Arab Gulf J. Scient. Res., **10**(3), pp. 41-55 (1992)

Geological Interpretation of Several Gravity and Magnetic profiles from the Nile Delta, Egypt

H.A. Ibrahim

Geology Department, Faculty of Science, Assiut University, Assiut, Egypt.

ABSTRACT. Interpretation of three Bouguer gravity and total intensity magnetic profiles from the Nile Delta region suggests a northward increase in basement depth (2-8km). A prominant basement uplift is found to the south, which is considered a part of the major basement high that includes Khatatba-Abu Roash. In addition, a significant deepending of the basement is found to the north. This is considered a part of the major subsidence including the Mediterranean. The abnormal thickness of the sedimentary section of various sedimentry facies, and the occurrence of a deep causative intrabasement body (> 23 km) are considered the main causes for the major negative gravity anomaly and the relatively low magnetic intensity in the Nile Delta region. Ignoring density changes with depth in delta, and ignoring the possible presence of fluids within the productive horizons that give abrupt change in densities are considered the main causes responsible for the failure of the Agarwal method for determining the expected basement depths using gravity data.

The study area lies in the northern part of Egypt including the present Nile Delta and small parts of northwestern and northeastern portions of the Eastern and Western Desert respectively (Fig. 1). It is considered an important province for oil and gas in Egypt. Therefore, a number of wells have been drilled in this region (Fig. 1).

The initial data for this area consist of a Bouguer gravity anomaly map compiled by the Egyptian General Petroleum Corporation (E.G. P.C) in 1982, and a total intensity aeromagnetic map compiled by the Egyptian Geologic Research and Mining Department in 1963. The profiles are marked AA′, BB′ and CC′ on the location map (Fig. 1) as well as on the gravity (Fig. 5) and aeromagnetic maps (Fig. 6).

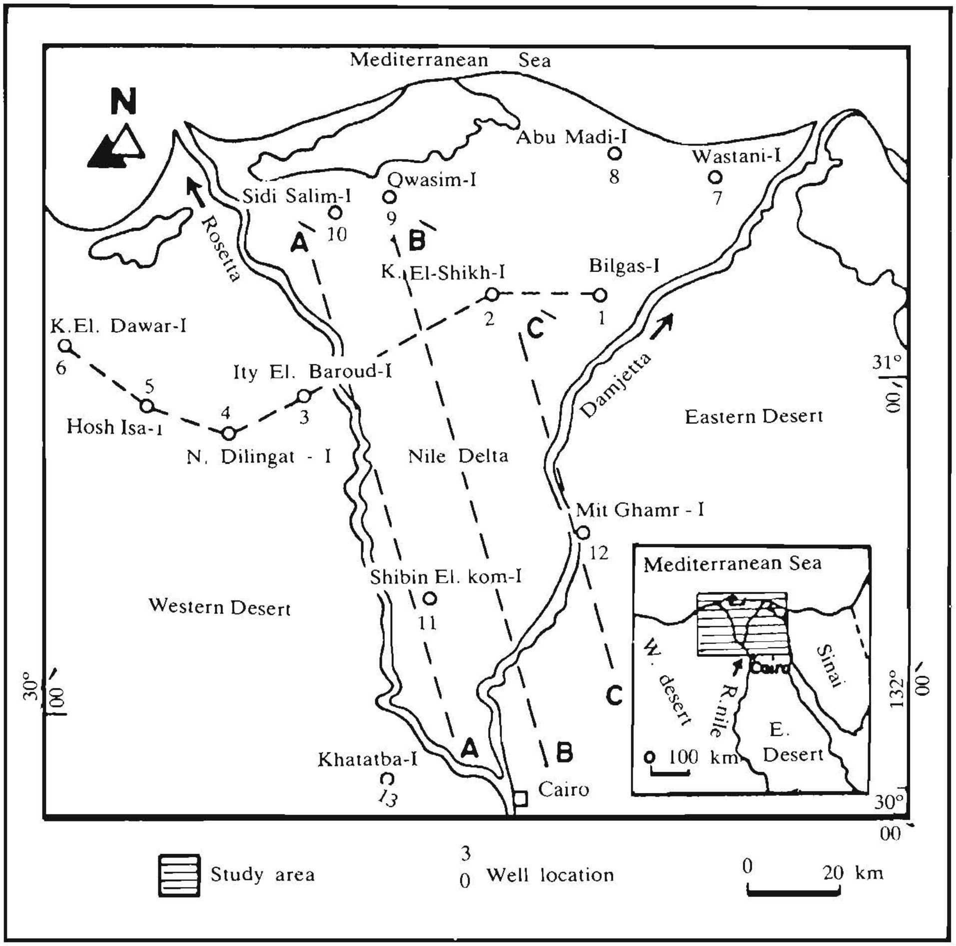

Fig. 1. Location map.

Although the geology of this part of Egypt has been studied by many authors (Rizzini *et al.* 1976, Salem 1976, Said 1981, Schlumberger Middle East S.A. 1984, Saleh 1985), there is no detailed subsurface treatment because of insufficient subsurface data and the complete absence of any surface outcrops.

