DETERMINATION OF THE DEPTH TO MOHOROVICIC DISCONTINUITY IN THE MINNA AREA IN NIGERIA, USING BOUGUER GRAVITY DATA

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Abstract

The present study deals with the determination of depth to Mohorovicic discontinuity beneath the Minna area, Nigeria using Bouguer gravity data. The Empirical relation, Power Spectral analysis and 2–D modeling techniques were used on the Bouguer gravity data covering the study area. Three Empirical relations were used to mathematically compute the Mohorovicic depth for the area. From Spectral analysis carried out on the gravity data, depth to major density boundaries was obtained which are the Basement depth, Conrad discontinuity and Moho discontinuity. The Moho depth results obtained from Empirical analysis and spectral analysis, summed and averaged were used on straight line equation to obtain the relationship between the Moho depth H_C in kilometer. Two 2-D gravity models along two profiles trending NW–SE and N-S direction were constructed with the available geological and geophysical information to obtain a correlated Moho depth for the study area. The obtained result from the model indicates that the average density of the upper mantle is 3.2 g/cm^3 underlying the Migmatitic-Gniess, lower crust of average density 2.8 g/cm^3. The considerable Moho depth range of 30 to 47 km and Conrad depth range of 4 to 24 km obtained for the study area gives an indication that the tectonic stability of the area is further enhanced.

Keywords: Empirical analysis, Power Spectral analysis and 2–D modeling techniques Basement depth, Conrad discontinuity and Moho discontinuity

1. Introduction

The crustal thickness of the Earth varies from place to place and it is necessary to know the crustal thickness of the area which indicates the thickness of the Lithosphere and the stability in terms of tectonic movement. The area with high crustal thickness gives an indication of stability of that area. Previous work on the study area was limited to the use of empirical method. This study will use empirical relationship and Spectral analysis to ascertain the crustal thickness of the study area. The aim is to determine the crustal thickness within parts of minna batholith using bouguer gravity data. The study area is located in Niger state Nigeria, whose Capital is Minna and the study area is located between longitudes 6.0^0 - 7.0^{o}E and Latitude 9.5^0- 10.5^{0}N. It possesses the focal segment of the Nigeria basement complex. The area contains meta-sedimentary and meta-volcanic rocks which have experienced polyphase disfigurement and changeability. In these rocks, there are intrusions of granitic rocks of pan – African age. The three different rock groups that make up the complex, migmatite-gneiss, the low – grade schist belt and the older granites are well represented in the area (Trustwell and Cope 1963; Ajibade 1980). The gravity is a potential field; it is a force that acts at a distance which involves the measuring of the acceleration due to the earth's gravitational field. Variations in gravitational field result from density lateral variations of subsurface rocks within the portion where the measurement is observed (Mariita, 2007). The aim of studying elaborate gravity data is to obtain appreciable knowledge level of subsurface geology. The Moho demarcates the boundary between crust and mantle (Lewis, 1983). The boundary separation between the crust and the mantle (Moho) which interfaces lies at a depth ranging from 30 to 50 km on the continents and about 7km beneath the oceanic crust. Mohorovicic discovered the discontinuity between the surface of the crust and mantle. Depth to Moho can be evaluated by seismic or the gravimetric strategy (Coch and Ludman, 1991).

2. Geology of the Area

The area of study is part of north-central Nigeria Precambrian basement complex rocks. The lithologic units include granites, gneisses, migmatites and meta-sediment (Adeleye, 1976). Three rocks type exist in minna comprises of the: granites, schists, and gneiss with quartzite intrusion. The granites belong to the older granite suites occurring as Minna batholith of several high, the texture and colour of these granites vary from medium to coarse grained and light to dark colour. The area has witnessed fracturing and joint values. The Batholith is a massive body intrusive igneous rocks created during the cooling of magma crystallising beneath the Earth's surface. Magmatic intruitions in them is notcontinuous but rather repeated (multiple individual plutons). This cool and solidified magma becomes exposed after some time as a result of erosion (Udensi, 1984).). Figure 1 (Map of Nigeria) shows the location of the Study Area and Figure 2 is the geological map of the area.

Figure 1: Map of Nigeria showing the study area (Obaje *et al.,* 2009).

