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Application of Gravity Survey for the Investigation of the Presence and Depth of Iron-Ore Deposit

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Abstract

Ground gravity survey was carried out in Gbede, Oyo State Southwestern Nigeria in the E-W direction using the LaCoste and Romberg Gravity Meter type G309. 500 stations distributed in 10 traverses were established over a distance of 1000 m by 500 m with station spacing of 20 m and a traverse interval of 50 m. Observed gravity values were corrected for Drift, Latitude, Free Air and Bouguer while the subsequent results were analyzed qualitatively and quantitatively. The corrected results were plotted as 2D contour and 3D surface distribution maps using the surfer to obtain the qualitative analysis. Quantitatively, the corrected bouguer gravity data are presented as bouguer anomaly graphs, which were obtained by plotting the corrected bouguer values against their corresponding station positions. Peter's half slope approach was used on the anomaly to compute the depth to source for structural index of a thin body (1.2), an intermediate body (1.6) and a very thick body (2.0) respectively. The result revealed a depth range of 12.91 m-21.03 m, 9.69 m-15.78 m and 7.75 m-12.63 m for the structural index respectively. An average depth of 13.05 m±2.75 m was estimated for the entire area. The overall computed results signified the presence of mineral deposits at low depths across the study area.

Keywords: *Qualitative; Quantitative; Traverses; Bouguer; Anomaly.*

1. Introduction

Gravity surveying is a geophysical survey technique that investigates subsurface geology based on variations and contrast in the earth's gravitational field arising from differences of density between subsurface rocks. Gravity surveys are used for large-scale crustal study, where measurements of earth's gravitational field are used for mapping variations in subsurface rocks densities [1-4]. It has found numerous applications in engineering, environmental and geothermal studies including locating voids, faults, buried stream valleys, water table levels and geothermal heat sources [5].

There is a wide division of geophysical surveying methods, some make use of natural fields of the Earth and others require direct ground input of artificially generated energy. The natural methods utilize the gravitational, magnetic, electrical and electromagnetic fields of the Earth, searching for local perturbations in these naturally occurring fields that may be caused by concealing geological features of economic and other interest [6]. Artificial source methods involve the generation of energy that may be used analogously to natural fields.

Over time, ground gravity surveying has not been given much attention globally with comparison to aerogravity surveying and aerogravity data will not give details of structures of small dimension. Hence, justifying the use of this method to delineate the subsurface structure for the presence of iron-ore mineral and to estimate its depth over a small dimensional area. Gravity data can be used in many ways to solve different exploration problems, depending on the geologic setting and rock parameters [7-8], the data when analyzed provide insight to elements of petroleum exploration and production [9-10].

The gravity method works because different earth materials have different densities (mass) and hence produce different gravitational fields. Gravitational field variations can be interpreted to determine a source's depth, geometry and its density. The method has good depth penetration compared to ground penetration radar, high frequency electromagnetic and dc-resistivity techniques; and is not affected by high conductivity values of near-surface clay rich soils [11].

Previous studies carried out on gravity in Nigeria include; The Application of high resolution gravity data for litho-structural and depth characterization at Igbabi area [12] where Igbabi aerogravity dataset was interpreted to delineate litho-structural architectures that could favour the exploitation of potential economic minerals. Gravity anomalies were investigated through the interpretation of aerogravity data with the objectives of determining the thickness of the sedimentary basin, establish the basement topography, density contrast and the geological models using Aerogravity data [13] and; The evaluation of gravity data derived from Global Gravity Field Models using Terrestrial gravity data in Enugu [14].

Other similar research works carried out outside Nigeria include; Delineation of the Sumatra fault in the Central part of West Sumatra based on gravity method [15]. In Indonesia, Determination of Tin zone in Tanjung Gunung village was carried out with gravity method [16]. Also, Mapping of the buried ancient structure was done using gravity method [17] and; the computation of residual and regional anomaly of gravity method by polynomial filter using Microsoft Excel [18] amongst many others.

In this study, the ground gravity method was used to investigate iron deposited mineral materials. It aimed at locating its positions and depths through the approach of the Peters half slope method [19].

1.1. Description and geology of the study area

The study area, Gbede is located in Surulere Local Government Area of Oyo-State South Western Nigeria, between latitudes $N8^{o}17'37.7''$ to $N8^{o}17'49.8''$ and longitude $E4^{o}20'45.9''$to $E4^{o}20'58.8''$. The area lies within the Southwestern part of the basement rocks, which is part of the much larger Pan-Africa mobile belt that lies in between the West African Craton and Congo Craton, suspected to have been subjected only on a thermotectonic event [20].

