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QUANTITATIVE DEPTH ESTIMATION USING ANALYTIC SIGNAL AT LOW-LATITUDE FOR GROUND GRAVITY SURVEY OF GBEDE, OYO STATE

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ABSTRACT

This paper presents the insitu gravity survey of basement complex rock in Southwestern Nigeria. In the E-W direction, LaCoste and Romberg Gravity Meter type G309 was used to carry out a ground gravity survey where ten traverses were established over a distance of 1000 m by 500 m with station spacing of 20m and a traverse interval of 50 m. Observed gravity values were corrected, analyzed and interpreted quantitatively. The corrected bouguer gravity data were presented as bouguer anomaly graphs. Analytic Signal at low-latitude was adopted to compute the depth to source of iron-ore for a contact, a thin sheet (dyke) and a horizontal cylinder. The result revealed a depth range of 5.45 m-8.25 m for a contact, 9.44 m-14.29 m for a thin sheet (dyke) while a depth range of 12.31 m-18.05 m was estimated for a horizontal cylinder respectively. An average depth of 11.81±3.64 m was estimated for the entire area irrespective of the structural model, this was compared with published magnetic results of the study area and a small disparity of potential field measurements was recorded. The overall computed results signified the existence of iron mineral deposits at low depths across the study area.

INTRODUCTION

Researches on the Precambrian basement complex of Nigeria have attracted the attention of many geophysicists, in particular to determine the position and depth of fault established by gravity anomalies in the basement rocks. The gradual diminishing prospect of crude oil dependency in Nigeria conversely presents the need for the Country's diversification and resuscitation of the solid mineral sector.

Gravity study is a non-vicious geophysical technique that estimates the disparity in the gravitational field of the Earth at varying positions. Gravity prospecting can be conducted insitu on the earth's surface as ground gravity survey, in the air, as airborne or aerogravity survey, and at sea as marine gravity survey. Gravity studies are applied for enormous scope crustal examination, where estimations of earth's gravitational field are utilized for mapping variations in subsurface rocks densities, basement topography, sedimentary basin and its underlying engineering, and for territorial groundwater investigation (El-Bohoty *et al.*, 2012; Mandal *et al.*, 2013; Biswas *et al.*, 2014 and Sultan *et al.*, 2017). Other applications include a variety of engineering and environmental problems such as the location of shallow subsurface voids, faults and the thickness of soil layers amongst others.

In many ways, gravity data can be utilized from numerous points of view to take care of various exploration issues, depending upon the geologic setting and rock boundaries (Ezekiel *et al.*, 2013; Okiwelu *et al.*, 2013). After analysis, the data give understanding and insight to components of petroleum investigation and production (Johnson, 1998 and Obiora *et al.*, 2016).

Gravity technique works in light of the fact that distinctive earth materials have various densities (mass) and subsequently produce diverse gravitational fields. Gravitational field disparities can be translated to determine a source's depth estimate, geometry and its thickness. The method has great depth penetration in comparison with other methods such as ground penetration radar, high frequency electromagnetic and dc-resistivity methods and is not influenced by high conductivity estimations of close surface clay rich soils (Mickus, 2004).

There are previous studies carried out on gravity in Nigeria, such include; the study of gravity anomalies in some parts of Niger Delta area in Nigeria by Ekpa *et al.* (2018), where through the analysis of aerogravity data, gravity anomalies in parts of the Niger Delta area were investigated with the goals of determining the thickness of the sedimentary basin, establishing basement topography, density contrasts, and geological models that will provide information about variation of geological structures. Also, in the structural estimation of bouguer gravity data covering parts of Southern Niger Delta, Ofoha *et al.* (2018) employed gravity survey to evaluate structures that could serve as passage and entrapments for hydrocarbon and other earth resources. In the Geophysical investigation in the lower Benue Trough by Ugbor and Okeke (2010), ninety eight gravity stations were established and analyzed in Akataka and environs in Abakaliki, the residual anomaly data further reveal the geometry of the buried body which was determined from the interpretation of the gravity anomalies.

The evaluation of gravity data derived from Global Gravity Field Models using Terrestrial gravity data in Enugu (Apeh *et al.*, 2018) and the application of high-resolution gravity data for litho-structural and depth characterization at Igbabi area (Okpoli and Akigboye 2019) are earlier research works also carried out in Nigeria.

Equally, gravity method was used in Tanjung Gunung Village of Indonesia to determine Tin zone as reported by Mardiah *et al.* (2018), while delineation of the Sumatra fault in the Central part of West Sumatra based on gravity method was carried out by Saragih and Brotopuspito (2018). Ismail *et al.* (2018) applied the gravity method to map the buried ancient structure while the computation of residual and regional anomaly of gravity method by Polynomial filter using Microsoft Excel was published by Mahajirin *et al.*(2020) amongst many others.

