ESTIMATION OF THE DEPTH TO MOHO OF PARTS OF NORTH – CENTRAL, NIGERIA USING BOUGUER GRAVITY DATA

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Abstract
Estimation of the depth to Moho was carried out using Bouguer gravity data in parts of North Central Nigeria. Empirical relations were used on the Bouguer gravity data of the study area. Three empirical relations were used to calculate the Moho depth within the study area which are, Demenistkaya, Woollard, Woollard and Strange. Results of Moho depth obtained from empirical analysis ranges from 29.5 to 41.5 km for Demenistskaya, 28.50 to 36.0 km for Wollard, and 27.0 to 37.5 km for Woollard and Strange. The average of the three of the empirical relations were 28.5 to 38.5 km. The considerable Moho depth range of 28.50 to 38.5 km obtained within this tectonically stable area gives an indication that the tectonic stability of the area is further enhanced.

Keywords: Bouguer Gravity, Moho Depth, Empirical Relations.

Introduction
The Earth and its contents have long been of concern to mankind. Man has tried to unravel its complexity and delve into its origin using various geophysical methods. The Earth, which is the main planet that harbours life, was formed about 4.5 billion years ago. The Earth's surface has different types of features due to its complexity. The surface is unique from other planets because it is the only planet that has water in large quantities. Water forms some features of Earth's surface such as rivers, oceans, beaches and lakes. Other surface features, such as mountains, earthquake and volcanoes are formed when large pieces of the Earth's outer layer move slowly by plate tectonic (Engdahl *et al*., 1998). The subsurface has been of utmost concern to the geoscientists who attempt to research it using different means, some to obtain data while others do it for the examination of economic resources, for instance, minerals and hydrocarbon. With the advancement in development, technology and the need for a clearer picture of the earth subsurface and its substance, the earth scientist deem it necessary to utilise the properties associated with earth's interior.

Geophysics utilizes physical principles and quantitative physical measurements in order to study the earth's interior, its atmosphere and space. The investigation of these measurements can uncover how the earth interior varies both vertically and horizontally and the analysis of which can uncover significant information on the geological structures underneath. (Bonde *et al*., 2014). This study brought scientist to discover that the earth subsurface is divided into three sections-the crust, mantle, and core. The crust is the outer layer of the earth. It is also the solid rock layer of the earth. The crust being the upper surface of the earth, houses the ocean and the continent hence it is said to be divided into oceanic crust and continental crust. The thinner oceanic crust (7-12km thick) which carries water and the thicker continental crust (20-70km thick) which carries land. The mantle is the widest section of the Earth. It has a thickness of approximately 2900km. It is made up of semi-molten rock called magma. The rock magma is hard at the upper part of the mantle, but lower down the rock is soft and beginning to melt. The core is divided into two parts namely; the inner core and the outer core. The inner core is in the centre and is the hottest part of the earth. It is solid and comprises of iron and nickel with temperatures of up to 5,500 ℃. The outer core is the layer surrounding the inner core. It is a liquid layer, also made up of iron and nickel. It is extremely hot, with temperatures similar to the inner core. (Bonde *et al*., 2014).

The crust is separated from the underlying mantle by a boundary known as the Mohorovicic discontinuity. In otherwords, Mohorovicic discontinuity is the boundary between the Earth's crust and its mantle. The Mohorovicic discontinuity marks the lower limit of the earth's crust. Mohorovicic was able to use his discovery to study thickness variations of the crust. He discovered that the oceanic crust has a relatively uniform thickness while continental crust is thickest under mountain ranges and thinner under plains (Matrinic, 1994)

Determination of the mohorovicic discontinuity (Moho), which outlines the boundary between crust from the mantle (Lewis, 1983) is a major concern to geophysicist. Some geophysical parameters change at this surface, such as density, gravity field and speed of seismic waves. This moho interface can be imaged precisely through costly profound seismic profiling, but financial contemplations make gravity modeling a more applied approach for mapping Moho depth over regional scales (Jamal and Mahmoud, 2015). Figure (1) shows the image of the earth's internal structure showing the Mohorovicic discontinuity, the red line is the Mohorovicic discontinuity which separates the crust from the mantle.