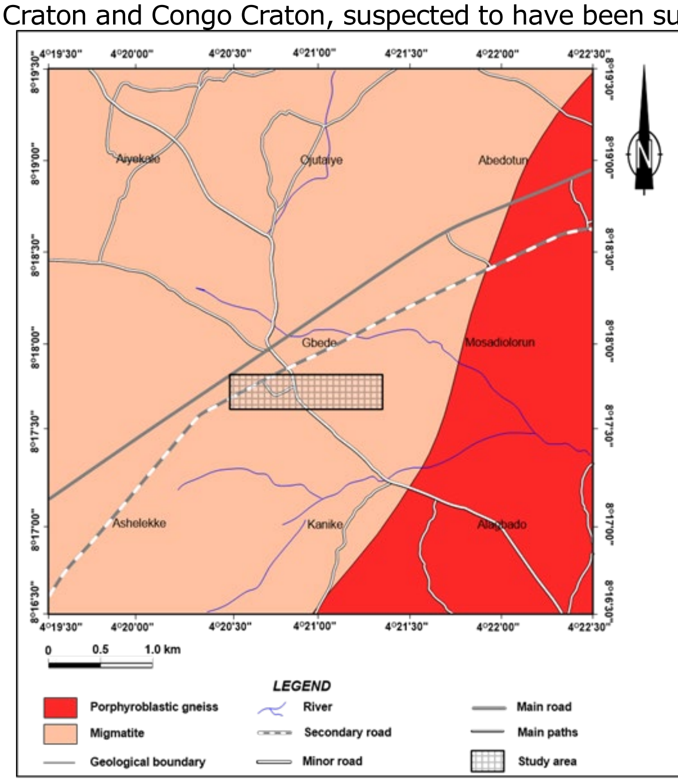


Figure 1. Geological map of the study area

The local geology of the study area (Figure 1) consists of migmatite-gneiss, which is a mixture of metamorphic rock and igneous rock. It is created when a metamorphic rock such as gneiss partially melts, and then re-crystallizes into an igneous rock, creating a mixture of the unmelted metamorphic part with the re-crystallized igneous part. They can also be known as diatexite. Migmatites form under extreme temperature conditions during prograde metamorphism, where partial melting occurs in pre-existing rocks. Migmatites are not crystallized from a totally molten material, and are not generally the result of solid-state reactions [21].

Commonly, migmatites occur within extremely deformed rocks that represent the base of eroded mountain chains, typically within Precambrian cratonic blocks. Precambrian rocks are typical for the basement complex of Nigeria [22].

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.

2. Methodology

In gravity method, spatial variations of measured gravitational field data are responses of spatial variations of density of subsurface material [23]. The study focused on the subsurface geological structures based on the quantitative interpretations of the ground gravity data collected during the fieldwork that was carried out in Gbede. The gravity survey was designed in such a way that deep insight into the depth to sources in the area was delineated. The data acquisition technique requires measurements of the gravity variations at discrete points along traverses regularly distributed within the area of interest.

2.1. Data acquisition

The gravity measurements were recorded using a LaCoste and Romberg model G 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) eTrexGermin 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.

2.2. Data correction

For gravity data to be most useful, it was noted that [24] observed gravity values should be corrected for latitude, station elevation, and the influence of the nearby topography. In general, the values are all reduced to a common datum in order to show anomalous areas [25]. The corrections of Earth tides, tilts of the measuring system, temperature changes and a long term drift were applied by the instrument during the data collection. The base station readings were recorded every hour during the survey to acquire diurnal variation of gravity data. Complete Bouguer anomaly data were obtained after drift, latitude, free air, and bouguer corrections were effected on the measured observed gravity data set obtained on the field. These corrections produced the bouguer gravity data sets that were eventually interpreted.

2.3. Data interpretation

The results obtained were interpreted qualitatively and quantitatively. Quantitatively, the corrected bouguer gravity data are presented as bouguer anomaly graphs (Fig. 2). The anomaly graphs were obtained by plotting the corrected bouguer values against their corresponding station position to obtain the anomalies using the Microsoft Excel 2007 software. The depths to the basement were manually estimated and analyzed on each anomaly traverse graph using the Peters half slope method [19].

The qualitative interpretation involved plotting and analysis of the contour map, 3D surface distribution map and the vector map using the surfer software. It also involves the visual inspection of the traverses, maps and sections for trends that do not conform.

3. Results and discussion

3.1. Depth-to-basement calculation

Peters half slope method was used to estimate the depth to the top of the anomalous body in this study. Table 1 shows the computation of the depth estimations, while Table 2 revealed the range of depth of various geologic bodies. The step-to-step procedure is illustrated as thus. The maximum slope which is the steepest part of the bouguer anomaly graph was located. A straight line (i.e. slope line) was drawn through the maximum slope extending beyond the slopes top and bottom end and intersecting with the charts x-axis beyond the bottom end. A vertical line was drawn to connect the maximum slopes top end with the charts x-axis, the midpoint of this line was marked and a half slope line was drawn to connect the slope lines intersection with the x-axis and the middle point of the vertical line.

