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CRUSTAL STRUCTURE OF THE EASTERN PROVINCE OF SAUDI ARABIA DEDUCED FROM GRAVITY DATA

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التراكيب القشرية للنطاق الشرقى من السعودية والمستنبطة من بيانات التثاقلية

الخلاصة: تم عمل سبعة نماذج جاذبية توضح سمك وتركيب القشرة الأرضية للمنطقة الشرقية بالمملكة العربية السعودية إعتماداً على متوسط قيم الكثافة لهذه التراكيب وأعماقها. وقد تم إعداد هذه النماذج بناءاً على تحليل القياسات الجاذبية لمنطقة الدراسة ومن ثم تحديد واختيار سبعة مقاطع من خريطة بوجير الكاملة لعمل هذه النماذج بإستخدام البرمجيات. وقد أوضحت هذه النماذج أن القشرة الأرضية تتكون من ثلاث طبقات رئيسية هي: طبقة الرسوبيات والتى تتراوح سمكها تقريباً بين ٣,٢ كم الى ١٣ كم بزيادة تدريجية باتجاه الشرق، ثم القشرة السفلية بعمق يتراوح تقريباً بين ١٩ كم الى ٢٩ كم ومن ثم يظهر سطح الموهو ،الذى يفصل بين القشرة وأعلى الوشاح، ويمثل سمك القشرة والذى يتراوح بين ٤٠ كم الى ٤٩ كم. ويظهر من النماذج أن اكبر سمك للقشرة والذى يصل الى ٤٩ كيلومتر كان فى الجزء الشمالى من منطقة الدراسة ويتناقص تدريجياً إلى أن يصل ٤٠ كيلومتر تقريباً فى الجزء الجنوبى والجنوبى الغربى من منطقة الدراسة . ونستنتج من هذه الدراسة أن سمك القشرة الأرضية فى المنطقة الشرقية يقل تدريجياً كلما اتجهنا للدرع العربى غرباً أو للخليج العربى شرقاً. ويستدل من ذلك على أن الجزيرة العربية تقع بين حدين من الحدود التكتونية والتى كان لها بالغ الأثر فى بناء وتهيئة التراكيب الجيولوجية التحتسطحية.

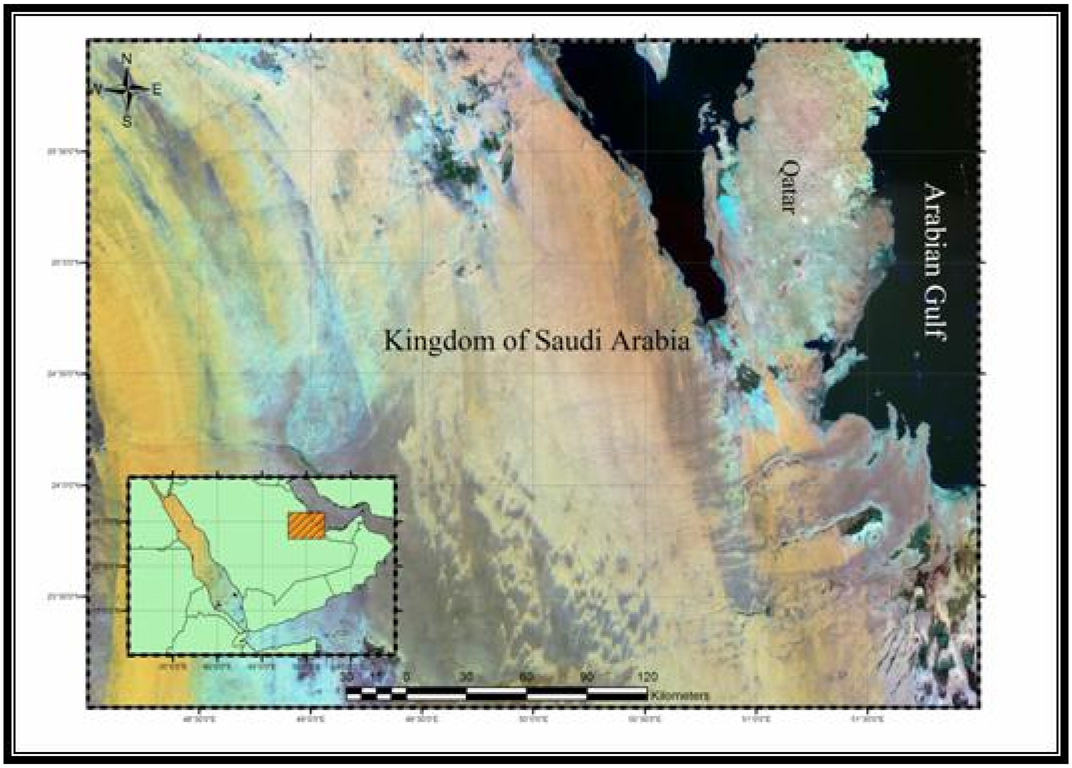
ABSTRACT: *Gravity modeling technique has been applied for the eastern province of Saudi Arabia to estimate both the thickness of the crust and crustal structures, based on the average densities for these structures and their depths. These models have been prepared depending on the analysis of gravity field measurements at the study area. Seven cross-sections have been selected along the complete Bouguer anomaly map. Modeling has been carried out using GMSYS-2D software. Matching process between the measured and calculated gravity values has been carried out during modeling taking into consideration the available geological maps and the previous studies. The proposed models indicate that the earth's crust is composed of three main layers as follows; upper crust of thickness ranging between 3.2 and 13 km with gradual increasing towards the east; Middle crust extends to depth from 13 to 29 km; and the lower crust with depth ranges between 29 and 49 km, where the Moho discontinuity, which separates crust from the upper mantle, is reached. The thickness of the crust ranges from 40 to 49 km. The greater thickness of the earth's crust reaches 49 km in the northern part of the study area, while decreasing gradually to reach 40 km in the southern and southwestern parts of the area.*
According to these models it can be concluded that, the thickness of the crust in the eastern province decrease gradually towards the Arabian shield in the west and the Arabian Gulf in the east. This suggests that, the Arabian Peninsula lies between two major tectonic boundaries that have great impact on the creation of the subsurface geological structures. One of the most important results that have been reached is the ability of gravity measurements to providing us with the clear perception for the changing of crustal structures and how these changes occurred.

