Nigerian Journal of Physics (NJP)

ISSN: 1595-0611

Volume 32(3), September 2023

Geological Interpretation Using Derivatives of Magnetic Signal from Ground Survey over a Granitoid Bedrock Area in part of South-Western Nigeria

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ABSTRACT

Few researchers located and identified granitoid rocks in the course of determining the thickness of the clay deposits with the use of electrical resistivity method of geophysics in the Basement Complex of Southwestern Nigeria. Another set of researchers have related elemental abundances were to tectonic evolution of certain granitoid rocks from the Precambrian rocks of Southeastern Nigeria. It was also established that their ferromagnesian phase oriented clots followed the magmatic flux direction. However, the analysis, modification and synthesis of magnetic signal in the interpretation of magnetic anomalies granitoid bodies are rare in the geophysics literature of Southwestern Nigeria. This study is aimed at deciphering the physical and geometric limitations from magnetic causative body. In this study, ground magnetic data was acquired using advanced GSM 19T Proton Precision Magnetometer. Quantitative data was transformed to magnetic signal. Carefully chosen derivatives include the Total Magnetic Intensity (TMI), Regional Magnetic Intensity (RMI), Residual Anomaly (RA), Tilt Derivative (TD), HTD, Euler Deconvolution, Analytical Signal (AS), Pseudo-gravity data, 2-D Power Spectrum. Results clarified doubts on the structural trend and tectonics of the igneous bodies. It was established that granitoid rocks which underlain Idofe-Oru area experienced crustal thickening during the period of Pan African orogeny, and were related to convergent boundaries.

Keywords:
Magnetic,
Derivative,
Granitoid,
Tectonics
Pan African.

INTRODUCTION

The magnetic field that surrounds the globe is pondered to be created by electrical currents in the magma, which is the liquid portion of the planet's interior (Fowler, 1994; Mattsson & Wahlgren, 2010). According to Fowler (1994), the magnetic field lines are horizontally close to the equator and vertically close to the magnetic poles hence the magnetic field of Earth has a striking resemblance to the shape of a bar magnet. .

The search of the earth's magnetism is believed to be the oldest branch of geophysics (Telford, Geldart, & Sheriff, 1990). For over three centuries, scientists have known the Earth acting as a massive and rather inconsistent magnet. The magnetic method of exploring the subsurface of the earth is capable of either mapping or locating rock types that contain varying amounts of magnetically susceptible minerals or man-made ferromagnetic (e.g. iron) substances (Ives & Mickus, 2019). Exploration investigations have employed magnetic method for a variety of reasons, such as mapping geological formations, locating voids, and locating metal containers that hold poisons. Certain rocks have enough magnetic materials to produce visible magnetic anomalies, despite the fact that the minerals that compose the rock, such as feldspar and quartz, are fundamentally magnetically inactive. (Kearey, *et al*., 2002).

Unlike other geophysical techniques such as Ground Penetrating Radar (GPR), High Frequency Electromagnetics (HFE) and Direct Current Electrical Resistivity (DCER), the magnetic method has much better depth penetration capacity. Total Magnetic Intensity (TMI), the measure of the strength of the entire magnetic field, is obtained from current standard magnetic surveys used in exploration. A residual map was produced by deducting the TMI from the International Geomagnetic Reference Field (IGRF) that was modeled. This indicates differences in the rock's magnetic characteristics that are important locally (MacLeod & Ellis, 2013).

Since it requires less data processing manipulation, the magnetic method is both reasonably simple to use and reasonably cheap. The idea is that magnetic signal can be converted from complex back to real forward by discarding the imaginary part. Using the anomaly width at half the amplitude, the depths of magnetic sources from the Earth's surface have been calculated (Rao, *et al*., 1981; Roest, *et al*., 1992). In order to further mitigate the effect of overlap, other features of the analytic signal that was employed were referred to as "complex gradient" (Rao *et al.* 1981; MacLeod & Ellis, 2013).

The analytical representation of a signal comprises the original function, which facilitates mathematical manipulations (Boashash, 1992). This makes magnetic attributes more accessible and derivable. The analytic representation is a generalization of the magnetic signal, and allows for other variable parameters. Magnetic signal analysis modifies and synthesizes magnetic measurements. Therefore, magnetic derivatives aid in enhancing the observed magnetic signal's subjective quality as well as highlighting and identifying its interesting components.

In literature, little or no research work is known to have been done on analysing and modelling of the magnetic data in the Basement Complex. However, granitoid rocks in the Older Granite Suite of the Precambrian Basement Complex have been discussed. (Ajibade & Fitches, 1988). Granitoids are a kind of plutonic rock with coarse grains, which includes quartz monzonite, quartz diorite, granodiorite, syenite, *etc*. The granitoid rocks that underlain Oru/Idofe area have been located and identified in the course of determining the thickness of the clay deposits using electrical resistivity method of geophysics (Mosuro, *et al*., 2011) . At Oru/Idofe area, several granitoid intrusions were found within variable amounts of migmatized Older Gneissic Complex.