Most of the Nile Delta and its nearest adjacent areas are covered with alluvium deposits (clay and sandy clay) of Holocene age. These are termed Neonile sediments (Said 1981). To the north (near the Mediterranean Sea) belts of sand dunes and vast areas of Sabkha are present. To the northwest of Abu Roash, plains of gravels and pebbles from the Oligocene, Pliocene, and Pleistocene extend to the Mediterranean coast. Miocene rocks appear at the southwestern margin of Wadi El-Natrun and disappear to the east of the depression. Faulting and folding northwest of Abu Roash caused Cretaceous limestone and Nubina sandstone layers to be uplifted until they outcrop. Their thickness becomes thinner toward the north. East of the delta, the region east of Cairo is characterized by a complicated geologic structure with many domes and monoclines indicative of faulting and folding. Along the faults, volcanic lava is distributed in isolated patches (Fig. 2).

A generalized stratigraphic column of the Nile Delta area from the Paleozoic (?) to the Holocene is shown in Fig. 3. The Paleozoic formations have not been encountered to date, and if indeed they are present, they would be at inaccessable depths. The sedimentary section in this part of Egypt is very depths. The sedimentary section in this part of Egypt is very thick and consists of successions which unconformably overlie the basement. Carbonates and clastic sediments are abundant (Fig. 3). In general, the depth to the top of the basement increases northward. It reaches 2 km near the latitude of Cairo and then increases northward (Schlumberger Middle East S.A. 1984).

Rizzini *et. al* (1976) classified the classic sediments of the onshore Nile Delta into three sedimentary cycle :

1. The Miocene cycle which comprises of deep sea clays (Sidi Salem Formation), fluvial-deltaic deposits (Qwasim Formation), and Messinian evaporites (Rosetta Formation).
2. The plio-pleistocene cycle comprising of open marine sediments (Kafr El-Shikh Formation) and deltaic deposits (El-Wastani and Mit Ghamr Formations).
3. The Holocence cycle (the youngest), represented by the present day coastal and lagoonal section.

The Nile Delta area is located on the unstable shelf of northern Africa and the Mediterranean (Henson 1951, Said 1962) and at the same time in the mobile belt (Weeks 1952) which is characterized by a complex subsurface structural framework (Fig. 4). A pronounced flexure affecting pre-Miocene formations extends E-W across the mid-delta area. South of the flexure, asymmetric folds referred to as the Syrian Arc fold system extend along an accurate trend from the northern Sinai and north of the Gulf of Suez across the southern part of the Delta into the Western Desert. This folding is related to the Laramide Phase of the Alpine orogeny and was formed in early Miocene time. North of the hinge line, large normal faults cross the Nile Delta (Fig. 4) (Schlumberger Middle East S.A. 1984).