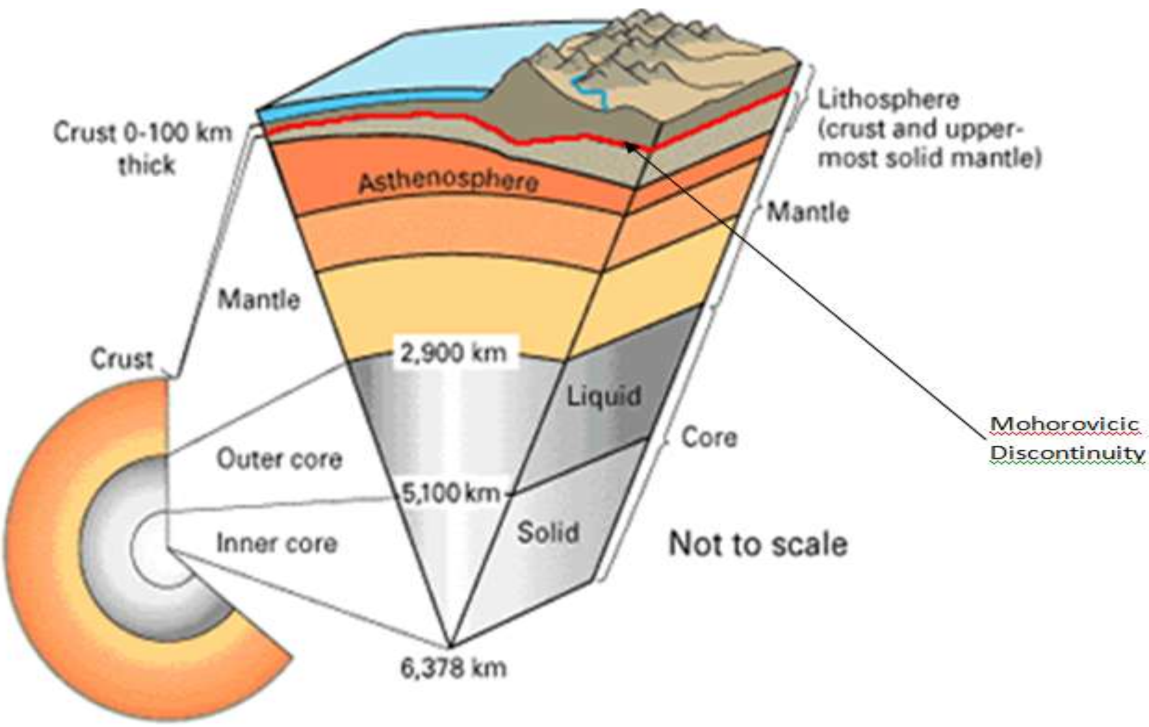

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Figure 1: Image of the Earth's internal structure showing the Mohorovicic discontinuity (red line) (Brown & Girlder, 1980)

Geology and Location of the Study Area

The area of study is part of North -Central Nigeria. It has high economic value as it contains some mineral resources and hydrocarbon. Kogi state which is part of the study area has a geological setting which is unique in view of the occurrence of the two major components of Nigerian geology (Basement Complex and Sedimentary Basin). Approximately, half of the State is covered by crystalline Basement Complex while the other half is covered by Cretaceous to Recent sediments (Bamidele, 2018)

The Basement Complex are predominantly underlain the western flank of the State. They are made up of Migmatite-Gneiss Complex which include rocks of migmatites, gneisses and granite-gneisses; the Schist Belts (metasedimentary and metavolcanic rocks) which include phylites, schists, pelites, quartzites, marbles and amphibolites; and the Pan-African Older Granites consisting of granites, granodiorites, syenites, monzonites, gabbro and charnockites. The crystalline complex contained economic minerals such as iron ore, gemstones, quartz, feldspar and other associated minerals, while the Pan-African Older Granite contained cassiterite, tantalite, columbite, gemstones and other associated minerals (Bamidele, 2018)

The eastern flank of the State is on the alluvium (youngest and most recent sedimentary rocks) and other sedimentary rocks, which form part of Cretaceous to Recent sediments of Nigeria. This area lies within the Anambra Basin and the geology is the same with the geology of the Lower Benue Trough, through south of the Benue River. It is mainly made up of different Formations of Nkporo, Mamu, Ajali and Nsukka. These Formations are inter-bedded with sandstones, siltstones, carboniferous-shale, coal, sandstones of fluvial marine nature with distinct across beddings and laterite. These Formations control the localization of coal, kaolin, clay, sandstones, limestone, gemstones, slate, phosphate, gypsum and other associated minerals (Bamidele, 2018)

The area of study which lies within parts of North- Central Nigeria except at the south east and south south region of the study area where Nsukka, Isoko, Auchi and Ubiaja are located is bounded by Longitude 6°.00°E and 8°.50°E and Latitude 7°00°N and 9.5°00°N with an approximate area of 75625km^2 (figure 2). Some towns found within the study area include: Aiyegunle, Kotonkarifi, Katakaga, Kogi, Kabba, Lokoja, Dekina, Isoko, Auchi, Idah, Ayigba, Ankpa, Ubiaja, Illushi, Nsukka and Igumale.