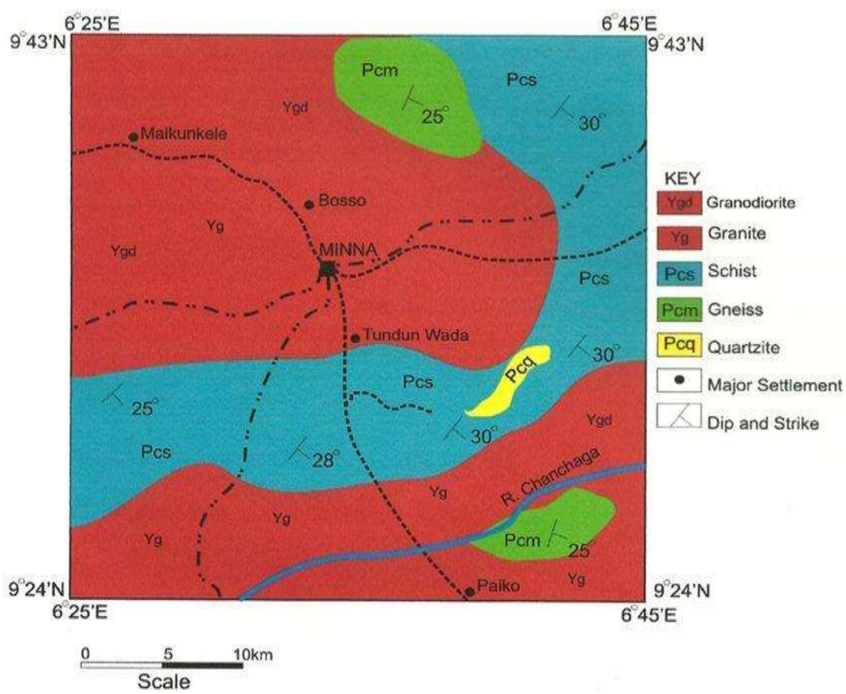

Figure 2: Geology Map showing Location of the Study Area (Alabi A.A., 2011)

3. Materials and Method

Materials

The Bouguer gravity anomaly map of the study area was prepare from the gravity data which was acquired from the Nigeria Geological Survey Agency (NGSA) for this research. About 957 gravity data point was used to prepare a complete Bouguer anomaly map.

Equipment

Materials used for this research study including the following

- Gravity data of the study area
- Oasis Montaj software
- Surfer 10 software
- Excel software
- Work station (Laptop)

Methods

This study basically integrate the use of three different methods to determine the crustal thickness of the study area.

I. The Empirical Relation
II. The Spectral Analysis
III. 2- D Modeling

DETERMINATION OF THE MOHO DEPTH

Empirical Relation

The available data set comprises of Bouguer gravity data anomaly of the study area will be gridded at an interval of 10 km. The Bouguer gravity anomaly data values will be substituted into the following empirical relation below, which will aid in calculating the crustal thickness of the study area using Demeniskaya (1958), Woollard (1959), Woollard and Strange (1962).

The outcome of the below process will be useful for the determination of the crustal thickness, deducing the geological history of an area, and also essentially in tectonic study (Udensi, 2000).

The empirical relation equations are as follow:

$$H_D = 35(1 - TANH(0.037BG)) \quad (1.1)$$

$$H_W = 32.0 - 0.08BG \quad (1.2)$$

$$H_{WS} = \frac{40.50 - 32.50TANH\ ((BG + 75)}{275} \quad (1.3)$$

Where H_D, H_W and H_{WS} are in km and BG is mGal. The average of value estimated from the computed relation at any given location is the crustal thickness at that particular location (Raid *et al.,* 1981).
The data are inputted into the Microsoft excel package in the form of X,Y and Z, the excel package was used to estimate the depth to Moho using the above equation 1.1, 1.2, and 1.3.
Thereafter, the average values estimated from the relation H_D H_W and H_{WS} is the depth to Moho of the study area.