The economic prospective and minable potential of Iron-Ore deposit in Gbede, Southwestern Nigeria using magnetic method by Adegoke and Layade (2019) necessitated the gravity study to further reveal the state of affairs of the subsurface geological structures. Therefore, in this study, the ground gravity method was used to estimate the depth of iron deposited mineral materials through the analytic signal approach at low-latitude.

Description and Geology of the Study Area

Gbede is situated in Surulere Local Government Area of Oyo-State and lies between latitudes $N8^o17'37.7''$ to $N8^o17'49.8''$ and longitude $E4^o20'45.9''$to $E4^o20'58.8''$ within the Precambrian basement complex of the southwestern Nigeria. The region is a division of the larger mobile Pan-Africa belt between the West African Craton and the Congo Craton suspected of being subjected only to thermotectonic event.

The Migmatite–Gneiss Complex (MGC), Schist belt (metasedimentary and metavolcanic rocks), and older granites (Pan-African granitoids), which also included the undeformed acid and simple dykes, are the three major subdivisions of Nigerian Precambrian rocks (Solomon 2010).

The study area's local geology as shown in Figure 1 consists of migmatite-gneiss, which is a blend of metamorphic rock and igneous rock. It is produced when a metamorphic rock, such as gneiss, partially melts and then re-crystallizes into an igneous rock, creating a mixture with the re-crystallized igneous part of the unmelted metamorphic part. During prograde metamorphism, migmatites develop under intense temperature conditions, where partial melting happens in pre-existing rocks. Migmatites are not crystallized from a substance that is fully molten and are not normally the results of reaction in the solid-state (Layade *et al.*, 2018)

Migmatites are found in highly distorted rocks, most often Precambrian cratonic blocks that form the base of eroded mountain chains. Nigeria's basement complex is characterized majorly by Precambrian rocks. The area lies in between the Ogbomoso-Ilorin road, about 20km from Ogbomoso town in the NNE direction. It is easily accessible with a network of roads and shares boundaries with Kwara State and Osun State.