INTRODUCTION

The study area lies in the eastern part of Saudi Arabia (Fig.1), between latitudes (24° - 26° N) and longitudes (48° - 51°19' E) including the largest oil field in the world (Al-Ghawar oil-field) which was discovered in 1948 and began production in 1951. There are some of previous studies concerning with the crustal structures and the depth to the Moho discontinuity in the study area using other geophysical methods but this study depends mainly on the gravity field measurements.

Gravity is one of geophysical methods that capable for identifying some of the physical characteristics and thickness of the earth's crust in the form of contour maps showing the difference in the crustal structures, thickness and depth of subsurface layers from one site to another. There are a number of empirical equations and models that have been used to calculate the thickness of the earth's crust for different regions of the world using Bouguer anomaly values.

The main task of the current research is to give an accurate way to calculate the crustal thickness of the eastern province of Saudi Arabia using gravity data. Thus the results of this study have been evaluated by comparing with the results of the previous studies. This study based on a large number of measuring points (more than 35000



points) including the relative value of gravity, the latitude and longitude, altitude to sea level (Fig. 2)

DATA PROCESSING AND ANALYSIS

It is noticed that, there are some problems that must be solved and overcome to be able to begin processing and analysis of these measurements. One of these problems is; there is no measurements were taken to one reference surface with some reference points (Base stations). So, it was necessary to restore all these measurements to one reference surface by using some reference points in the area and thus to overcome this problem.

Since the measured values of relative gravity in the field not only reflect the real value of the mass changing, the impact of mass objects and subsurface structures that have low intensity values or more than the neighbor structures, but also there are other influential factors played an important role in the changing of the measured values of gravity. These factors vary depending on the location and access method for the measured gravity values. The most important factors are; variation of gravity values because of the elevation (high or low) of the measuring points above sea level, as well as the impact of attraction force and the centrifugal force of the earth. In addition to, the change of latitude, which may causing the change in the radius of the earth at the measuring point, and other factors that caused the change of the measured values of gravity. Therefore a set of corrections must be applied for processing of the measured data and elimination of these external influences. These corrections are carried out for the field measurements as shown in Figure (3).

As the main goal of this research is to estimate the crustal structure and depth to Moho discontinuity, it is important to define both deep and shallow structures to rely on the results, of the complete Bouguer anomaly map. Final modeling is characterized by all of these influences, without the need for progress in corrections. This may lose important information, whether from the effects of the near earth's surface or deep structures, which would give not correct perception in the modeling.

