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Spectral Analysis and Modeling of Magnetic Anomalies in Part of Northern Anambra Basin, Nigeria

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Key words: Aeromagnetic data, spectral analysis, forward and inverse modeling, susceptibility values, northern Anambra basin

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Abstract: Spectral analysis and modeling (forward and inverse) methods were employed in the geophysical investigation of Ubiaja and Illushi areas through the interpretation of aeromagnetic data. The purpose is to determine the depth to magnetic anomalies and possible cause of the anomalies in Ubiaja and Illushi areas which are located in the Northern Anambra basin. The spectral analysis reveals two prominent magnetic layers (the deep and shallow depth layers). The depth to deep layers ranges from 1114.087-3978.874 m with an average depth valueof 2105.014 m while the depth to shallow layers ranges from 163.836-460.057 m with an average depth value of 295.708 m. The depth results from forward and inverse modeling for profiles 1-4 were 4118, 3611, 2964 m and 5489 m, respectively. The susceptibility values obtained for profiles 1 and 2 were 0.0100 which is associated with a group of minerals such as gneiss, hematite, granite or gabbro. Profile 3 with susceptibility value of 0.0613 is typical of igneous rock porphyry while profile 4 with susceptibility value of 0.0288 is typical with minerals like slate and hematite.

INTRODUCTION

Spectral analysis is a very good method for determining the sedimentary thickness of a particular area. The method seeks to describe the frequency content of a signal based on a finite set of data[1]. Spectral analysis method has an advantage over other geophysical methods because it has the ability to filter all the noise from the data, information is not lost during the process and in most cases operations are easier to perform in the transform domain[2]. Modeling method is used in determining the possible minerals/cause of magnetic anomalies of an area and their subsurface depths (sedimentary thickness).

Magnetic surveying investigates the subsurface based on variations in the Earth's magnetic field that result from the magnetic properties of the underlying rocks. In geophysics, a magnetic anomaly is a local variation in the Earth's magnetic field resulting from variations in the chemistry or magnetism of the rocks. Mapping of variation over an area is valuable in detecting structures obscured by overlying material. The main purpose of the aeromagnetic survey is to detect minerals or rocks that have unusual magnetic properties which reveal them by causing anomalies in the intensity of the Earth's magnetic field[3]. The aeromagnetic survey is applied in mapping these anomalies in the Earth's magnetic field and this is correlated with the underground geological

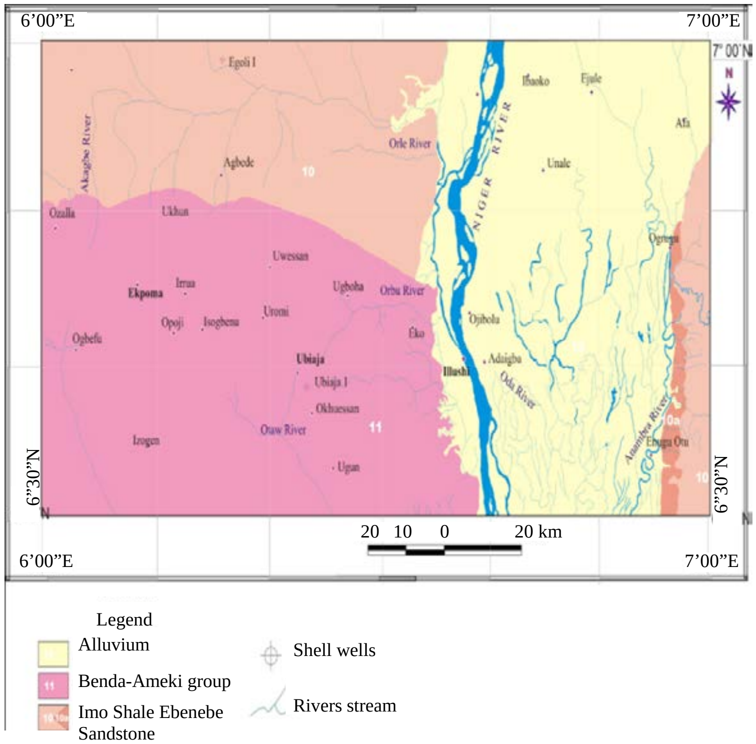


Fig. 1: Geology map of the study area (Ubiaja and Illushi)

structure. The aeromagnetic geophysical method plays a distinguished role when compared with other geophysical methods in its rapid rate of coverage and low cost per unit area explored. It can be used over water and in regions inaccessible for ground work[2].

Some previous researcher shave worked on some parts of Anambra basin using spectral analysis, forward and inverse modeling and/or other methods[4-8] but not in Ubiaja and Illushi areas in northern Anambra basin. The present study involves the employment of spectral analysis and modeling methods in geophysical investigation of magnetic anomalies over Ubiaja and Illushi areas in northern Anambra basin using aeromagnetic data. The purpose of the study is to determine the depth to basement and the possible cause of the magnetic anomalies (minerals) in the area.

Location and geology of the study area: Ubiaja and Illushi areas are located within the Northern Anambra basin which falls between latitude 6°30’-7°00’N and longitude 6°00’-7°00’E. The study area which is situated in the Southwestern Nigeria has an area of about 6050 km^2. Ubiaja is located in the Ishan district of Edo State and Illushi is located in sub-locality of Illushi locality district, Edo state, Nigeria. The area is covered by two aeromagnetic sheets (285 and 286). The study area consists of two formations (Ameki and Imo shale) and alluvium deposit. Stratigraphically, the Ameki formation overlies the impervious Imo shale group, characterized by lateral and vertical variations in lithology. The Imo shale of Paleocene age is underlain in succession by Nsukka formation, Ajali sandstones and Nkporo shales[9]. Figure 1 shows the geologic map of the study area.

Source of data: The aeromagnetic data of Ubiaja and Illushi areas (sheets 285 and 286) which were conducted in 2009 by FURGO Airborne surveys were obtained from the Nigerian Geological Survey Agency (NGSA). The magnetometer used for the aeromagnetic data survey is ‘3 X scintrex CS2 Cesium vapour’. The aeromagnetic surveys were flown at 500 m flight line spacing and 5000 m tie line spacing with 75 m sensor mean terrain clearance. The average magnetic inclination for the area was -12.7° while the declination was -1.6°. The geomagnetic gradient was removed from the data using International Geomagnetic Reference Filed (IGRF) and the data were collected in digitized form (X Y Z). The data collected in digitized format have X and Y representing the longitude and the latitude in meters, respectively while the Z represents the magnetic intensity measured in nanoTesla (nT). The flight path processing used was the ‘Real Time Differential Global Positioning System (GPS)’.

