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Deep Tectonics of Northern Eastern Desert of Egypt as Integrated from Gravity and Seismic Data

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ABSTRACT. Deep tectonics of the northern part of the Eastern Desert, between latitudes 25°-28°N, are delineated using two-dimensional (2-D) modelling of the gravity field, supplemented with deep sounding seismic (DSS) data.

Basement, Conrad and Moho discontinuities depth maps are prepared based on ten 2-D density models covering almost the study area. Obtained results, integrated with surface and subsurface geologic information, show that the study area could be subdivided into two distinct tectonic blocks of different crustal types and isostatic characters. The first block comprises the coastal zone of the Red Sea and is characterized by isostatically uncompensated transitional crust. Its average thickness is 18-22 km and may have been subjected to stretching. The second block includes the Red Sea mountainous zone, represented by more or less isostatically compensated continental crust of thickness ranging between 28-34 km.

Introduction

The study area (Fig. 1) covers a considerable part of the Eastern Desert of Egypt, in the Arabian-Nubian Shield of East Africa. Its geology, based on the previous published data (mainly Egyptian Geological Survey 1982, and El Gaby *et al.* 1990) comprises Precambrian and sedimentary rocks. The Precambrian basement rocks cover about 40% of the area (Fig. 2) and include; i) Pre-Pan-African association and their mylonitized and remobilized equivalents, ii) Pan-African ophiolites and island arc assemblage, and iii) Cordilleran stage associations. On the other hand, the sedimentary rocks cover about 60% of the area and rest unconformably above the basement. These include; i) Paleozoic rocks including Araba, Naqus, and Gilf formations, ii)

Mesozoic rocks including Malaha, Galala, Wata, Nubia, Duwi and Dakhla formations, iii) Tertiary rocks including Suder, Tarawan, Esna, Theibes, Minia, Samalut and Rayan formations, and iv) Quaternary sediments (Fig. 2). Tectonically, the study area may be upheaved during the Pan-African orogeny along a major right-lateral shear zone trending NE-SW, whereby the Pan-African suprastructural rocks were almost entirely eroded away (El Gaby *et al.* 1990).

The purpose of the present work is to provide additional information about the deep structures of the crust and upper mantle as well as to throw some light on the geometry and evolution of the study area. The available geophysical data employed during this investigation include Bouguer gravity anomaly map (Scale, 1:500,000)

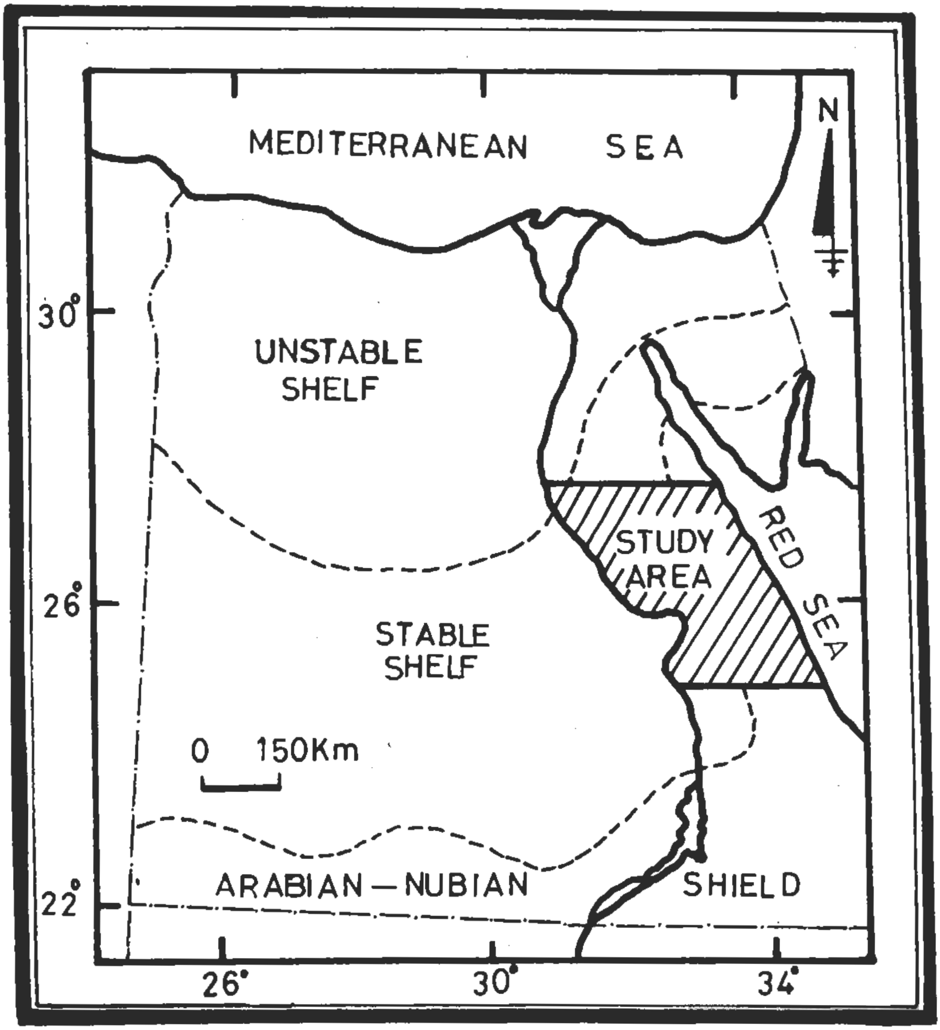

FIG. 1. Location map of the study area.