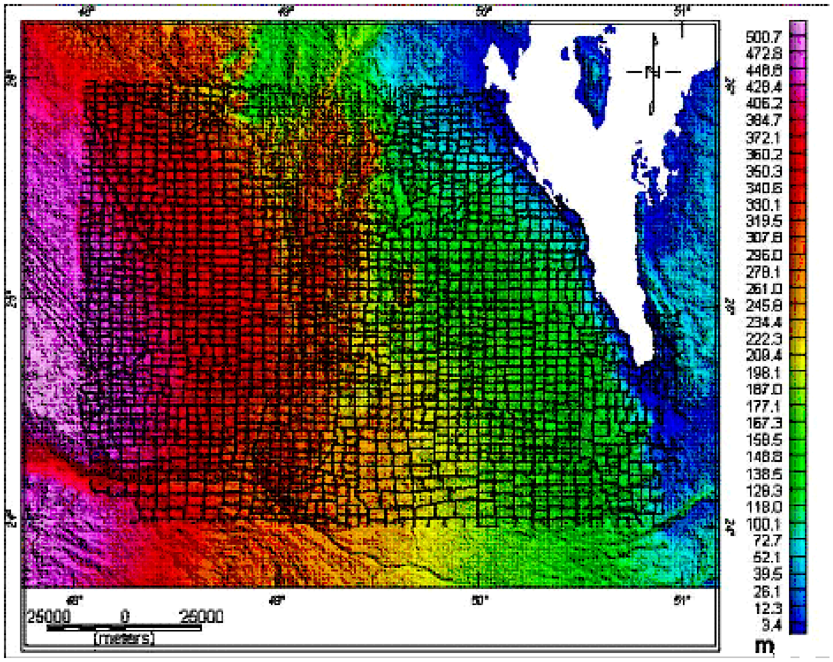


Fig. (2): Topographic map for the study area includes field measurement points (35000 points) with 1-km spacing.

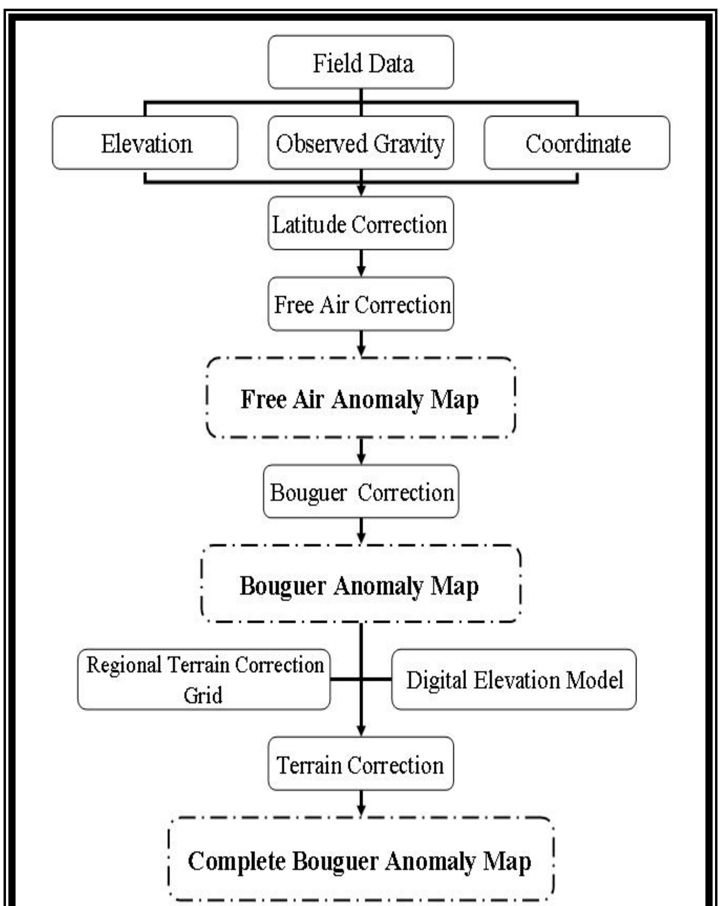


Fig. (3): Flow-chart for processing and analysis of gravity-field measurements.

Therefore the complete Bouguer anomaly map been adopted to carry out the modeling techniques (Fig.4).