The Power Spectral

Power spectrum analysis (Dimri 1992; Blakely 1995). Power spectral analysis estimates the mean depth of the interfaces considering the log power of the Bouguer gravity spectrum as a function of wave number / frequency. This assumes that the distribution of sources or the scaling natures of the sources are uncorrelated, (Spector and Grant, 1970; Pilkington *et al* 1994; Maus and Dimri (1992). The gravity anomaly spectrum due to layered source is separated into multiple segments in frequency domain that can be interpreted in terms of mean depth of the interface. The half of the slope of the segments gives the mean depth of the interfaces. The method is used to map geological structure from the observed gravity data at the surface.

Two Dimensional Modeling (2-D)

The 2 – D gravity modeling is an essential tool to study the crustal structure and usually the final stage in gravity interpretation. Gravity data reveal a regular relationship between crustal structure, crustal composition (density) and the surface elevation. Bouguer anomalies are enough to give evidence of changes in mass distributions in the lower and the upper mantle, for any regional scale (Tealeb, A and S. Raid, 1986).

The modeling technique commonly involues using a residual gravity anomaly, in this technique the interpreter must use a density contrast between the body of interest and the surrounding material, in the process of modeling Bouguer gravity anomalies the density of the body is used (Mariita, 2007).

The model system is based on the geology of the area and the geophysical data obtained from the gravity data. The gravimetric model will be performed using the GM, sys program, which is hosted by the interface of Oasis Montaj 6.4.2. Gravity modeling is considered an important tool to study the crustal structures. This method is straight forward, which is by means of trial and error method, varying the body geometry allow to obtain a good fitting between theoretical and observed anomalies. (Tealeb, A and S. Raid, 1986).

5. RESULTS AND DISCUSSION

Empirical Method

Table 5.1 show some of the result obtained from the calculated depth to Moho, the empirical relation used was developed by Demenitskaya (1958), Woollard (1959) and Woollard and Strange (1962). The average values obtained from the three relation at any given location is the crustal thickness at that location. The values obtained were interpolated into the excel spread sheet, which was used to produce contour crustal thickness map of the study area. Figures 3, 4, 5 and 6 respectively are the result from Demenitskaya (1958), Woollard (1959), Woollard and Strange and the average crustal thickness, using Surfer 10 software package. (Raid *et al.,* 1981).

Table 5 .1 Sample Results of the Calculated Empirical Relations

H_D (Km)	H_W (Km)	H_{WS} (Km)	Average
57.02008	33.60	34.08530	41.56846
57.02008	33.60	34.08530	41.56846
57.02008	33.60	34.08530	41.56846
55.80530	33.48	33.91510	41.06681
55.38199	33.44	33.85840	40.89349
56.21940	33.52	33.97181	41.23707
57.78435	33.68	34.19896	41.88777

Key: H_D, H_W and H_{WS} are the crustal thicknesses using Demenistskaya, Woollard, Woollard and Strange in Kilometre respectively.

Demenistskaya Relation

Figure 3 shows the map of Demenistskaya relation. The crustal thickness values ranges from 53.5 to 67.5 km with an increase of 0.5 km interval. The maximum value 67.5 km is at the south west part of the map, the minimum value 53.5 km is at the South western and South Eastern part of the map.

Woollard Relation

Figure 4 represent the map of Woollard relation, whose values ranges from 33.2 to 35.6 km with an increase of 0.1 km interval. The highest value 35.6 km is at South western, the lowest value 33.2 km at the North western and South Eastern region of the map.

Woollard and Strange Relation

Figure 5 shows the map of Woollard and Strange relation, the values ranges from 33.6 to 37 km increasing in the trend of 0.2 km interval. The maximum value 37 km at South Western part and the minimum value of 33.6 km at South Eastern part of the map.

Average Empirical Relation

Figure 6 show the average empirical relation developed by Demenistskaya (1958), Woollard (1959) and Woollard and Strange (1962). The average empirical map showed that the crustal thickness of the study area ranges from 40 to 47 km with an increase of 0.5 km interval. The thickness varies from maximum value of 47 km to a minimum value of 40 km. The maximum depth is located at the South Western, its minimum Moho depth is located at North West, South Western and South Eastern part of the map.