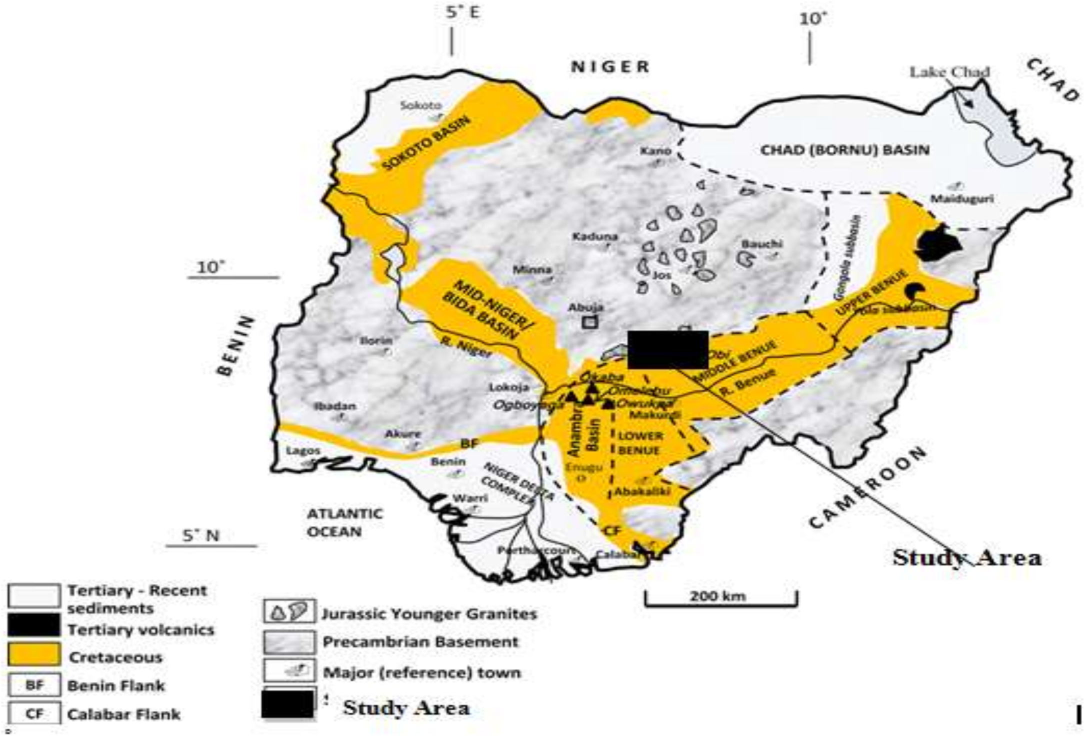

Figure 2: Generalized Geological Map of Nigeria Showing location of the study area (Akpan *et al.*, 2015)

Materials and Method

The materials used for this study include the following

Gravity data covering areas such as Aiyegunle, Koton karifi, Katakaga, Kogi, Kabba, lokoja, Dekina, Isoko, Auchi, Idah, Ayingba, Ankpa, Ubiaja, Illushi, Nsukka and Igumale

- Oasis Montaj Version 6.4.2
- Sulfer 13
- Matlab

Methodology

The following procedures were carried out on Bouguer gravity data to estimate the Moho depth for the study area as well as to ascertain the tectonic stability of the study area from Moho depth determined.

Digitization of the Map

Visual interpolation method was used to digitize the Bouguer gravity map of the study area to obtain data on grid layout to be used for qualitative interpretation. Digitization is simply a process of converting information into a digital (discrete) format so that computer and many devices with computing capacity can process.

