1987; Wycisk, 1993).

---

* Corresponding author.
E-mail address: mmsenosy@yahoo.com (M.M. Senosy).

1464-343X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jafrearsci.2013.02.001

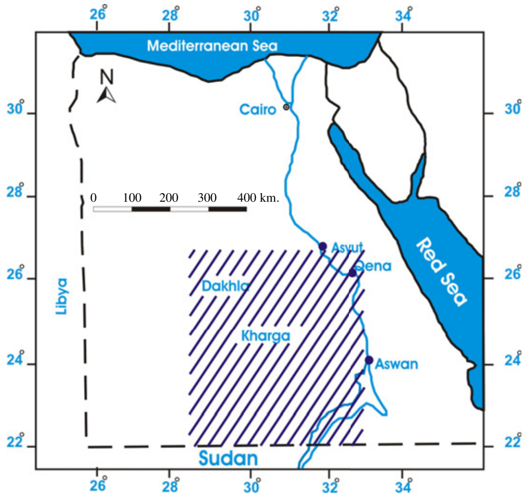

Fig. 1. Location map of the study area.

Two large interacratonic basins; Dakhla basin and Nile valley basin characterizing the area under study, which are separated from each other by Precambrian basement uplifts. These two basins are separated by Kharga uplift which extends in N–S direction. To the south the basins are delimited by the Uweinat–Bir Safsaf–Aswan uplift, which trends in E–W direction at the southern rim of the Dakhla basin and in NE–SW direction at the southern margin of the upper Nile Basin which separates the deep interacratonic basins from the more shallow basins of Northern Sudan (Barakat and Milad, 1966; El-Etr et al., 1982; Schandelmeier et al., 1987; Hermina, 1990; El-Younsy et al., 1991, Heinel and Thorweihe (1993)).

Major parts of the area are covered by large numbers of sand dunes and sand sheets that mask any surface expression of the subsurface structural framework. Consequently, geophysical methods offer the best tools to study the subsurface geology. The gravity method is one of the best geophysical techniques used to solve many geological problems. In practice the gravity method enables the study of the whole rock thickness, and structural details of the crust. The aim of the present study is to detect the predominate subsurface structures and tectonic framework of the southern part of the Western Desert of Egypt and to determine the whole thickness of the sedimentary cover, and consequently the basement tectonic features, which probably control the thickness of the cover. Data obtained from drilled boreholes and interpretation of Bouguer gravity data are used for drawing the configuration of the underlying basement complex.

Table 1
Average density and density contrast of the main rock types in the El Kharga Oasis (after Senosy (2003)).

Rock type	Density (g/cm^3)	Density contrast (g/cm^3)
Nubian sandstone	2.65–2.67	0 to −0.02
Variegated shale	2.63–2.65	−0.02 to −0.04
Limestone	2.5–2.7	−0.02 to −0.05
Granite	2.67	–

2. Geophysical data

Geophysical methods are generally a reflection of the physical properties of the subsurface media even rocks and its pore space contents (water and/or oil) and the structures which effect later on these rocks. The gravity method is one of the geophysical methods which is a powerful tool, can produce useful information about the subsurface conditions. The present study uses the Bouguer gravity anomaly map with a scale 1:500,000 compiled by the Egyptian General Petroleum Corporation (EGPC) (1980) as well as the density of predominant rock units in the area.

For gravity interpretation, the contrasts between rock bulk densities are of prime interest since these contrasts are partially responsible for the anomalous gravity field. In the study area the

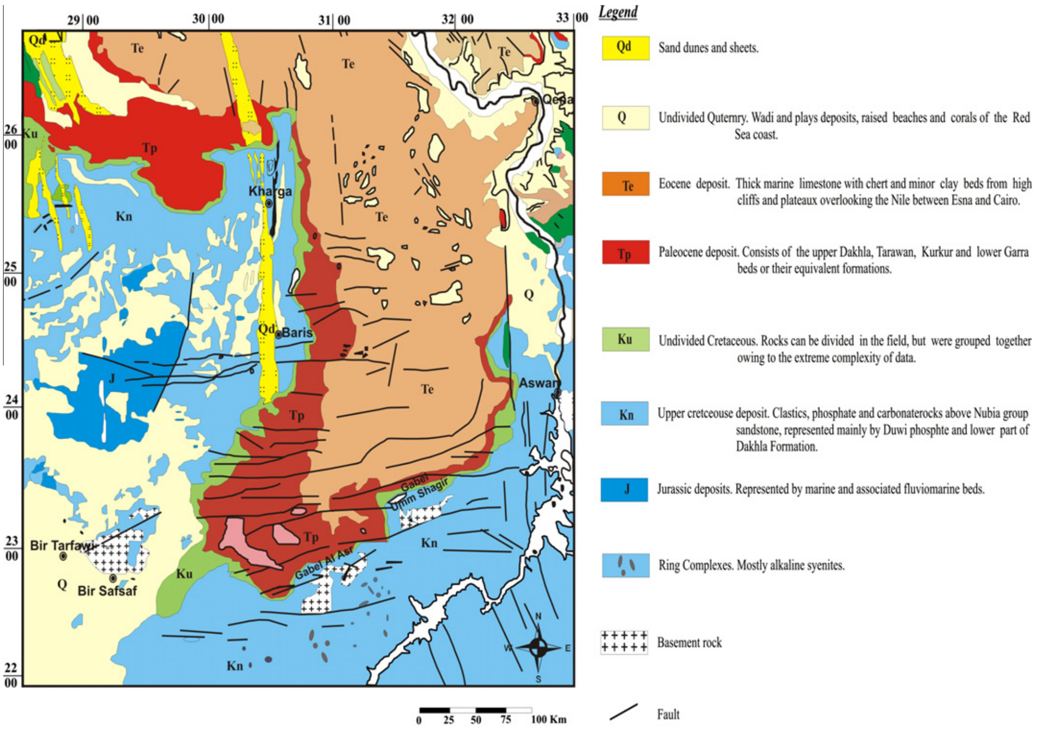

Fig. 2. Geological map of the study area (after EGPC and Conoco Coral (1987)).

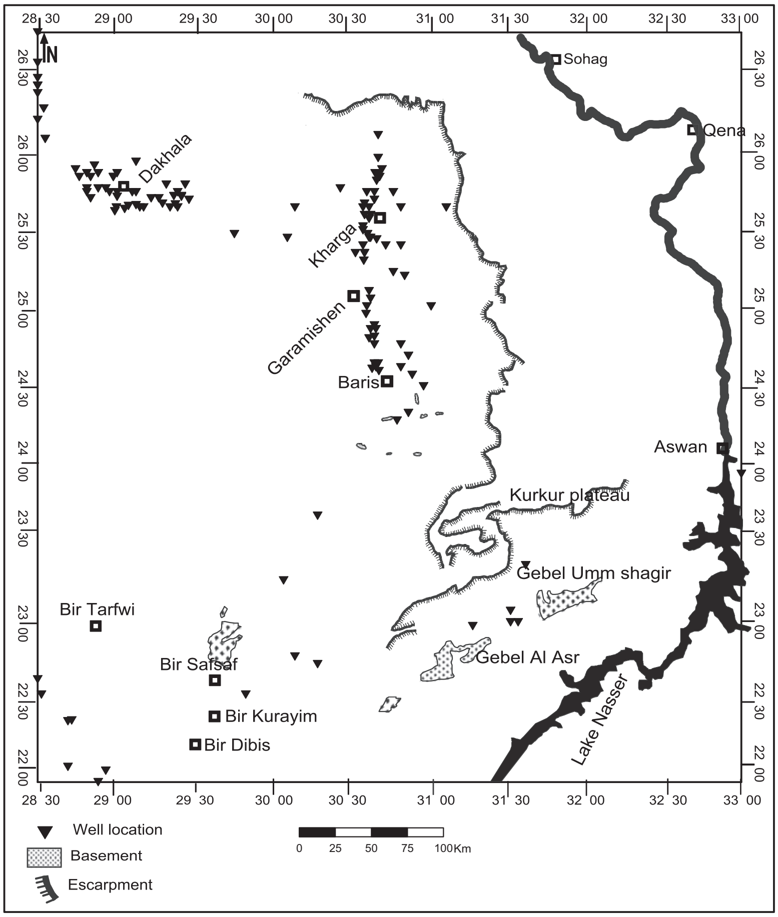

Fig. 3. Locations of deep wells scattered in the study area.

