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Estimation of Crustal Thickness within the Sokoto Basin North-Western Nigeria Using Bouguer Gravity Anomaly Data

T. T. Olugbenga, A. I. Augie

Abstract**—**This research proposes an interpretation of the Bouguer' gravity anomaly data of some parts of Sokoto basin for the estimation of crustal thickness. The study area is bounded between latitudes $11^0$0′0″N and $13^0$0′0″N, and longitudes $4^0$0′0″E and $6^0$0′0″E that covered Koko, Jega, B/Kebbi, Argungu, Lema, Bodinga, Tamgaza, Gunmi,Daki Takwas, Dange, Sokoto, Ilella, T/Mafara, Anka, Maru, Gusau, K/Namoda, and Sabon Birni within Sokoto, Kebbi and Zamfara state respectively. The established map of the study area was digitized in X, Y and Z format using excel software package and the digitized data were processed using Surfer version 13 software. The Moho and Conrad depths based on a relationship between Bouguer' gravity anomaly determined crustal thickness were estimated as 35 to 37 km and 19 to 21 km, respectively. The crustal region has been categorized into: Crustal thinning zone that is the region with high gravity anomaly value due to its greater geothermal energy and also Crustal thickening zone which the region with low anomaly values due to its lower geothermal energy. Birnin kebbi, Jega, Sokoto were identified as the region of hydrocarbon potential with an estimate of 35 km thickness within the crustal region which is referred to as crustal thickening as a result of its low but sufficient geothermal energy to decompose organic matter within the region to form hydrocarbons.

Keywords**—**Bouguer gravity anomaly, crustal thickness, geothermal energy, hydrocarbons, Moho and Conrad Depths.

I. Introduction

THE Nigerian section of the Iullemmeden basin is a major structure in West Africa which has attracted the attention of geologists, geophysicist, and hydro-geologists [1]. The Basin is characterized by the existence of interesting geological structures, the presence of zones of mineralization of economic importance and potential for hydrocarbon [2], [3].

This study employed gravity method using bouguer gravity data to estimate the crustal thickness of some part Sokoto basin North-western part of Nigeria. The aim of the study is to determine the Moho and Conrad depths from bouguer gravity anomaly data in order to estimate the crustal thickness of some part of Sokoto Basin. This would be achieved by; digitize the bouguer gravity anomaly data, produce the contour map of the bouguer gravity anomaly data within the study area, produce the Moho and Conrad map within the study area, determine the thickness of the crust (Moho- discontinuity between the lower crust and the upper mantle), the Moho and the Conrad depth. The research has relevant significance in locating a region of crustal thinning with low gravity anomaly value and the region of crustal thinning that has the potential of hydrocarbon prospects.

Gravity geophysical method has been widely used since its inception [4]. The use of this method makes it possible for geophysicists to acquire data regardless of ownership or accessibility of remote lands of interest [5]. The gravity method is a nondestructive geophysical technique that has the ability to measures differences in the earth‘s gravitational field at specific locations [6]. The method has found many applications in engineering and environmental studies that normally used to detect; voids/or karst features, buried stream valleys, structural features, water table levels and the determination of soil layer thickness [7]. It usually depends on the different earth materials (rocks) having different bulk densities (mass) that primarily lead to produce variations in the measured gravitational field [7], [8]. These variations can then be processed and interpreted by a variety of analytical and computers methods in order to determine the depth, geometry and density the causes the gravity field variations [9].

The gravity method can be a relatively easy geophysical technique to perform and interpret [10]. It requires data processing, and for detailed studies the determination of a station‘s elevation is the most difficult and time-consuming aspect [9], [10]. The technique has the ability to achieve desired depth of penetration when compared to ground penetrating and is not affected by the high conductivity values of near-surface clay rich soils. Furthermore, lateral boundaries of subsurface features can be easily obtained especially through the measurement of the derivatives of the gravitational field [11]. The main drawback is the ambiguity of the interpretation of the anomalies, meaning that given gravity anomaly can be caused by different source bodies on both surface and subsurface of the earth. However, in order to determine the accurate source of these gravity anomalies, the geophysical or geological information is required [12].

