APPLICATION OF BOUGUER GRAVITY DATA TO ESTIMATE CRUSTAL THICKNESS OVER PARTS OF SOUTHERN NIGERIA

EJEMBI, Q. A. [1], UDENSI, E. E.[2], ALHASSAN, D. U. [3], SALAKO, K. A. [4], LAWRENCE, J. O. [5], & ADIKWU, O. S. [6]

[1,2,3,4,5]Department of Geophysics, Federal University of Technology, Minna, Nigeria.
[6]Department of Geology, Federal University of Technology, Owerri, Nigeria.
E-mail: ejembiqueencess@yahoo.com
Phone Number: +234-703-641-4765

Abstract
In this study, Spectral analysis of the bouguer anomalies was utilised on the bouguer gravity data covering the study area from which the depth ranges to the major density interfaces (basement surface, Conrad and crustal thickness) were determined by dividing the bouguer gravity map into thirty (30) sections. Results obtained show three major depths with an average crustal thickness ranges from -30.2 to -35.6 km. These values obtained within the study area suggest that the region is tectonically stable, which implies that the crustal thickness and density have influence on the tectonic stability of the study region. Hence, the area is located in a non-major fractured zone.

Keyword: Spectral, Analysis, Gravity, Data, Crustal, Thickness, Tectonic, Stability

Introduction
Geophysics which entail all portions of the physics of the earth incorporates the utilisation of physical principles and quantitative measurements in order to study the earth interior, its space as well as the atmosphere. Investigation of these measurements can uncover how the earth interior varies vertically and horizontally and the analysis which review important information on the geological structures (Bonde *et al*., 2014). This discovery show scientist that the earth subsurface is divided into three sections the crust, mantle and core. The crust being the upper rigid part of the lithosphere, it is an extremely thin layer of rock that makes up the outermost solid shell of our planet. In relative terms its thickness is like that of apple skin, the base of which is defined by a prominent seismic discontinuity, the mohorovicic discontinuity. The crust is said to be divided into three crustal, the ocean, transition and the continental crust. One of the important of geophysical method is the study of the earth crust in cases of tectonics incorporating the distance between the earth surface and mohoor crustal thickness. This limit can be controlled by isostatic/gravimetric and seismic strategies. Significant number of isostatic speculations, gravimetric and seismic models exist for assessing the crustal thickness (Nafiz *et al*., 2008). The benefit of utilising an isostatic/gravimetric model to decide the crustal thickness is the uniform scope and generally point by point determination of the presently accessible worldwide geo potential models and satellite information. Crustal thickness is a meticulous parameter for understanding the process of continental rifting and break up. There is need to study crustal thickness in Nigeria since very little portion is known about the structure of the sedimentary basins as it relates to the geosciences development of key tectonic features, such as the west Africa passive margin where some southern parts of Nigeria are located (Akpan *et al*., 2015). Some southern part of Nigeria like the Niger delta and Anambra basin is a geographical feature which is the largest wetland and it keeps up the third largest drainage sedimentary basin in Africa. Due to its amazingly oil well and mineral resources. Seismic measurement of crustal thickness is widely used spaced interval and expensive Huismans & Beaumont, (2011) and Sutra & Manatschal, (2012). The distance between the earth surface and the, the interface can be imaged accurately through deep seismic profiling, but for

economic considerations make gravity modelling more practical approach for mapping crustal thickness over regional scalesmoho (Nafiz *et al.*, 2008).

The crustal thickness of the earth varies from one place to another. It is very important to determine the crustal thickness of the crust, which is the rigid part of the earth. If the crustal thickness of an area is high, it gives an indication of the stability of that area, in terms of tectonic movement. Therefore, the occurrence of natural earthquakes in Nigeria is uncommon because of its location on a passive continental margin with the nearest active plate boundaries lying very far away at the mid-Atlantic ridge; hence the country is referred to as being aseismic (Yakubu, 2014). However, recent seismic activities in some parts of the West African sub-region (e.g Congo) have shown that the West African region may be unstable. Nigeria has experienced tectonic instability in form of earth's tremor between the year 2015 and 2021, among which is Kaduna State in 2016 and Abuja FCT in 2018. For this reason, there is need to continuously monitor the crust and the upper mantle to ascertain the tectonic stability of various regions of the country. To this end, spectral analysis of gravity data over some parts of southern Nigeria in order to determine the crustal thickness so as to predict the tectonic stability of the study area.