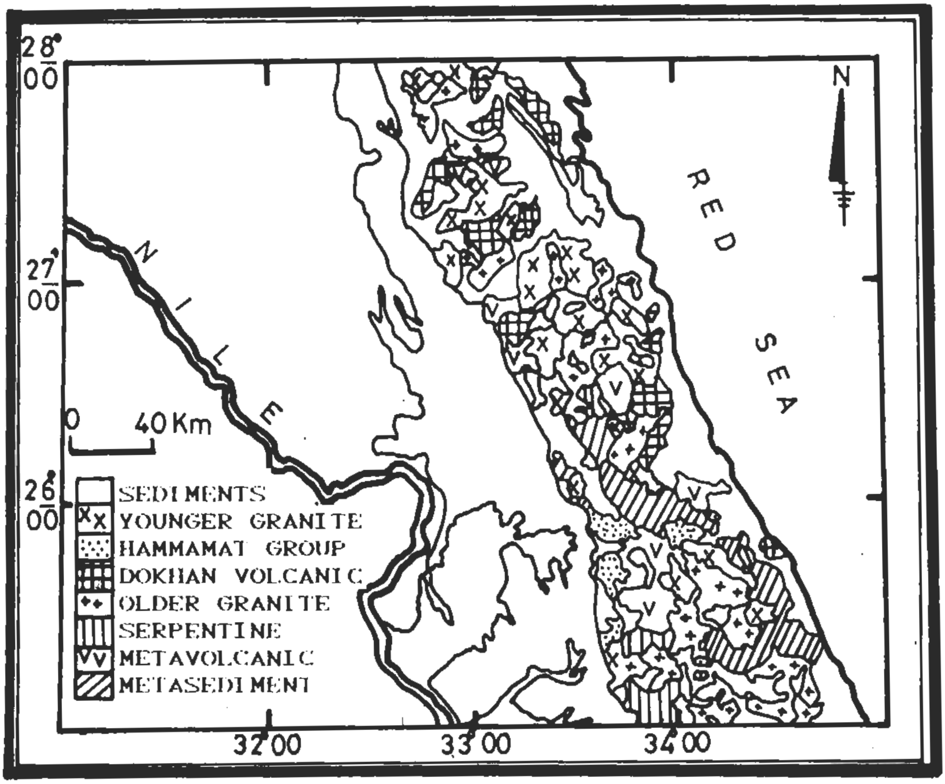

FIG. 2. Geological map (after Egyptian Geological Survey, 1982).

compiled by the Egyptian General Petroleum Company (1986), Fig. 3, and some deep seismic measurements along Qena-Safaga road and western coast of the Red Sea after Makris *et al.* (1979), Fig. 4.

Data Processing and Results

Refraction seismic data alone, can't yield a unique solution for the crustal structures. However, some authors, such as Theilen and Meissner (1979), were able to define that seismic refraction boundaries resemble density boundaries. Accordingly, gravity data can be correlated with the available refraction results. Seismic velocities derived from different studies in the prospect area can be used as a base for the starting modelling since, the study area represents one tectonic unit (Garson and Krs 1976). Similar crustal studies were developed by Setto and Meissner (1988). Consequently, our starting gravity models are based on the seismic refraction profiles, made along Qena-Safaga road and Red Sea coast (Fig. 4).

Construction of the Crystalline Crustal Models

Crustal models are made along ten profiles trending in NW-SE and NE-SW directions (Fig. 4). The profiles are selected to cross nearly all the anomalies recorded on