The basis on which the gravity method depends is encapsulated in two laws derived by Sir Isaac Newton, namely his universal law of gravitation and his second law of motion [13]: Newton’s Universal Law of Gravitation states that the gravitational force is proportional to the product of the two masses (M, m) attracting each other as well as inversely

A. I. Augie, is with the Department of Applied Geophysics, Federal University Birnin Kebbi, Kebbi State, P.M.B 1157 Nigeria (corresponding author, phone: +2348137330559; e-mail: ai.augie@fubk.edu.ng).

T. T. Olugbenga is with the Ministry of Mineral Resources, Bayelsa State, Nigeria (phone: +2347032514071; e-mail: olugbengatheophilus@gmail.com).

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proportional to the distance (d) squared between them:

$$F = \frac{GMm}{d^2} \quad (1)$$

where G is the gravitational constant $6.67\times10^{-11}\text{Nm}^2\text{ kg}^{-2}$.

Newton's second law of motion states that a force is equal to mass (m) times acceleration (g): combining the two basic equations yields another simple expression:

$$F = mg \quad (2)$$

Equating (1) and (2)

$$F = \frac{GMm}{d^2} = mg \quad (3)$$

$$g = \frac{GMm}{d^2} \quad (4)$$

Let's substitute d with the R (radius of the Earth) in order to describe acceleration g, on the subsurface or earth surface due to the M (mass of the earth) itself.

$$F = \frac{GMm}{R^2} \quad (5)$$

Therefore, the acceleration expressed in (5) is only dependent on the R (radius) and the M (mass of the Earth). Theoretically, the acceleration g should be unchanged (constant) over the Earth in different locations. In reality, however, gravity varies from place to place because the Earth has the shape of a flattened sphere (i.e. d is not constant), rotates, and has an irregular surface topography and variable mass distribution (especially near the surface). The shape of the Earth is a consequence of the balance between gravitational and centrifugal forces causing a flattening to form an oblate spheroid, mathematically referred to as ellipse of rotation [6], [13]. It is further helpful to define a hypothetical gravity surface, called the geoid. The shape of the surface that the oceans would form if left undisturbed by wind, tides etc. is defined as the geoid. Irregular mass distributions in the Earth disturbs (warps) the geoid so that it is not identical to the ellipse of rotation [14].

II. Location and Geological Setting of the Study Area

The study area is located in some part of Sokoto, Kebbi and Zamfara State North-Western Nigeria. The study area lies between latitudes $11^0 0'0''$N and $13^0 0'0''$N, and longitudes $4^0 0'0''$E and $6^0 0'0''$E. These areas covered; Koko, Jega, B/Kebbi, Argungu, Lema, Bodinga, Tamgaza, Gunmi, Daki Takwas, Dange, Sokoto, Ilella, T/ Mafara, Anka, Maru,Gusau, K/Namoda, and Sabon Birni (Fig. 1).

The Sokoto Basin of Nigeria forms the Southeastern sector of the Iullemmeden Basin, one of the young (Mezoic-Tertiary) inland cratonic sedimentary basins of West Africa [15]. The Iullemmeden Basin of West Africa extends from Mali and the Western boundary of the Republic of Niger through northern Benin Republic and northwestern Nigeria into eastern Niger [16].

The entire basin which covers an area of about 800,000 km^2, has its centre in the north of Niamey in Niger Republic, and lies entirely within the Pan African province of West African. There are three major fault trends in the basin [1]. These faults are responsible for the existence of several structural depressions within the basin [1], [15].