FINAL MODELS

After application of the necessary corrections to the gravity measurements and the complete Bouguer anomaly map is obtained, it is become ready to carry out modeling to clarify the subsurface geological structures, that responsible for these gravity anomaly values. Gravity modeling, the comparison between both of the observed and calculated gravity values to get the identical correlation taking into account the geological maps and previous studies in the area and the likelihood of those changes geologically. Seven cross-sections have been selected for modeling of Bouguer map, then cross-sections are perpendicular to the direction of the anomaly from west to east with quarter degree as difference between each section and the other (i.e. 28 km distance) and 240 Km length for each section so, as to get the sections covering the area of study (Fig. 4).

Since our study is considered as a regional so, the changes of depth which may occur at deeper layers will be displayed clearly at far-distance. Therefore, the difference between the selected sections was chosen as 28 km and thus seven models have been constructed to represent the cross-sections (A-A', B-B', C-C', D-D', E-E', F-F', and G-G') using GMSYS- 2D software for modeling (Fig. 5).

RESULTS

After the completion of the modeling, the values of depth to each subsurface layer have been collected to construct contour maps represents the depths of these layers. It is now possible to conduct maps showing the depth to the lower crust and thickness of the crust in the eastern province of Saudi Arabia. It was difficult to construct contour maps to the depth of the middle crust (Basement layer) due to the great variation in depth of this layer (Fig. 5).

As illustrated in figure (6) the contour map for the depth to lower crust, gives us perception for the changes of depth from south to north. It is noticed that, the greater depth is present in the north, while this depth decreases markedly in both of eastern and western parts of the area. This can be interpreted due to the presence of the Arabian Gulf and then Zagros Mountains from the east, as well as the presence of Arabian Shield to the west, which reduced the thickness of sedimentary layer significantly and causing increasing in the value of gravity. This map shows that, the change in the depth to the surface of the lower crust at the central part of the map. This indicates the existence of some subsurface geological structures formed by great tectonic movements that affected the area during the past geological times. The Arabian plate subjected to tectonic movements of convergence and divergence with neighboring plates, which led to these variations for the depth of the lower crust and that is left clearly the complicated geological setting for this area. This confirms the results of several tectonic studies about the area of interest that proved this result (Sharland et al., 2001). Based on these results it can be concluded that, the eastern province of Saudi Arabia has experienced a series of tectonic developments which have led to the occurrences of complicated structures in the basement rocks and regional tilting of rocks toward Arabian Shield in the northern and northeastern parts. This is due to the partial collapse of the shield rocks and forming of sedimentary basins within the area.

Figure (7) shows contour map for the crustal thickness (depth of Moho discontinuity) as deduced from the results of models. It shows that, the thickness of the crust increases towards the north where it reaches up to 49 km representing the highest values of crustal thickness. On the other hand it is noticed that, the crustal thickness decreases in almost all directions, especially in the southeastern region. This increasing in the thickness of the crust in the northern part is related to the tectonic movements as well.

The results of the current study have been compared with the results of previous studies (Table 1). The nearest model assumed in the previous studies to the study area is that proposed by Al-Amri (1999). It is assumed by deriving the velocity of the crust and upper mantle within the Arabian platform. The earthquakes have been recorded at Dhahran (RYD) station in the city of Dhahran eastern Saudi Arabia. Al-Amri has to obtain the depth of upper mantle reaches up to 46 Km. This station located to the north of the study area and the greatest thickness of the crust in this area reaches up to 49 km, with the presence of other points in the same area gave us a very similar result to the results of this model taking into account the earthquake studies give us a result of just one point, which is the monitoring station while this study is considered one of the studies which gives us a clearer perception and comprehensive to all the area.

From the results of previous studies, the study that have been done by Al-Damegh et. al., (2005). They assumed that the depth of Moho in the Arabian platform, which includes our study area, ranges between 41 and 53 km.