Two straight lines parallel to the half slope and tangent to the bouguer anomaly line were drawn to touch the curve but not to intersect it. Two new vertical lines were then drawn starting from the two points where the tangent lines touch the curve and ending at the x-axis. The distance between these two vertical lines were measured and noted as distance [26].

Because of the unknown size of the iron ore deposit in the basement complex, the average values for an index factor of a thin body, (1.2) an intermediate body (1.6) and a thick body, (2.0) were considered.

Table 1.Gravity depth to the sources with varying structural indices

	Depth for thin body(m) SI=1.2	Depth for intermediate body (m) SI=1.6	Depth for thick body (m) SI=2.0	Average depth (m)
T 1	14.53	10.91	8.72	11.39±2.40
T 2	14.75	11.07	8.86	11.56±2.43
T 3	21.03	15.78	12.63	16.48±3.47
T 4	18.78	14.09	11.27	14.71±3.10
T 5	12.91	9.68	7.75	10.12±2.13
T 6	17.63	13.22	10.58	13.82±2.91
T 7	18.09	13.57	10.86	14.17±2.98
T 8	17.5	13.12	10.5	13.70±2.89
T 9	16.16	12.12	9.7	12.66±2.67
T 10	15.27	11.46	9.16	11.97±2.52
average depth of s.i	16.67±2.27	12.5±1.71	10±1.36	13.05±2.75

Table 2. Range of depth for various geologic bodies

Structural index	Range of depth (m)
Thin body	12.91-21.03
Intermediate thickness	9.69-15.78
Thick body	7.75-12.63

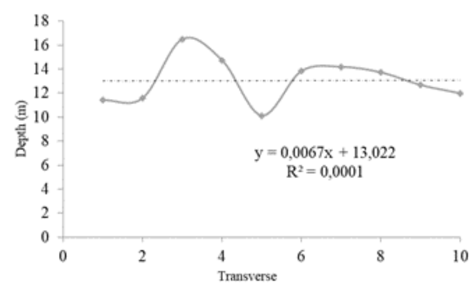


Figure 2. Graph of the calculated depth using peters half slope method

3.2. Discussions

The depth to source variation of the 10 traverses were calculated with structural index ranging from 1.2 – 2.0 for the three structural bodies using the Peters Half Slope Method (PHSM) and results are presented table 1. A depth range of 12.91 m-21.03 m was estimated for a thin structural body, a depth range of 9.69 m-15.78 m was estimated for an intermediate structural body while a depth range of 7.75 m-12.63 m was estimated for a very thick structural body respectively (Table 2). Figure 2 gives the 2D graphical representation of the average depth across the 10 traverses with a maximum depth of 16.4 m and a minimum depth of 10.1 m on traverses 3 and 5 respectively. Irrespective of the structure of the iron-ore deposit in the study area, an average depth of 13.05 m±2.75 m was estimated for this gravity study using the PHSM.