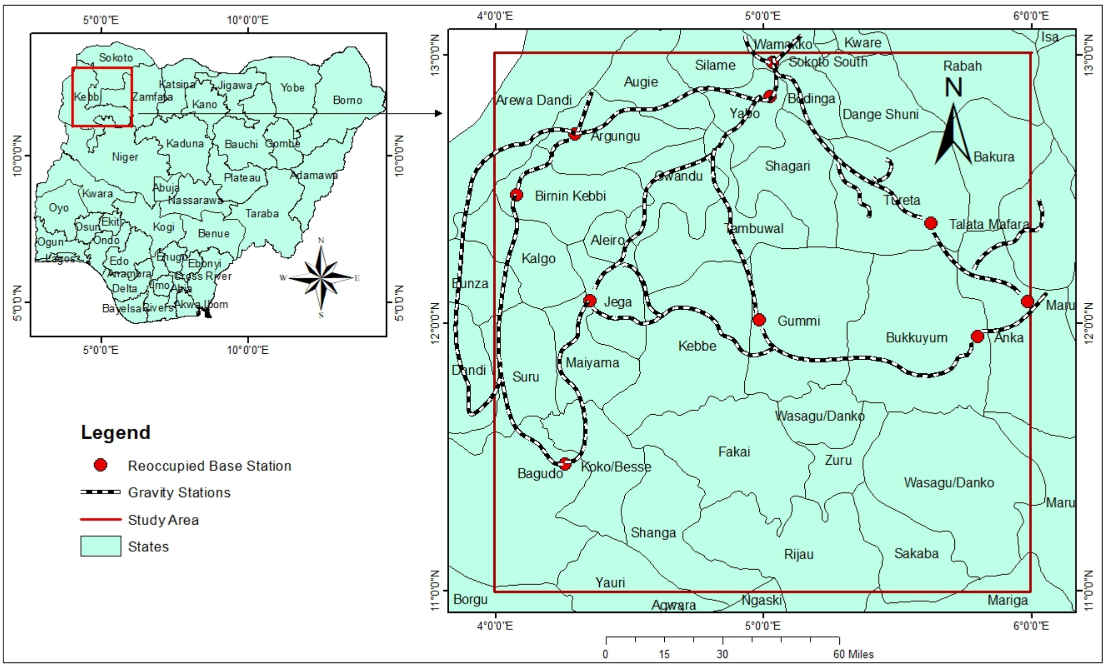

Fig. 1 Location of the Study Area

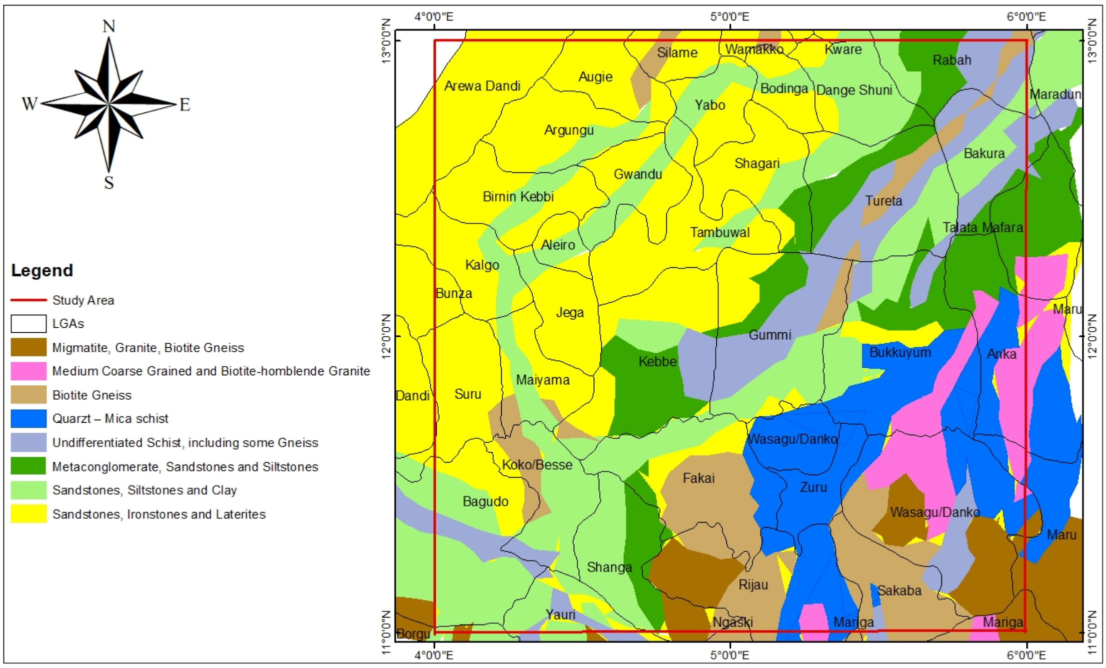

Fig. 2 Geological Map of the Study Area

The major part of the study area is underlain by younger sedimentary rocks consisting mainly of sandstones, siltstones, clays shale's, limestone and laterites (Fig. 2). The sedimentary rocks in the mapped area can be grouped into four major rock types: siltstone (with fine-grained sandstone), medium to coarse-grained sandstone, shale and limestone [16]. Generally, Sokoto basin is divided into two groups, Sokoto group and Rima group. The latter consists of Dukamaje Formation, Kalambaina Formation, Taloka Formation, Illo Formation and Gundumi Formation, while the former group consists of Gwandu Formation, Dange Formation and Wurno Formation [17]

III. Materials and Method

The main material for this study is an established Bouguer gravity anomaly map of some part Sokoto basin measured in mGal. Other relevant materials include a software package (Oasis Monstaj Version 6.4.2 and Surfer Version 13), a meter rule, a paper and a pen, a personal computer and a Microsoft Excel package. The ground gravity survey which is usually a passive, low impact, non-invasive geophysical technique used instrument called a gravimeter for data acquisition. It transported by one person with a backpack and weighs roughly 8 kg. The instrument was carried to the measurement station, placed on the ground surface, and levelled. The measurement takes a few minutes, and then the instrument was picked up thereby transported it to the next station.

A. Digitization of the Bouguer Gravity Anomaly Map