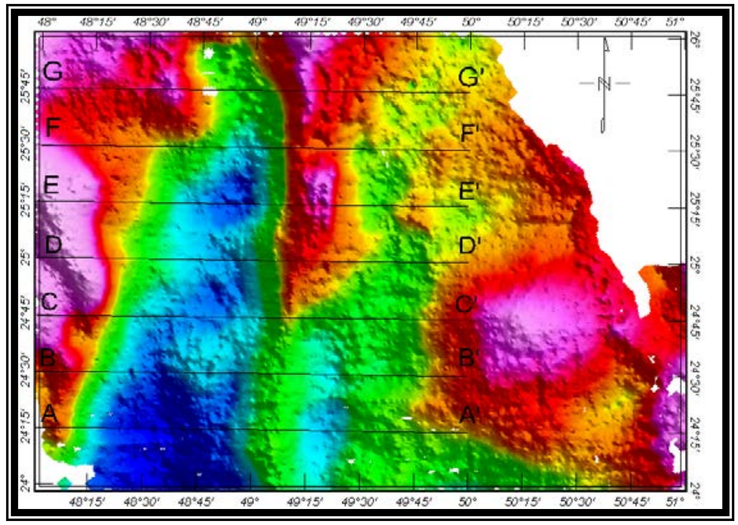
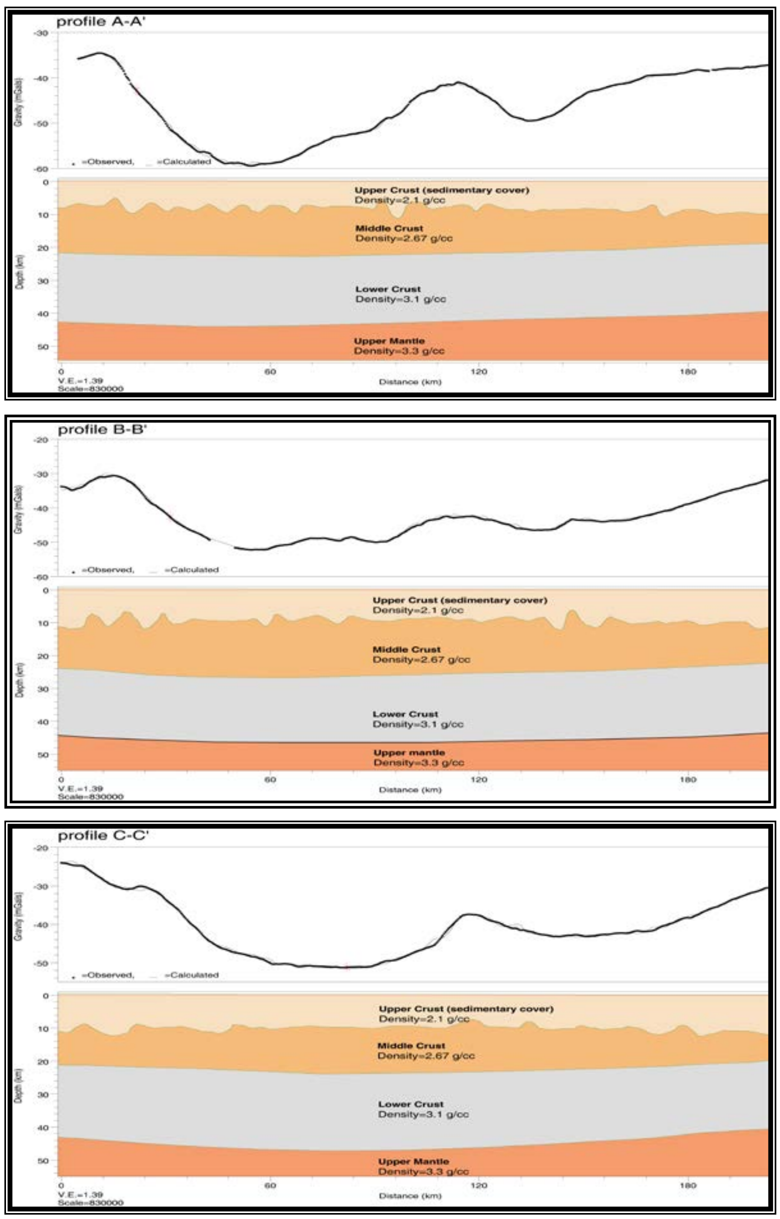


Fig. (4) Complete Bouguer map and the selected cross-sections for modeling.