MATERIALS AND METHODS

Method and data analysis: The interpretation of the aeromagnetic data was carried out qualitatively and quantitatively. The qualitative interpretation was done by inspecting the Total Magnetic Intensity (TMI) map which was produced using Oasis Montaj software. From the TMI, the regional anomaly was separated from the residual anomaly by applying polynomial fitting of the first order. In quantitative interpretation, spectral analysis and modeling method were employed. The initial stage of quantitative interpretation is the application of mathematical filters to TMI map to enhance anomalies of interest[2, 10] (Fig. 2).

Spectral analysis involves measurement of the amplitude of the component of the complex waveform all through the frequency range of waveform. The Fourier Transform expresses a magnetic field as an integral of sine/cosine wave, each defining a wave of Amplitude A(k) and phase φ(k) where $k/2\pi = 1/\lambda$ is the wave number. Plotting A (k) gives the amplitude spectrum and $A^2(k)$ gives the power spectrum[2].

The spectral depth method is based on the principle that a magnetic field measured at surface can be considered as the integral of magnetic signatures from all depths. The power spectrum of the surface field can be used to identify average depths of source ensembles[11]. This same technique can be used to attempt identification of the characteristic depth of the magnetic basement on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum, assuming that this part of the spectrum is sourced consistently by basement surface magnetic contrast. A depth solution is calculated for the power spectrum derived from each grid sub-set and is located at the center of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates. This approach can be automated with the limitation however that the least squares best-fit straight line segment is always calculated over the same points of the power spectrum which is performed manually would not necessarily be the case. For an anomaly with n data points, the solution of Laplace equation in 2D is written as:

$$M(x_j, z) = \sum_{j=0}^{n-1} A_k e^{i2\pi kx} e^{\pm 2\pi kz} \quad (1)$$

where the wave number k is defined as $k = 2\pi/\lambda$ and A_k are the amplitude coefficients of the spectrum given as:

$$A_k = \sum_{j=0}^{n-1} M(x_j, z) e^{-i2\pi kx_j} e^{\pm 2\pi kz} \quad (2)$$

For, z = 0 (Eq. 2) becomes:

$$(A_k)_0 = \sum_{j=0}^{n-1} M(x_j, 0) e^{-i2\pi kx_j} \quad (3)$$

Equation 2 can be written in terms of (Eq. 3) as:

$$A_k = (A_k)_0 e^{\pm 2\pi kz} \quad (4)$$

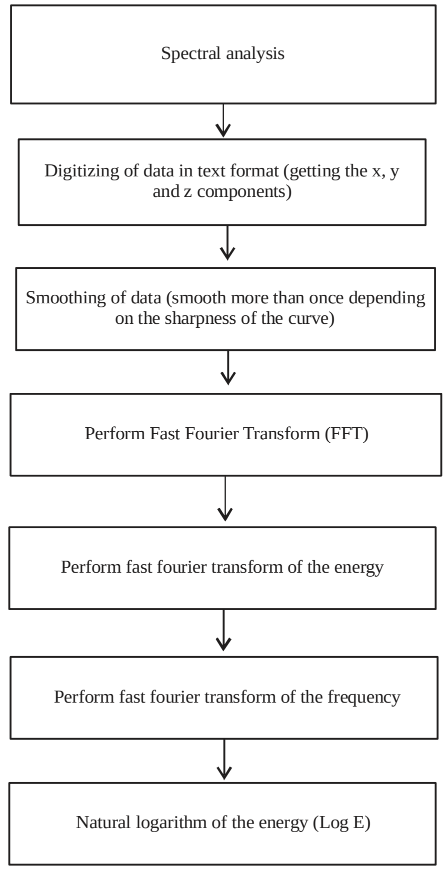


Fig. 2: Spectral analysis procedure using microsoft excel

The power spectrum P_k is defined as:

$$P_k = (A_k)^2 = (P_k)_0 e^{\pm 4\pi kz} \quad (5)$$

Taking the natural logarithm of both sides, we have:

$$Log_e P_k = log_e (P_k)_0 \pm 4\pi kz \quad (6)$$

The estimated depth of anomalous body from power spectrum[11] is given as:

$$h = -\frac{\log \Delta E}{4\pi \Delta f} = -\frac{1}{4\pi} \times slope = -\frac{m}{4\pi} \quad (7)$$

$$h = -\frac{m}{4\pi} \quad (8)$$

where, the slope (m) is $\log\Delta E/\Delta f$, E is the spectral energy, f is the spectral frequency and the negative sign (-) indicates that the logarithm of energy against frequency has an inverse relationship.

The steps taken in the analysis of aeromagnetic data using spectral analysis is summarized by the flow chart in

Fig. 2. Depth to the buried magnetic anomalies, susceptibilities of rocks in the modeled area, angle of dip of anomalous body, plunge and strike angles of the bodies, length, width and height of the bodies (shape) are determined by modeling method. The process of creating a shape that could be attributed to the shape of the causative magnetic anomaly buried below the Earth's surface by software is known as forward modeling. This involves generating a field which could be compared with the observed field displayed. The process of comparing the field is achieved by inputting the total magnetic field intensity parameters: susceptibility, inclination, declination and profile azimuth. These parameters were changed until the calculated curve best-fits the observed curve. The depth and dimensional parameters of the body are adjusted by trial and error until a satisfactory agreement is achieved between the calculated and observed values[12]. Inverse modeling is the reverse procedure of the forward modeling and involves determining the geometry and the physical properties of the source from measurement of the anomalies. Modeling was performed using PotentQ software which is an extension of Oasis Montaj software.

RESULTS AND DISCUSSION

The TMI map (Fig. 3) which ranges from -48.7 nT to 100.7 nT was produced using Oasis Montaj software. Higher values of magnetic intensity were found in the Eastern and Southern parts of the study area while the lower values were found in the central and Northern parts of the area. The residual anomaly map (Fig. 4) has magnetic intensity ranging from -39.9 nT to 60.5 nT. The central and North Western parts of the residual map are characterized by low magnetic intensity values. The Northwestern part of the residual map shows smaller magnetic contours which is an indication of a distinct lithology from the surrounding or possibly a lava flow as evidenced by in homogeneity of the magnetic units[13].