Digitization has to be done properly and carefully since improperly recorded digital data can be totally worthless or completely misleading, and once the data have been improperly recorded digitally, it will be difficult to recover a correct data. The latitude and longitude position must be included 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 (6, 4, 7.0). This means longitude 6, latitude 4, data 7.0. (Lawrence, 2017)

All the available Bouguer gravity anomaly map was gridded at an interval of 10 km as gridding at smaller intervals may introduce aliasing (Noise) and also crustal thickness is a regional feature and as such does not vary rapidly as most surface features. The data from each digitized map is recorded in a coding sheet which contains the longitude, latitude and the Bouguer gravity anomaly data (BG).

Gridding

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. Gridding is the first step in the data processing which interpolates the Bouguer anomaly values of the data base to a square grid. The interpolation methods of (x, y and z) data within Geosoft Oasis Montaj software are Bi-directional, Minimum curvature and Kriging.

For this study, 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 this case the curvature of surface is minimised.

Contouring

There are techniques use in determining elevations or altitudes and depths on maps which Contouring is one of them. Contours are one of the several methods of such that can be used to denote elevation or altitude and depths on maps. From these contours, an idea of the general terrain can be deduced and determined. Topographic maps are contour lines that show the shape of the earth. The shape of the land surface is shown by contour lines which join points 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), determining the geological history of an area, predicting future geological movement and unconformities. Before contouring, the data are arranged in three columns in form of X, Y and Z where X, Y, and Z represent longitude, latitude and Bouguer gravity anomaly values respectively. These contour maps are the bases of the gravity interpretation before the development of the computer programs. Software such as Sulfer 13 produces these Contour maps. Nowadays, the gravity data is displayed as colour maps, where the colour represents 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 all the 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.

Determination of Moho depth by Empirical relations

The empirical relations were developed by Demenitskaya (1958), Woollard (1959), Woollard and Strange (1962). The respective empirical relations are:

$$H_D = 35(1\text{-TANH}(0.037)BG) \quad (1)$$

$$H_W = 32.0 - 0.08BG \quad (2)$$

$$H_{WS} = 40.50 - 32.50\ \text{TANH}\left(\frac{BG+75}{275}\right) \quad (3)$$

where;

H_D = Demenistkaya relation in kilometre for Moho depth calculation

H_W = Woollard relation in kilometre for Moho depth calculation

H_{WS} = Woollard and Strange relation in kilometre for Moho depth calculation

BG = Bouguer gravity anomaly in milligal (mGal)

The dataset comprising of Bouguer gravity data anomaly for the study area in the form of (x, y, BG) was inputed into Microsoft excel software for application of empirical relations to estimate the Moho depth of the study area. To mathematically estimate the Moho depth of the study area, the empirical relations was used. Empirical relations show linear relationship between Bouguer gravity anomaly (BG) and the Moho depth (H). To determine the Moho depths from equations 1, 2 & 3, the average result obtained from these three relations at any given location is taken as the estimated Moho depth at that particular location (Raid et al., 1981).

Results and Discussion

Bouguer Gravity Anomaly

Figure 3 shows the Bouguer gravity anomaly map of the study area with contour interval of 5 milligal was produced using surfer package. The Bouguer gravity map of the study area (Figure 3) shows that the gravity values trends in the SW-NE direction. The gravity values ranges from -50milligal at the North eastern parts of the study area which increases Southwards and reaches 45mGal at the central region of the study area.