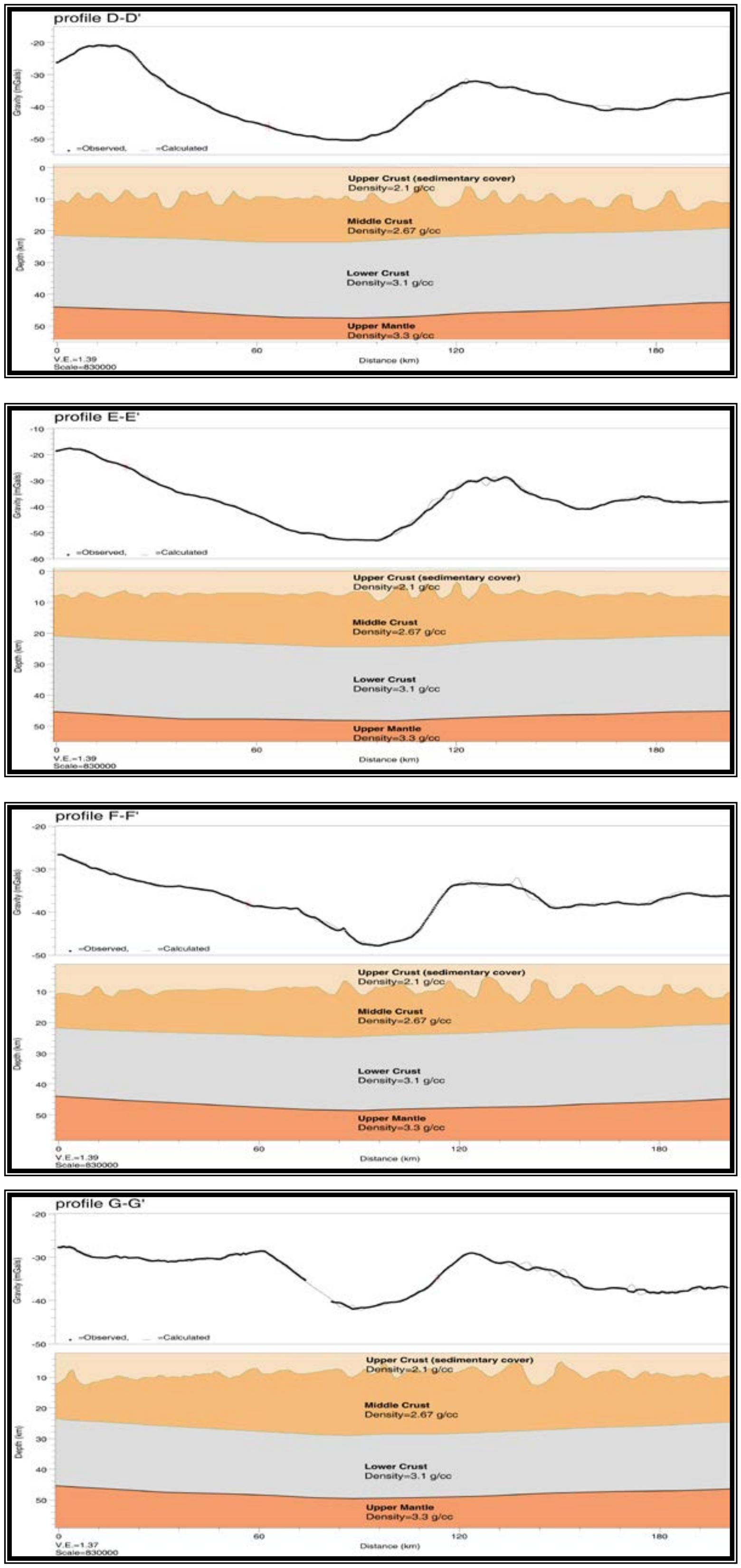


Fig. (5) Seven models from the complete Bouguer map of study area.

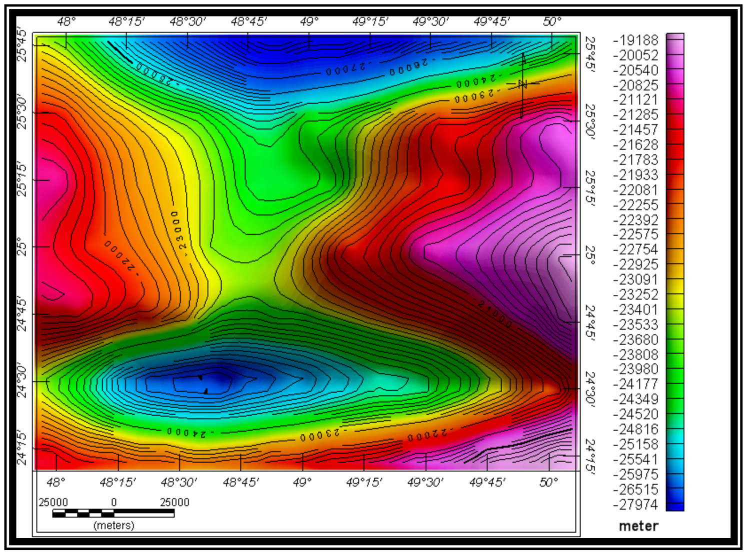


Fig. (6) contour map for depth of lower crust.