Digitizing is the process that involves picking gravity values across a gridded line. Having digitized the map, the data were stored in a computer storage device and subsequently fed into a computer program (Surfer 12). This program was written to pick all the data points row by row, calculate the longitude and latitude using base values already supplied. The output is in the form of columns of x, y, z where x, y and z represent longitude, latitude and gravity value respectively. The results obtained will be fed into a contouring package called Surfer.

B. Digitization of the Bouguer Gravity Anomaly Map

Moho depth can be estimated from gravity anomaly data. [18], [19] give the empirical relationships between Bouguer anomaly and crustal thickness for whole earth as follows:

$$H = 32 - 0.008\Delta g \tag{6}$$

$$H_c = 18.6 - 0.031\Delta g \tag{7}$$

where Δg is the gravity anomaly, H is the Moho depth and Hc is the Conrad depth. Reference [20] proposed the other empirical relationships to estimate Moho depth from gravity data as:

$$H = 29.98 - 0.0075\Delta g \tag{8}$$

Recently, these relationships have been applied successfully by several authors to gravity data [7], [8], [21]. In this study, the Moho and Conrad depths of the study area were estimated from (6) and (7) respectively.

IV. Results and Interpretation

Figs. 4, 5 and 6 are the results for estimation of the crustal thickness of some part of Sokoto basin. The bouguer gravity anomaly map (Fig. 4) of the study area mainly reflects the general geological structure of the surface and the sub-surface (Fig. 2). The anomaly is negative with values ranging from mainly -42 to -64 mGal in the north-east to south-west trend as showed in the contour map.

The Moho depth (discontinuity between lower crust and upper mantle) and the Conrad depth (discontinuity between upper and lower crust) of the study area shown in Figs. 5 and 6 were calculated using (6) and (7) respectively to estimate the crustal thickness over the study area.