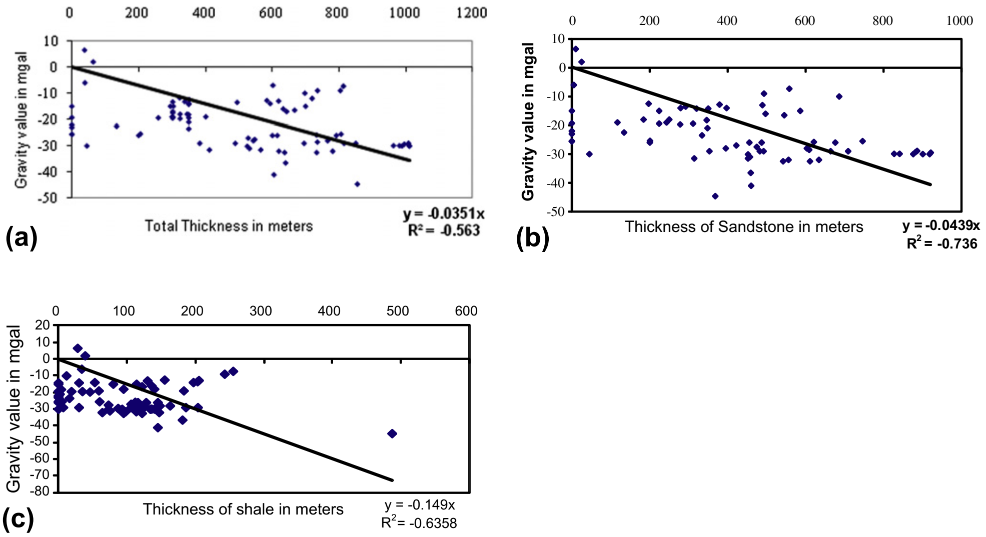

Fig. 4. Empirical relationships between gravity values and (a) total thickness of the sedimentary cover, (b) thickness of sandstone layers, (c) thickness of shale layers.

main rock types are basement rocks (mainly granite), sandstones, siltstones, shales, and limestones, which have direct effect on the Bouguer gravity values in the area.

Senosy (2003) had determined the density of the predominant lithological units in the El-Kharga Oasis (Table 1) by comparison between density contrast ranges of different rocks reported in literature (e.g., Nettleton, 1976; Dobrin, 1983; Paterson and Reeves, 1985; Telford et al., 1990; Parasniss, 1997; and other) and density measurements derived from Formation Density Compensated logs (FDC) of some deep wells in Northwestern Desert of Egypt by Abu El-Ata and Abd El-Nabi (1991) and other geophysical logs carried out by REGWA (General Company for Research and Groundwater) on some boreholes in Dakhala and Owinat regions.

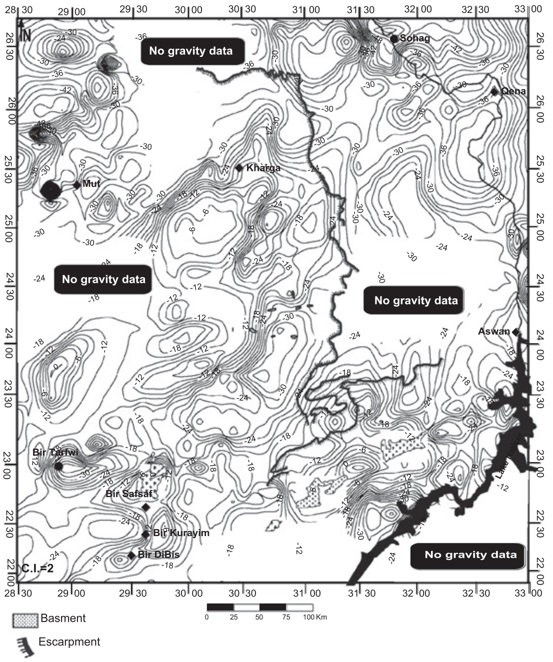

Fig. 5. Bouguer gravity anomaly map of the study area modified after EGPC (1980). Original scale 1:500,000.

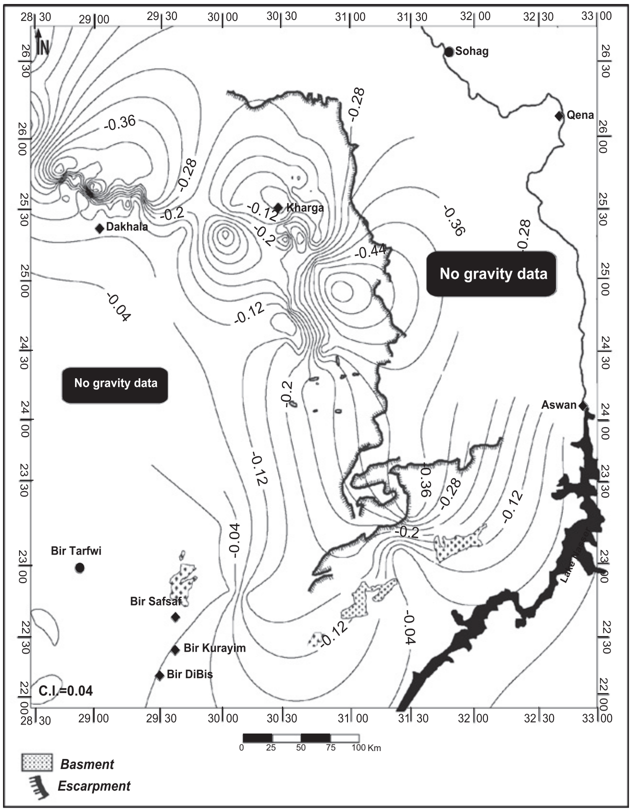

Fig. 6. Gravity effects of shale layers.

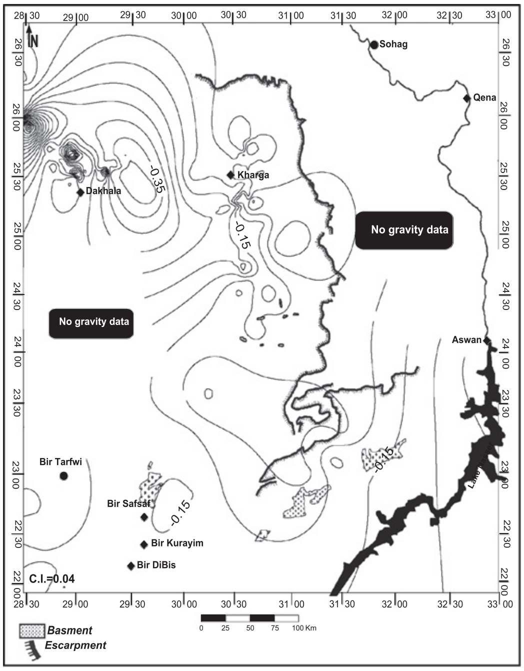

Fig. 7. Gravity effects of sandstone layers.

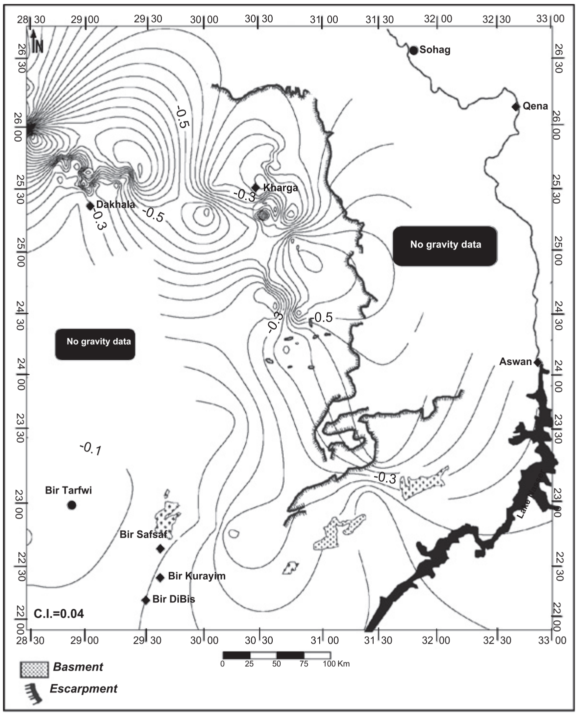

Fig. 8. Gravity effects of sandstone and shale layers (sedimentary cover).

The density contrast determined by considering the density of granite as represent the base density as the granitic rocks are the most prevailing rock types of the basement complex in the study area. The lithological units in the southern part of the Western Desert are probably similar to those occurring in the central and northern parts, and consequently, the density contrasts determined by Senosy (2003) can be widely used in all parts of the study area.