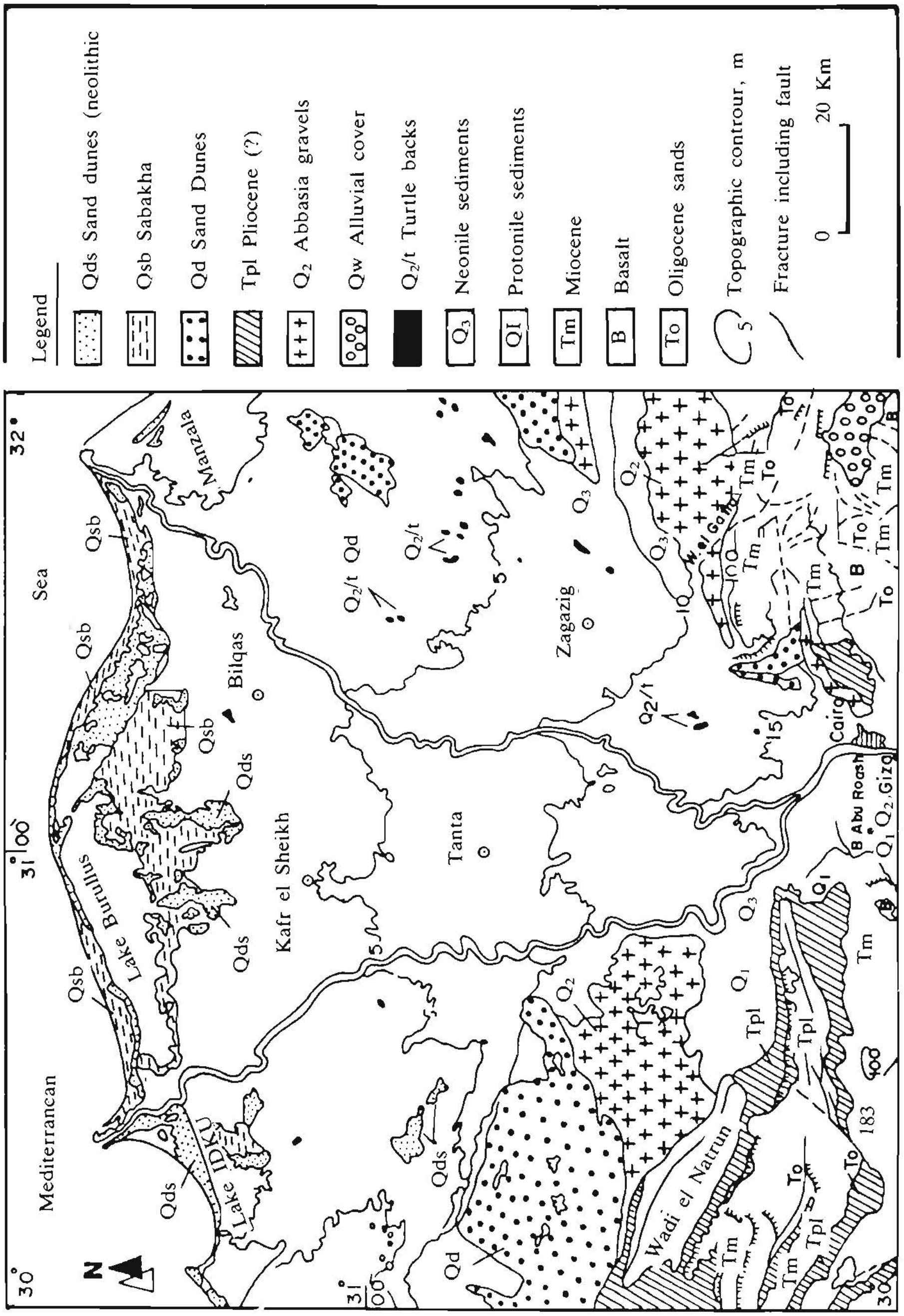

Fig. 2. Geological map of the study area (after Said 1981). For location see Figure 1.

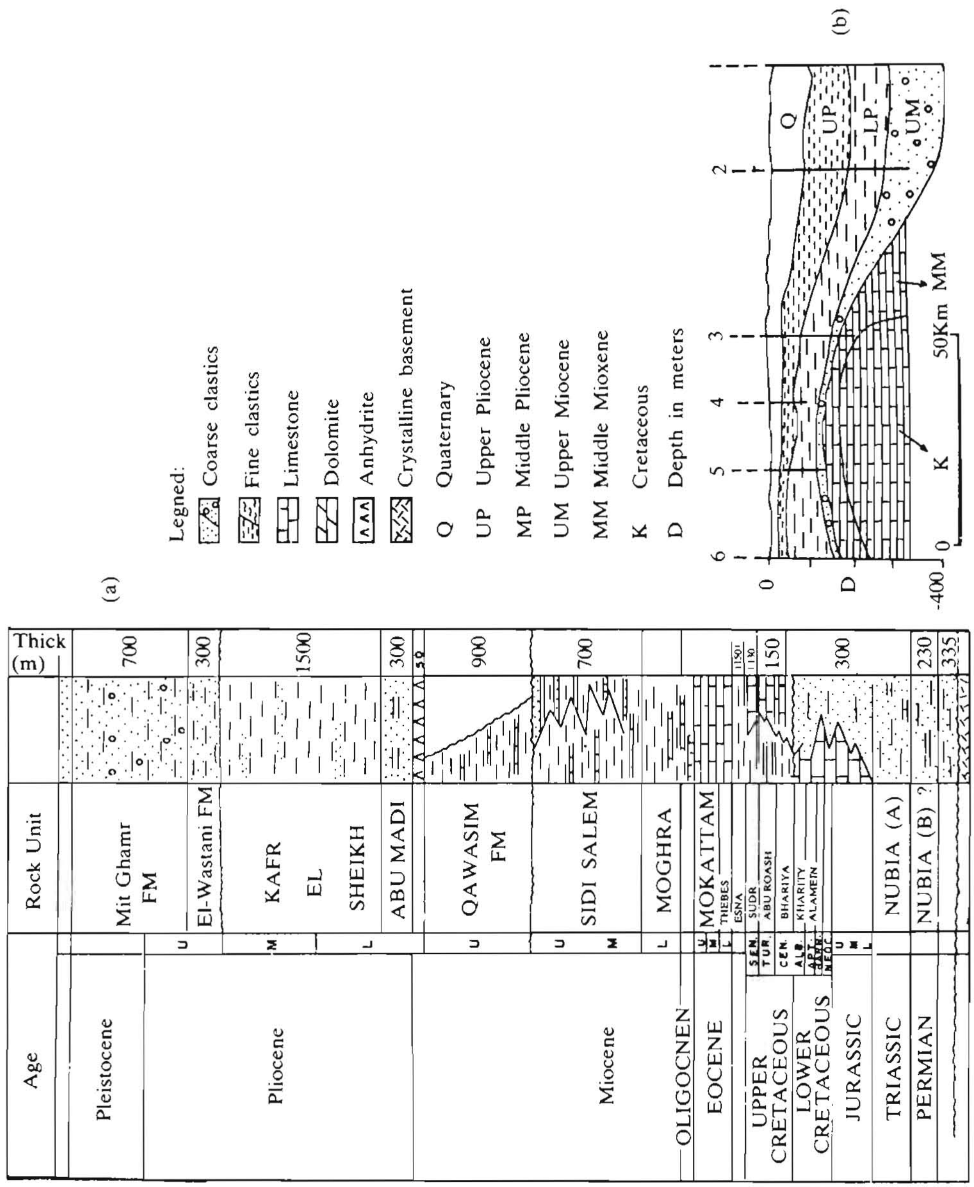

Fig. 3. Generalized lithostratigraphic column of the Nile Delta with inferred old Tertiary and pre-Tertiary sequences (Schlumberger Middle East S.A. 1984) (a) and cross section in the Nile Delta (Said 1981) (b) For location see Figure 1.