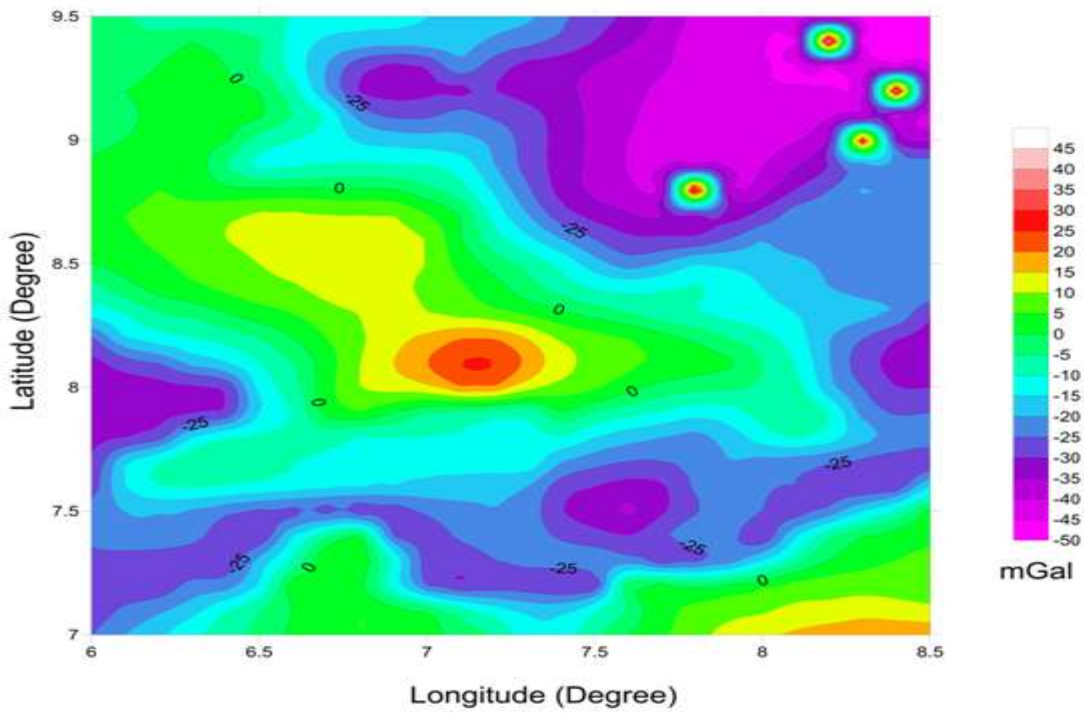

Figure 3: The Bouguer Anomaly Map of the Study Area

Empirical Calculations

The values of the digitised gravity data were inputted into the excel spread sheet to calculate the depth to Moho using equations 1, 2, & 3 and also the average Moho depth for each point calculated. Table 1 shows the results of the empirical relation. The Moho depth of the study area obtained from the three empirical relations was averaged as shown in table 1.0 and contoured using ''SURFER'' graphic package. The average values obtained from the three relations at any given location is the Moho depth at that location

Table 1: Results of Empirical Calculations of depth to Moho

LONGITUDE (Degree)	LATITUDE (Degree)	BG (mGal)	H_D (Km)	H_W (Km)	H_{WS} (Km)	AVERAGE $H_D + H_W + H_{WS}/3$ (Km)
6.00	7.00	-25.00	38.23	34.00	34.65	35.63
6.10	7.00	-20.00	37.58	33.60	34.08	35.09
6.20	7.00	-16.00	37.07	33.28	33.63	34.66
6.30	7.00	-11.00	36.42	32.88	33.07	34.12
6.40	7.00	-7.00	35.90	32.56	32.62	33.69
6.50	7.00	-4.00	35.51	32.32	32.29	33.37
6.60	7.00	1.00	34.87	31.92	31.74	32.84
6.70	7.00	3.00	34.61	31.76	31.52	32.63
6.80	7.00	5.00	34.35	31.60	31.30	32.41

6.90	7.00	3.00	34.61	31.76	31.52	32.63
7.00	7.00	2.00	34.74	31.84	31.63	32.73
7.10	7.00	-3.00	35.38	32.24	32.18	33.26
7.20	7.00	-5.00	35.64	32.40	32.40	33.48
7.30	7.00	13.00	36.68	33.04	33.29	34.33
7.40	**7**.00	-13.00	36.68	33.04	33.29	34.33
7.50	**7.**00	-6.00	35.77	32.48	32.51	33.58

Empirical Result

Figure (4) represents the map of Demenistskaya relation, the moho depth ranges between 29.5 km and 41.5 km and Figure (5) shows the map of Wollard relation, the value ranges between 28.5 km and 36.0 km while Figure (6) shows the map of Wollard and Strange relation, the value ranges from 27.0 km and 37.5 km. Figure (7) shows the average empirical relation of Demenistskaya, Wollard, Wollard and Strange. The average empirical map showed that the moho depth ranges from 28.5 km and 38.5 km. The three empirical relations and the average have the same contour interval of 0.5 km and follow the same trend of maximum Moho depth located around the North Eastern, South Eastern and South Western region while its minimum Moho depth is located around the central region of the study area. This decrease and increase of Moho depth of the study area could be as a result of the Basement Complex and Sedimentary Basin found in the study area. The Basement Complex are predominantly underlain the western flank of the area.