Location of the Study Area

In the southern section of Nigeria, the study is located between longitudes 5.0° E and 8.5° E and latitudes 5.0° N and 7.5° N. It is situated in the south-eastern portion of Nigeria. Several academics and workers have documented the structural disposition of those parts of southern Nigeria.

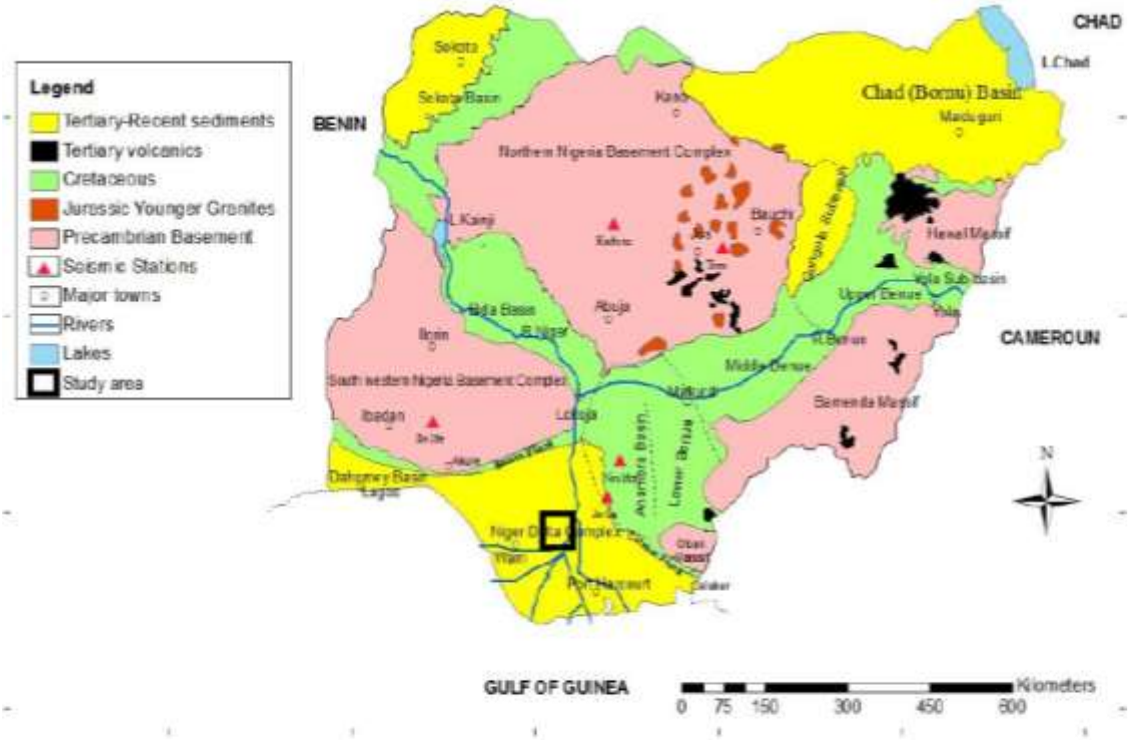

Figure 1.2: Map of Nigeria showing the study area (Modified after Akpan *et al.*, 2015)

Materials and method

Data acquisition

The study area is parts of Southern Nigeria are covered by thirty-five (35) Bouguer Anomaly maps in half – degree sheets. The maps obtained for the research work are onshore gravity data which covers an area of longitude 5.0^0E to 8.5^0E and latitude 5.0^0N to 7.5^0N.
These maps were obtained from the department of physics, Federal University of Technology Minna. The Microsoft Excel, surfer 13, oasis Montaj and Matlab Geophysics software were used for the data analysis, processing and interpretation.

Estimation method

Bouguer gravity anomalies are necessary for determining crustal thickness, deducing the geological history of an area, and even for predicting future geological movements. It is also of great interest in tectonic studies (Udensi, 2000). The following procedures were carried out on Bouguer gravity data to obtain an estimate of the crustal thickness for the study area as well as to ascertain the tectonic stability of the study area from the average crustal thickness determined.