The study area was divided into 18 spectral cells (Fig. 5), each cell is 18.33 km by 18.33 km in order to accommodate longer wavelength and give room for an in-depth analysis of the area.

The graph of natural logarithm of the energy against frequency was plotted for each cell (Fig. 6) and the slopes, calculated. The spectral depths gotten from spectral analysis revealed two major anomaly source depths, shallow and deep. The red tangent was used in calculating the deep depths while the blue tangent was used in calculating the shallow depths as shown in Fig. 6a-r. The deep lying magnetic source bodies have sedimentary thickness ranging from 1114.085-3978.874 m with an average depth of 2105.014 m whereas the shallow anomalous bodies have sedimentary thickness ranging from 163.836-460.057 m with an average depth of 295.708 m (Table 1). The

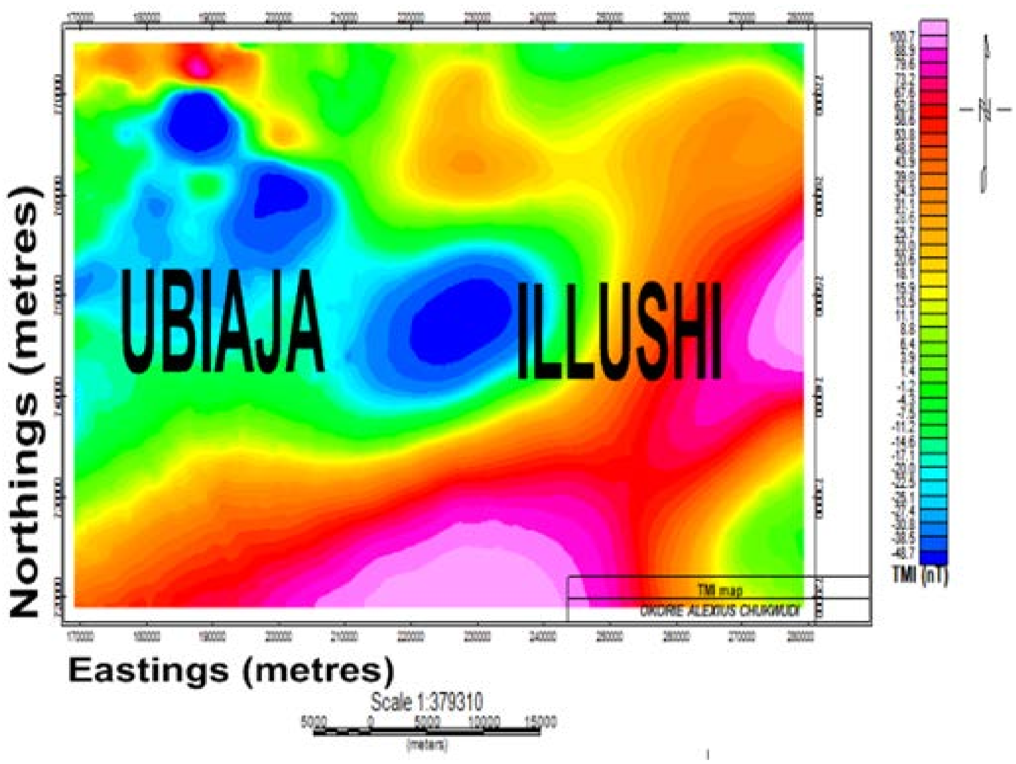


Fig. 3: Total Magnetic Intensity (TMI) map of the study area

Table 1: Spectral depths for the (18) blocks

	Centre values (degress)		Depth (meters)	
Spectral cell	Longitude (x)	Latitude (y)	Deeper source	Shallow source
1	6.083	6.583	1894.702	378.940
2	6.250	6.583	2081.257	416.834
3	6.417	6.583	1503.129	298.416
4	6.583	6.583	2586.268	290.764
5	6.750	6.583	2025.608	234.051
6	6.917	6.583	2685.740	703.955
7	6.083	6.750	1407.909	460.057
8	6.250	6.750	1114.085	163.836
9	6.417	6.750	1989.437	198.944
10	6.583	6.750	2387.324	306.067
11	6.750	6.750	2586.268	312.626
12	6.917	6.750	2652.582	209.414
13	6.083	6.917	1663.893	187.241
14	6.250	6.917	2546.479	229.550
15	6.417	6.917	1338.348	298.416
16	6.583	6.917	3978.874	265.258
17	6.750	6.917	1856.808	183.640
18	6.917	6.917	1591.549	184.733
Average depths (metres)	-	-	2105.014	295.708