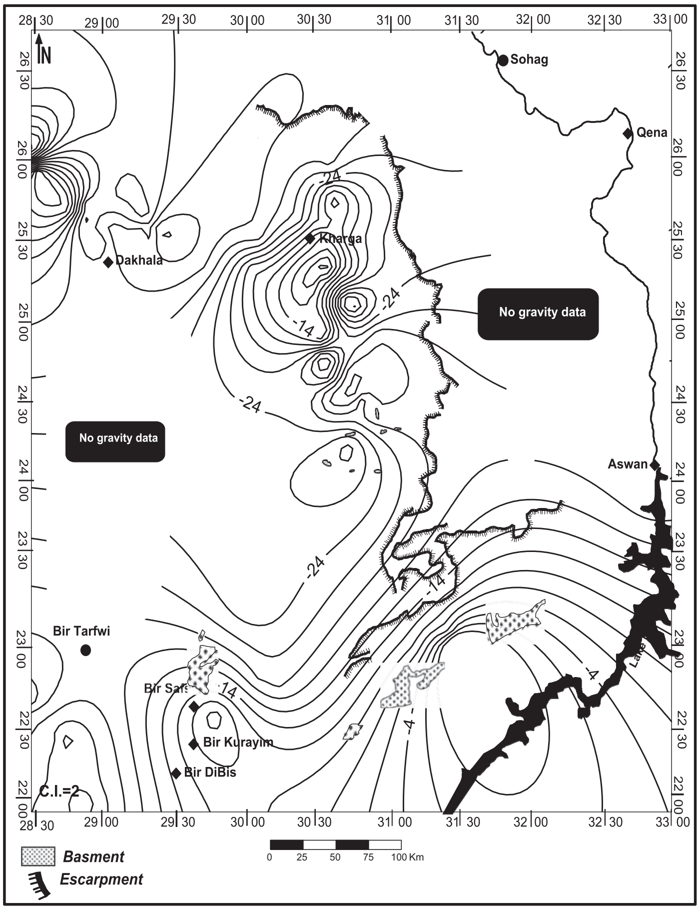

Fig. 9. Bouguer gravity map after removing the gravity effect of sandstone layers.

3. Subsurface information

Subsurface data of 120 groundwater wells drilled to the basement in the southern part of the Western Desert were used. These wells are scattered in the whole area as given in Fig. 3. The geophysical and lithological logs of these wells were formulated and the subsurface rock units were discriminated.

Generally, the density of the subsurface rock formations increases with depth due to compaction. The linear relationship between density and depth is also accepted between Bouguer gravity and depth discarding the thickness of sedimentary cover. In the present work the thickness of the sedimentary cover and the included rock units were plotted against the Bouguer gravity values at each well and the linear relationships between them were obtained (Fig. 4a–c). It can be noticed that the correlation coefficients of the relationships between gravity and shale formation and total thickness of the sedimentary cover are 0.5625 and 0.6358, whereas they are equal 0.720–0.736 in case of sandstone formation and gravity relationship. Accordingly, the obtained relations between Bouguer gravity and the thickness of the rocks within the sedimentary cover were found to satisfy the following relation:

$$\Delta g = A_o + A_1 h \tag{1}$$

where (Δg) is the mean value of the gravity anomalies, (A_o) is the base density for the crustal rocks (2.67 g/cm^3), (A_1) is the rate of increase of density with depth (density gradient), and (h) is the thickness of the sedimentary rocks in meter. Accordingly, this relation was used in calculating the thickness of the shale and sandstone rock units and the total thickness of the sedimentary cover. The calculated thicknesses were used in preparing isopach maps for each rock unit and the sedimentary cover.

4. Gravity data processing and interpretation

The major problem in gravity interpretation is separating anomalies of interest from the overlapping effects of other features; usually the main obscuring effects result from deeper features. The Bouguer anomaly map of any area is a continuation of gravity effects of the various litho-stratigraphic units composing the sedimentary cover as well as that of the basement complex, which we can assume that the total gravity effect of anomalous bodies is acquired by summation of the gravity effects of n-sided vertical prisms with horizontal bases.

Gravity surveys have been used in investigations of wide range of scales such as tectonic studies and mineral explorations (Paterson and Reeves, 1985) and engineering and environmental problems (Hinze, 1990; Ward, 1990).

Some authors prescribe the density variation and seek to invert for the geometrical parameters of the model. The most noticeable application is the inversion for the thickness of sedimentary basin given the density variation as a function of depth (e.g. Oldemburg, 1974; Pederson, 1977; Chai and Hinze, 1988; Reamer and Ferguson, 1989; Guspi, 1990). Alternatively, others

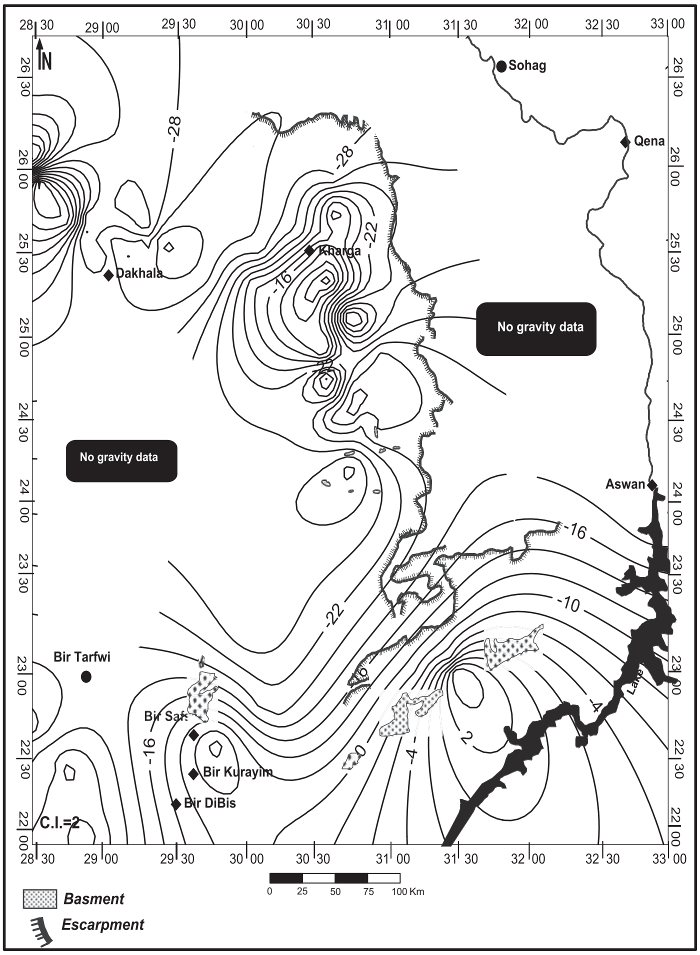

Fig. 10. Bouguer gravity map after removing the gravity effect of shale layers.

assume a constant density contrast and invert for the position of a polygonal (in 2D) or polyhedral (3D) body from isolated anomalies (e.g. Pederson, 1979).

Li and Oldenburg (1998), introduced two methods for inverting surface gravity data to recover a 3D distribution of density contrast. In these approaches the earth is modeled by using a large number of rectangular cells of contrast density, and the final density distribution is obtained by minimizing a model objective function subjected to fitting observed data. Application of these techniques on real Bouguer map shown that the 3D density contrast inversion of gravity data with a property designed objective function can yield geologically meaningful information.

The gravity effect of the sediments must be taken into account. Such gravity effect can be determined if the thickness and density of the overlying sedimentary sections are known from independent sources (e.g. well data and seismic reflection). This process is known as gravity stripping and has for example, been applied very successfully different regions to study the deep structure of the basement below well-explored sedimentary cover (e.g. in northern Britain by Hinpkin and Hussian (1983), in Gulf of Suez – Egypt by Abu El-Ata and Helal (1985) and in Kharga oasis – Egypt by Senosy, 2003).

In the study area, gravity stripping was applied. The stripping procedure has a more accurate physical foundation than any other mathematical method of gravity field analysis, provided that the geometry and density of the disturbing bodies are known with sufficient accuracy. This technique involves several steps including: (1) preparation of the available data (e.g. Bouguer gravity data, geometry of upper and lower surface of the rock units as obtained from geophysical and lithological well logging, and density distribution), (2) calculation of the gravity effects of each layer incorporating the upper and lower geometrical boundaries and density distributions, and (3) subtracting the gravity effect of the individual layers from the original gravity values to obtain the behavior of the Bouguer gravity anomalies that reflect the predominant structures at each boundary separating between different rock units.

The base equation used in calculating the values of any rock unit is:

$$\Delta g = 2\pi G\sigma h \qquad (2)$$

where (Δg) is the gravity effect of a certain rock unit in gal, (G) is the international gravitational constant, which equals 6.67×10^{-8} c.g.s. unit, (σ) is the density contrast between the rock unit density and the base density of the crustal rocks (2.67 g/cm^3) and (h) is the unit thickness in meters.

Based on the above concepts, Bouguer gravity maps for the shale and sandstone units as well as the total sedimentary cover were prepared. Furthermore, Bouguer gravity maps were obtained after removing the gravity effects of shale and sandstone units. The Magmap Software (1992) was used in processing and preparing the mentioned maps. The following is a brief discussion of the obtained maps.