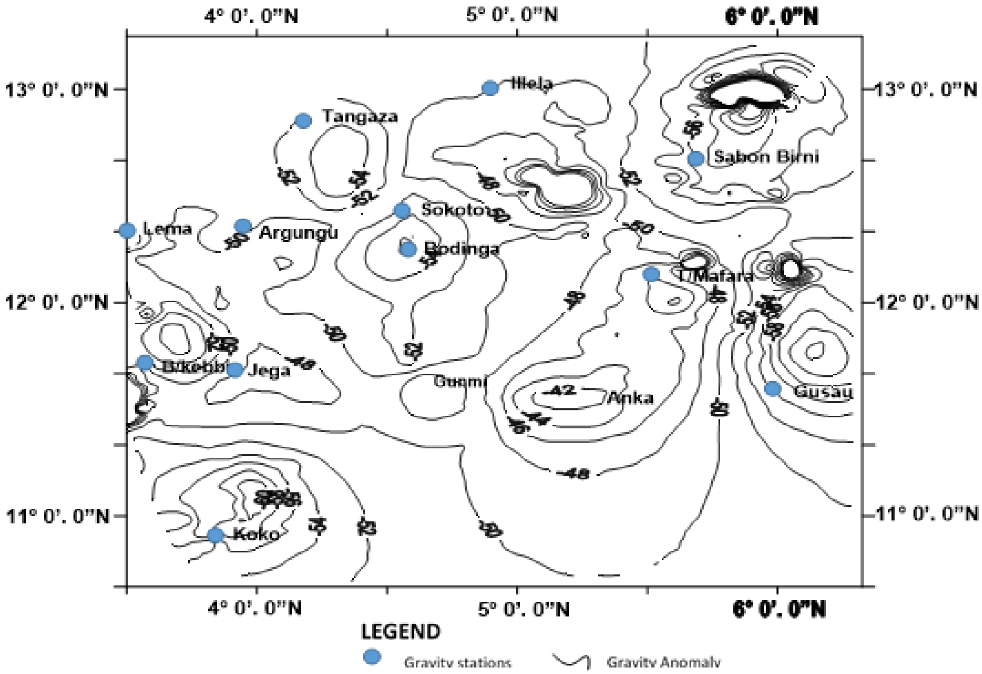

Fig. 3 Bouguer Anomaly Map of the Study Area Showing the Gravity Anomaly Values and their Respective Stations within Sokoto Basin. (Contour Interval 2mgals)