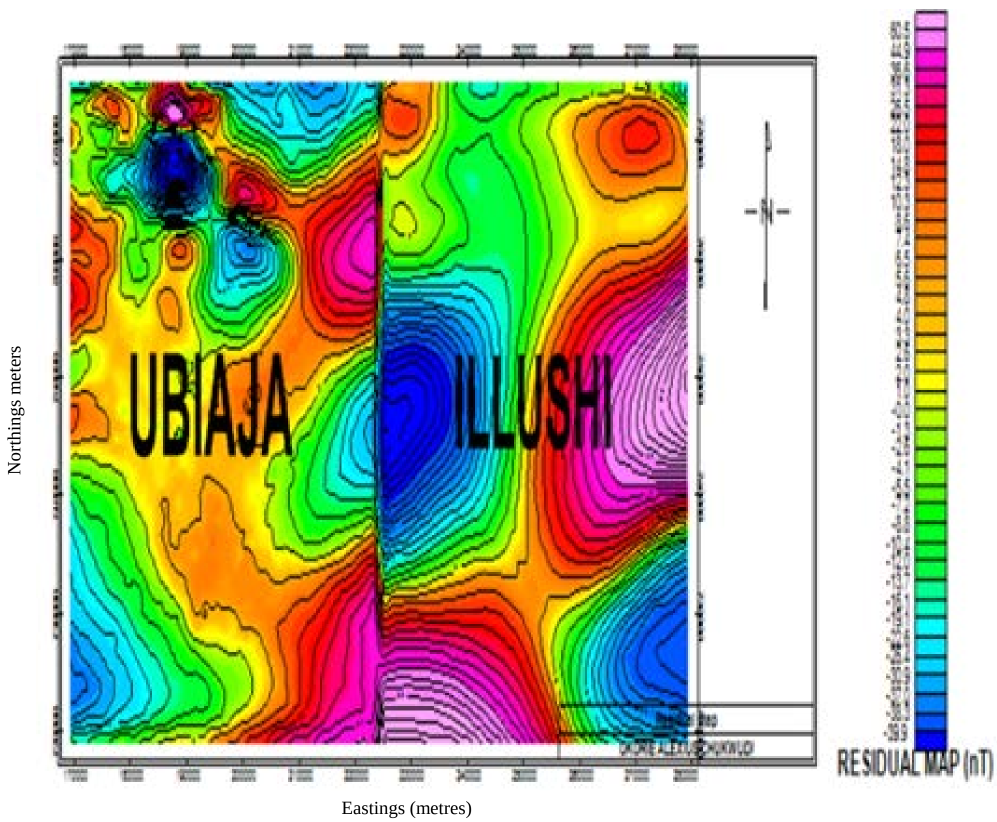


Fig. 4: Residual anomaly map of the study area

calculated depths for the cells show that spectral cell 16 has the highest depth of 3978.874 m while spectral cell 8 has the shallowest depth of 163.836 m. The summary of the spectral depths for the (18) cells is given in Table 1. The contour 2D map and 3D surface plots of the deep depths (Fig. 7 and 8) were produced using Surfer 11 software. The thickest sedimentary cover occurred at spectral block 16 located at the northern part of the map (Fig. 7).

The contour 2D map and the 3D surface plots of the shallow depths (Fig. 9 and 10) were also produced using Surfer 11 software. The 2D contour map of the shallow