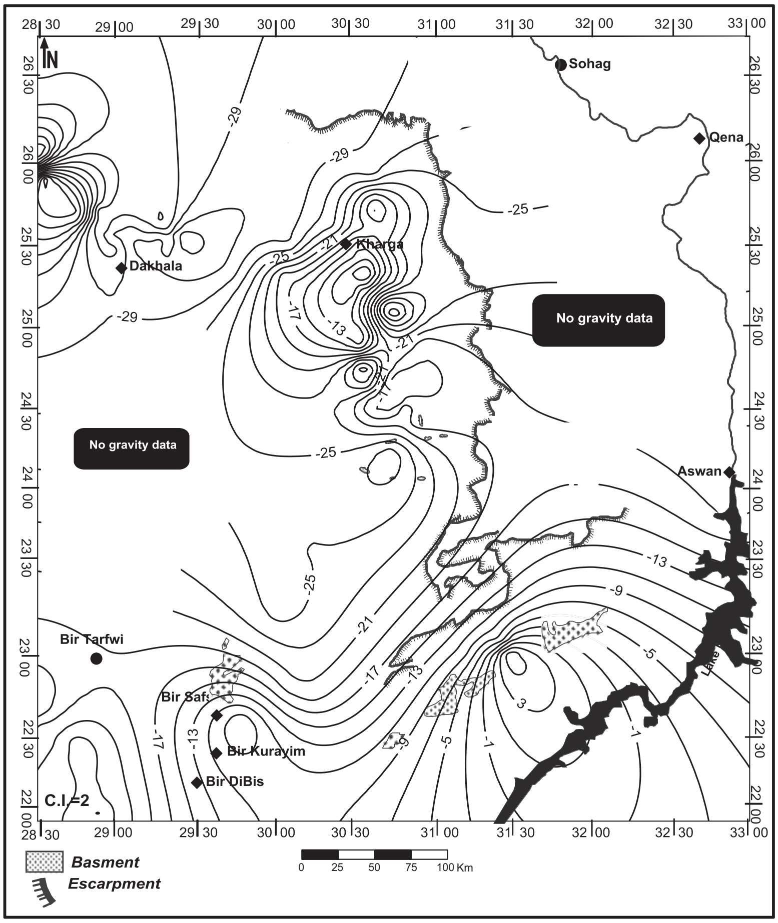

Fig. 11. Bouguer gravity map after removing the gravity effect of shale and sandstone layers.

4.1. Description of the Bouguer gravity anomaly map and stripped gravity maps

1. On the Bouguer gravity anomaly map of the study area (Fig. 5) the positive gravity anomaly is mainly due to uplift of more denser basement rock in Gabel Umm shaghir and Gabel El Asr, however, the lower gravity values indicate sedimentary basins except at the occurrence of acidic intrusions.
2. Linear Bouguer gravity contours represent regional structures mainly faults striking in a NE–SW direction. These faults cut the basement rocks and propagated vertically through the sedimentary cover.
3. Closed anomalies of different amplitudes are observed in different parts of the area. These anomalies are negative at the northern parts of the area and positive at the south. The positive closed anomalies may reflect uplifted and/or up-faulted basement blocks, whereas negative anomalies reflect basins and/or subsided blocks. A large closed positive anomaly (+3 mgal) representing major gravity high is observed at the southeastern part of the area adjacent to Gabel Umm Shaghir and Gabel El Asr. This anomaly extends NE–SW delineating basement outcrops characterized by a dense fracture system with an East–West major faults as reported by Said (1990). Another closed positive anomaly (0 mgal) occurs in the southwestern part adjacent to Bir Safsaf region. This anomaly extends in a NE–SW direction coincident with Bir Safsaf basement outcrops.
4. A large negative anomaly (−40 mgal) appears in the northeastern corner of the area on the Bouguer anomaly map adjacent to Qena city. This anomaly has a NE–SW trend parallel, to the Qena bend of the Nile Valley (Qena–Safaga Shear Zone). This anomaly may be due to a thick sedimentary sequence in a local basin.
5. On the gravity anomaly maps of the shale and sandstone layers separately (Figs. 6 and 7) and the combination of shale and sandstone layers (Fig. 8), it can be seen that the gravity values varies from −0.04 to −0.4 mgal and to 0.7 mgal in Fig. 8. The low gravity values are recorded at the northwestern and central parts of the study area corresponding to Dakhla and Kharga regions respectively. These values are compensated with increasing thickness of shale and sandstone layers. The gradient in the map is mostly gentle indicating gradual variation in thickness of the shale and sandstone layers. At the southwestern part of the area the gravity values reaches −0.04 mgal, where there are smaller amounts of shale and sandstone layers.
6. The Bouguer gravity anomaly map of the basement surface (Fig. 11) that was abstained after removing the effects of shale layers (Fig. 6), sandstone layers (Fig. 9), and the combination between them (Fig. 8) shows separation of the major anomalies observed on the original map into local isolated closed anomalies pointing to rigid basement surface that may be structurally and/or topography originated. Also, distribution of the positive and negative anomalies reflects structures with lithologic variations in the basement rocks.

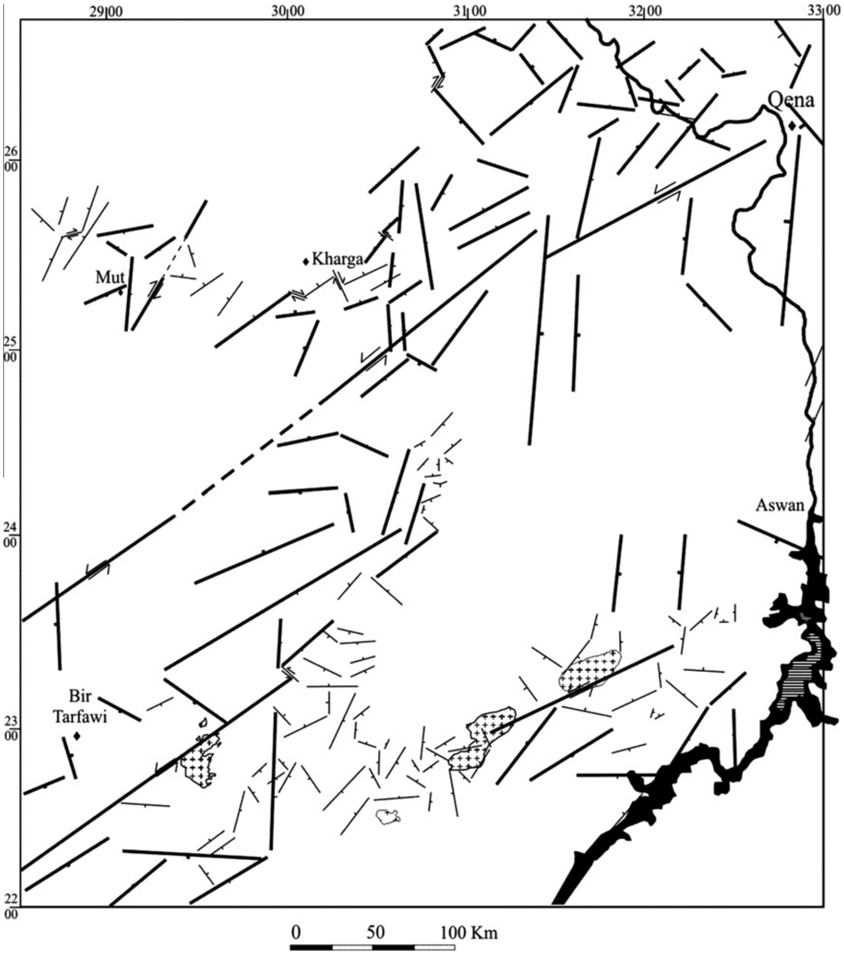

Fig. 12. Gravity lineaments deduced from the Bouguer gravity map.

4.2. Gravity lineaments analysis

The gravity lineaments were detected from the original Bouguer gravity anomaly map, the gravity map of the basement and the gravity map of the sedimentary cover (Figs. 5, 10, and 11) aiming at tracing the structures from the surface of sedimentary cover to the surface of the basement rocks. Trend analysis of the lineaments detected from the gravity maps is given in Figs. 12–14. From the analysis it can be seen that the major gravity lineaments suggest a deep seated effect are recorded in the sedimentary cover and extend downward in the basement trend generally in ENE–WSW direction and locally in N–S and NNE–SSW directions. Dextral and sinistral sense of movements which noticed from the offset in fault line of the same strike and opposite downthrown directions (Riad, 1977) could be detected along some of the ENE–WSW faults. Along the strike slip fault trends a hot spring were occurred and most of the drilled groundwater wells are flowing. The groundwater temperature of theses springs or well is ranging between 30 and 40 °C. The local lineaments are trending in NW–SE, NE–SW and E–W with limited lengths (5–50 km). Most of these lineaments are recorded in the sedimentary cover and disappear in the basement indicating that these structures are of local tectonic effect most probably of shallower occurrence accompanying major structures.