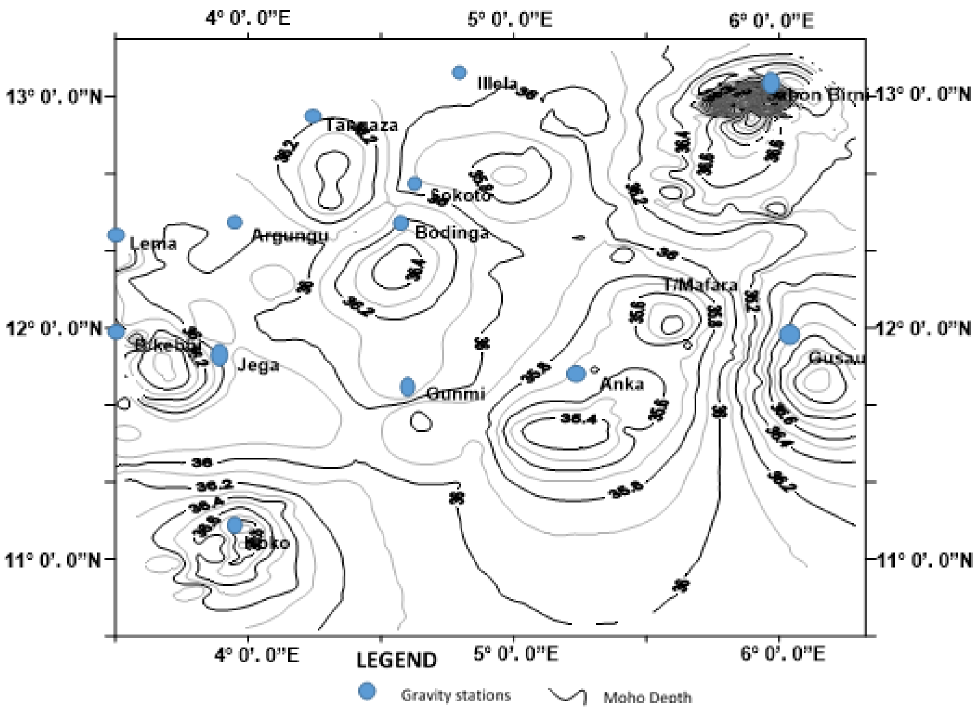

Fig. 4 Contour Map Showing the Moho Depth of the Study Area

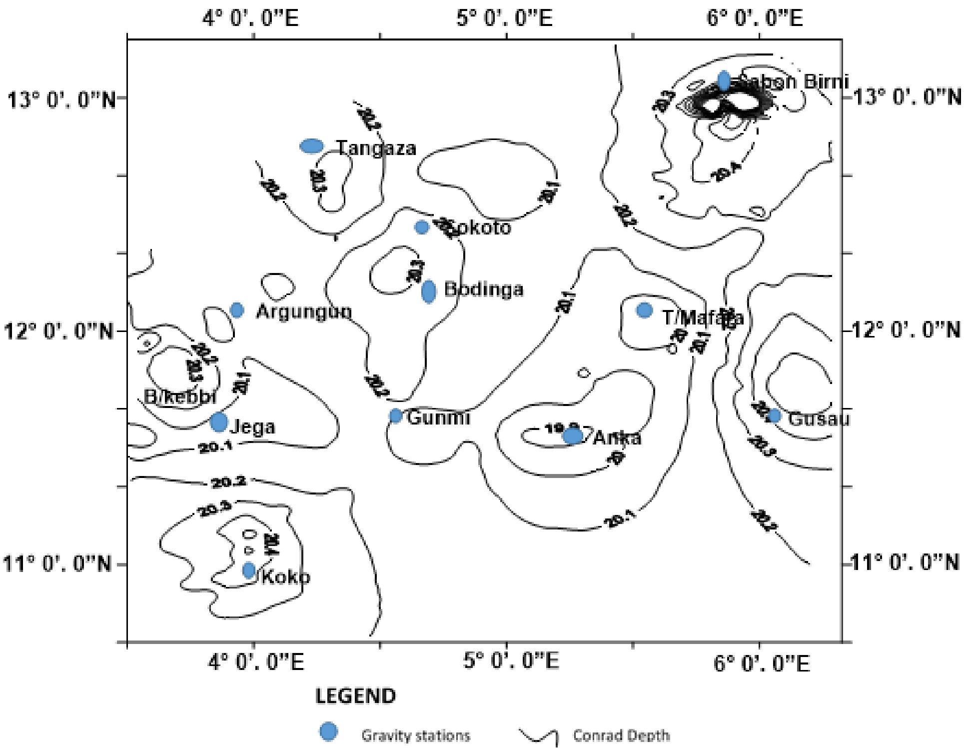

Fig. 5 Contour Map Showing the Conrad Depth of the Study Area

It was observed that Fig. 5 shows the Moho depth of the study area ranging from 35 km to 37 km with the average of 36 km and Fig. 6 shows Conrad depth ranging from 19 km to 21 km with the average of 20 km respectively. The contour map (Fig. 4) produced shows the anomaly values of -52, -48 and -50m Gal termed as crustal thickening caused by low geothermal energy at the locations of Birnin Kebbi, Jega and Sokoto. These regions of low geothermal energy indicated the presence of hydrocarbon potential. The low geothermal energy was sufficient to decompose organic matter within the region to form hydrocarbons. Hydrocarbon generations are traceable to organic sources which eventually decompose in the course of time under certain buried temperature condition in a sedimentary basin.

The region with higher anomaly values of -58, -60 and -62 mGal respectively such as Koko, Sabon Birnin, Gusau do not have hydrocarbon potential due to high geothermal energy which decomposed the organic matter within the region completely leaving the region without any trace of hydrocarbon. These crustal regions are referred to as Crustal thinning. The locations; Birnin kebbi, Jega, Sokoto were identified as the region of hydrocarbon potential with an estimate of 35 km thickness within the crustal region which is referred to as crustal thickening as a result of its low but sufficient geothermal energy.

V. Conclusion

An estimation of the crustal thickness using Bouguer anomaly data of some part of Sokoto basin indicated that the average thickness of Moho (i.e. discontinuity between lower Crust and upper mantle) of the study area was 36 km and that of Conrad (i.e. discontinuity between upper and lower crust) was 20 km. The crustal region of the study area has been categorized into: Crustal thinning (region with high gravity anomaly value due to its greater geothermal energy) and Crustal thickening (region with low anomaly values due to its lower geothermal energy). The region with low geothermal energy was identified as the region with hydrocarbon potentials.

It is highly recommended that other geophysical techniques such as seismic methods and electromagnetic methods should be used for further investigation over the study area so as to compare and contrast the results obtained from this study. It is also recommended if the government can pull resources together to exploit these areas of greater geothermal gradient in order to generate electricity and the region with hydrocarbon potential which will in turn boost the economy.

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