Digitisation. The bouguer gravity (BG) map of the study area was digitised using picture of unknown estimated value that fall between known value methods to obtain data on grid layout to be used for qualitative interpolation. Digitisation is a process of converting information into a digital (discrete) format so that computers and many devices with computer capacity can process.

Digitization is not a trivial process since a host of potential pitfalls are lurking within this simple step. Nothing is more important since improperly recorded digital data can be totally worthless or completely misleading. And once the data have been improperly recorded digitally, correct data cannot be recovered. The latitude and longitude position must be added to the data showing its position when imputing it into the system. For example, a data to be imputed into a computer system must be represented as (4, 2, 7. 0). This means longitude 4, latitude 2, Data 7.0.

The entire available bouguer gravity anomaly map will be grided at an interval of 10 km as gridding at smaller intervals may introduce aliasing (Noise) since the area is a sedimentary terrain and also, crustal thickness is a regional feature and as such does not vary rapidly as most surface features. The data from each digitised map is recorded in a coding sheet which contains the longitude, latitude and the bouguer gravity anomaly data (BG).

Gridding

Gridding is the first step in the data processing which interpolates the bouguers anomaly values of the data base to a square grid. The term grid refers to the files that contain location (x,y) and data (z) gravity observation values, which was interpolated to create a regular and smoothly sampled representation of the locations and data. The interpolation methods of (x,y and z) data within Geosoft oasis Montaj software are Bi-directional, Minimum curvature and gridding.
For this research work, the Bi-Directional Gridding was used as it interpolates the (x,y,z) data by fitting a two dimensional surface to the (x,y,z) data, in the case the curvature of surface is minimised.

Contouring

Contours are one of several common methods use to denote elevation or altitude and depths on maps. From the contours, a sense of the general terrain can be determined. Contour maps are topographical maps on which the shape of the land surface is shown by contour lines which join point of equal elevation about a given level. These maps are used to show the below ground surface of geologic strata, fault surfaces (especially low angle thrust faults) and unconformities. These contour maps are the bases of the gravity interpolation before the development of the computer programs. Software such as sulfer 13 produces this contour.

Nowadays, the gravity data is displayed as colour maps, where the colour represent different gravity anomaly from high to low within the gravity map using advance Geosoft software like the oasis Montaj. The oasis Montaj is a program written to pick data points row by row, calculate the longitude and latitude using base values already supplied and produces the coloured map of the bouguer gravity data of the study area with a contour interval of 5milligals. Therefore, at this stage, the gravity grid produced using the Bi-directional gridding is displayed in coloured shaded grid.

Spectral Depth Analysis (SDA)
Determination of the depth to Mohorovicic discontinuity is one of the principal applications of gravity data. This statistical approach has been found to yield good estimates of mean depth to basement underlying a sedimentary basin (Udensi, 2001).

Spectral analysis of gravity data uses the 2- D Fast Fourier Transform and first transforms gravity data from the space domain to the wave number domain and then analysing their frequency characteristics. Thus, if b(x) represents the discrete N data array of gravity data obtained by sampling a continuous profile at evenly spaced intervals Δx, the finite mean depth z= h; Δρ is the density contrast between two layers; F(k) is the Fourier transform of f(x), the derivation of the interface from the mean depth z; G is the gravitational constant. Thus, the power spectrum of B (k) is simply:

$$E = (2\pi\Delta\rho G)^2 . \mid F(k) \mid^2 \exp(-4\pi kh) \quad (1)$$

(Telford *et al.*, 1980)

The expected values of the power spectrum are expressed as the product of a depth factor and size. This power spectrum exhibits intervals of wave numbers in which the logarithm of increasing wave number within discrete segments of the spectrum and the slopes of these linear segments are proportional to the depths of the possible layers in this case the Moho and Conrad discontinuity.

The total gravity anomaly values are used to obtain the two-dimensional Fourier Transform from which the spectrum is to be extracted consisting M rows and N columns in X-Y. For the purpose of easier handling of the large data involved, the four residual blocks of the study area were divided and sectioned into nine (9) spectral cells labelled section 1-9. Each section was subjected to spectra analysis using Oasis Montaj software.