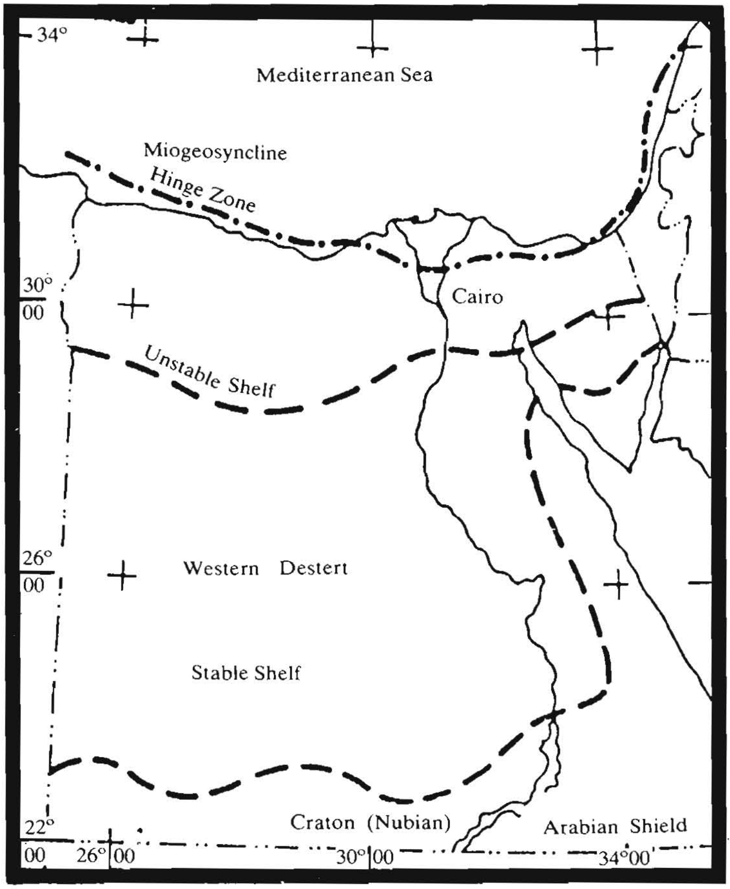

Fig. 4. Sketch of the structural aspects of the Nubian-Arabian shield margin in northern Egypt.

Methods of Analysis

The present study aims at obtaining information on the source of the major negative gravity anomaly (-43 mgal) and the relatively low intensity magnetic anomaly (-100 gamma) which occupy the mid-delta region using the available Bouguer gravity (Fig. 5) and total intensity aeromagnetic (Fig. 6) data. The techniques applied include:

1. Variable density contrast modelling of the Bouguer anomalies by using the method of Agarwal (1971 b).

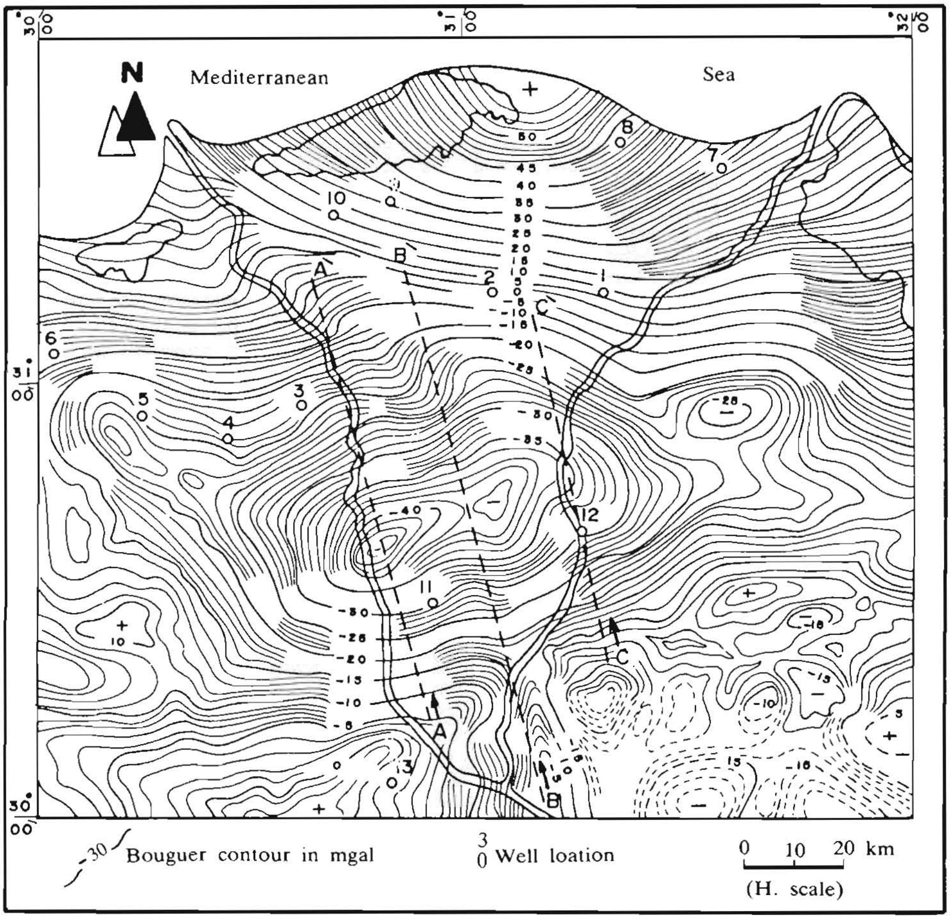

Fig. 5. Bouguer gravity anomaly map of the Nile Delta region (compiled by the E.G.P.C. 1982).