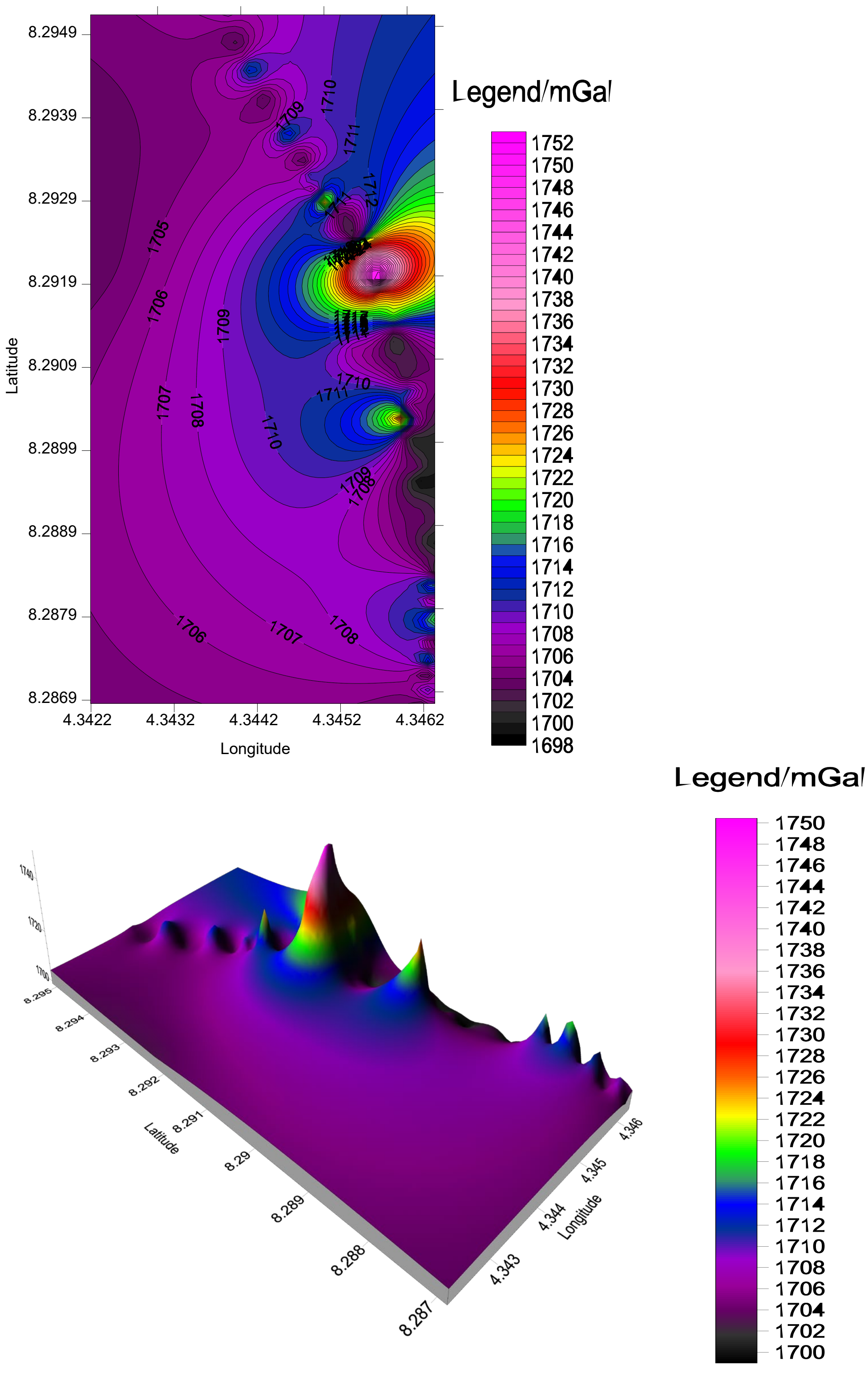


Fig 3a & b. Contour map and 3D surface distribution map of transverse 1