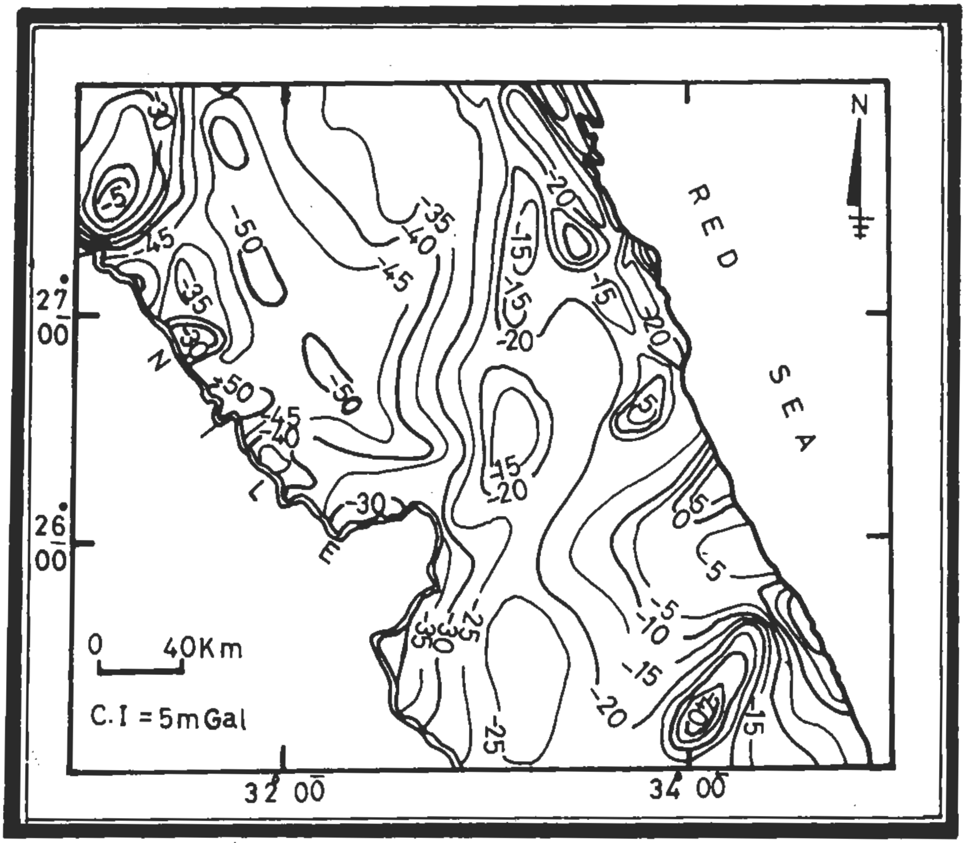

FIG. 3. Bouguer gravity map (after EGPC, 1986).

the gravity map. The starting models along the first group of parallel (NE-SW) profiles (marked 1-1ˉ, 2-2ˉ, 3-3ˉ, 4-4ˉ, 5-5ˉ and 6-6ˉ) are performed based on seismic data. At the intersection points of NE-SE and NW-SE profiles the starting crustal models for the intersecting (NW-SE) profiles (7-7ˉ, 8-8ˉ, 9-9ˉ and 10-10ˉ) are constructed.

Generally, 2-D gravity modelling are based on assuming a certain subsurface geologic set-up, aided by the available subsurface stratigraphic and structural information, then fitting the computed theoretical gravity profile. Different iteratives are carried out for readjustment, reaching to the matching needed. The calculation of the theoretical gravity profiles, in this work, is based on the use of the 2-D gravity field algorithm (Talwani *et al.* 1959) and a modified Fortran Program (Rudman and Blakely 1983). During the calculation of the 2-D gravity effect, all layer densities are subtracted from a reference density of 2.8 g/cm^3. The densities for different layers of the model are obtained from the empirical seismic velocity-density relationship after Barton (1986). He stated that plots of seismic velocity and density of rock samples show that a range of densities is possible for rocks of each seismic velocity and vice

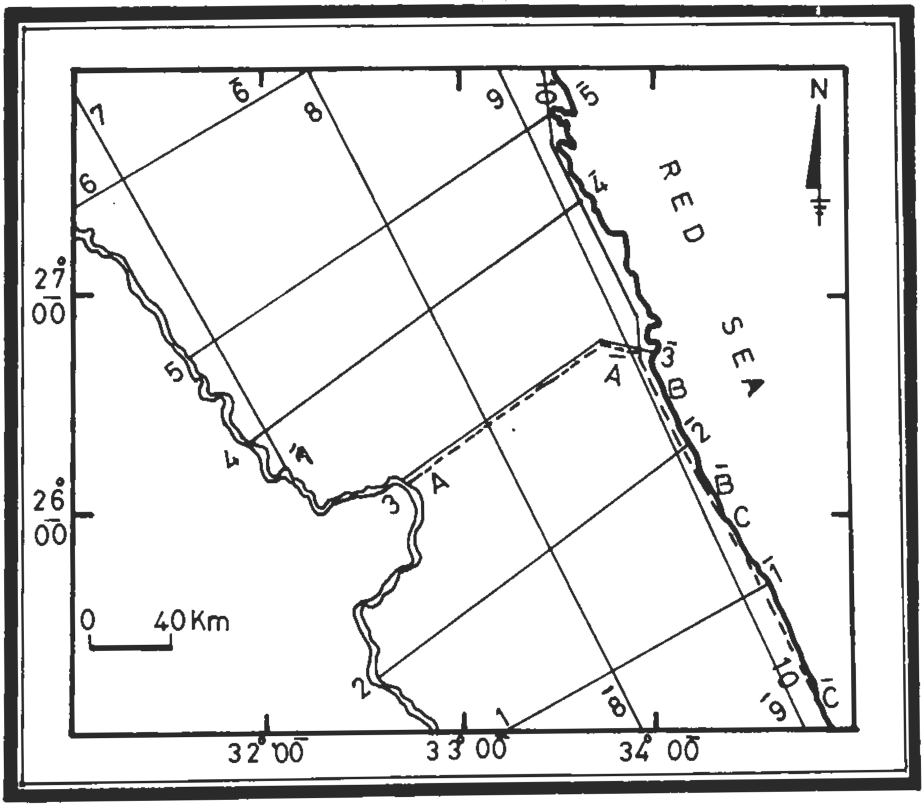

FIG. 4. Location map of both deep seismic and studied profiles. 1-1⁻, 2-2⁻, ... are the studied profiles A-A⁻, B-B⁻ & C-C⁻ are the DSS profiles.

versa, although a single linear relationship is often assumed in crustal gravity calculation.

Based on the discrepancy between the observed and calculated gravity data, the starting models were modified. In the final models, the surface geology along each profile and the variations of both Conrad and Moho boundaries are taken in consideration. Two examples of crustal models along profiles 3-3⁻ and 7-7⁻ are presented here as Fig. 5-8.

The Profile 3-3⁻ (Fig. 5 & 6)

The profile extends for about 150 km from west crossing basement and different sedimentary rocks to the east. In the western part, between 0-20 km, the profile exhibits a gravity low (reaching about – 30 mGal). In the central part, between 30-70 km, the gravity values increase to reaching about – 15 mGal. To the east, between 80-150 km, the gravity values increase from – 20 mGal to – 10 mGal. Fig. 5 shows the crustal model along profile based on seismic data and the disagreement between the observed and the computed gravity anomalies. Fig. 6 shows the modified crustal model and the best fitting between the observed and computed gravity fields.