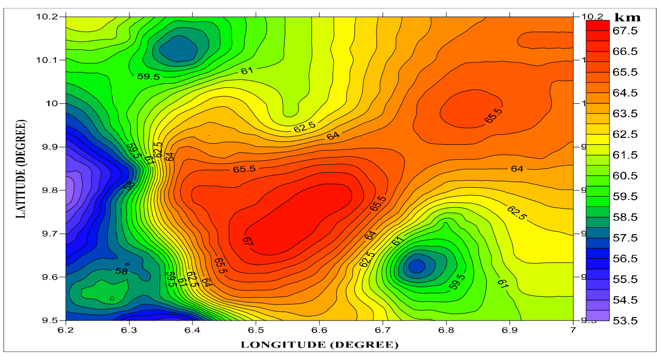

Figure 3: Contour Map of Demenistskaya relation of the Study Area. Contour Interval of 1 km. The legend shows Values of the Moho depth in the study Area.

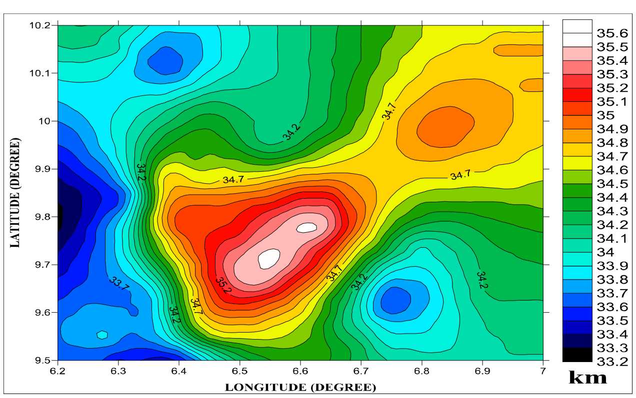

Figure 4: Contour Map of Woollard relation of the Study Area. Contour Interval is 0.1 km. The Legend shows Values of the Moho depth in the study Area

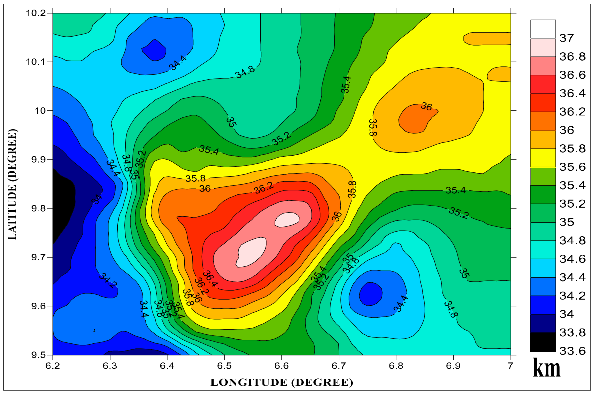

Figure 5: Contour Map of Woollard and Strange relation of the Study Area. Contour Interval is 0.2 km. The Legend shows Values of the Moho depth in the study Area

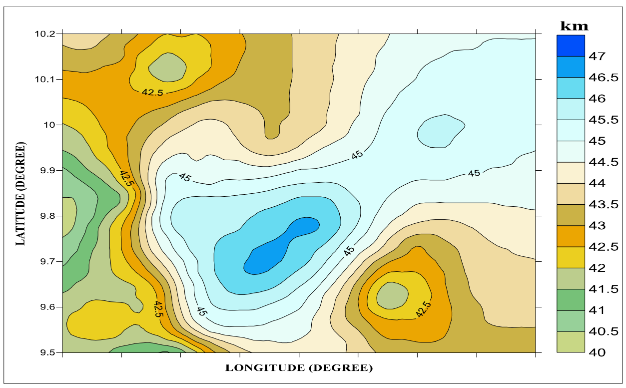

Figure 6: Contour Map of Average Crustal Thickness of the Study Area using the empirical relation. Contour Interval is 0.5 km. The Legend shows Values of the Moho depth in the study Area

Power Spectral Analysis

Table 5.2 which shows the three (3) line segment represent slope 1, 2, and 3. M_1, M_2, and M_3 are the corresponding slopes of each of the segment. The values generated from each of the slopes, are used to estimate the H_1 which is attributed to the shallowest depth sources from crystalline rock (basement interface/ intrusion), H_2 is associated to the average depth to conrad discontinuity which may correspond to the depth variation between the upper and lower crust and the last level H_3 is attributed to the average depth of the seated Moho discontinuity.