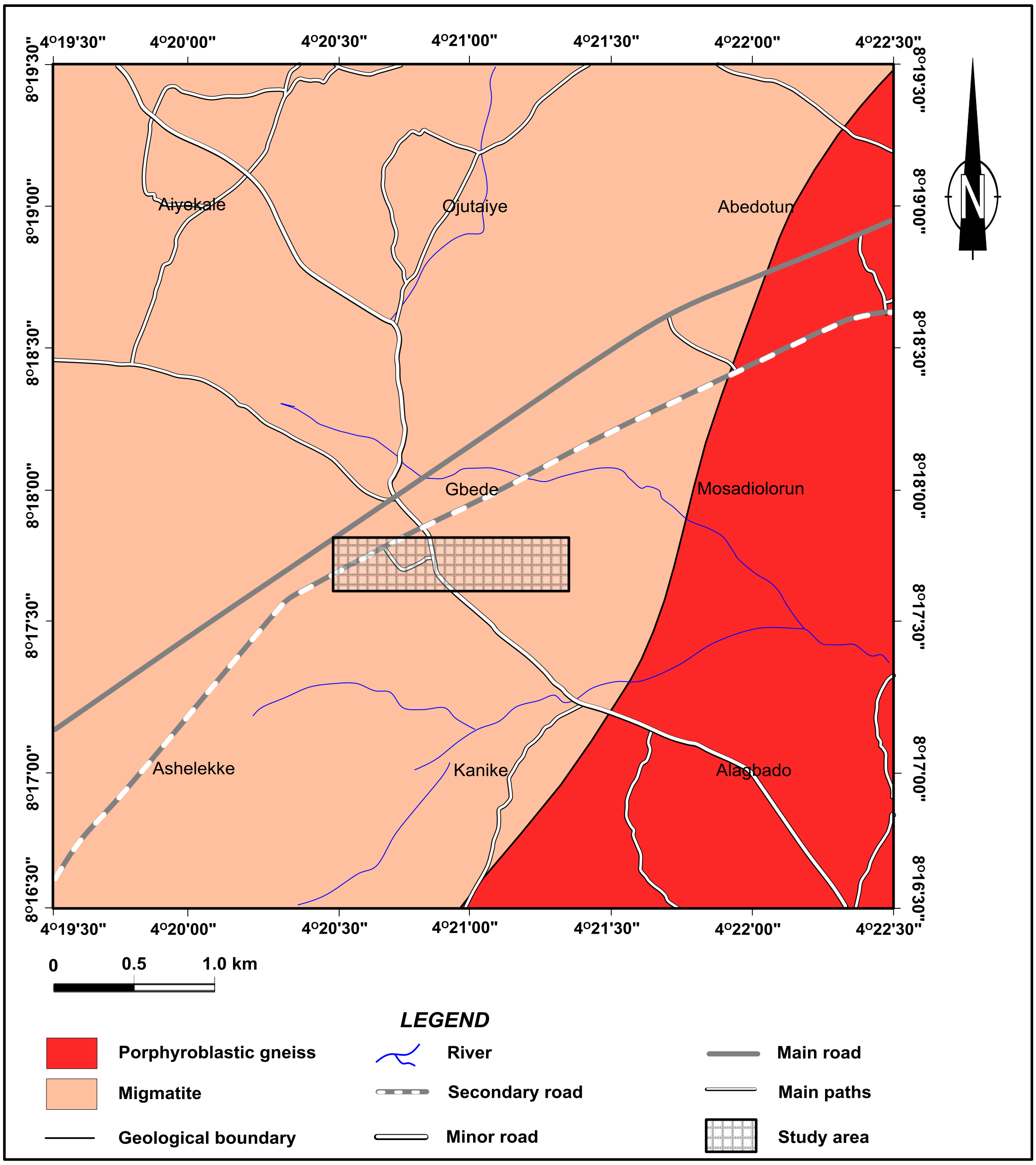

Figure 1: Geological map of the Study Area

Theory of the Analytic Signal

There are a number of methodologies that include working with quantities derived from observed magnetic and gravity data with little emphasis on magnetization direction (Nabighian, 1972; 1984). The analytic signal approach introduced in 1972 comprises the best-known technique of this type (Nabighian, 1972). It can be shown that by using the Hilbert transform, denoted as H, the vertical derivative of the magnetic and gravity field can be calculated from the horizontal derivative, allowing for a fast and accurate method of computing the vertical derivative from a given magnetic or gravity profile.

$$\frac{\partial M}{\partial z} = H\left[\frac{\partial M}{\partial x}\right] \qquad (1)$$

M is the magnetic or gravity anomaly data.

These two quantities can be combined into a two-dimensional quantity known as the analytic signal (AS)

$$AS(x\,,z) = \frac{\partial M}{\partial x} + i\,\frac{\partial M}{\partial z} \qquad (2)$$

where x, z are unit vectors in x, z direction and i is an imaginary number.

The amplitude of the analytic signal is then defined as

$$|A\,S_z| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad (3)$$

The amplitude of the analytic signal is asymmetric bell-shaped function (Hsu *et al.*,1998; Ansari and Alamdar, 2010). By examining its profile across a gravity or magnetic source, the interpreted analytic signal can give an indication of the edges of the causative body (Ansari and Alamdar, 2012).

For a three-dimensional case similarly, the analytic signal is given by;

$$A\,S\,(x\,,y) = \left(\frac{\partial M}{\partial x}\right) + \left(\frac{\partial M}{\partial y}\right) + \left(i\,\frac{\partial M}{\partial z}\right) (4)$$

And its amplitude is given by Blakely (1996) as

$$\left|A\,S_{(x\,,y)}\right| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad (5)$$

The maximum value of the analytic signal determines the edges of a gravity or magnetic body as mentioned above. The source-depth can be calculated as the half width at half maximum amplitude from the climax of the analytic signal's maximum amplitude. Since it includes the square of the variance of magnetic anomalies with direction, the amplitude of the analytic signal will always be positive. The signal's width will be proportional to its horizontal axis location (Adegoke and Layade, 2019).

Thus, the depth to source can be estimated as follows;

(a) For contact

$$X_{1/2} = \sqrt[2]{3h} = 3.46h \qquad (6)$$

(b) For thin sheet (dyke)

$$X_{1/2} = 2h \qquad (7)$$

(c) For horizontal cylinder

$$X_{1/2} = 2\left(\sqrt[3]{4} - 1\right)^{1/2} h = 1.533h \qquad (8)$$

where $X_{1/2}$ is the width of the anomaly at half the amplitude and h is the depth to the top of the contact.

Data Acquisition

The gravity survey was built in such a way as to delineate profound insights into the deepness of sources in the region. The technique for data acquisition involves measurements of gravity variations at discrete points along regularly spaced traverses within the region of interest.

The gravity readings were recorded using a LaCoste and Romberg model gravimeter. The point at which a discrete geophysical measurement is made is called a station while the distance between successive measurements are called station intervals. The station interval on a traverse in this study is 20 m while the interval between traverses is 50 m on a survey area of 1000 m by 500 m; Observations were therefore made along 10 traverses at equal spacing. A global positioning system (GPS) eTrex Garmin vista model was used for the location of position on the globe as well as the direction and elevation above the sea level. Measuring tape, pegs and lines also aid an effective data acquisition as they were used to mark the position of base stations along every profile and to measure the distance between one stations to the other at equal intervals.