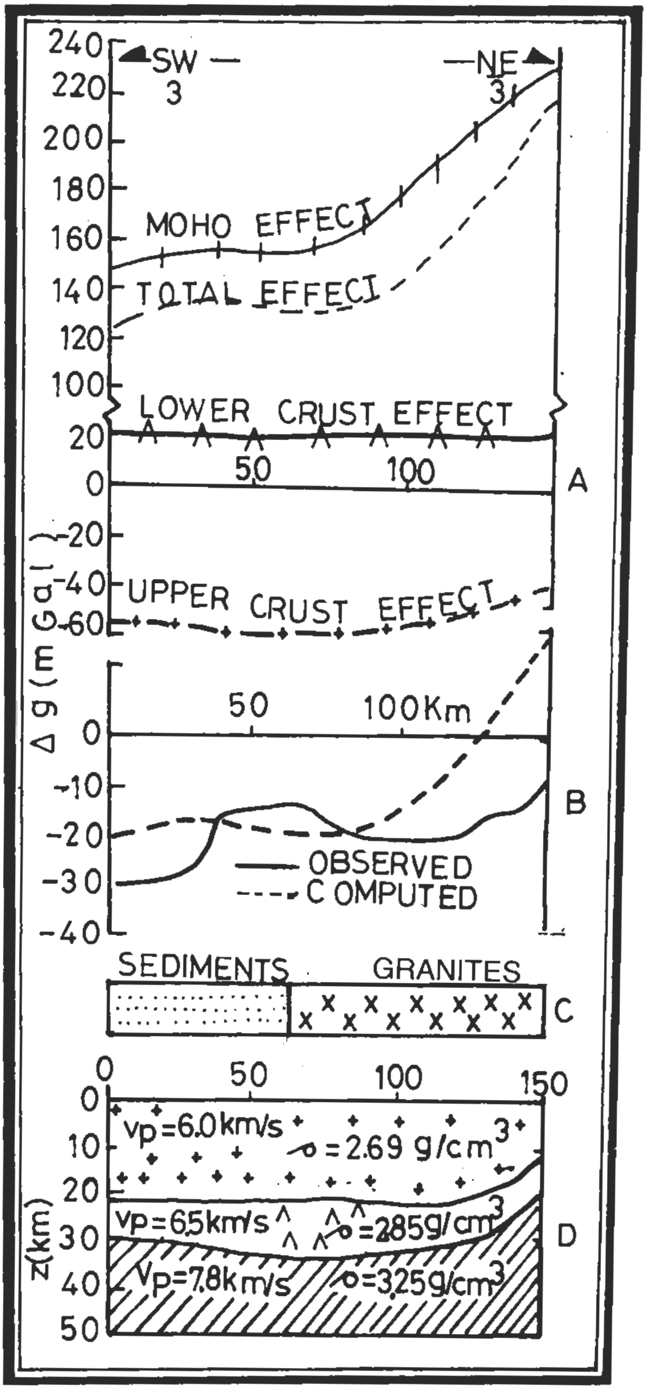

FIG. 5. The starting model along profile 3-3', based on seismic data, A; shows the gravity effect due to each layer of the model, B; shows the disagreement between the observed and computed gravity fields, C; is the surface geology, D; is the derived seismic model.