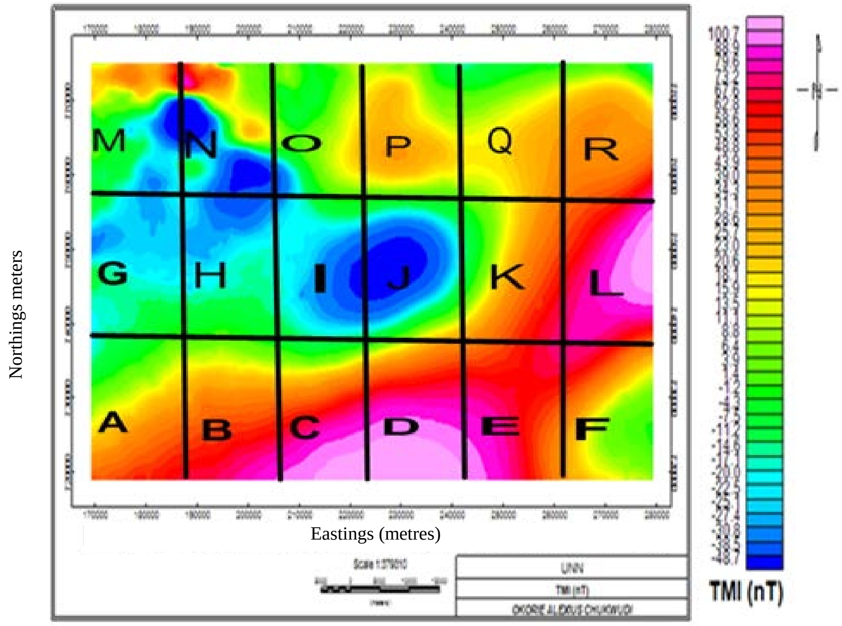


Fig. 5: The TMI map of the study area showing the spectral cells

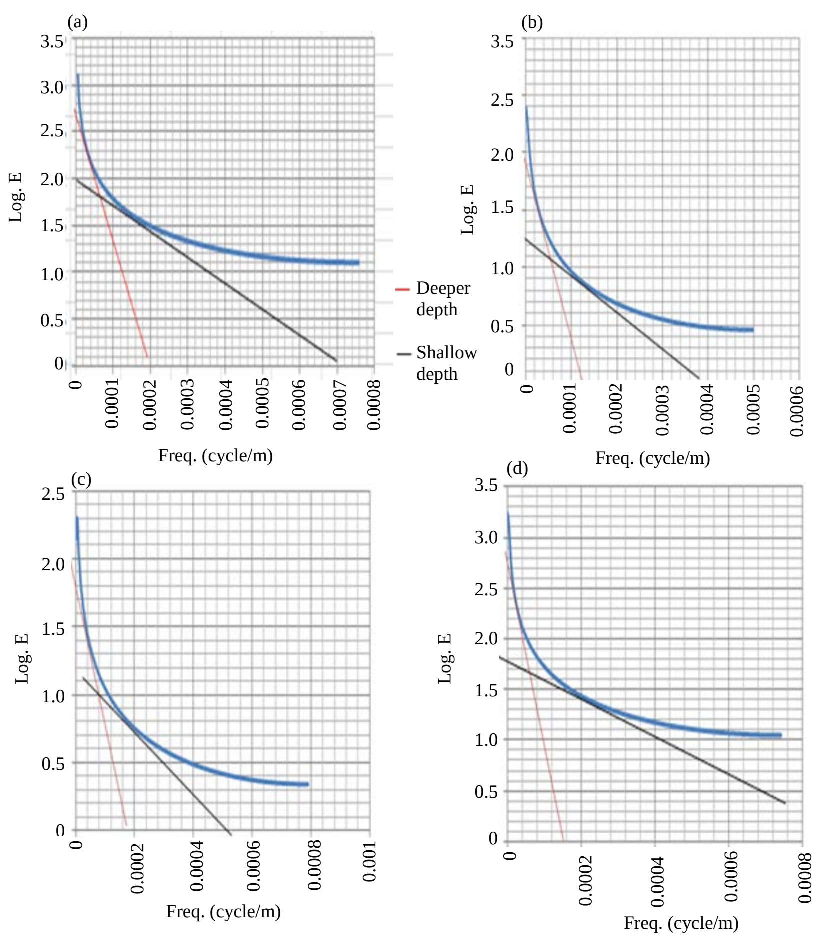
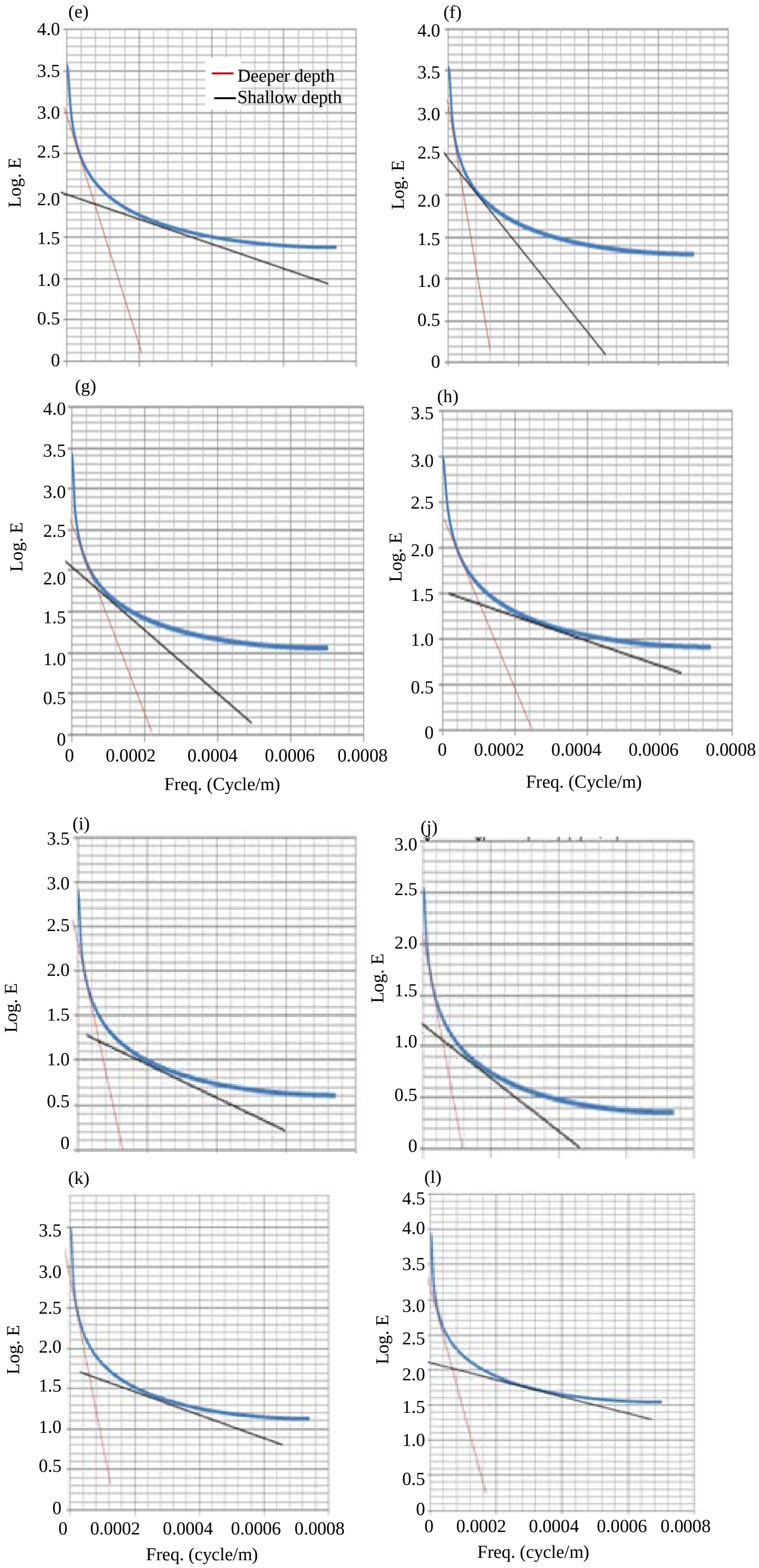


Fig. 6(a-r): Continue



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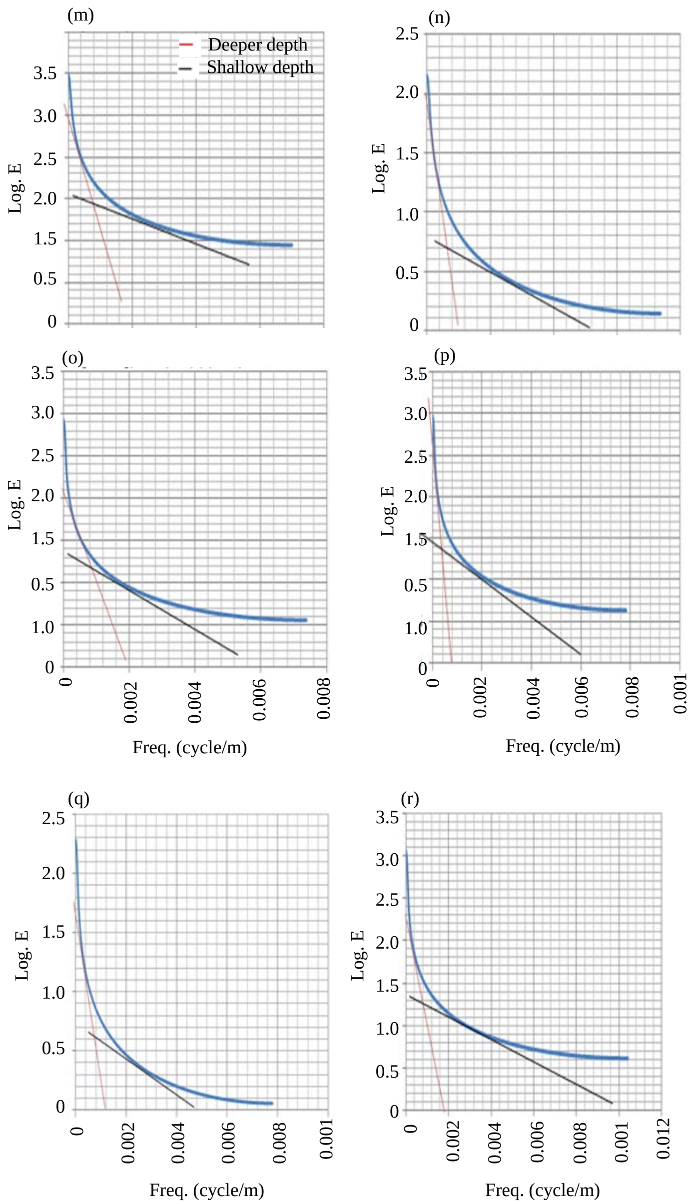


Fig. 6(a-r): A graph of deeper and shallow depths of cell 1-18; Log of energy vs. frequency (cycle/m) for cell1-18

depth (Fig. 9) shows clearly that the area is very shallow except for the area in purple as indicated by the colour legend bar at depths of -560 to -720 m. The 3D surface plot (Fig. 10) shows that the area is generally flat except the point indicated by the black colour from the colour legend bar.