Data correction

Dobrin (1960) states that observed gravity values should be corrected for latitude, station height, and the impact of the surrounding topography in order for gravity data to be most useful. In general, to display anomalous areas, the values are all reduced to a common date Daniel and Libby (1968). During data collection, the instrument implemented earth tide corrections, measuring unit tilts, changes in temperature, and long-term drift. The base station readings were recorded every hour during the survey to obtain diurnal variation of gravity results. Bouguer anomaly data were attained after drift, latitude, free air, and bouguer corrections were applied on the measured observed gravity data set obtained on the field. These corrections created the bouguer gravity data sets that were ultimately interpreted.

Data Interpretation

The results obtained were interpreted quantitatively. The corrected bouguer gravity data are presented as bouguer anomaly graphs (Figs 2-11). The anomaly graphs were obtained by plotting the corrected Bouguer values against their corresponding station positions to obtain the anomalies using the mapping application software. The depths to the basement were manually estimated and analyzed on each anomaly traverse graph using the Analytic signal computations.

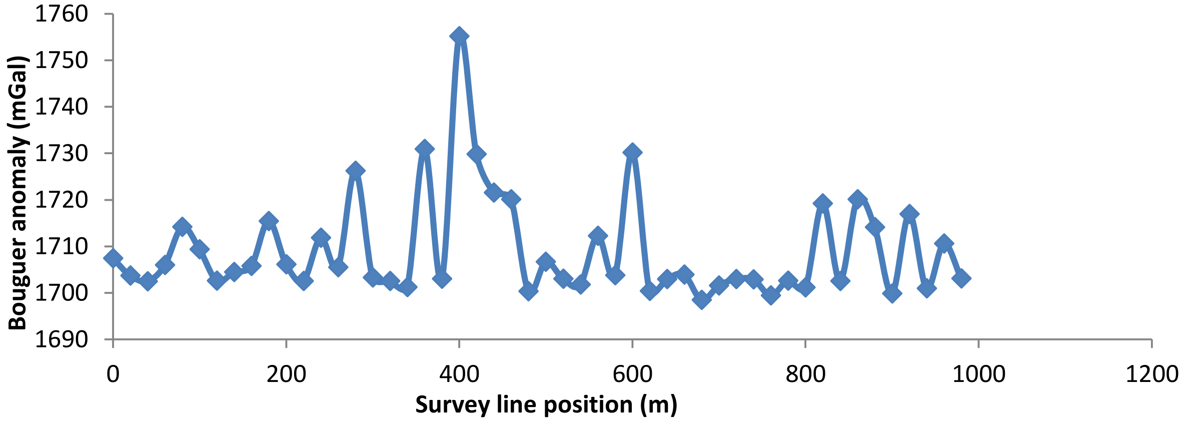

Figure 2: Bouguer anomaly graph of Traverse 1

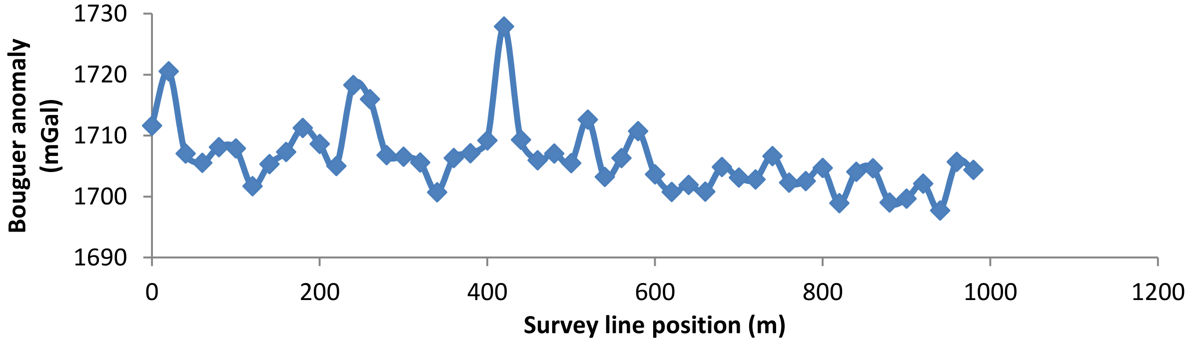

Figure 3: Bouguer anomaly graph of Traverse 2

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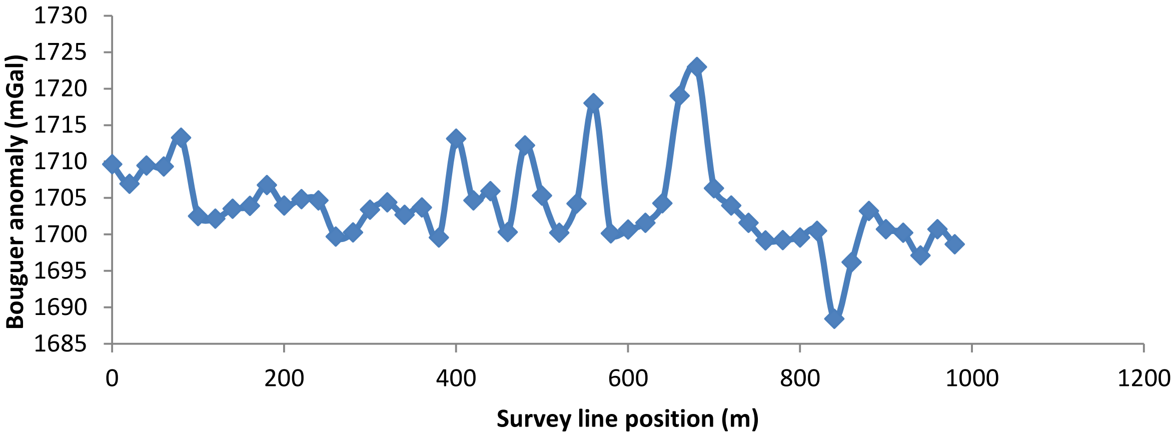