Table 5.2 Representing Spectral Plot Values and the corresponding Depth of the Study Area

SECTION	M_1	M_2	M_3	H_1	H_2	H_3
A	0.000151	0.000682	0.00137	4.5981	20.7674	41.7174
B	0.00016	0.000785	0.00124	4.8721	23.9038	37.7588
C	0.000172	0.000653	0.000608	5.2375	19.8843	18.5140
D	0.000159	0.000798	0.00119	4.8417	24.2996	36.2363
E	0.00175	0.000414	0.00139	5.3289	12.6066	54.2022
F	0.00175	0.000275	0.00116	5.3289	8.4044	35.0255
G	0.000205	0.000265	0.00132	6.2424	8.0694	40.1949
H	0.000156	0.000608	0.00159	4.7503	18.5140	48.4166
I	0.000154	0.000789	0.00128	4.6894	24.0256	38.9768

Where M_1, M_2, and M_3 values are linear gradient and $H_{1,}$ is the depth to the seated features.$H_{2,}$ is the Conrad depth and H_3 is the Moho depth (in Kilomtre)

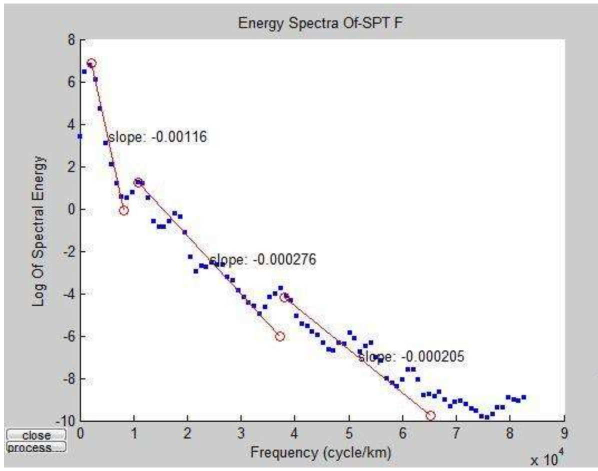

Figure 7: Typical plot of energy spectrum against frequency of section

Analysis of the Moho Depth

Figure 8 represent the Moho depth map, the depth range from 18 to 48 km. The minimum depth value of 18 km is located at of North West region, while the maximum depth value of 46km is located at North Eastern part of the map. The values vary at 2 km interval with an increases down North -West and a decrease in the south Eastern part of the study area.

Analysis of the Conrad depth

Figure 9 represent the Conrad depth, the depth which ranges from a minimum of 8 km to a maximum of 25 km, the maximum value 25 km is located at the North Eastern and minimum value 8 km is located at Northern and Western part of the map with a steady increase down West to Southern region of the map.

Analysis of the Basement Depth

Figure 10 represent the Basement depth, the depth which ranges from a minimum 4.5 km and 6.3 km. The maximum value 6.3 km is located at the Western region and minimum value 4.5 km is located at the North East and South West of the map.

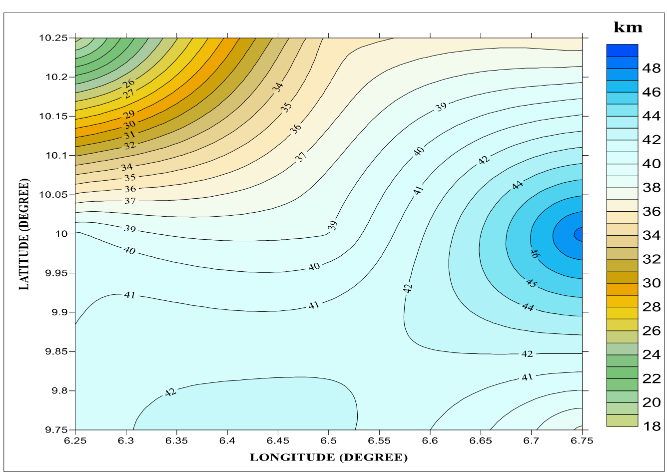

Figure 8: Contour map of Moho Depth of the Study Area. Contour interval of 2 km depth shown at the Legend