To model the area and find the possible minerals and rocks, four profiles (P1, P2, P3, P4) were taken at different locations (Fig. 11). From the modeling results (Fig. 12), the blue curves represent the observed field while the red curves represent the calculated fields due to the model. The modeled Profiles are taken based on their good fit and geology of the study area. P1 was modeled using ellipsoid and P2 was modeled using sphere. Their susceptibility values were both 0.0100 which depicted that the possible bodies causing the anomalies are probably hematite, gneiss, granite or gabbro[2]. P3 was modeled using ellipsoid and the susceptibility value is 0.0613 which suggest that the possible body causing the anomaly is porphyry, a hard igneous rock made up of feldspar[2]. P4 was modeled using ellipsoid and the susceptibility value is 0.0288 which suggests that the possible bodies causing the anomaly are slate and hematite[2]. The depths

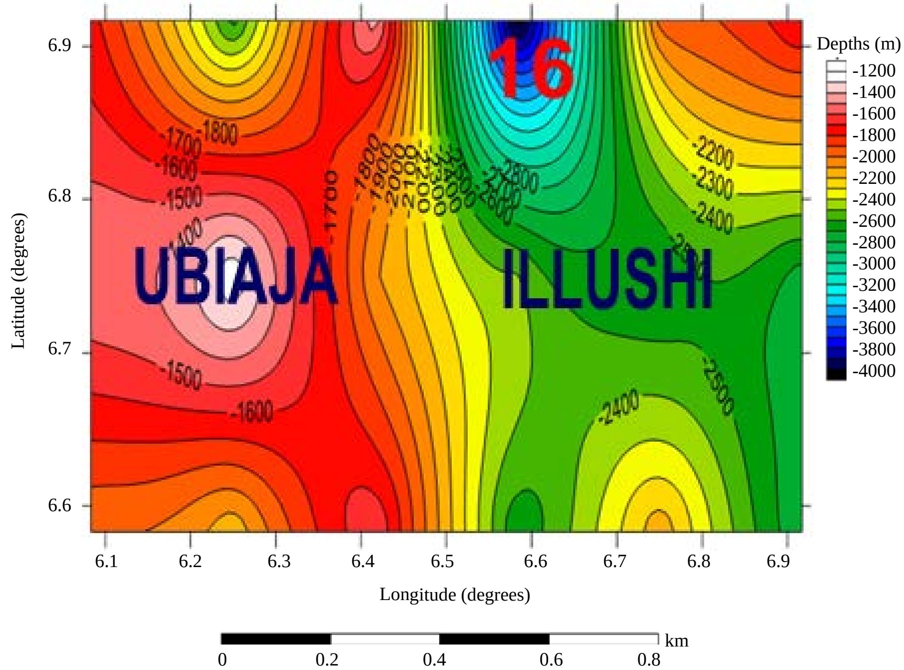


Fig. 7: A grid map of deeper depths (2D representation)

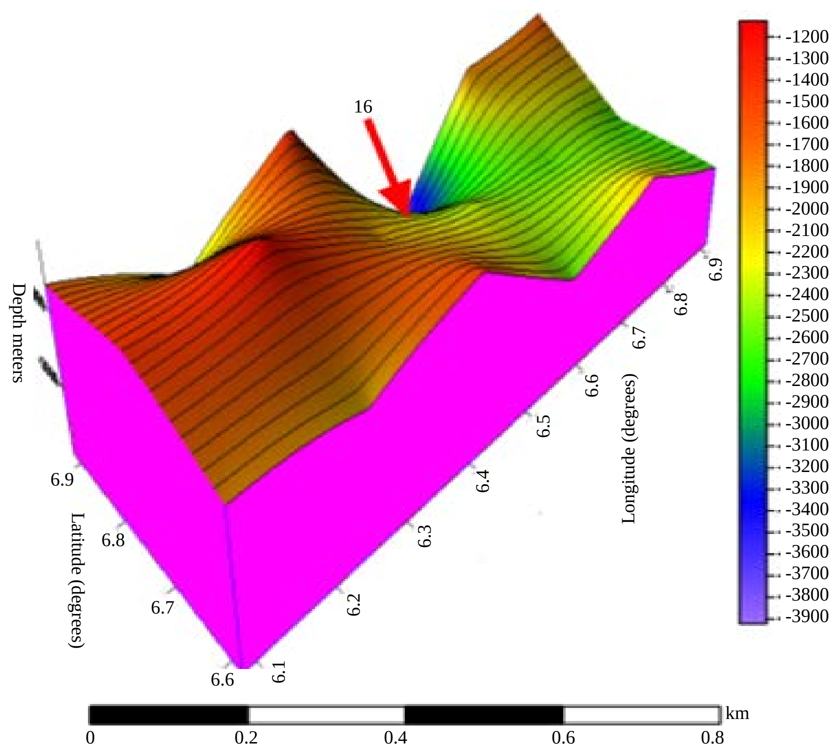


Fig. 8: A diagram showing the 3D view of the deeper depth (depth to basement or sedimentary thickness) of the area