Figure 4: Bouguer anomaly graph of Traverse 3

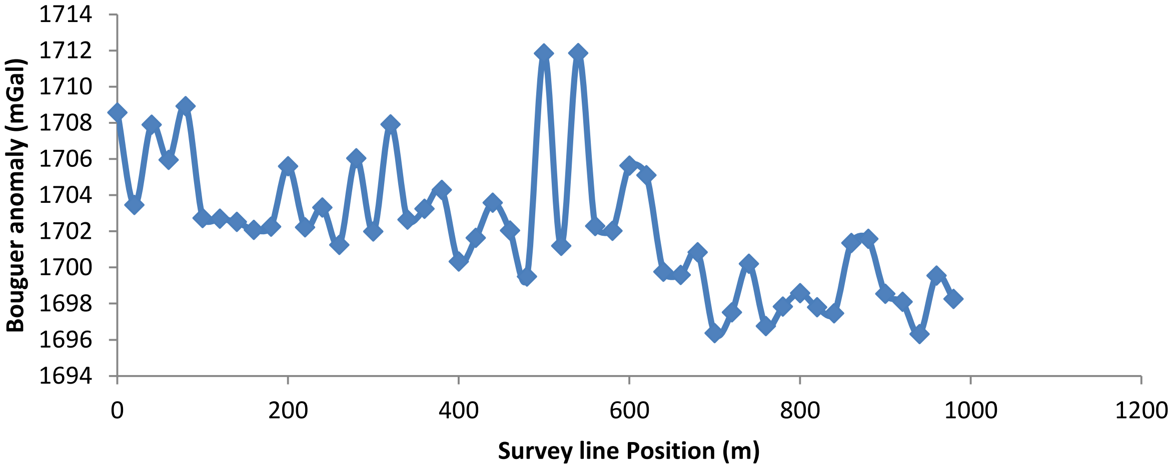

Figure 5: Bouguer anomaly graph of Traverse 4

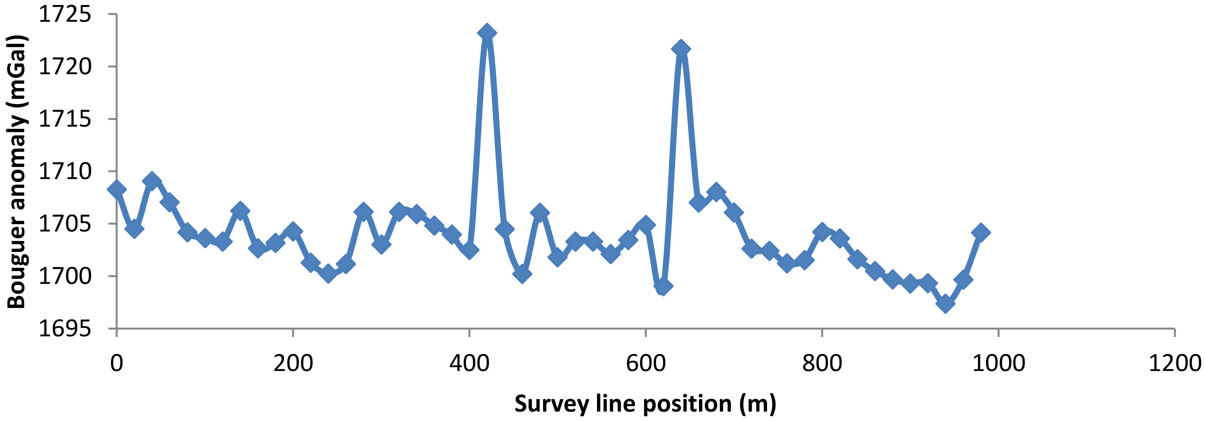

Figure 6: Bouguer anomaly graph of Traverse 5

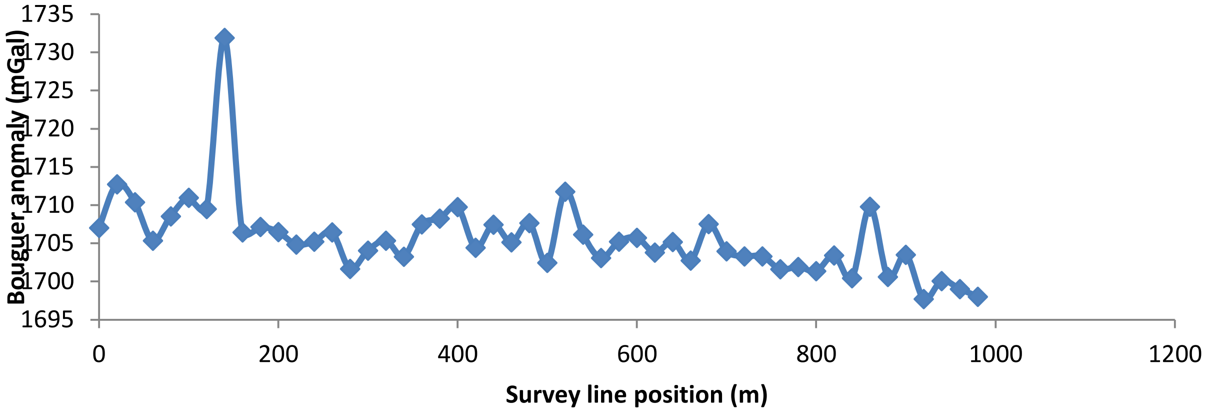

Figure 7: Bouguer anomaly graph of Traverse 6

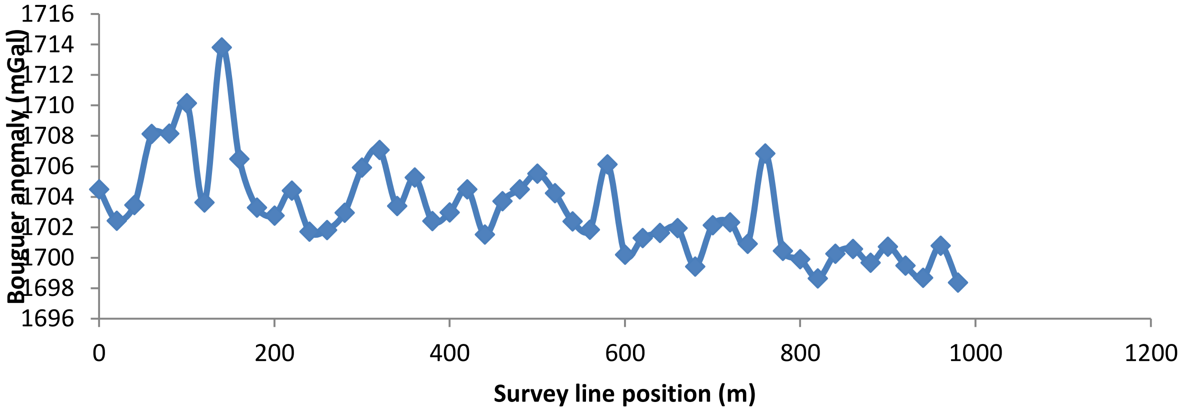

Figure 8: Bouguer anomaly graph of Traverse 7

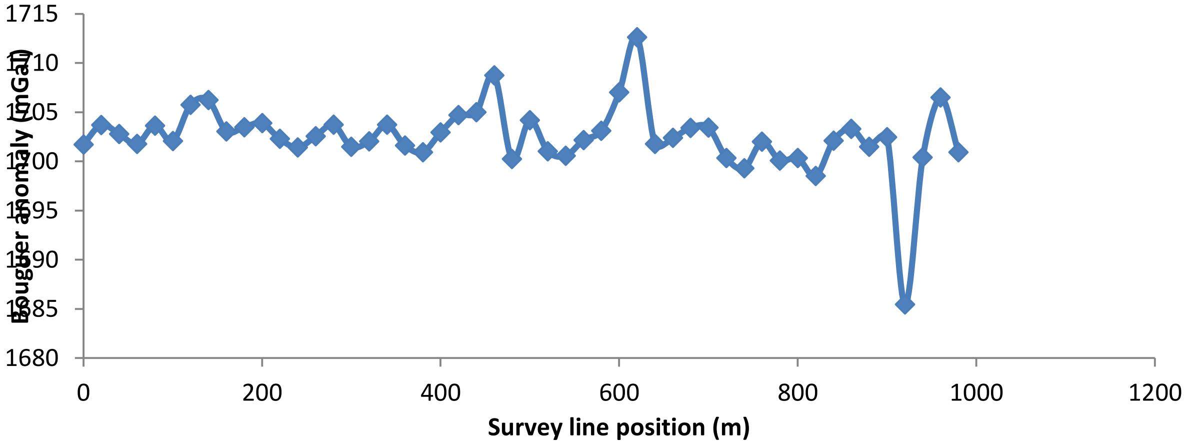

Figure 9: Bouguer anomaly graph of Traverse 8

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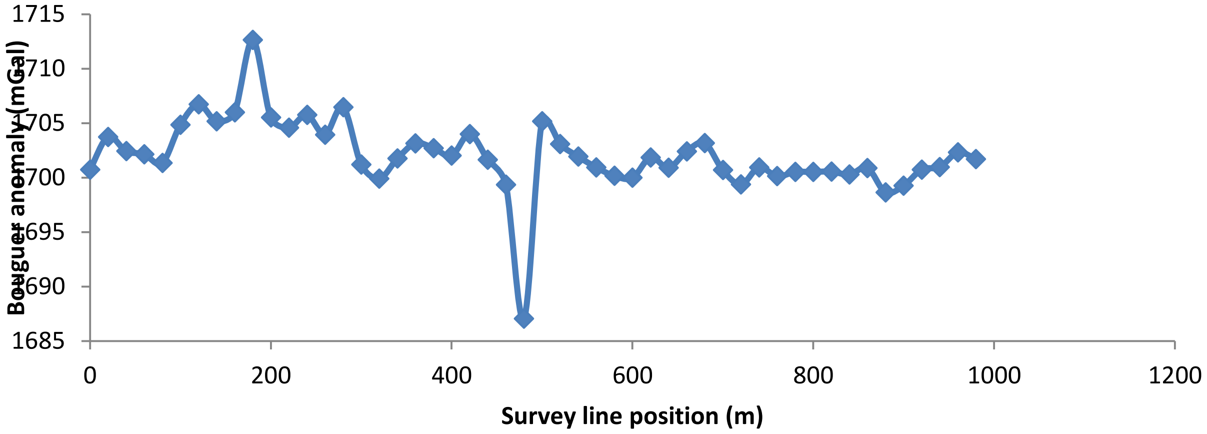