2. Calculation of residual gravity anomalies by removal of the regional field using Griffin's method (1949).
3. Half-width modelling of the Bouguer gravity profiles to estimate the depth of the causative body buried in the area of the mid-delta.
4. Basement depth determination by applying the maximum slope and half-slop techniques of Sharma (1976) to the magnetic profiles.

In the past, many techniques for rapid interpretation of gravity anomalies have been developed (Bott 1956, Talwani *et al.* 1959, Morgan and Grant 1963,

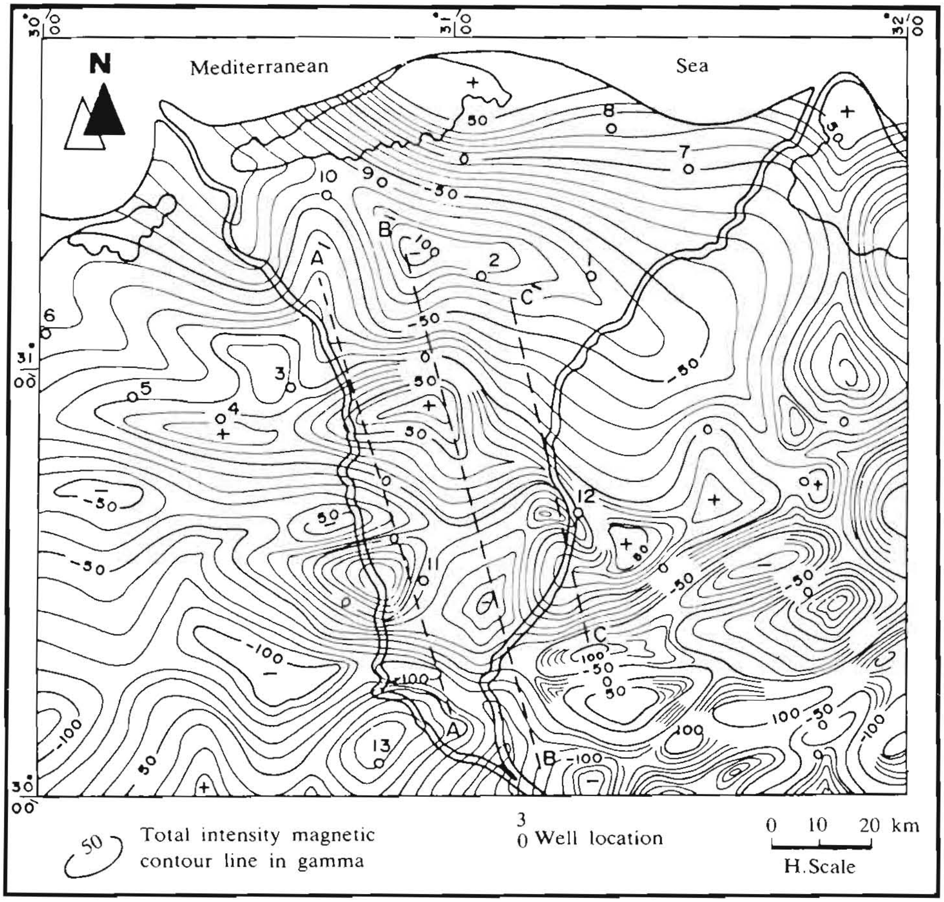

Fig. 6. Total intensity aeromagnetic map of the Nile Delta region (compiled by the Geologic Research and Mining Department 1963).

Tanner 1967). In principle, all these methods depend upon idealizing a body by a two-dimensional mass distribution which is either divided into a large number of vertical strips (Bott 1956, Tanner 1967), or is fitted by an n-sided polygon (Talwani *et al.* 1959, Morgan and Grant 1963) to determine its structural configuration by the method of successive approximation. In all these methods, the effects of the surrounding mass and the deposition of sediments under the influence of the earth's gravitational field on the gravity profile have not been accounted for in a realistic way (Agarwal 1971 a).

In this study, the gravity profiles in question are modelled using a computer program based on the formulas of Agarwal (1971 b) at the Computer Centre of Assiut University (VME/2900). The mass distribution is approximated by a number of vertical strips. These strips have a uniform width. Dimensions of the modelled bodies are inferred from the trend of the profiles themselves. Because deep density logs in the study area are not available, different density contrasts have been assumed. The maximum and minimum contrast values that give an acceptable fit are -0.5 and -0.4 gm/cm^3 respectively for all profiles.

Local/regional anomaly separation (Griffin 1949) has been carried out using a depth of separation of 7 km. This method is simple and accurate, and yielded gravity residuals for the preliminary determination of basement depths.

The depth to the centre of the causative body along each Bouguer gravity profile is estimated by using the half-width technique and by assuming that the causative body is spherical.