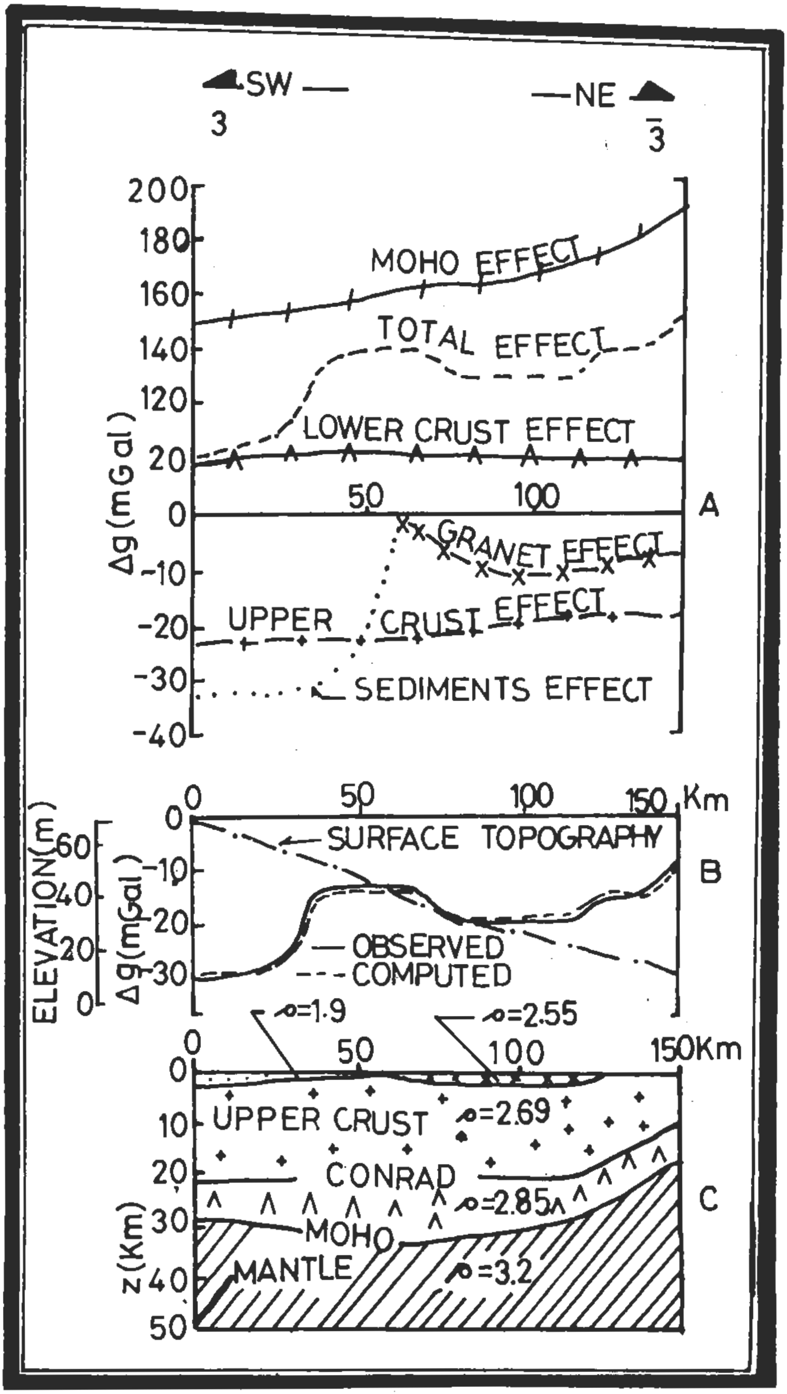

FIG. 6. The final crustal model along profile 3-3¯. A; shows the gravity effect due to each layer. B & C; show the close agreement between both observed and computed gravity.

Studying the final model gives :

1. The gravity low at the western part between 0-20 km of the profile can be mainly due to the sedimentary section (1.9 g/cm^3) with about 2 km depth and 50 km extension.

2. The gravity low between 80-110 km, could be attributed to the low density granite body (2.55 g/cm^3), in this area. This granite body shows a maximum depth of about 1.8 km.

3. The Conrad and Moho reliefs indicate that the eastern part of the model (between 120-150 km) is characterized by a transitional phase between the Oceanic and Continental crusts.

The Profile 7-7¯ (Fig. 7 & 8)

This profile measures about 226 km. It runs from south to north through sediments. The profile at its southern part exhibits a gravity low, between km 0 and km

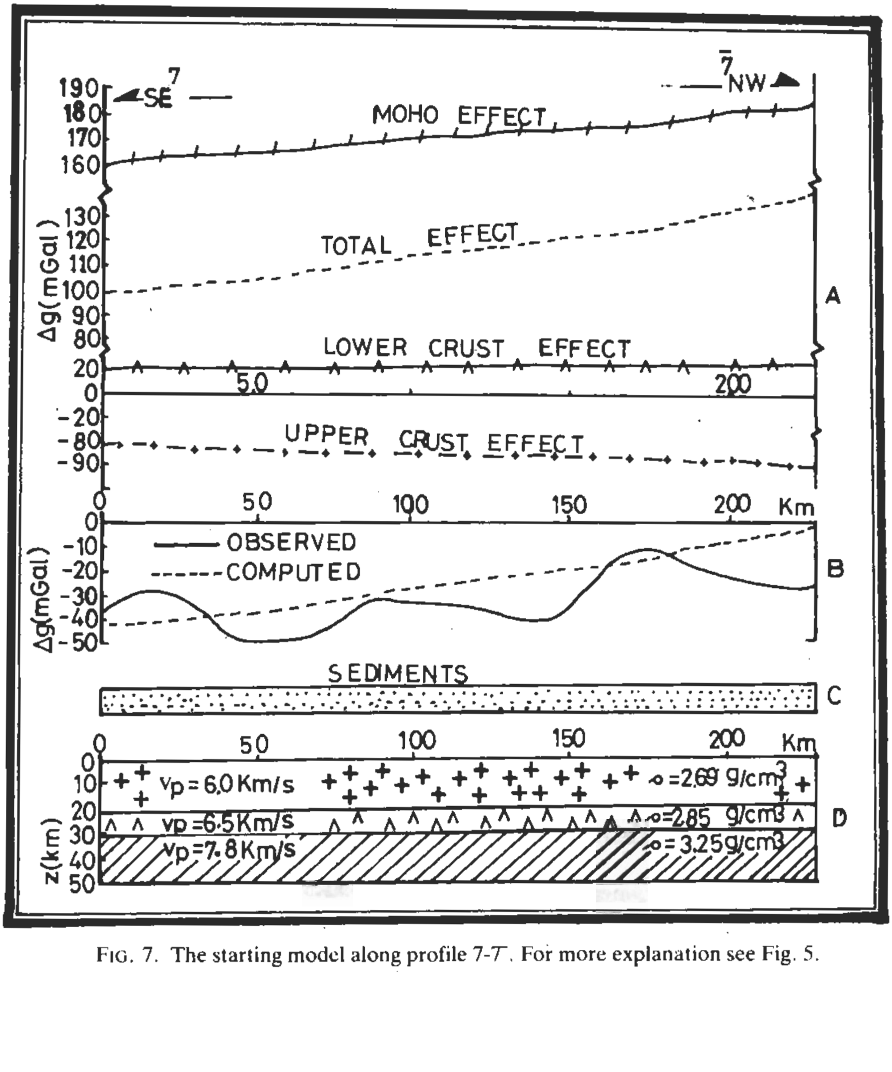

FIG. 7. The starting model along profile 7-7¯. For more explanation see Fig. 5.