Figure 10: Bouguer anomaly graph of Traverse 9

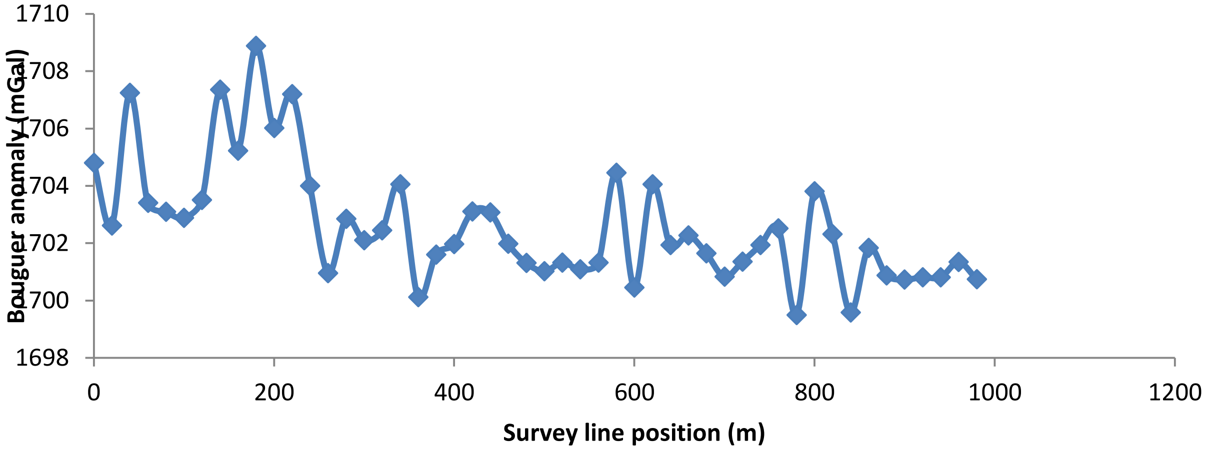

Figure 11: Bouguer anomaly graph of Traverse 10

DISCUSSIONS

The gravity trend obtained from the bouguer anomaly graphs of T1 – T10 (Figures 2 – 11) indicates high gravity anomalies with varying amplitudes and prominent slopes evenly distributed across the study area, this denotes a high variation in density properties of the underlying rocks. Of utmost interest are T1, T2, T4 and T6 where high spikes of gravity anomalies were revealed, these traverses clearly symbolizes regions of high rock densities which are indications of metallic ores. Also, high gravity anomalies can indicate the existence of shallower or near-surface denser basement rocks underneath the surface. A decline in gravity values was observed from T7 to T10 with the lowest gravity value of 1685 mGal obtained in T8. These may be accredited to the presence of distorted or deformed rocks as a result of intense metamorphism in that part of the study area. Gordon *et. al*. (2006) suggested that such decrease in gravity represents increasing thickness of the continental crust.