The total intensity aeromagnetic map of the study area (Fig. 6) compiled by the Egyptain Geologic Research and Mining Department in 1963 is used to determine the depth and structural configuration of the basement surface along the profiles AA', BB' and CC'. This gives valuable information on the thickness and general geologic setting of the overlying sediments, which in turn permits a better estimates of the basement depths from the gravity profiles.

For a proper interpretation of the geomagnetic field, several considerations must be take into account:

1. Where the basement is 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, Parasinis 1972, 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 faults and folds and changes in magnetic susceptibilites.
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 centre of the sherical causative body) are the same. Only the horizontal dimension of the anomaly will be changed.

Results and Discussion

A. Description of the Gravity and Magnetic Fields

The Bouguer gravity anomaly map of the study area (Fig. 5) shows a general northward increasing trend starting from the mid-delta (+ 53 mgal near the Mediterranean shore and a minimum -43 mgal to the north of Shibin El-Kom). This trend continues offhosre into the Mediterranean Sea. The most salient negative gravity anomaly is east-west trending and areally extensive, conciding with the mid-delta area.

In contrast to profiles AA′ and BB′, profile CC′ (Fig. 5) which lies close to the Damietta branch does not intersect the large negative gravity anomaly. This oval-shaped anomaly attains its absolute minimum of -43 mgal along profile AA′. To the north along the profile, the Bouguer values increase rapidly suggesting rocks of higher densities. The gravity minima along profiles BB′ and CC′ are smaller by to 7 mgals.

The magnetic intensity pattern and its trends are very complicated (Fig. 6). The northern part of the study area is occupied by parts of a magnetic high trending nearly E-W. To the south, alternating high an low magnetic belts of smaller aerial extent and larger magnetic gradients are obsrved. Moreover, the area east of the Damietta branch is characterized by a remarkable increase in the number of magnetic anomalies, especially to the southeast. Some of these magnetic zones have the highest amplitudes within the study area ($> 150\ \gamma$) and exhibit very steep gradients.

B. Interpretation of Selected Gravity and Magnetic Profiles

Although a good fit between the observed and calculated gravity values can be reached by using the assumed density contrasts mentioned above after several trials, the basement depths obtained by applying a discrete linear variation of density contrasts below each gravity profile (Fig. 7a) do not agree with those reported in the literature (Schlumberger Middle East S.A 1984). The maximum depths obtained below the profiles AA′, BB′ and CC′ are 2280, 2070, and 1900 m respectively. Also, our profiles show an increase in basement depth to the north followed by a decrease, in contrast to geological findings.

The numerous residual gravity anomalies with varying amplitudes in the south suggest structures and density contrast within the basement due to differential uplift (Fig. 7b). The central and northern parts of the residual profiles, show an alternation of anomalies with longer wavelengths, implying local and widely-separated structural and lithologic variations within the sedimentary sequence.