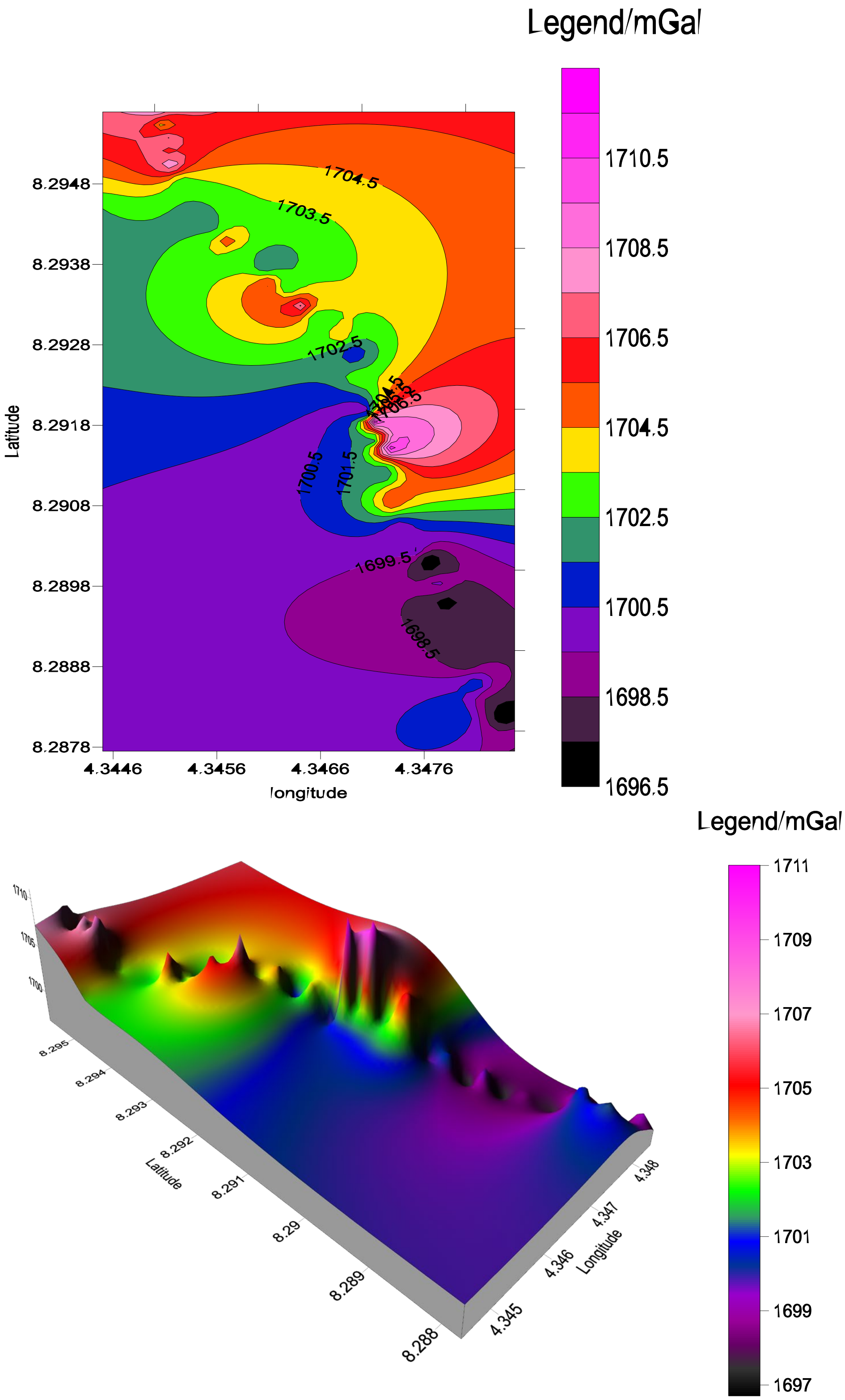


Fig 4a & b. Contour map and 3D surface distribution map of transverse 4