The depth to source variation of the 10 traverses was calculated using the analytic signal method for a contact, a thin sheet (dyke), a horizontal cylinder, and the results are presented in Table 1. A depth range of 5.45 m – 8.25 m was estimated for a contact, 9.44 m – 14.29 m was estimated for a thin sheet while a depth range of 12.31 m – 18.05 m was estimated for a horizontal cylinder respectively (Table 2). Figure 12 gives the 2D graphical representation of the average depth across the 10 traverses with a maximum depth of 13.29 m and a minimum depth of 9.06 m on traverses 8 and 3 respectively. Irrespective of the structure and shape of the iron-ore deposit in the study area, an average depth of 11.81 m±3.64 m was estimated for this gravity study using the ASM.

Comparing this result with previous ground magnetic studies published in the study area, using the same source to depth method (ASM) for the three distinctive structural models, Adegoke and Layade (2019) estimated an average depth of 5.79m±2.07 m, this implies a slight varying depths of gravity and magnetic potential field measurements.

Table 1: Estimated gravity depth (m) of different geological model of Iron-Ore deposits

	CONTACT	THIN SHEET	HORIZONTAL CYLINDER	AVERAGE DEPTH	STANDARD DEVIATION
T1	6.23	10.78	14.05	10.35	±3.21
T2	7.51	13	16.96	12.49	±3.87
T3	5.45	9.44	12.31	9.07	±2.81
T4	6.85	10.94	15.47	11.09	±3.52
T5	7.68	13.89	17.42	12.99	±4.03
T6	7.99	13.83	18.04	13.29	±4.12
T7	7.63	13.21	17.23	12.69	±3.94
T8	8.25	14.29	17.33	13.29	±3.77
T9	6.80	11.33	15.52	11.21	±3.56
T10	6.87	12.37	15.72	11.66	±3.65
AVERAGE DEPTH	**7.12**	**12.30**	**16.00**	11.81	±3.64
STANDARD DEVIATION	**±0.81**	**±1.53**	**±1.68**	±1.32	

Table 2: Range of Depth (m) for various Geologic bodies

STRUCTURAL INDEX	RANGE OF DEPTH (m)
CONTACT	5.45 - 8.25
DYKE	9.44 - 14.29
HORIZONTAL CYLINDER	12.31 - 18.05

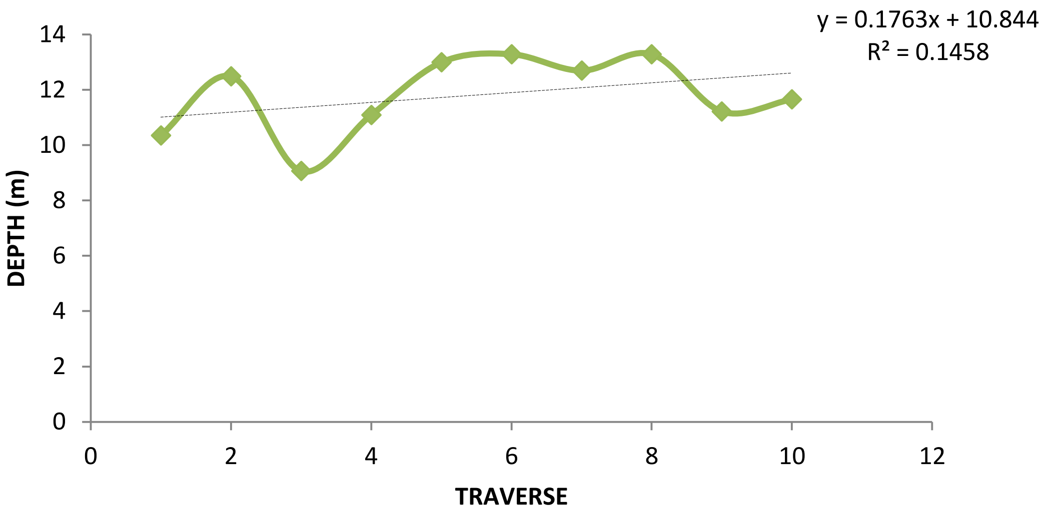

Figure 12: 2-D Graphical Representation of depths across the study area

CONCLUSION

The ground gravity study of this area has helped to further authenticate the presence of iron ore deposit and to evaluate its average depth using the Analytic Signal Method. The results in this work were found to be in the same order of magnitude with other published works in the study area. The average gravity depth to the top of the material which was estimated to be 11.81 m±3.64 m clearly depicts and confirms that a small variation in disparity occurs when compared relatively with previous magnetic study in the study area.

It is also worthy to note that this study has added to the progress of research works on potential field measurements. Ground gravity analysis has hereby been used to probe and validate the prospect of economic and cost-effective iron-ore deposit exploration of Gbede, Oyo-State Nigeria as near surface.

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