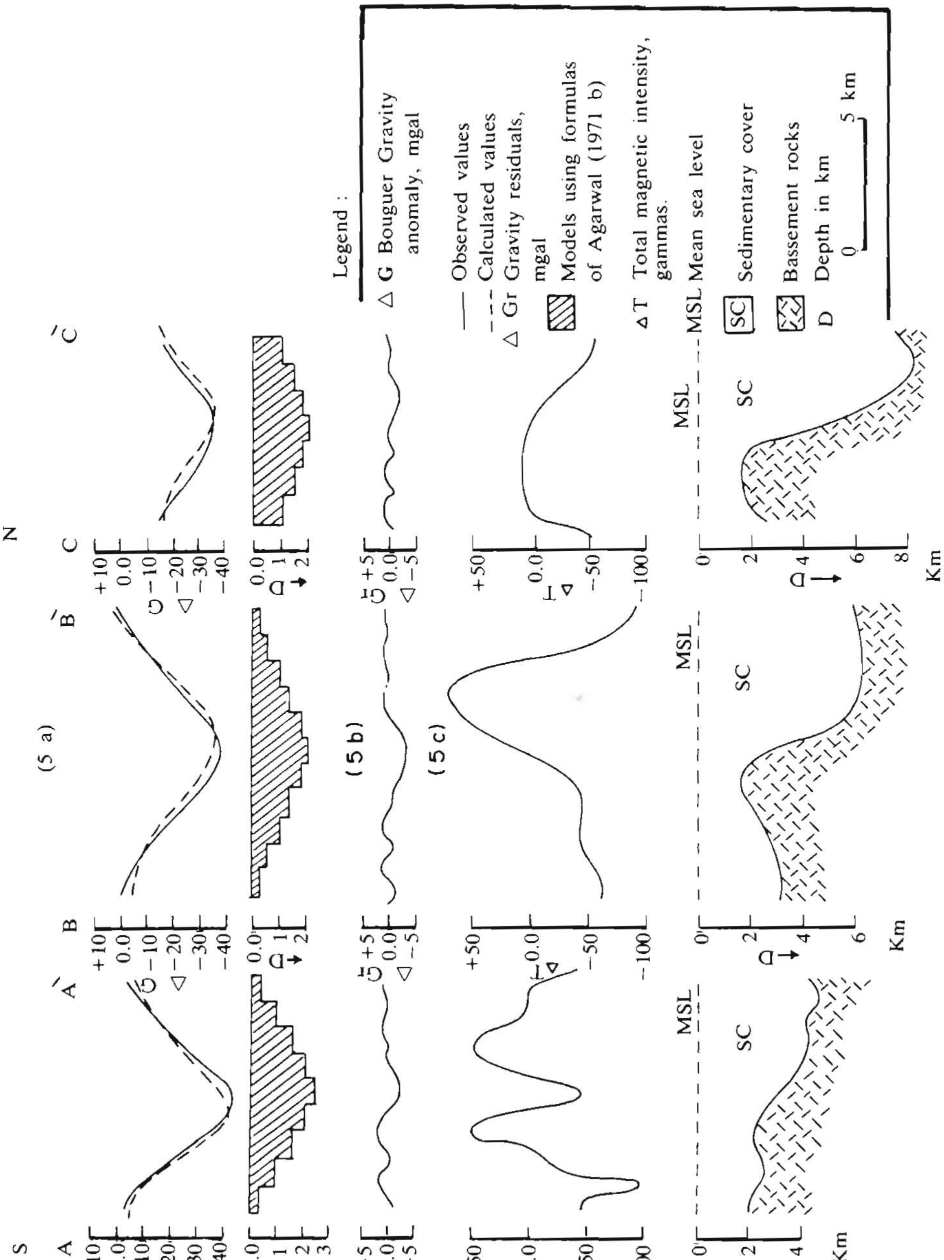

Fig. 7. Cross sections along the profiles AA′, BB′ and CC′ using the method of Agarwal (1971b) (7a), Residual gravity (7b), and magnetic profiles with interpreted basement depths in the Nile Delta (7c).

The depths to the major causative intrabasement body buried in the mid-delta area below the gravity profiles AA′, BB′ and CC′ are calculated to be 26, 37, and 24 km respectively.

The basement depth results obtained by both methods show a spatial variability. They lie between 2-4.5 km, 3-6 km, and 3-8 km along the profiles. A visual inspection of these results reveals the presence of a major uplift in the southern part of the area, which could be a part of the Khatatba and Abu Roash high lying at the southwestern most part of the delta. Likewise a basement trough may be postulated for the northern part of the delta area toward the Mediterranean Sea shore (Fig. 7c).

Conclusion

1. The depths to basement obtained using a linear variation of density contrasts (Agarwal 1971b) do not exceed 2280 m. Thus the Agarwal method does not give the expected basement depths in the Nile delta region.
2. The distribution of gravity residuals and magnetic intensities suggests a general northward increase in basement depth (2-8 km). A prominant basement uplift lies to the south and represents a part of the major uplift including the Khatatba-Abu Roash high. Also, the northward deepening of the basement detected is considered a part of the major northern subsidence which includes the Mediterranean.
3. The origin of the major negative gravity anomaly and the relatively low magnetic intensity in the area of the Nile Delta may be due to the abnormal thickness of the sedimentary succession and the occurence of the intrabasement causative body ($>$ 23 km).
4. Probably the main causes for the failure of the Agarwal method for determining the basement depths of the study area using gravity data are: a) the method ignores the possibilities of increase and decrease of density contrasts (it assumes only an increase in density with depth) that accompany lithologic changes especially in deltas; and b) it also ignores the presence of fluids and gases within the productive horizons which cause abrupt change in densities.

References

Agarwal, B.N. (1971 a) Direct gravity interpretation of a sedimentary basin using digital computer-part I, *Pure and Applied Geophysics,* **86**(3): 5-12.

Agarwal, B.N. (1971 b) Direct gravity interpretation of a sedimentary basin using digital computer part-II, *Pure and Applied Geophysics,* **86** (3): 13-17.

Bott, M.H.P. (1956) A geophysical study of the granite problem, *Q. J. Geol. Soc.* Lond., **112**: 54-67.

Egyptian General Petroleum Corporation (1982) Bouguer gravity anomaly map of the Nile Delta Region, Scale, 1:500,000, Cairo.

Egyptian Geologic Research and **Mining Department** (1963) Total Intensity and Aeromagnetic map of the Nile Delta Region, Scale 1:500,000 Cairo.

Griffin, W.R. (1949) Residual gravity in theory and practice, *Geophysics,* **14**: 39-56.

Henson, F.R. (1951) Observations in the Middle East, in 3*rd* World Petr. *Cong., Proc. Sec.* 1: Leiden Netherlands **Brill , E.I.** pp. 118-140.

Morgan, N.A., and **Grant, F.S.** (1963) High speed calculation of gravity and magnetic profiles across two-dimensional bodies having an arbitrary cross-section, *Geophys. Prosp.,* **2**: 10-25.

Nettleton, L.L. (1940) *Geophysical Prospecting for Oil,* McGraw-Hill Inc., pp. 157-228.

Nettleton, L.L. (1976) *Gravity and Magnetics in Oil Prospecting,* McGraw-Hill Inc., 464 pp.

Parasinis, D.S. (1972) *Principles of Applied Geophysics, Chapman* and Hall, London, 213 pp.

Rizzini, A., Vezzani, F., Coccoetta, V. and **Milad, G.** (1976) Stratigraphy and sedimentation of Neogene-Quaternary section in the Nile Delta area, 5th Explor. *Sem., E.G.P.C,* Cairo, 30 pp.