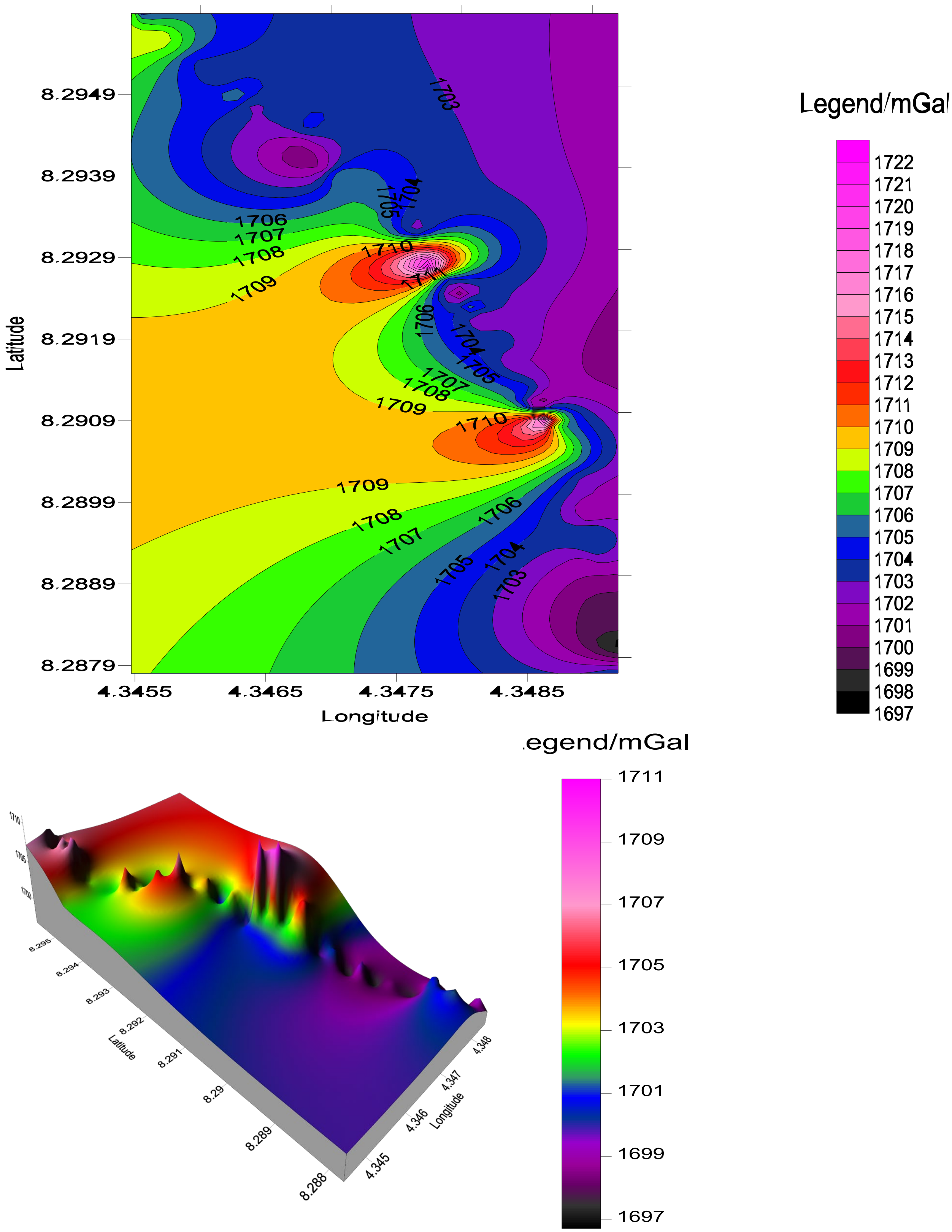


Fig 5a & b. Contour map and 3D surface distribution