4.3. Quantitative interpretation

The quantitative interpretation of the gravity data is focused in preparation of isopach maps of the different predominant sedimentary rock units in the area as well as the construction of subsurface geological cross sections. Accordingly, the thickness of the shale and sandstone layers which represents the sedimentary cover in the area, was calculated from the Bouguer gravity values by using Eq. (2).

4.4. Isopach maps

About 120 control points were used to verify the thickness calculations. At these control points the thickness was obtained from the lithological logs of the deep ground water wells. Finally the actual and calculated thickness was plotted at each grid node, and the values controlled to obtain isopach maps of both shale and sandstone layers as well as the sedimentary cover (Figs. 15–17). These maps show that the depth to top of the basement rocks in the study area ranges between 0 at the southern part (as the basement outcrop on the surface) and 1500 m below sea level (b.s.l.) at the northeastern and northwestern parts of the area. The maximum thickness of sedimentary rocks was found at west Oweinat,

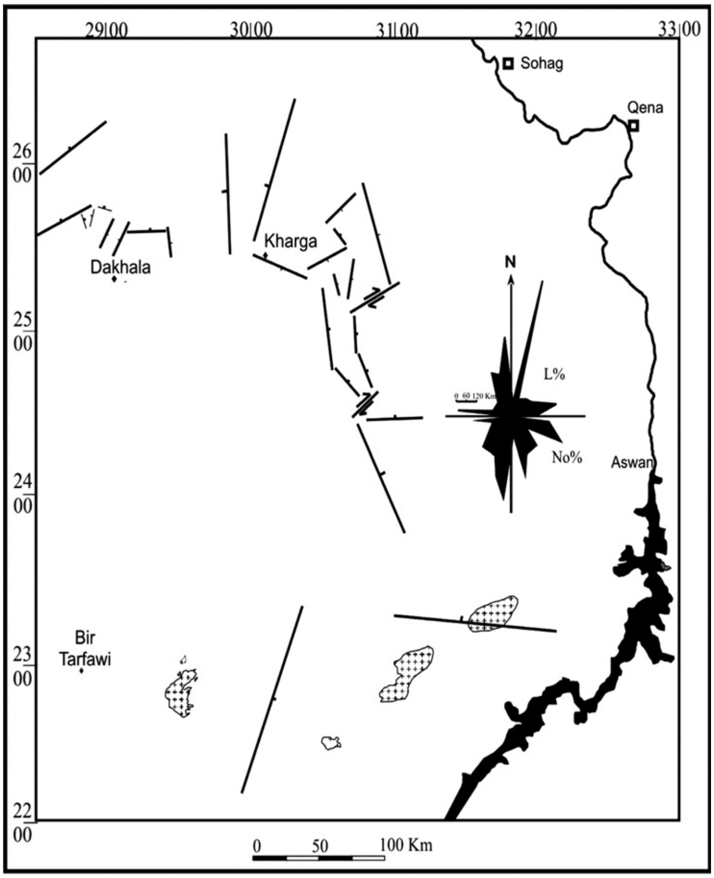

Fig. 13. Gravity lineaments predominant in the sedimentary cover.

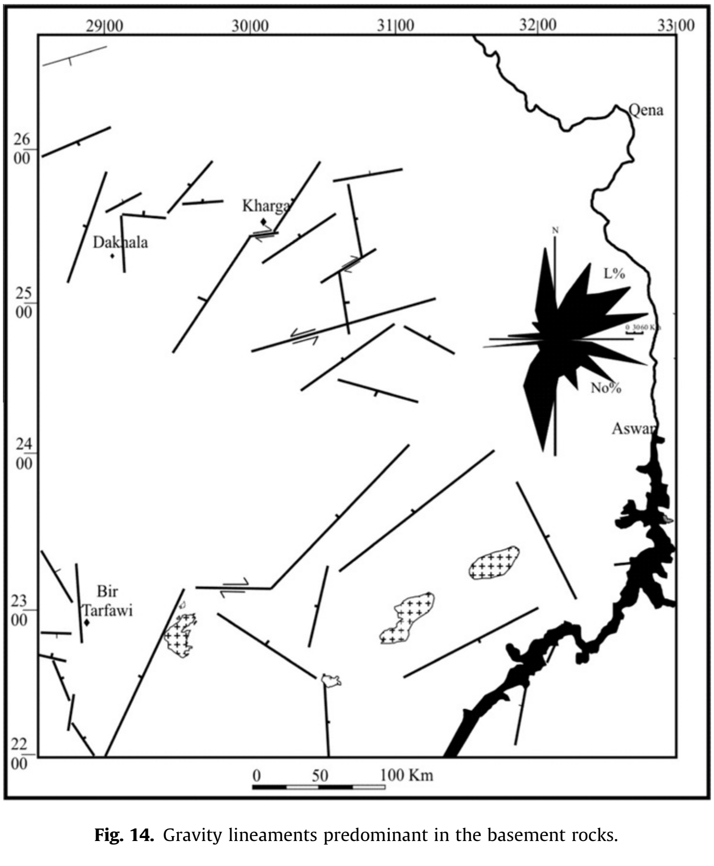

Fig. 14. Gravity lineaments predominant in the basement rocks.

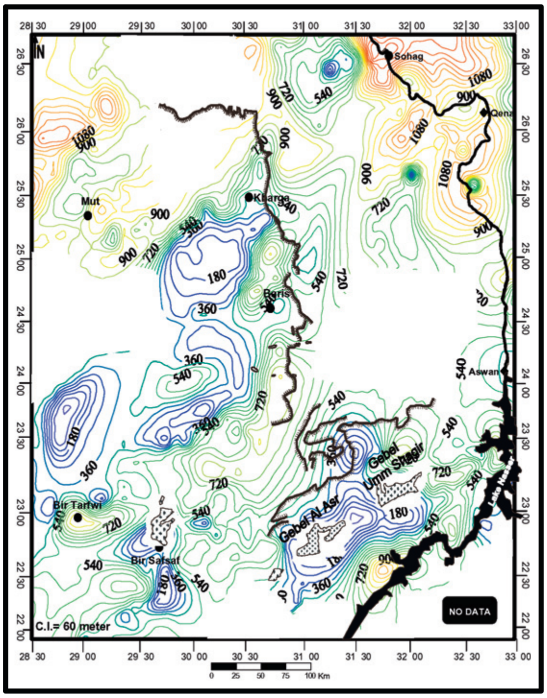

Fig. 15. Isopach map of the sedimentary cover with contour interval 60 m.

west Kurkur, southwest of Aswan, Gramashin, Dakhla oasis and some localities west of Sohag and Qena towns. These areas are considered as separate sedimentary basins.

The basement surface is characterized by the presence of many topographic highs and lows. Two large highs can be recognized at the southern part of the area under study at Bir-Safsaf and Gabel Umm Shaghir and Gabel El Asr, where the basement crops out in these areas. To the north of this region the thickness of sedimentary rocks increases and reaches 1500 m at Dakhla Basin. A more or less N–S trending group of high and low structures can be traced in the vicinity of El-Kharga oasis and between Kharga and Dakhla oasis. The Kharga oasis is underlain by a structural high in the basement rocks. A more or less E–W trending group of high and low structures in the basement rocks extend parallel to the Dakhla oasis.

The isopach map of sandstone is very useful for groundwater exploration as it is an appropriate reservoir rocks. The chances of finding commercial quantities of groundwater are greater in areas containing thick sandstones. Areas that have porous and permeable sandstone alternating with shale cap rock are considered a good reservoir rock. From isopach map of sandstone we can recognize that the area of Dakhla Basin and Nile valley Basin and some localities at southern part of the area in Tushka and West of El-Oweinat regions can be considered as the best localities for ground water exploration.