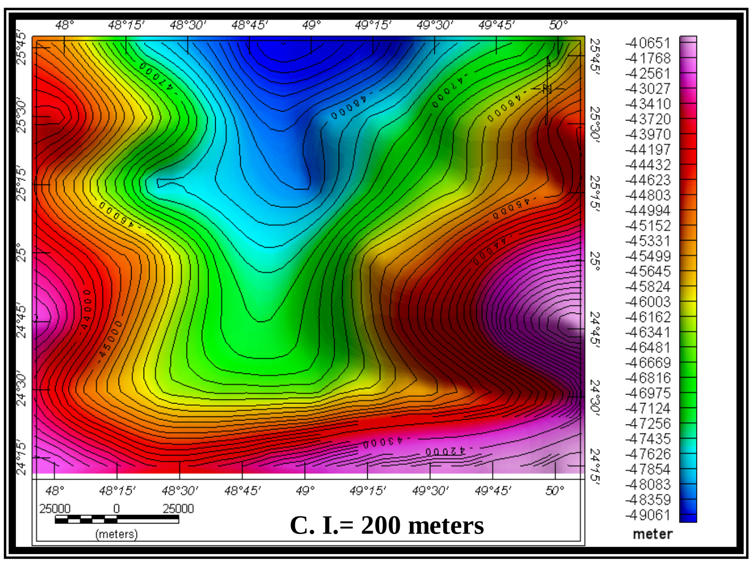


Fig. (7) Contour map for the crustal thickness at study area.

Table (1) Comparison between the final results of current study and the previous studies.

	The present study 2007	**Jerry and William, 1998**	**Al-Amri, 1999**	**Al-Amri and Gharib, 2000**	**Al-Damegh et al., 2005**	**Al-Amri and Al-khalifah, 2007**	**Hansen et al., 2007**
Middle Crust	2.2-13 km	—	—	8 km	—	4 km	—
Lower Crust	18.6-29 km	24 km	—	—	—	20 km	—
Upper Mantle	40-49 km	42 km	46 km	51 km	41-53 km	40 km	40-60 km

CONCLUSIONS

The eastern province of Saudi Arabia is part from the Arabian platform which located between two major tectonic provinces, the Arabia Gulf and Zagros Mountains to the east and the Arabian Shield to the west.

This complicated tectonic leads to the great variation of the crustal structure and the depth of Moho discontinuity in this area. Gravity modeling has been applied throughout seven cross section covering the area and the results of modeling reveals that there are three layers constitute the crust as; sedimentary layer with thickness to 13 km; middle crust with depth extends to 13-29 Km; and Lower crust ranges from 29- 40 km while depth to Moho ranges from 40-49 Km. These results are correlated well with the previous studies for the area and this indicates the application of the gravity method is of quite importance better than some other methods.

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REFERENCES

A. M. Al-Amri., 1999. The crustal and upper-mantle structure of the interior Arabian platform, Geophys. J. Int. 136, 421-430.

Al-Amri, and Gharib, A., 2000. Lithospheric seismic structure of the easten region of the Arabian Paninsula: . Journal of Geodynmaics 29, 125-139.

Al-Amri, A. M. and T. Al-khalifah., 2007. Crustal and Upper-Mantle Structure Beneath the Arabian Shield and Red Sea. Project no, AR-23-40, king Abdulaziz city for Science and Technology

Al-Damegh, K., Sandvol, E., and Barazangi, M., 2005. Crustal structure of the Arabianplate: New constraints from the analysis of teleseismic receiver functions, EarthPlanet. Sci. Lett., 231, 177-196.

Hansen, S., A. Rodgers, S. Schwartz, and A. Al-Amri, and (2007). Imaging Ruptured Lithosphere Beneath The Red Sae And Arabian Peninsula. Accepted for publication in *Earth and Planetary Science Letter*.

Jerry , S., and William, R., 1998, Preliminary Definition of Geophysical Regions for the Middle East and North Africa.

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D., and Simmons, M.D., 2001, Arabian Plate sequence stratigraphy: GeoArabia Spe- cial Publication 2, Gulf Petrolink, Manama, Bahrain, 371 p.