The depth to causative mass distributions was obtained by analysing a plot of the logarithm of the power spectrum as a function of the wave number or frequency. Taking the logarithm of both sides of equation (2), one has:

$$Log\ E = \mathrm{Loga}(k)_{z=0} - 4\pi kh \quad (2)$$

Where:

K = the wave number

h = the depth to boundary surfaces;

A (k) = the amplitude spectrum (Telford *et al.*, 1980).

One can plot the wave number k against LogE to obtain the average depth to the Moho interface and the Conrad discontinuity. The interpretation of LogE against the wave number k requires the best-fit line through the lowest wave number of spectrums. The most commonly encountered situation is the one in which there are two ensembles of sources; deep and shallow. These ensembles are recognizable by a change in the rate of decay of the power spectrum with wave number. The mean ensemble depth dominates the spectrum so that a significant change in depth of the ensemble results in a significant change in the rate of decay. Then the average depth can be estimated by plotting equation (3) as:

$$H = -\frac{\Delta LogE}{4\pi\Delta k} \quad (3)$$

Where;

h= the average depth to boundary surfaces

$\Delta LogE$ = variation of energy log and

Δk= variation of wave number (Telford *et al.*, 1980).

The graph of each energy spectra was obtained with the aid of a MATLAB software specifically designed to accept the longitude and latitude values alongside with its respective gravity values for each of the spectra sections where the log of spectra energy against frequency was plotted. To evaluate the corresponding depths from the slopes of the plotted graph, equation (4) is used as it gives a relationship between the obtained slopes and the various depths to be calculated.

$$h = -\frac{m}{2\pi} \quad (4)$$

Where:

m = m1, m2 or m3 slope of the best fitting straight

h = h1, h2 or h3 which is sedimentary thickness, Conrad depth and Moho depth in kilometres

The depths to the gravity sources can be calculated from power spectrum profiles computed from the Potential Field data. The spectral method allows the estimation of depths to the top of assemblages of source bodies from the wavelengths of gravity fields. Frequency analysis using the Fast Fourier Transform (FFT) which is widely utilised technique for processing and interpretation of the potential field data, particularly for depth estimation has been applied to the digitised Bouguer gravity data for the estimation of average depths to different density discontinuities within the study area. At this stage, the MAGMAP facility in Geosoft Oasis is used to process the original grid map- total gravity anomaly map in order to enhance it. Thirty cross sections are constructed from the gravity anomaly map and Fast Fourier Transform (FFT) applied using the MAGMAP facility in Oasis Montaj software in order to analytically estimate the crustal thickness of the study area.

Gridding and Sectioning of the Bouguer anomaly map into thirty spectral sections (SPCA-SPCAD which is equivalent to SPC1-SPC30 was carried out using Oasis MontajGeosoft and the radial spectral energies were plotted within it. The *SPC files for the thirty spectral sections obtained from the radial spectral energy were exported into the Microsoft excel worksheet one after the other on a comma separated values (*csv*) file format. The Microsoft excel worksheets file data obtained was then used as an input file into a spectral program plot developed with Matlabsoftware. Graphical Results of logarithm of Spectral energy with respect to the frequency in cycles per kilometre which gives the spectral energy section generated from the Matlab program of which Figure 2.1 shows the sample result.

Results and Discussion

The results of the depth estimate for the 30 spectral sections (SPCA-SPCAD) are presented in Table 1. It gives summary of spectral result and obtained depths for basement depth (shallow depth) h_1, the Conrad discontinuity h_2, and the Crustal thickness (depth) h_3.

Table 1. Basement depth, Conrad depth and crustal thickness obtained from Spectral analysis