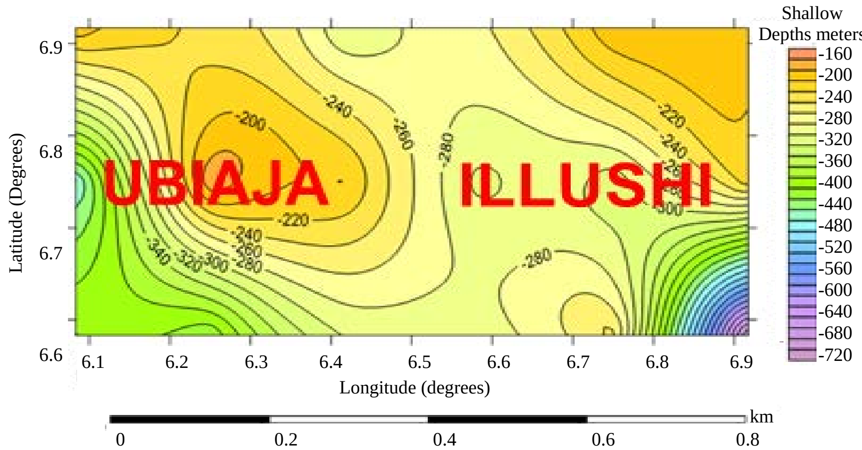


Fig. 9: A diagram showing the 2D view of the shallow depth

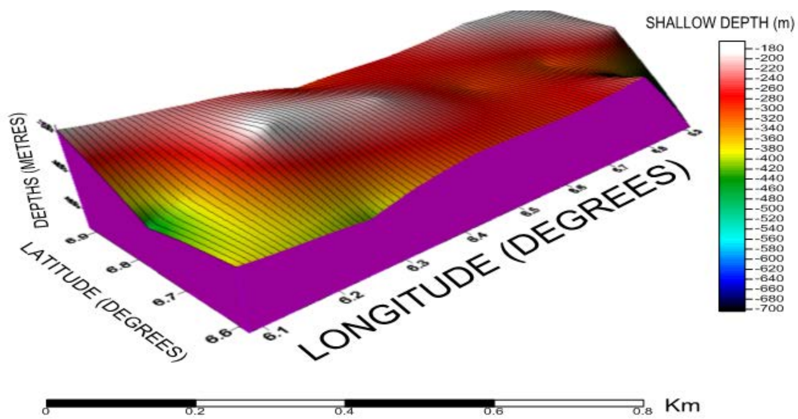


Fig. 10: A diagram showing the 3D view of the shallow depth of the area

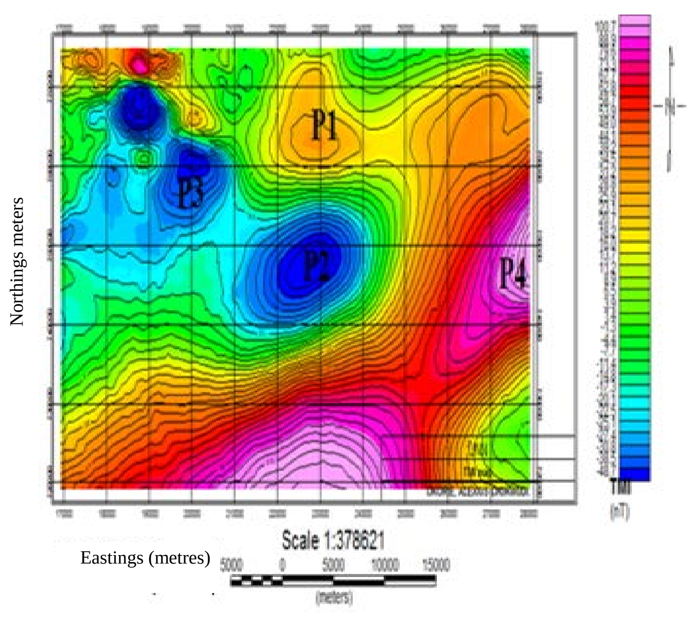
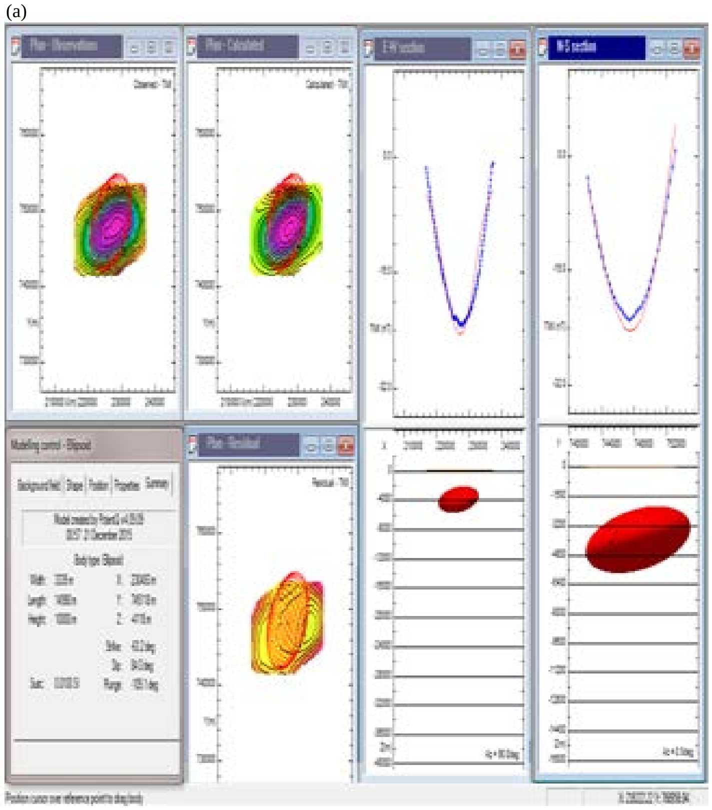


Fig. 11: TMI contoured grid showing four profiles

(a)



(b)