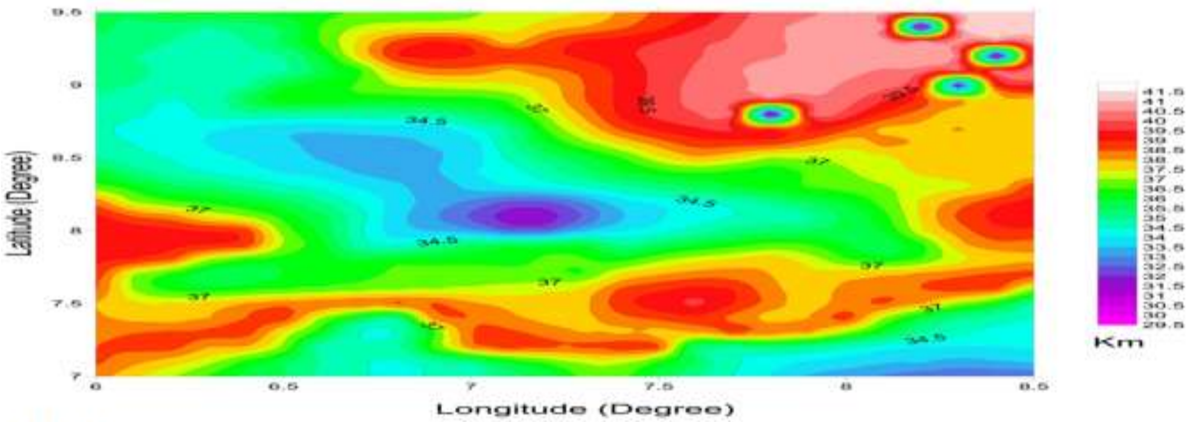

Figure 4 : The Contour map of Moho depth obtained using Demenistkaya empirical relation for the Study Area

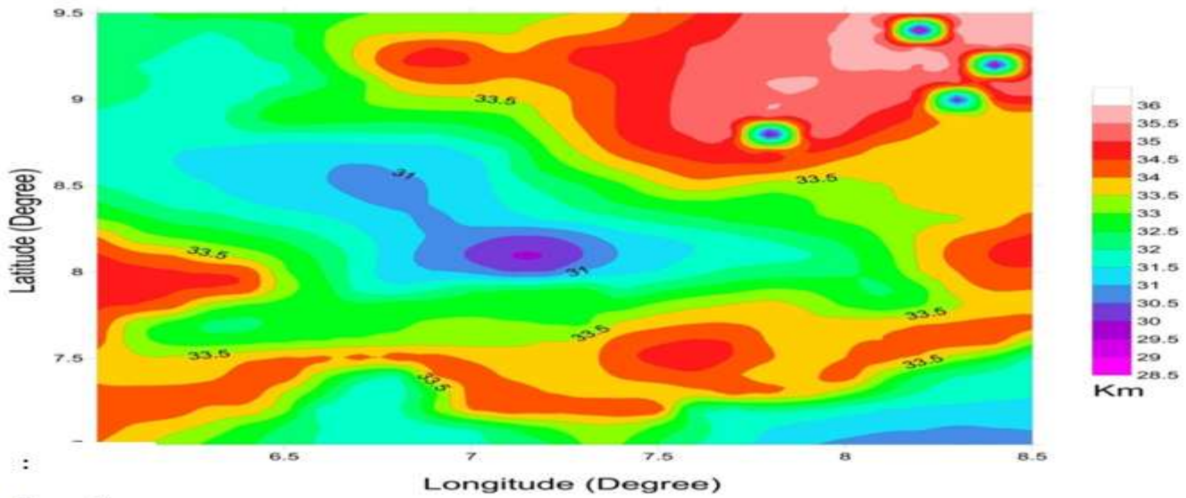

Figure 5: The Contour map of Moho depth obtained using Wollard empirical relation for the Study Area