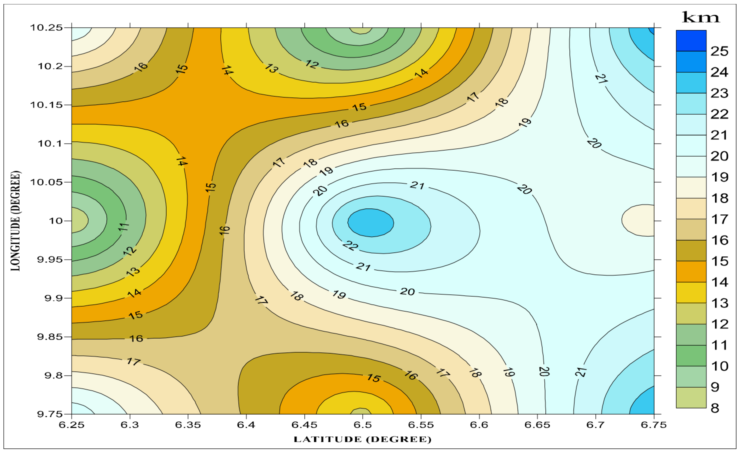

Figure 9: Contour map of Conrad Depth of the Study Area. Contour interval

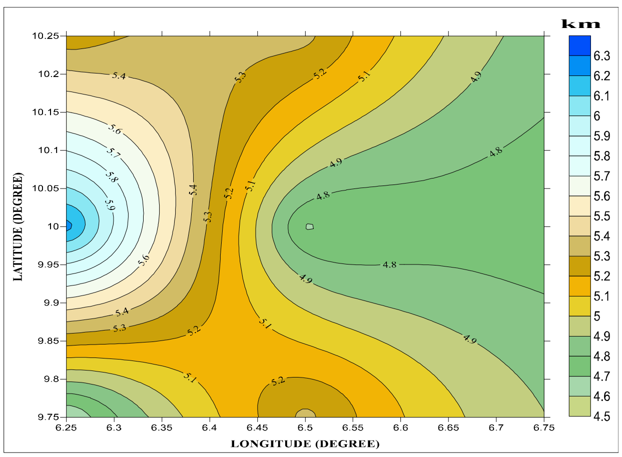

Figure 10: Contour Map of Average Crustal Thickness of the Study Area using the empirical relation. Contour Interval is 0.5 km. The Legend shows Values of the Moho depth in the study Area.

Crustal Thickness Map of the Study Area

Figure 11: Shows the Crustal thickness of the study area, the area has a maximum depth of 47 km, it increases down North – East and North - South region of the area. The minimum depth of 33 km, which has a contour interval of 1 km. The results obtained from the methods used shows no significant different.

2- D Modeling Analysis

In the present study, two gravitational Profile (AA[1] and BB[1]) as shown in Figure 12 and 13, were selected to be investigated with 2- D Modeling approach.

PROFILE AA[1]

The model profile of A (Figure 12) extends about 105 km long. The profile is distinguished by an Anomaly that ranges between -46 to 0 mGal. The model contains the Zungeru- Birnin Gwari Schist, sand, soil, clay, Batholith, Kushaka Schist, older granite and Migmatite – Gnesis complex. The Zungeru – Birnin Gwari Schist has a density of 2.73 gm/cm^3, the Batholith has a density of 2.65 gm/cm^3, Clay has a density of 2.35 gm/cm^3, Sand has a density of 2.19 gm/cm^3, Soil has a density of 2.27 gm/cm^3, the Kushaka Schist has a density of 2.72 gm/cm^3 and the older Granite has a density of 2.65 gm/cm^3. From the profile, the crustal thickness ranges between 32 and 47 km, the minimum value is 32 km and the maximum value is 47 km. In addition, the average density of the mantle is 2.8 gm/cm^3.