SPECTRAL SECTIONS	m_1	m_2	m_3	**BASEMENT DEPTH** h_1 **(km)**	**CONRAD DEPTH** h_2 **(km)**	**CRUSTAL THICKNESS** h_3 **(km)**
SPC A	-31.2	-68.4	-191	4.96	10.89	30.39
SPC B	-46.4	-74.1	-201	7.38	11.79	31.99
SPCC	-48.2	-74.3	-207	7.67	11.83	32.95
SPCD	-55.9	-92.6	-223	8.89	14.74	35.49
SPCE	-47.1	-96.1	-212	7.49	15.29	33.74
SPCF	-48.5	-79.6	-206	7.72	12.67	32.79
SPCG	-51.9	-94.5	-208	8.26	15.04	33.10
SPC H	-49.5	-92.4	-204	7.88	14.71	32.47
SPC I	-32.5	-85.5	-197	5.17	13.61	31.35
SPC J	-33.2	-74.7	-205	5.28	11.89	32.63
SPC K	-31.6	-83.5	-211	5.03	13.28	33.58
SPC L	-36.8	-86.6	-202	5.86	13.78	32.15
SPC M	-32.5	-97.7	-206	5.17	15.55	32.79
SPC N	-32.3	-95.8	-204	5.14	15.25	32.47
SPC O	-56.7	-87.7	-214	9.02	13.96	34.06
SPC P	-48.3	-82.2	-209	7.69	13.08	33.26
SPC Q	-50.2	-80.4	-208	7.99	12.79	33.10
SPC R	-46.5	-82.3	-219	7.40	13.09	34.85
SPC S	-49.9	-80.6	-206	7.94	12.83	32.79
SPC T	-58.5	-82.3	-209	9.31	13.09	33.26
SPC U	-51.3	-81.9	-202	8.16	13.03	32.15
SPC V	-54.2	-90.5	-212	8.63	14.40	33.74
SPC W	-48.9	-89.2	-212	7.78	14.19	33.74
SPC X	-47.7	-91.3	-208	7.59	14.53	33.10
SPC Y	-48.4	-92.3	-204	7.70	14.69	32.47
SPC Z	-55.5	-92.7	-206	8.83	14.75	32.79
SPC AA	-52.5	-89.7	-215	8.36	14.28	34.22
SPC AB	-53.3	-91.4	-212	8.48	14.55	33.74
SPC AC	-47.5	-73.4	-206	7.56	11.68	32.79
SPC AD	-47.4	-76.5	-208	7.54	12.18	33.10

The inspection of the results in Figure 2.1 reveals that three main slopes m_1, m_2 and m_3 representing slopes for shallow depth which is the basement, Conrad discontinuity and the crustal thickness was obtained.

From the earth's surface downwards, the slope (m_1) may be attributed to average depth of shallow sources from the crystalline rocks (basement and/or intrusions). Meanwhile, the slope m_2 is associated with the average depth to Conrad discontinuity which reflects a change in the rock type within the crust from dense silicon-aluminium rock type at the upper crust to denser silicon-magnesium rock type at the lower crust. However, slope m_3 may be connected with the average depth of the crustal thickness which comes about as a result of density contrast between the overlying crust and the underlying mantle.

There is need to contour the obtained depths from spectral technique in order to obtain a view of the crustal thickness across the study area in 2-Dimension and as such the average longitude and latitude values for each spectra section was included into the spectral results shown in Figures 2.2- 2.44.

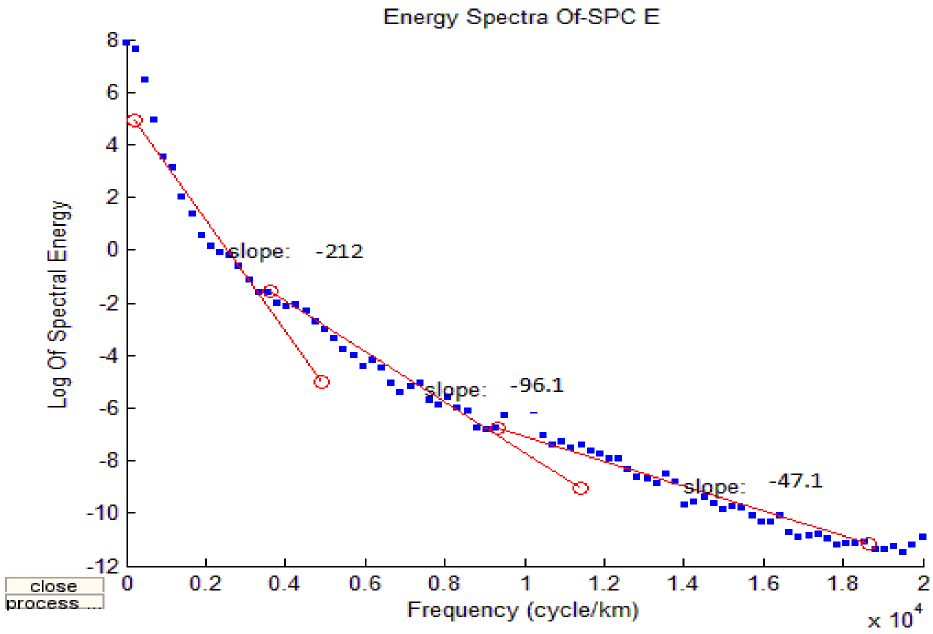

Figure 2.1: A graph of log of spectral energy against frequency spectral section E (SPC E)