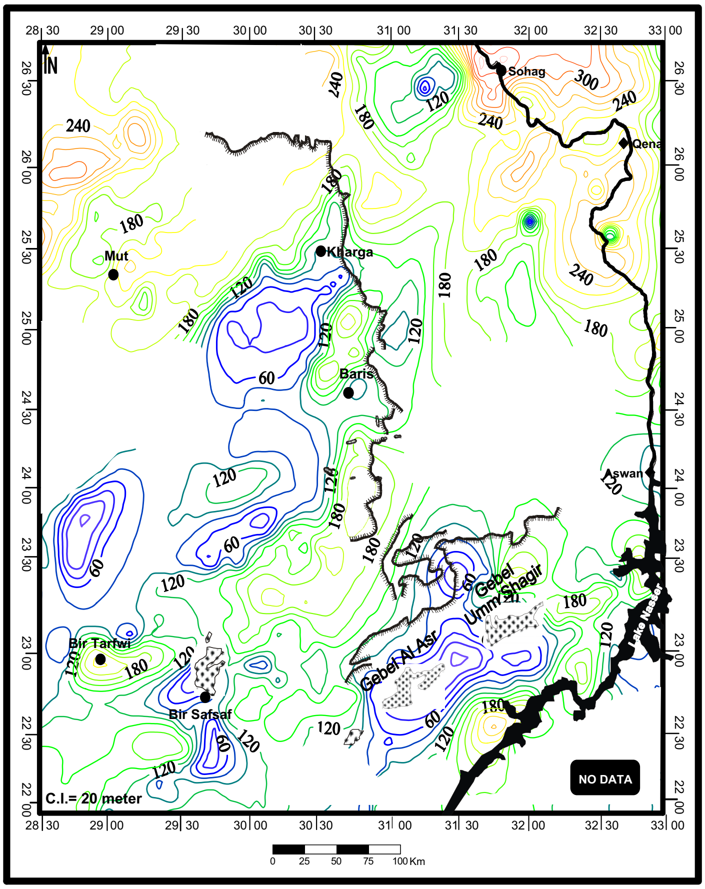

Fig. 16. Isopach map of the shale layers with contour interval 20 m.

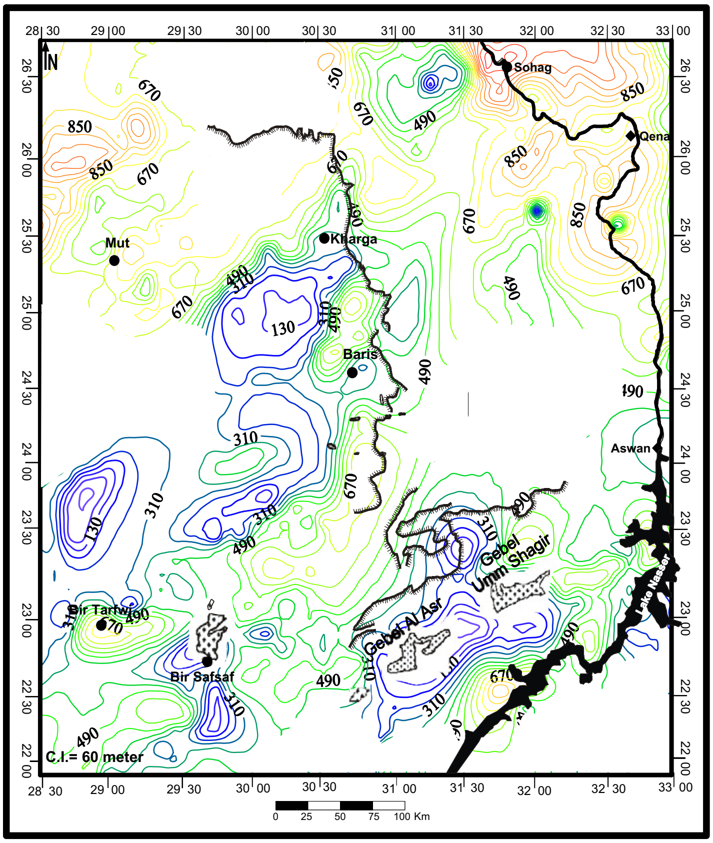

Fig. 17. Isopach map of the sandstone layers with contour interval 50 m.

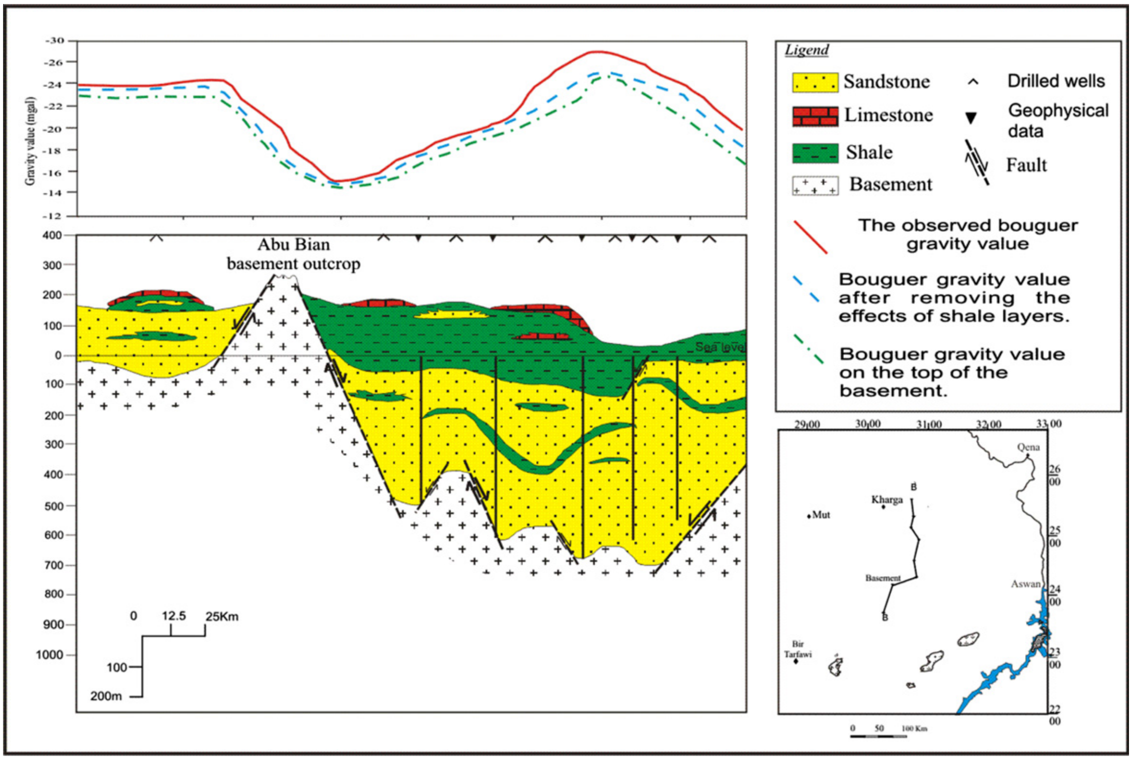

Fig. 18. Subsurface section AA′ extending from south to north crossing Baris and Kharga oases and the corresponding gravity profile (modified after Abdel Zaher et al. (2009)).