PROFILE BB'

Figure 13 represent the model profile B which cut across the study area in the direction, and extend about 110 km. The profile has an anomaly that ranges between -42 to -26 mGal. Profile B contain older granite with density of 2.65 gm/cm^3, sand with a density of 2.19 gm/cm^3, Kushaka schist has a density of 2.72 gm/cm^3, Batholith has a density of 2.35 gm/cm^3, Migmatite has a density of 2.8 gm/cm^3 and the Mantle has a density of 3.2 gm/cm^3. From the profile, the Crustal thickness has a minimum value of 30 km and a maximum value of 46 km.

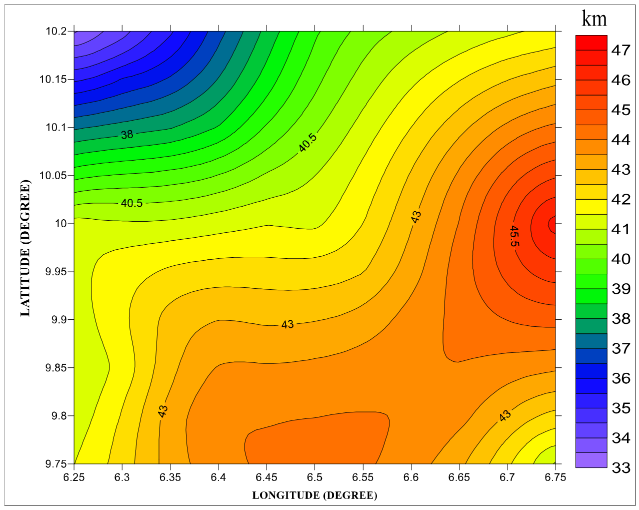

Figure 11: Contour Map of Crustal Thickness of the Study Area. Contour 1 km interval depth shown at the Legend

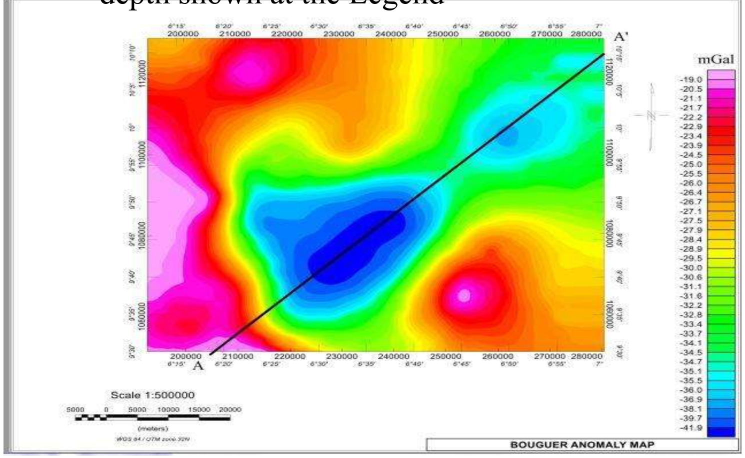

Figure 12: Bouguer gravity Map of the Study Area showing Profile AA[l]

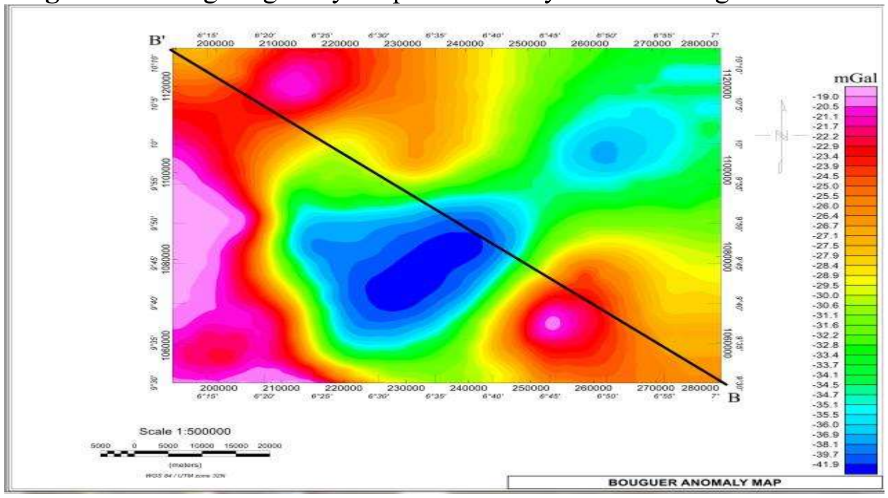

Figure 13: Bouguer gravity Map of the Study Area showing Profile BB[l]