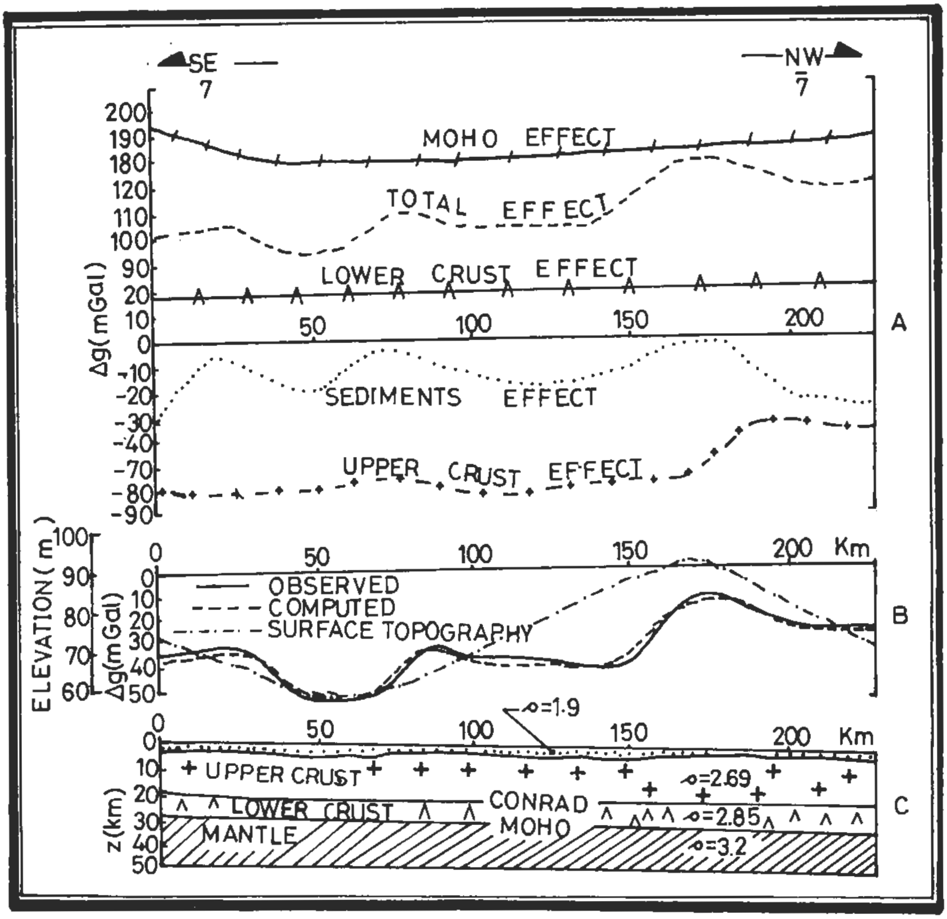

FIG. 8. The end crustal model along profile 7-7̄. For more explanation see Fig. 6.

30 of about – 30 mGal, and between km 40 and km 80 it exhibits a sharp gravity low of about – 50 mGal. At its central part, between km 90 and km 150, the gravity values range between – 30 mGal and – 40 mGal. At the northern part, between km 170 and km 180, it exhibits a gravity high reaching – 10 mGal, and between km 190 and km 226 the gravity values decrease to reach – 25 mGal.

Consideration of the end model can give;

1. Good correlation between the topography of Moho and regional gravity field can be observed.

2. The undulations between gravity lows and gravity highs can be explained by the variations of sedimentary cover thicknesses, reaching 4 km, between 45 and km 60 and about 1.5 km between km 190 and its end.

Depth to Basement, Conrad and Moho Maps

Three maps for sediments, (basement relief) and both Conrad and Moho boundaries are produced to enhance the deep crustal structures of the investigated area. The basement relief contour map (Fig. 9) illustrates that; 1) The maximum thickness value for sediments can be shown in the central part of the study area, reaching about 4 km, ii) The thickness of sediments decrease towards the east (*i.e.*, the Sea) reaching about 0.8 km, and towards the west (*i.e.*, the Nile) reaching about 1 km, and iii) Uplifted and down faulted basement blocks could be observed with NW & NE tectonic trends.