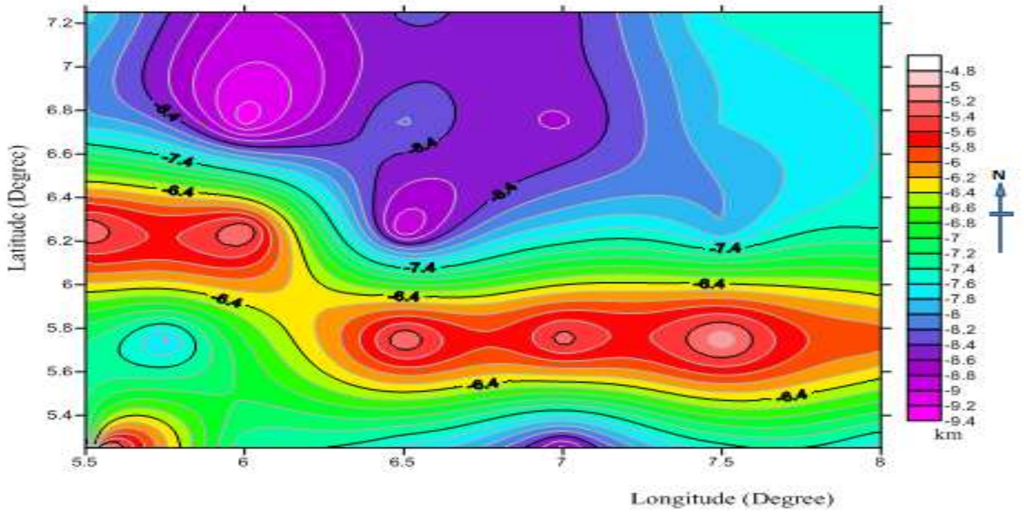

Figure 2.2: The basement depth map obtained from spectral analysis for the study area

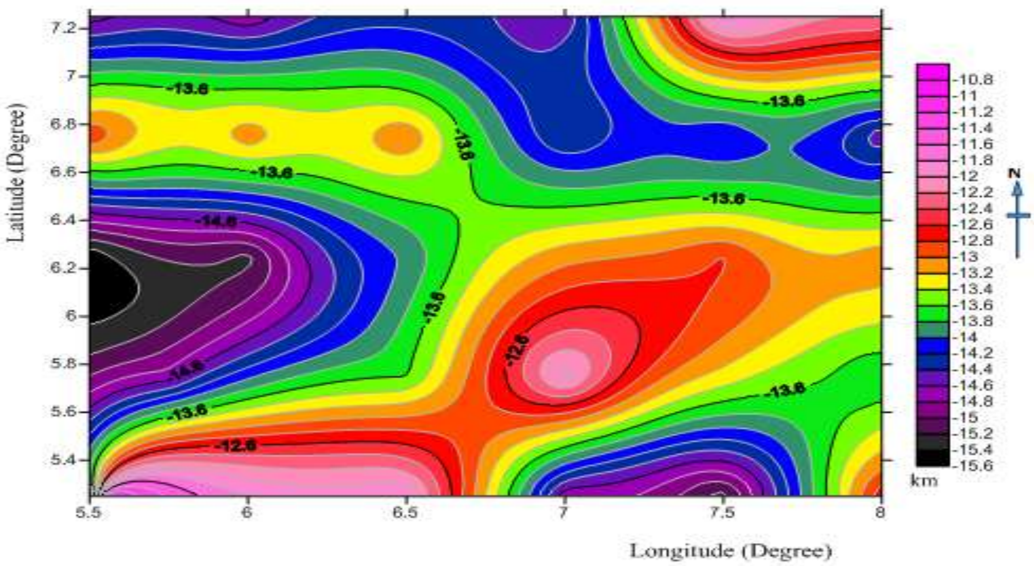

Figure 2.3: Contour map of conrad discontinuity obtained from spectral analysis for the study area