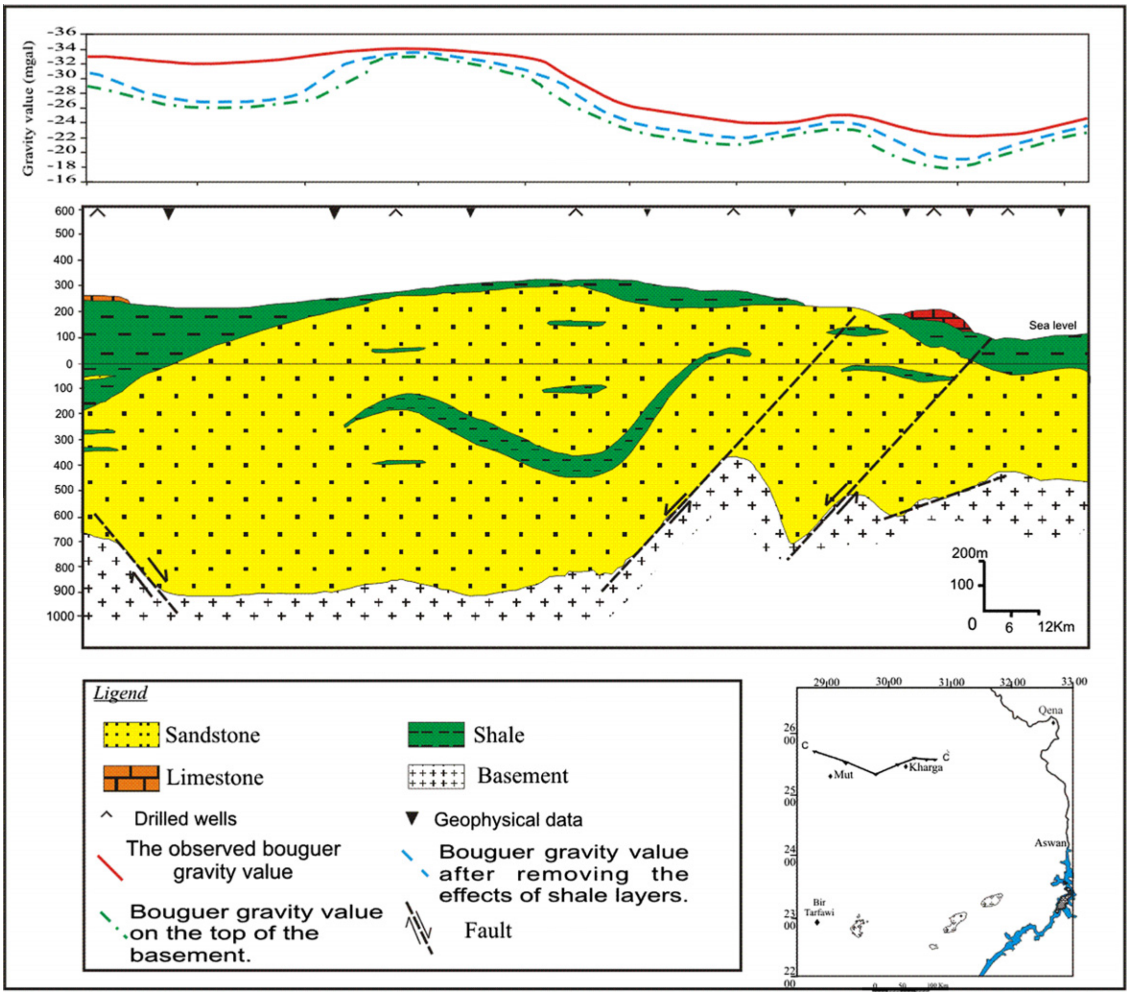

Fig. 19. Subsurface section BB′ extending from west to east crossing Kharga and Dakhla oases and the corresponding gravity profile (modified after Zaher et al. (2009)).

4.5. Subsurface cross sections and their corresponding gravity profile

The sections are constructed primarily to show structural relationships using the sea level as the plane of reference. Four subsurface geological cross-sections AA′, BB′, CC′ and DD′ (Figs. 18–21) distributed over the study area are constructed to emphasize the quantitative interpretation process. The thickness of the shale, sandstone layers and depth to the basement rocks obtained from the prepared isopach maps were used in construction of these cross sections. The Bouguer gravity values and the gravity values of shale and sandstone were used in preparation of gravity profiles corresponding to the subsurface cross sections The information obtained from the sections and the corresponding gravity profiles is used to illustrate the general tectonic setting of the basement rocks and also the sedimentary cover as well as the relationship between gravity values and thickness of sedimentary cover and consequently the uplift and subsidence in basement rock of the study area. The sections and profiles show that the maximum gravity values coincide with the basement outcrops or basement uplifts, while in contrast the minimum values point to thick sedimentary cover. Steep change from maximum gravity values to minimum values reflects steep normal faults bounding the basement outcrops and forming horst and graben structures.

5. Conclusion

The qualitative interpretation of the Bouguer gravity map and stripped gravity maps showed that the main irregularities in the gravitational field are caused by uplifted or subsided surface of basement rocks due to tectonic movements. Three predominant fault trends are extending ENE–WSW, N–S and NNE–SSW. These trends are representing deep-seated faulting that affect the basement rocks and propagate upward through the sedimentary cover. Dextral and sinistral sense of movement is recorded along the ENE–WSW fault trend. This trend is rejuvenated several times through the geologic history. It is predominant in southern Egypt crossing both the Western and Eastern Dessert, and forming the bends in the course of the Nile Valley. Along this zone in the study area the groundwater wells are flowing and the water temperature are ranging between 30 and 40 °C due to the thermal activities along this fault trend. Locally, lineaments extending in a NW–SE, NE–SW and E–W directions with limited lengths (5–50 km). Most of these lineaments are recorded in the sedimentary cover only.

The quantitative interpretation of the gravity and drill borehole data from which isopach maps for the main rock units and subsurface cross sections were constructed showed that the basement surface is characterized by the presence of many highs and lows.

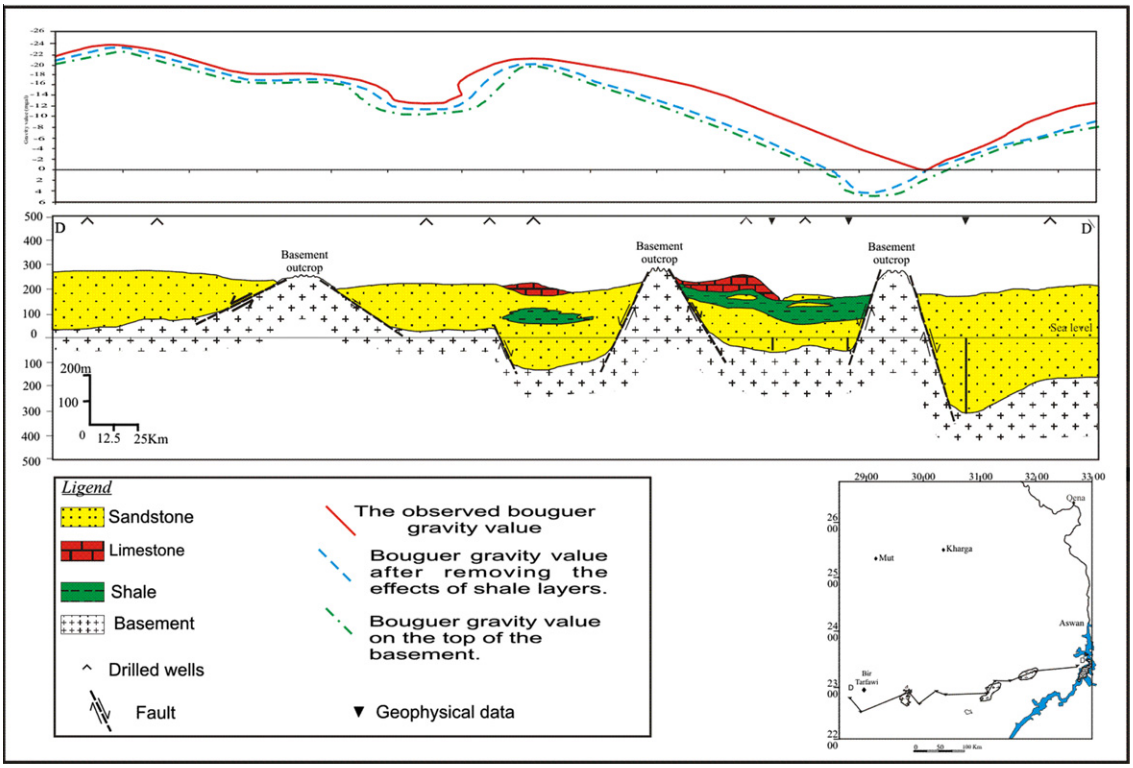

Fig. 20. subsurface section CC′ extending from west to east along Owinat–Bir Safsaf–Aswan uplift and the corresponding gravity profile.

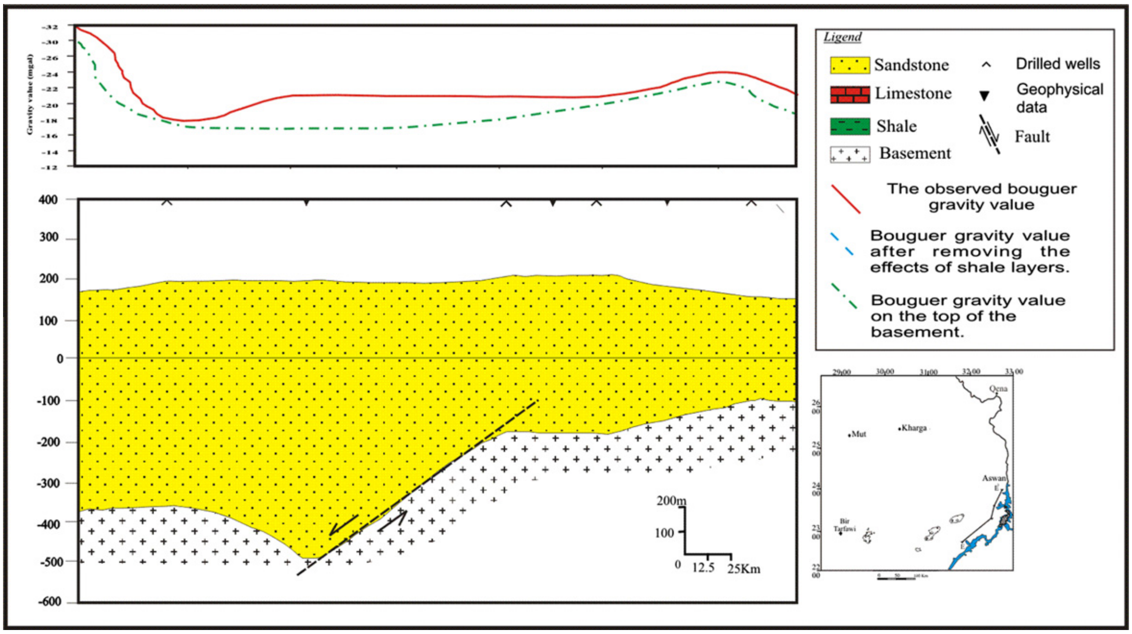

Fig. 21. Subsurface section DD′ parallel to the main course of Lake Naser and the corresponding gravity profile.