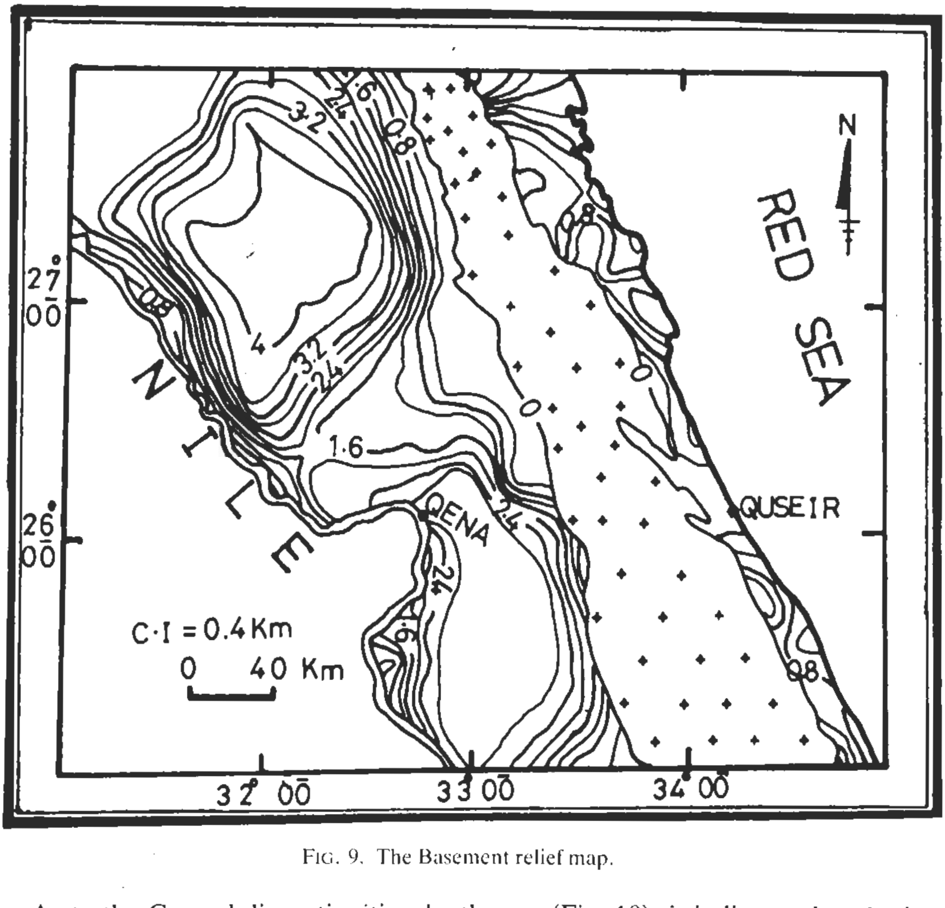

FIG. 9. The Basement relief map.

As to the Conrad discontinuities depth map (Fig. 10), it indicates that the intra crustal boundary attains its maximum value, about 23 km, in the central portion, along an axis aligned mainly in a NW-SE direction. To the east, the depth to the Conrad boundary decreases with a high gradient to reach a minimum depth, of about 11 km, along the Red Sea coast.

The Moho (Crustal thickness) map (Fig. 11) shows that the crust exhibits a maximum thickness, about 33-34 km in the central portion of the area and attains its

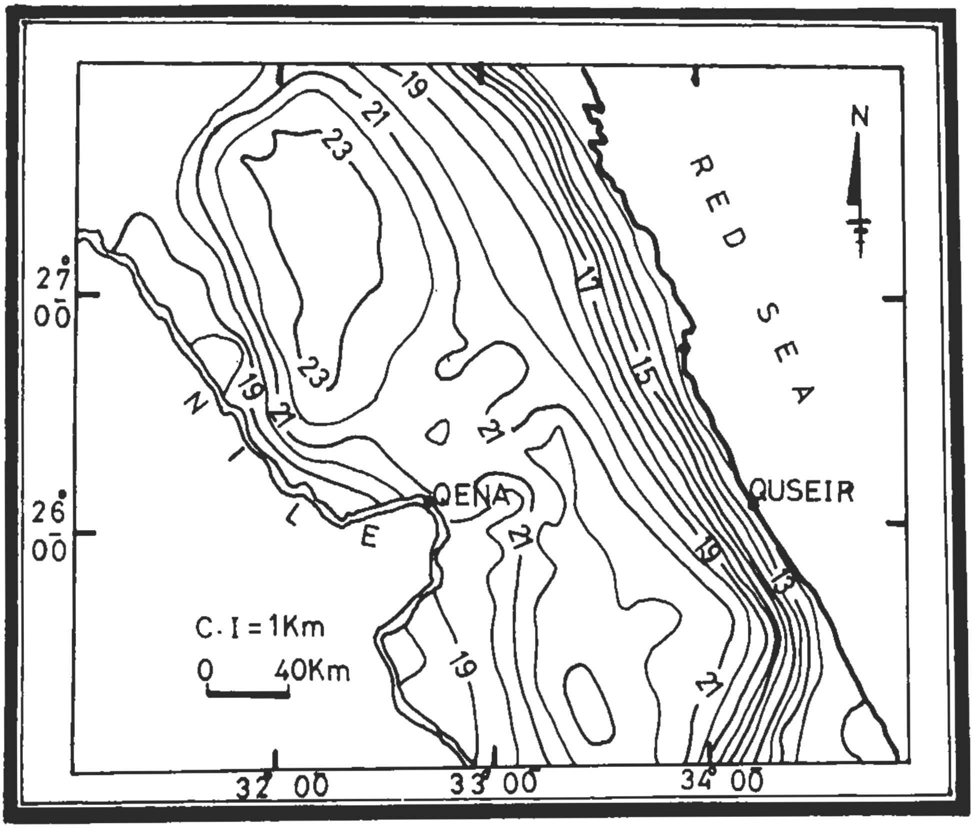

FIG. 10. The Conrad relief map.

minimum thickness, about 18 km, at the eastern portion along the Red Sea coast. The crust along the Red Sea coast shows periodic variations, increasing in thickness southwards. These variations may be attributed to the presence of old structural lines or subduction zones striking in NE direction.