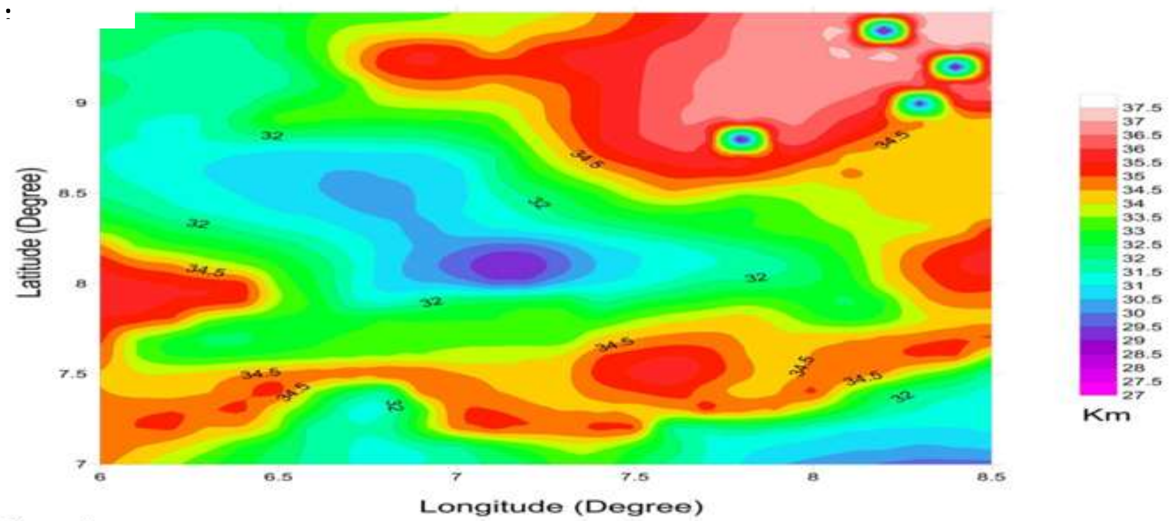

Figure 6: The Contour map of Moho depth obtained using Wollard and Strange empirical relation for the study area

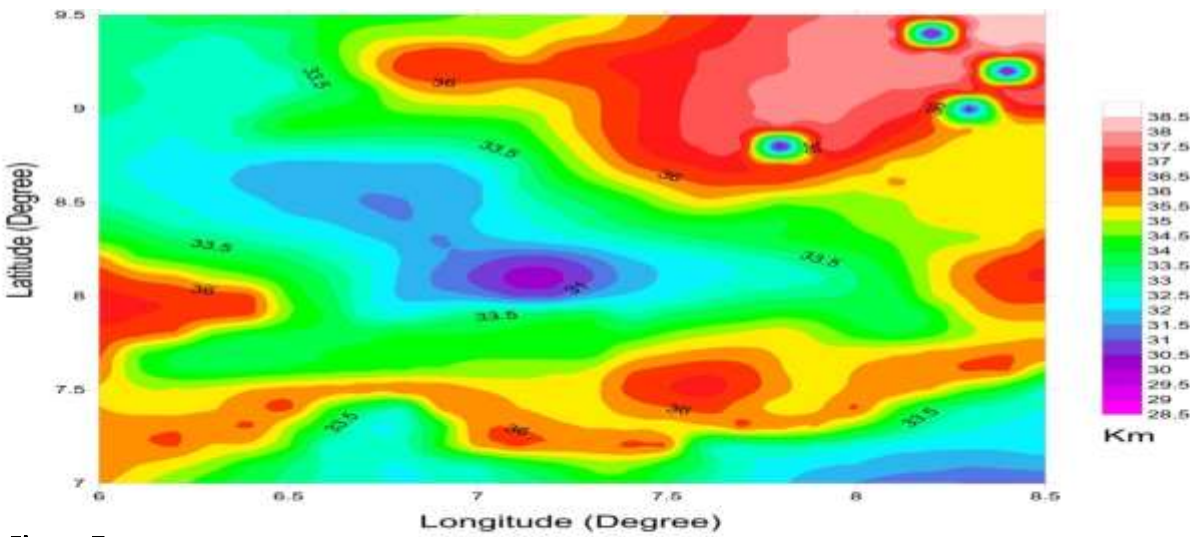

Figure 7: The Contour map of average Moho depth obtained using the three (3) empirical relations for the Study Area

Conclusion and Recommendation

Conclusion

From the Empirical Method using Demenistkaya, Wollard, Wollard and Strange, the average Moho depth ranges from 28.5 km to 38.5 km for the study area. This is closely in line with Jean et al (2014) that estimated the Moho discontinuity of the Cameroon volcanic line using gravity data and obtained a result of Moho depth between 30 – 34 km.

Based on the results obtained from Empirical, in this study, it is possible to conclude that the study area is tectonically stable, even though the tectonic stability of the study area is not dependent on the Moho depth but on its location on a plate boundary and on a passive margin of the Atlantic Ocean that is free from diastrophic activities. Although, considerable Moho depth gotten from a tectonic stable region can further enhance the tectonic stability of that region.

Recommendation

It is recommended that other geophysical methods like seismic studies should be carried out in the study area for a more detailed and confirmation of this result

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