map of transverse 5

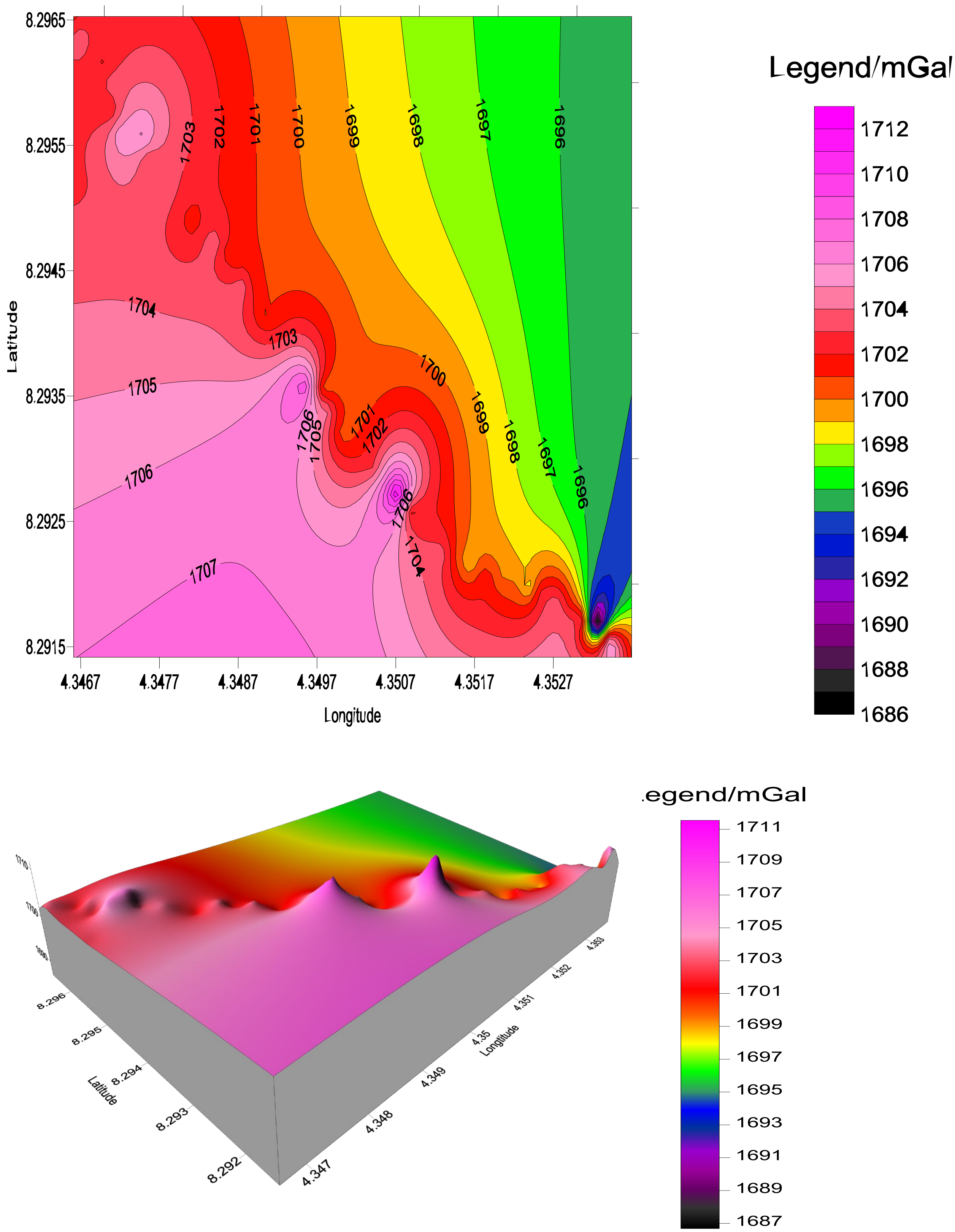
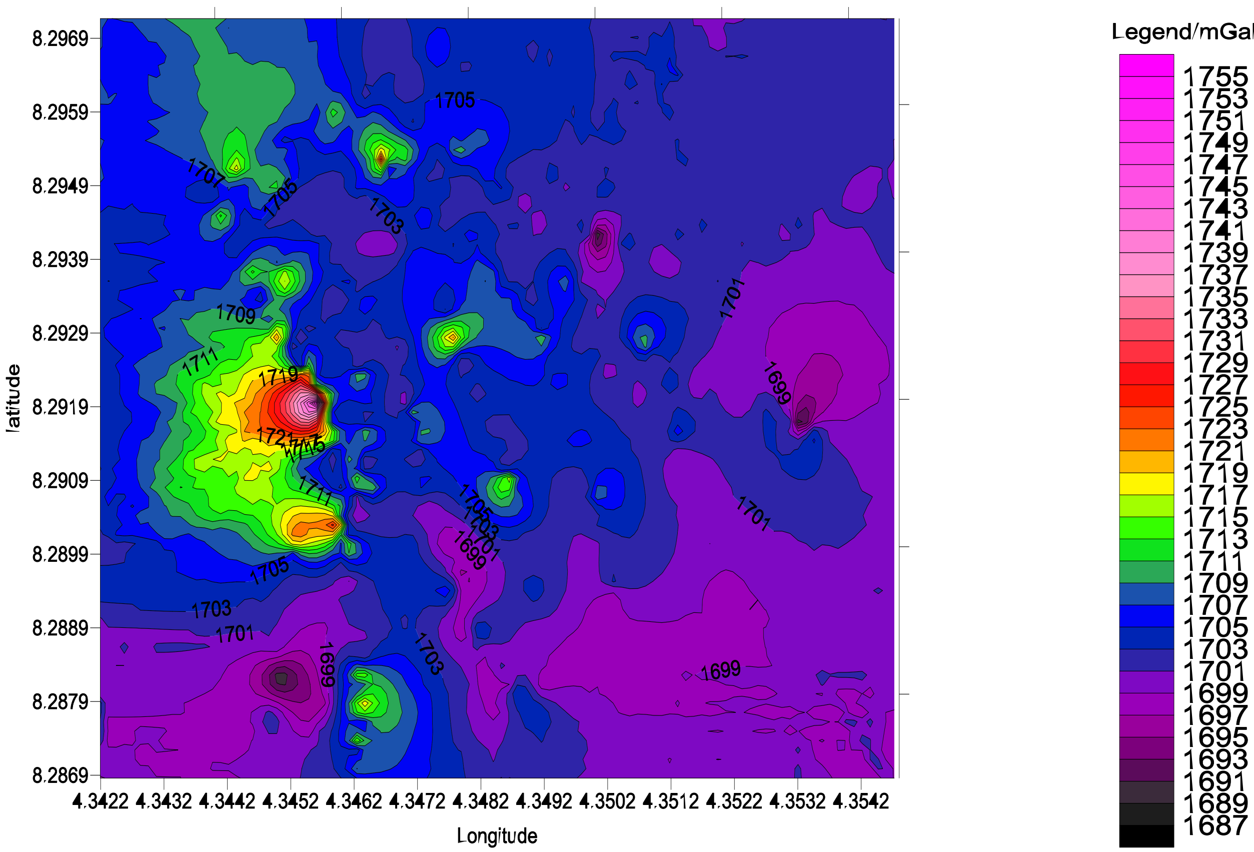