Said, R. (1962) *The Geology of Egypt,* Elseiver Pub. Comp., Amsterdam and New York, 377 pp.

Said, R. (1981) *The Geological Evolution of the River Nile,* Springer Verlag, New York, Heidelberg, Berlin, 151 pp.

Saleh, M.S. (1985) *Geophysical and structural studies of the Nile Delta area,* M. Sc. Thesis, Assiut Univ., Aswan branch, Egypt, 129 pp.

Salem, R. (1976) Evolution of Eocene-Miocene sedimentation patterns in parts of northern Egypt, *A.A.P.G. Bull.,* **60**(1): 34-64.

Schlumberger Middle East S.A. (1984) *Well evaluation conference in Egypt,* Imprimerie Modern du Lion, Paris, France, 245 pp.

Sharma, P.V. (1976) *Geophysical Methods in Geology,* Elseiver Publishing Company, Amsterdam, New York, 428 pp.

Talwani, M., Worzel, J.L. and **Landisman, M.** (1959) Rapid gravity computation for two-dimensional bodies with application to the Mendocino submarine fracture zone, *J. Geophys. Res.,* **64**: 49-59.

Tanner, J.G. (1967) An automated methods of gravity interpretation, *Geophys. J. Royal Astron. Soc.,* **13**: 339-347.

Weeks, L. G. (1952) Factors of sedimentary basin development that control oil occurrence, *A.A.P.G. Bull.,* **37**: 2071-2124.

(Received 22/07/1991;
in revised form 05/07/1992)

تفسير بعض البروفيلات التثاقلية والمغناطيسية في منطقة دلتا النيل، مصر

حمزة أحمد ابراهيم

قسم الجيولوجيا - كلية العلوم - جامعة أسيوط - أسيوط - مصر

تقع منطقة الدراسة في الجزء الشمالي من جمهورية مصر العربية، وتضم دلتا نهر النيل والجزء الشمالي الغربي من صحراء مصر الشرقية والجزء الشمالي الشرقي من صحراء مصر الغربية. وتعتمد الدراسة الحالية على البيانات التثاقلية المستمدة من خريطة البوجير (Bouguer Gravity Map) وأيضاً على البيانات المغناطيسية المستمدة من خريطة المغناطيسية الكلية (Total Intensity Aero - Magnetic Map) لمنطقة دلتا نهر النيل والأجزاء المجاورة لها.

وتتميز منطقة دلتا النيل بِسمُك كبير للرواسب ذات البيئات الترسيبية المتنوعة التي يتراوح عمرها من حقب الحياة القديم (Paloozoic) إلى الحديث (Recent) وتختلف في السُمْك من ٢ كم جنوباً إلى ١٣ كم ناحية حوض البحر الأبيض المتوسط. وتتمتع هذه المنطقة الآن بنشاط بترولي مكثف حيث تم حفر عدد كبير من الآبار المنتجة للبترول والغاز.

وتهدف الدراسة الحالية لمنطقة دلتا النيل إلى معرفة أصل الشذوذ التثاقلي السالب الكبير (- ٤٣ مللي جال) وأيضاً معرفة أصل الشذوذ المغناطيسي الصغير نسبياً (- ١٥٠ جاما) إلى الشمال من مدينة شبين الكوم بهدف معرفة التراكيب تحت السطحية التي أدت إلى وجوده وذلك من خلال تفسير بعض البروفيلات التثاقلية والمغناطيسية.

تشير نتائج الدراسة الحالية إلى التغير الواضح في عمق صخور الركيزة المعقدة (Basement Complex) والتي تتراوح من ٢ ـ ٨ كم .

عموماً يزداد عمق صخور الـركيزة المعقـدة نحو الشـمال حيث حوض البحـر الأبيض المتوسط الكبير، ويقـل هذا العمق نحـو الجنوب حيث الغـطاء الرسـوبي (Sedimentary Section) الصغـير المميز لمنـطقتي الخطاطبـة وأبو رواش (Khatatba - Abu Roash Basemet High) إلى الجنوب الغربي من دلتا نهر النيل .

ويعتقـد أن السبب الرئيسي لهـذا الشذوذ التثـاقلي السـالب لصخور الـركيزة المعقدة والمميزة أيضـاً بقيم مغناطيسيـة صغيرة نسبيـاً يرجـع إلى وجود جسم كبـير داخـل هذه الصخـور الموجـودة على عمق كبـير من سطح الأرض (> ٢٣ كم)، هذا بالاضافة إلى السمك الكبير للغـطاء الرسـوبي بمنطقـة الدلتـا المتميزة ببيئـات ترسيب متنوعـة . ويعتقد أن السبب الاسـاسي في فشل طـريقة آجـارول (Agarwal 1971b) في الحصول على النماذج المتوقعة التي تتفق مع توزيع أعماق صخور الـركيزة المعقدة بمنطقة الدراسة يرجع إلى إهمال إمكـانية زيـادة أو نقص فرق الكثـافة مـع العمق وليس إمكانية الزيادة فقط، هـذا بالاضـافة إلى إحتـمال تواجـد سوائـل في النطاقات تحت السطحية بمنطقة الدلتا .