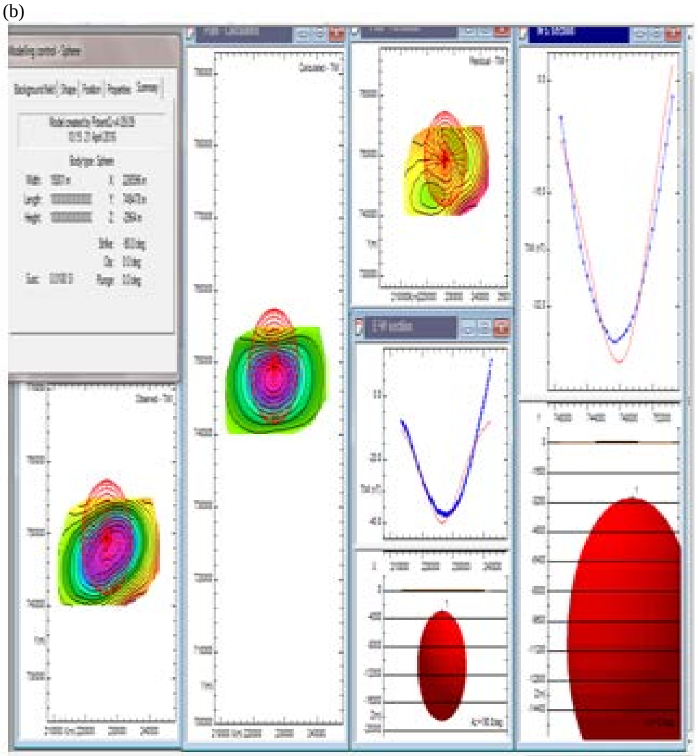


Fig. 12(a-d): Continue

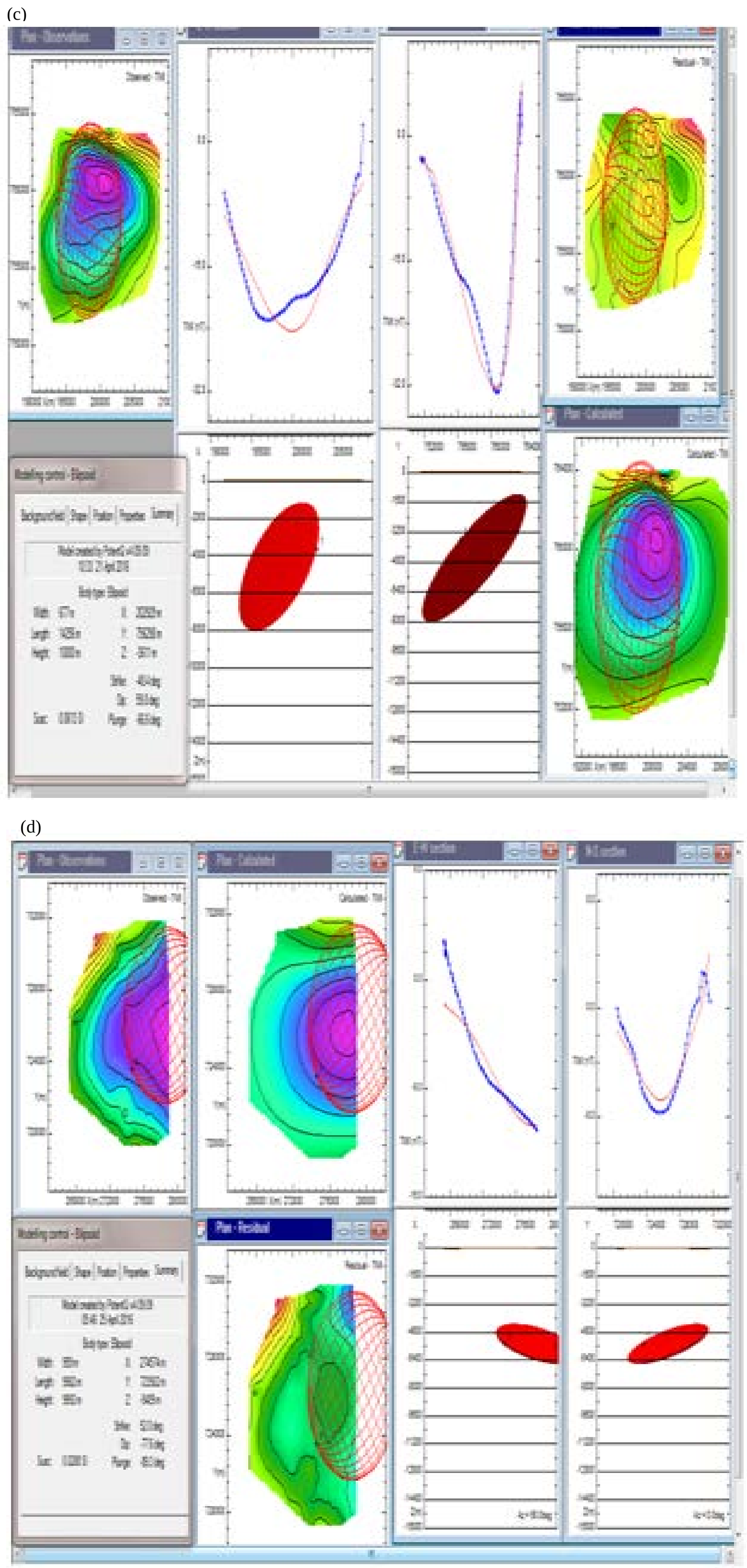


Fig. 12(a-d): Modeling pf profile p1-p4

Table 2: Summary of forward and inverse modeling results

Profiles	X (m)	Y (m)	Depth (m)	Dip (deg.)	Plunge (deg.)	Strike (deg.)	Body Shape	K value (SI)	Possible mineral
1	230493	745118	-4118	84.00	-105.1	-63.2	Ellipsoid	0.0100	Hematite, Gneiss, Granite or Gabbro
2	226596	749478	-2964	0.0	0.0	-90.0	Sphere	0.0100	Hematite, Gneiss, Granite or Gabbro
3	202929	756298	-3611	58.8	-66.6	-48.4	Ellipsoid	0.0613	Porphyry (igneous rock)
4	274574	723582	-5489	-77.6	-89.3	52.0	Ellipsoid	0.0288	Slate or Hematite

deduced from the modeling method for profiles 1-4 are 4118, 2964, 3611 and 5489 m, respectively. Table 2 shows the summary of the modeling results.

CONCLUSION

Aeromagnetic data over Ubiaja and Illushi areas were interpreted qualitatively and quantitatively. Spectral analysis and modeling methods were employed in the quantitative interpretation. The spectral analysis results gave two depth sources; the deeper and the shallow magnetic sources. The deeper depth ranges from 1114.085-3978.874 m with an average depth value of 2105.014 m while the shallow depth ranges from 163.836-460.057 m with an average depth value of 295.708 m. The susceptibility values obtained from the model profiles 1-4 were 0.0100, 0.0100, 0.0613 and 0.0288, respectively which depict dominance of paramagnetic minerals (hematite, gneiss, granite, gabbro, porphyry and slate) as indicated by their positive susceptibility values. The respective depths for the four profiles are 4118, 2964, 3611 and 5489 m.

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