Two large highs can be recognized at the southern part of the study area at Bir-Safsaf and Gabel Umm Shaghir and Gabel El Asr, where the basement crops out in these regions. To the north the thickness of sedimentary rocks increases and reaches 1500 m at Dakhla Basin. A more or less N–S trending group of high and low structures can be traced between Kharga and Dakhla oases.

The depth to the top of the basement rock in the study area is ranging between 0 and 1500 m (b.s.l.) and the maximum thickness of sedimentary cover observed in Dakhla Basin and north of Nile valley Basin at Qena and Sohag districts. The chance of finding commercial quantities of groundwater is greater at the areas containing a thick sandstones with a shale cap. The shale cap will prevent the groundwater from surface pollutants and increase the hydrostatic pressure that facilitates the extraction process.

Acknowledgments

The authors are greatly indebted to Research Institute for Groundwater (RIGW) and the General Company for Research and Groundwater (REGWA) for their great supports in collecting lithological wells data, and also to the Egyptian General Petroleum Company (EGPC) for providing the Bouguer gravity map used in the study. Special thanks are due to the reviewers for their critical and valuable comments.

References

Abdel Zaher, Mohamed, Senosy, M.M., Youssef, M.M., Ehara, Sachi, 2009. Thickness variation of the sedimentary cover in the SouthWestern Desert of Egypt as deduced from Bouguer gravity and drill-hole data using neural network method. Earth Planets Space 61, 659–674.

Abdel Zaher, M., Senosy, M. M., Youssef, M. M., Ehara, Sachio, 2008. Surface studies on the South Eastern part of the Western Desert, Egypt by using remote sensing technique. In: Proceedings of International Symposium on Earth Science and Technology, 2008. Kyushu University Fukuoka, Japan, pp. 267–274.

Abu El-Ata, A.S., Abd El-Nabi, S.H., 1991. Mapping the structural elements dissecting the Cretaceous rock units of the Qattara depressions area, western Desert, Egypt; using three-dimensional gravity modeling. In: Geological Survey of Egypt, Proc. of 4th Ann. M., pp. 103–123.

Abu El-Ata, A.S., Helal, A.A., 1985. Gravity stripping as a tool for deducing the paleotectonic implications for the Western coast of the Gulf of Suez, Egypt. In: Geological Survey of Egypt, Proc. of 4th Ann. M., pp. 124–141.

Barakat, M.G., Milad, G.S., 1966. Subsurface geology of the Dakhla oasis, Egypt. J. Geol. 10 (2), 145–154.

Bernau, R., Darbyshire, D.P.F., Franz, G., Harms, U., Huth, A., Mansour, N., Pasteel, Schandelmeier, H., 1987. Petrology, geochemistry and structural development of the Bir Safsaf – Aswan uplift, Southern Egypt. J. Afr. Earth Sci. 6 (1), 79–90.

Chai, Y., Hinze, W.J., 1988. Gravity inversion of an interface above which the density contrast varies exponentially with depth. Geophysics 53, 837–845.

Conoco Coral, 1987. Geological Map of Egypt, Scale 1:500,000, Sheets NF 35 NE, NF 36 NW, NG 35 SE, NG 36 SW, NG 35 NE and NG 36 NW. The Egyptian General Petroleum Corporation (EGPC), Egypt.

Dobrin, M.B., 1983. Introduction to Geophysical Prospecting, Mc-Graw Hil Book Company, New York, 630 pp.

Egyptian General Petroleum Corporation (EGPC), 1980. Bouguer Anomaly Map of South Western Desert of Egypt, Scale 1:500,000.

El-Etr, H.A., Yehia, M.A., Dowidar, H., 1982. Fault Pattern in the South Western Desert of Egypt; Mid., F., Res. Cent Ain Shams Univ. Sci. Res. Series, vol. 2, pp. 123–151.

El-Younsy, A.R., Mansour, H.H., Ahmed, E.A., Shaheen, M., 1991. Lithostratigraphy and Structural Evolution of Baris Oasis Area, Southwestern Desert, Egypt. Bull. Fac. Sci. Assiut Univ. 20(2-F), pp. 193–214.

Guspi, F., 1990. General 2D gravity inversion with density contrast varying with depth. Geoexploration 26, 253–265.

Heinel, M., Thorweihe, U., 1993. Groundwater Resources and Management SW Egypt. Catena Supplement 26. Meissner, Brend, Wycisk, Peter (Eds.), Geopotential and Ecology.

Hendriks, F., 1986. The Maghrabi Formation of the EL Kharga area (SW Egypt): deposits from a mixed estuarine and tidal flat environment of Cenomanian age. J. Afr. Earth Sci. 5, 481–489.

Hendriks, F., Lugar, P., Kallenbach, H., Schroeder, J.H., 1984. Stratigraphical and sedimentological framework of the Kharga–Sinn-EL-Kaddab stretch, Western and Southern part of the upper Nile basin, Western Desert, Egypt. Berliner Geowiss., Abh. A 50, 117–151.

Hermina, M.H., 1990. The surrounding of Kharga, Dakhla and Farafra Oases. In: Said, R. (Ed.), The Geology of Egypt. AA Balkema, Rotterdam/Bookfield, 734 p.

Hinpkin, R.G., Hussian, A., 1983. Regional Gravity Anomalies-1: Northern Britain, Scale 1:625,000: L Inst. Geol. Science (now British Geol. Survey) Rep. 82/10.

Hinze, W.J., 1990. The role of gravity and magnetic methods in engineering and environmental studies. In: Ward, S.H. (Ed.), Geotechnical and Environmental Geophysics, vol. 1. Soc. Expl. Geophys., pp. 75–126.

Kiltzsch, E., 1984. Northwestern Sudan and bordering areas; geological developments since Cambrian time. berl. Geowiss Abh. 50(A), 23–45.

Kiltzsch, E., Wycisk, P., 1987. Geology of sedimentary basin of northern Sudan and bordering areas. Berliner Geowiss. Abh. A 75(1), 97–136.

Li, Y., Oldenburg, W., 1998. 3-D inversion of gravity data. Geophysics 63 (1), 109–119.

Magmap Software, 1992. Geosoft Mapping and Processing System "Geosoft Incorporated", Toronto, Canada.

Nettleton, L.L., 1976. Gravity and Magnetics in Oil Prospecting. Mc-Graw Hill Book Co., New York, 464 p.

Oldemburg, D.W., 1974. The inversion and interpretation of gravity anomalies. Geophysics 39, 394–408.

Parasniss, D.S., 1997. Principles of Applied Geophysics, fifth ed. Chapman & Hall, 2–6 Boundary Row, London SE1 8HN, UK, p. 429.

Paterson, N.R., Reeves, C.V., 1985. Application of gravity and magnetic survey: the state of the art in. Geophysics 50 (12), 2558–2594.

Pederson, L.B., 1977. Interpretation of potential field data: a generalized inverse approach. Geophys. Prosp. 25, 199–230.

Reamer, S.K., Ferguson, J.F., 1989. Regularized two-dimensional Fourier gravity inversion method with application to the Silent Canyon Caldera, Nevada. Geophysics 54, 486–496.

Riad, S., 1977. Shear zones in north Egypt interpreted from gravity data. Geophysics 24 (6), 1207–1214.

Said, R., 1962. The Geology of Egypt. Elsiver Publishing Co., Amstrdam, New York, 337 p.

Said, R., 1990. The Geology of Egypt, Balkema, Rotterdam, 734 p.

Schandelmeier, H., Klitzsch, E., Hendriks, F., Wycish, P., 1987. Structure development of northeast Africa since Pre-Cambrian time. Berliner Geow. Abh. A 75 (1), 5–24.

Senosy, M., 2003. Application of density contrast stripping in studying subsurface geologic structures: a case study El-Kharga Oasis, western Desert, Egypt. Egypt. J. Geol. 47, 387–404.

Telford, W.M., Gelbart, L.P., Sheriff, R.E., Keys, D.A., 1990. Applied Geophysics. Cambridge Univ. Press, Cambridge, 770 p.

Ward, S.H., 1990. Geotechnical and Environmental Geophysics. Society of Exploration Geophysicists, Tulsa.

Wycisk, P., 1993. Outline of the geology and mineral re-sources of the southern Dakhla Basin, SW Egypt. In: Meissner, B., Wycisk, P. (Eds.), Geopotential and Ecology: Analysis of a Desert Region. CATENA Supplement, 26, Cremlingen, pp. 67–97.