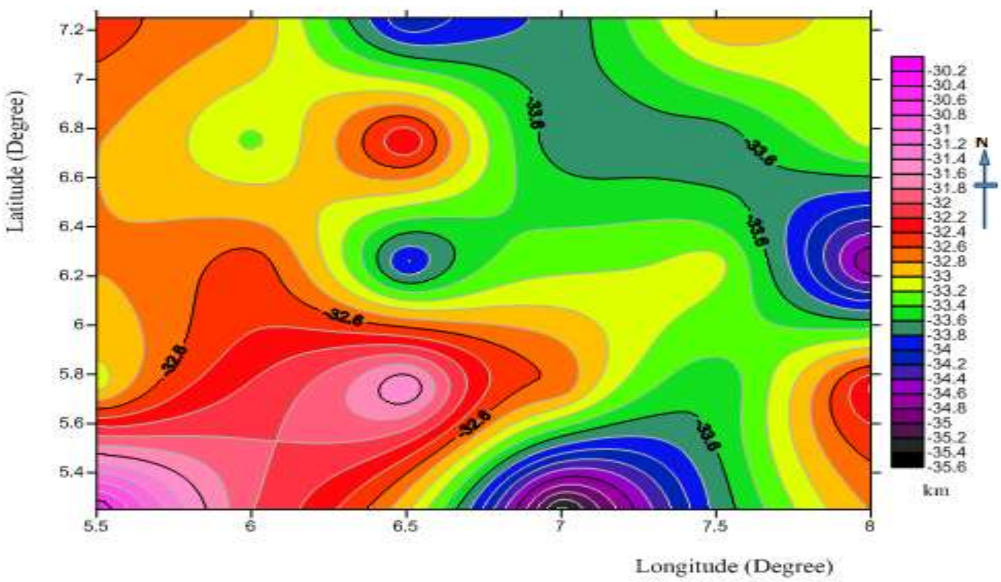

Figure 2.4: Contour map of the crustal thickness obtained from spectral analysis of the study area

The basement depth map, figure 2.2 shows the depth to the basement surface (sedimentary thickness) within the area which trend toward NW and SE region, ranges approximately from 4.8 km at its minimum level to9.4 km at its maximum level with an interval of 0.2 km. This thickness is below the stated maximum sedimentary thickness of the Niger delta of 14.2 km and Anambra (Emujakporue & Ofoha, 2015). The map exhibits common thickening of sedimentary cover towards the central region of the study area.

As can be seen in figure 2.3, the Conrad depth map shows the depth of Conrad discontinuity. This is the depth beneath the continent where the continental crust becomes close in physical properties to the oceanic crust. This is due to the change in velocity of seismic wave at this sub horizontal boundary. This depth ranges from -10.8 km at the minimum to -15.6 km at the maximum level with interval of 0.2 km within the study area. The low Conrad depth of -10.8 km shows that in the Niger delta and Anambra basin, the basement rock underlying the sediments is interpreted to be oceanic crust unlike other Sedimentary basins in Nigeria that are underlain by continental crust. This explains why the Conrad depth looks like the depth to basement as the range of the Conrad depth is interwoven with the range of the sedimentary thickness. The Conrad depth with highest thickness is seen at longitude 8.5^0W and latitude 15.5^0N and maximum value with the highest depth trending toward NW and shallow depth toward SE region within the study area.

From figure 2.4, the crustal thickness map reveals that the depth to the Moho achieved its maximum value of about 35.6 km along longitude 8.0^0E. This depth decreases gradually southward and westward reaching its minimum depth of30.2 km is seen at south-western part of the study area and maximum depth of -35.6 km is observed at the southern parts of the study area

Conclusion

Spectral analysis of Bouguer gravity data over some parts of southern Nigeria is presented. The results obtained from the interpretation of gravity data covering the study area based spectral analysis revealed three major depths with an average crustal thickness ranges from

-30.2 to -35.6 km. Findings show a good correlation in the average crustal thickness obtained in the present method and existing study (Emujakporue&Ofoha2015). In conclusion, the study area is made up of high crustal thickness (moho depth) ranging between -28 to -39 km and not located in any active plate boundaries (margins) which implies that the region is tectonically stable in terms of volcanic eruption and earthquake activities.

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