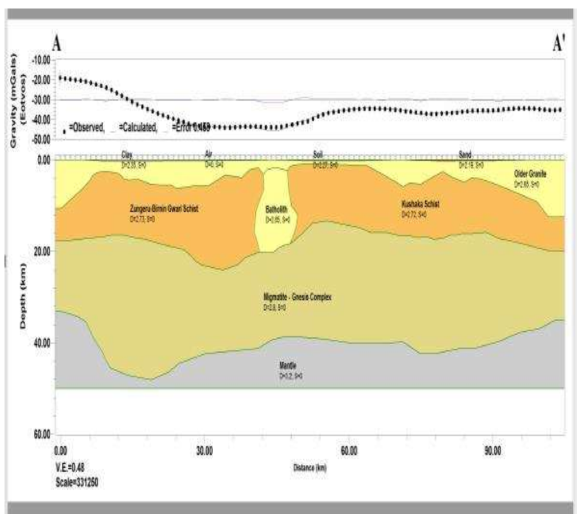

Figure 14: Gravity Model along Bouguer gravity Profile AA[l]

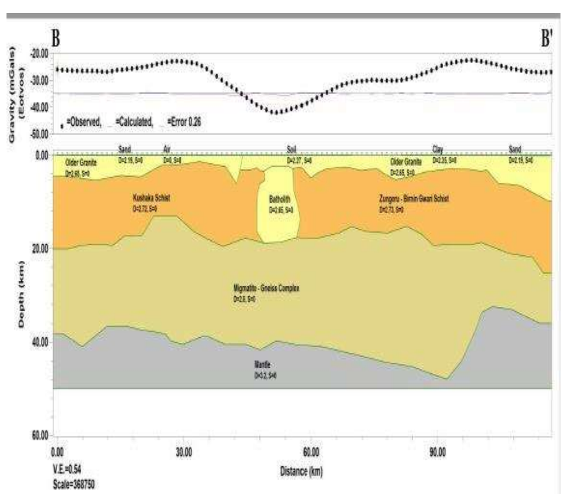

Figure 15: Gravity Model along Bouguer gravity Profile BB[l]

Tectonic Stability of the Study Area

Tectonically, Nigeria like other African Countries lies within a plate. Therefore, stable and Diastrophic activities, unlike other countries like Japan that lies in plate boundaries where tectonic activities is predominant, such country, no matter how large or small their moho depth is, will always be unstable obtaining a considerable moho depth. From the 2 –D modeling of the study area revealed depth of 35 to 48.5 km which has improve the stability of the area.

6.0 Summary and Conclusion

The empirical relation and power spectral analysis methods were employed for the estimation of the crustal thickness of the study area. From the power spectral analysis technique, shows a corresponding average depth of three level basement, conrad and the moho discontinuities within 4.5 to 6.2, 18.5 to 24.29 and 35 to 48.5 respectively. The result from the empirical relation revealed that the average depth 47km is in close correlation to the moho depth.

Two gravity profiles have been investigated with 2- D modeling to explain the shape and variation of the crust along these profiles. The results of these models are summarised in two maps (Figure 14 and 15) respectively.

The Moho discontinuity occures at a depth of 30.0 km and 47 km. The density model used indicate that the average densities of different rock layers and schist formation in the study area: Zungeru – Birnin Gwari schist has a density of 2.73 gm/cm^3, Kushaka schist has a density of 2.72 gm/cm^3, older Granite has a density of 2.65 gm/cm^3, Batholith has a density of 2.35 gm/cm^3, Migmatite has a density of 2.8 gm/cm^3, soil has a density of 2.27 gm/cm^3, and sand has a density of 2.19 gm/cm^3. The average density of the Mantle from the two profiles is 2.8 to 3.2 gm/cm^3. The computed results show that the crustal thickness of Minna area has a maximum depth of 47 km, it increase down North – East and North South region and a minimum depth of 33 km.

The result obtained correspond to the research result of Udensi, (2000) within the study area using empirical relation formula to estimate the crustal thickness

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