Fig 6a & b. Contour map and 3D surface distribution map of transverse 8



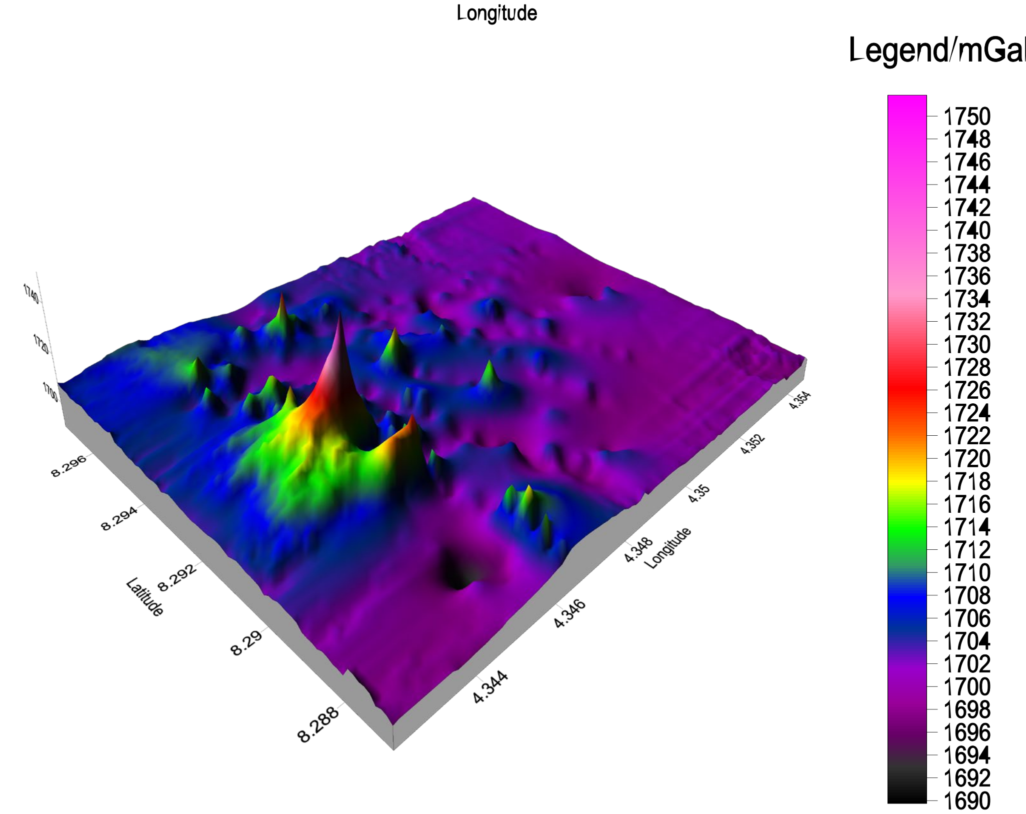


Fig 7a & b. Contour map and 3D surface distribution map of the entire study area

This result complement the previous magnetic study published in the study area, using the same source to depth method (PHSM) for the three distinctive structural models [26]. Further analysis was carried out on the data set using the qualitative approach. The contour map and 3D surface distribution map of Traverses 1 – 10 were generated, while some selected traverses are presented in Figures 3 – 7 (a&b respectively). A visual inspection of the contour plots in Figures 3a – 7a clearly shows the alignment of contour lines closely spaced at different intervals, this is a clear indication of the presence of mineral deposits at virtually low depths. This is also in conformity to the peak variations spread across on the 3D surface distribution maps of traverse 1 – 10 as showed in Figures 3b – 7b.

In addition, the lithology of the study area shows intriguing features which indicates a wide spread of mineral prospect across the surveyed region. The study area which covers a dimension of 500 m by 1000 m (500,000 m^2) was contoured as shown in Figure 7a and distributed in 3D in Figure 7b at 2 mGal interval as measured from the E-W direction. The gravity values are observed to be highest at contour values of 1751 mGal – 1755 mGal and contoured at very close intervals around the western part of the map and this is surrounded by intermediate values of 1711 mGal – 1721 mGal at relative close intervals. This specifies that the iron ore minerals around that area are very close to the surface as an outcrop. On the other side of the map, the ore minerals at the southeastern and northeastern part are at deeper depths with contour values ranging from 1699 mGal – 1701 mGal.

The 3D surface distribution map of the study area as shown in Fig. 7b reveals visible spikes at its eastern part and hollows slightly seen at the north and southeastern part of the map which is in conformity to what was revealed in the contour plot of the study area. The closely spaced, sub-parallel orientation of contours relatively distributed in the contour plot of the entire study area reveals the distribution of mineral deposits at shallow depths across the study area. While the vector distribution map of Fig. 8 shows the orientation of the mineral distribution across the survey area.

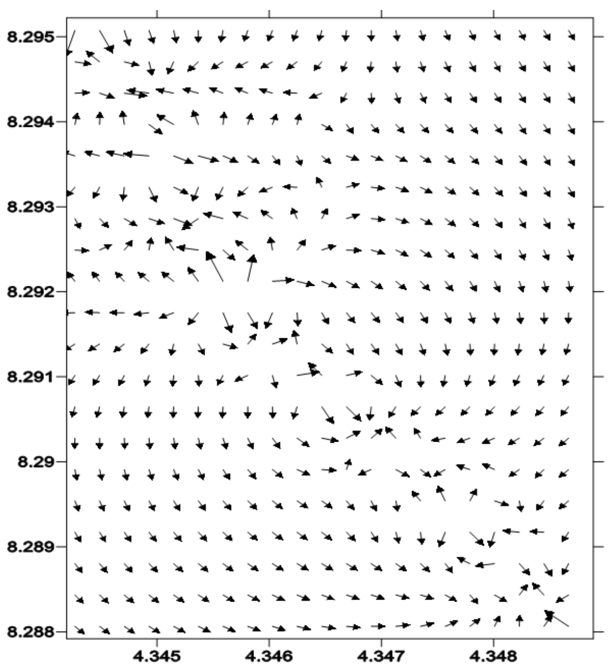


Figure 8. Vector distribution map of the study area

4. Conclusion

The ground gravity study of this area has helped in many ways to further confirm the presence of iron ore deposit and to estimate its average depth with varying structural index using the Peters Half Slope Method. The average gravity depth to the top of the material which was estimated to be 13.05 m±2.75m 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 of note that this study has added to the progress of research works on disparities between the gravity and magnetic potential field measurements. Ground gravity study has hereby been used to investigate and validate the prospect of iron-ore deposit exploration of Gbede, Oyo-State Nigeria as near surface which is economical and cost effective.

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