Obtained results, integrated with surface and subsurface geologic information show that the study area, with exception of the coastal strip, represents a type comprising a thin low-velocity crust of the outer parts of the continents (Beloussov and Pavlenkova 1984), with average seismic velocity in the consolidated part is 6-6.5 km/S. This kind of crust is common for the young platforms of western Europe (Giese *et al.* 1976). This crust is unusual for continents and is confined to areas with higher and heterogeneous heat flow. On the other hand, the eastern part of the study area represents a type considered as transitional between continental and oceanic crust. It is characterized by crustal thickness of about 18-20 km and average velocity 6-6.5 km/S. It is observed on continental margins (*e.g.*, in the north of Great Britain) and within micro continents (*e.g.*, the Rockall Plateau, the Faeroes ridge). This type of crust correlates with positive Bouguer anomalies (Beloussov and Pavlenkova 1984).

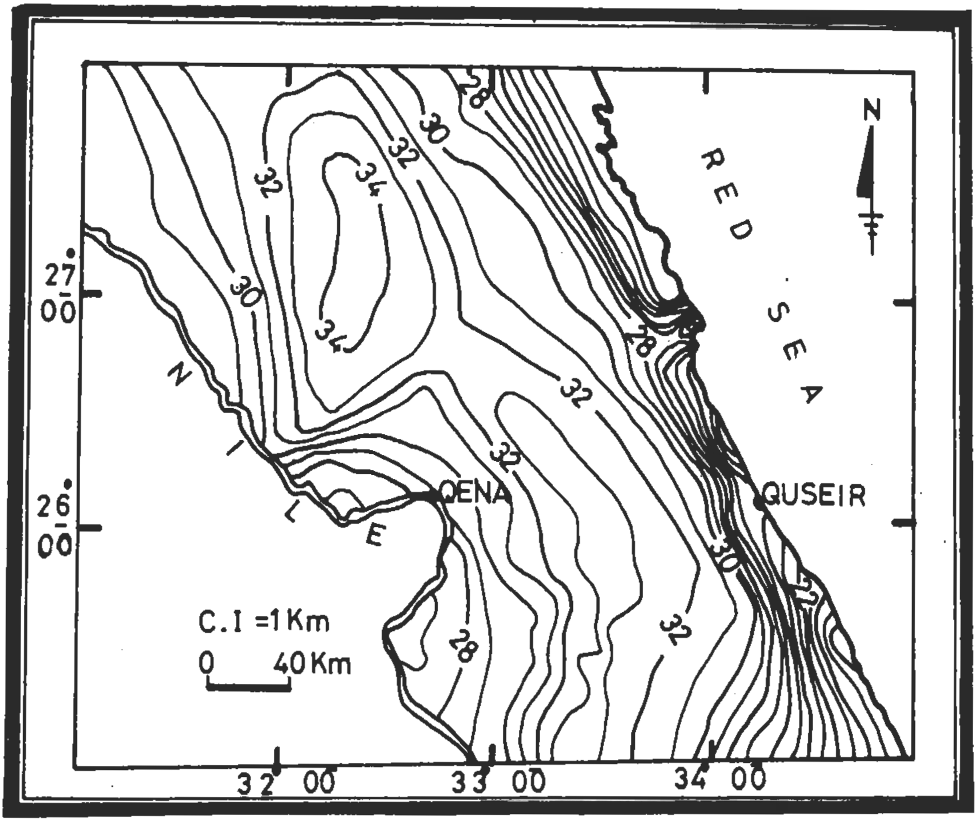

FIG. 11. The Moho relief map.

Furthermore, the outcropping granite intrusion (batholiths), corresponding to the gravity lows, suggest that basaltic lavas are absent and some sort of isostatic compensation is not pertained. This is evident as some of the uplifted part show distinct gravity lows, in spite of missing roots. This observation can be explained by a lower density lithosphere, *i.e.*, high temperature and low viscosity (Theilen and Meissner 1979).

Conclusion

The present study threw some light on the crustal thickness and deep structures of the investigated area. The basement, Conrad and Moho depth relief maps, derived from the density modelling along the ten selected profiles, indicated that;

i) The coastal zone of the Red Sea is characterized by transitional phase between oceanic and continental crust,

ii) The area have more or less isostatically compensated continental crust of thickness ranging from 28-34 km, and

iii) The behavior of the crust below the area may be structurally and tectonically connected with Afro-Arabian shield rifting process and evolution of the Red Sea.

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التراكيب العميقة بشمال الصحراء الشرقية المصرية بناء على بيانات التثاقلية والسيزمية

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المستخلص . تهدف هذه الدراسة إلى إلقاء بعض الضوء على سمك القشرة الأرضية وكذلك التراكيب العميقة بشمال الصحراء الشرقية المصرية . إذ أمكن رسم ثلاث خرائط توضح شكل وطوبغرافية أسطح صخور القاعدة ، والكونراد والموهو وذلك من خلال نتائج موديلات التثاقلية . ولقد بينت أن القشرة الأرضية تُمثِّل النوع القاري المتوازن ويتراوح سمكها بين ٢٨-٣٤ كم وذلك فيما عدا الشريط الساحلي بعرض ٢٠ كم على طول البحر الأحمر فهو يمثل قشرة أرضية انتقالية غير متوازنة يتراوح سمكها بين ١٨-٢٠ كم . كذلك أظهر شكل وتكتونية صخور القاعدة ، والكونراد والموهو ارتباط المنطقة الوثيق بتكتونية البحر الأحمر والدرع العربي الأفريقي .