On the other side, the elemental abundances were related to tectonic evolution of certain granitoid rocks from the Precambrian Basement Complex of Southeastern Nigeria (Obiora, 2012). The granitoid rocks in the South Eastern part of Nigeria have been identified as the basement's monzogranitic gneisses are where the gabbroic and doleritic intrusions are located. As directed clots, their ferromagnesian phase most likely follow the path of magmatic flux (Ephraim, 2012). This event suggests syntectonic emplacements of the granitoids, as does the regional N-S to NE-SW foliation of rocks in Southeast Nigeria. It is clear that the magnetic data was interpreted using less advanced characteristic procedures in these earlier methods.

In the present study, interpretation of anomalies arising from magnetic method is based on the measurement, identification and description of the ground magnetic field at predetermined points in an area underlain by granitoid rocks from part of Southwestern Nigeria. In order to achieve this goal, map data were analyzed and modeled so that, causative bodies could be seen as simple shapes. It is hoped that a ground magnetic survey of the Oru/Idofe area would enable the measurement of the Earth’s magnetic field at encoded points, evaluation of structural trend and magmatic flux from the Earth’s surface to the magnetic source based on the derivatives.

MATERIALS AND METHODS

Study Area and Bedrock Geology

The study area falls within Ijebu North East of Ogun state (Fig.1) located in the South Western, Nigeria. It is accessible through the Ijebu-Ode Ibadan road around Oru–Ijebu. In the area is an abandoned farm settlement, which containing trees shrubs and grasses. The region has a dendritic drainage system, which is characterized by tributary streams that irregularly branch off in various directions (Pidwimy, 2020; Ritter, 202). The Ogun River Basin is the source of the major river. The land area of Ogun River is over 23,000 km². Its principal tributaries are the Ofiki and Opeki rivers. It rises from the Iganran hill, which is located at an average elevation of 530 meters above mean sea level. With a gradient running north-south, the relief is typically minimal (Oke, *et al.* 2015).

The region is dominated by a tropical climate with periodic wet and dry seasons. November through March is when the dry season occurs. With an average yearly rainfall range of 900-2000 mm from the north to the south, the rainy season typically lasts from April to October (Ogunrayi, *et al.* 2016). The region is divided into two main vegetation zones. These include the high woodlands found in the north and center sections, as well as the mangrove/swamp forests that cover the southern shoreline and floodplains, next to the estuary.

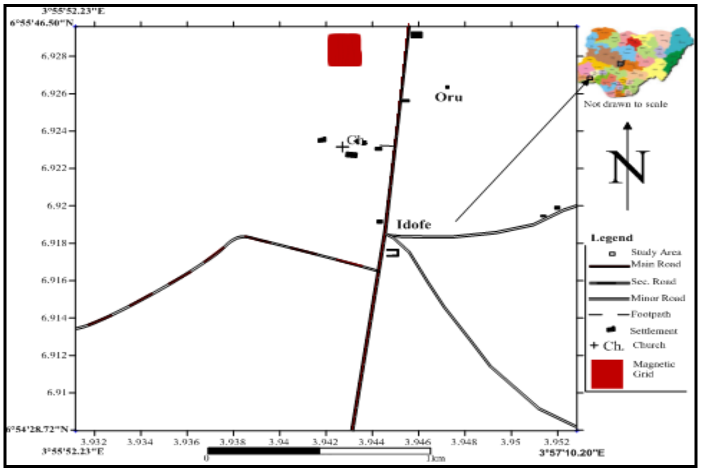

Figure 1: Map of Ogun North East in the South Western, Nigeria.

The research area is located at Ijebu. Idofe is geologically associated with Southwest Nigeria's Basement Complex. Aïr, Hoggar, Cameroon, and Borborema Pan-African (Brasiliano) provinces are purportedly related to the Nigerian portions of the Precambrian Tran-Saharan Pan-African Orogen, which lie between the Congo and West African cratons (Rahaman, 1988; Ephraim, 2012). At the volcanic/granitic ring complexes in the Jos Plateau region, the Mesozoic tin-bearing Younger Granite suite was distinguished from the Older Granite suite in Nigeria. The nature of the stones in these older granite suites varies greatly, ranging from granite to granodiorite, adamellite, quartz, monzonite, and syenite (Rahaman, 1988). The Nigerian Basement Complex is home to the Older Granite, which invaded at the time of the Pan-African Orogenic cycle. They exhibit a range of relationships with metasediments and differ in framework, texture, and mineralogy. The fundamental and intermediate intrusive rocks known as gabbro and small, irregular masses of quartz and pyroclase diorites are a defining feature of the earlier sections of the Older Granite, which are also rich in potash (Ephraim, 2012).

A broad range of compositions, including granite, granodiorite, adamellite, quartz-monzonite, and syenite, can be found among the members of the older granite suites. They are typically deposited in high-grade gneisses and paraschists of the Liberian (2700 Ma), Eburnean (2000–2700 Ma), and most likely Kibarian (1100 Ma) eras, as well as migmatitic rocks. Some of the Porphyritic Granite members of the rock suites are classified as Porphyroblastic Gneisses, Granite Gneisses, and so on because of their foliated character (Oyinloye, 2011). The granitoid rocks underlain Oru/Idofe area. Several granitoid intrusions are known to occur within variable amounts of the Migmatized Older Gneissic Complex (Mosuro, *et al.*, 2011). The Precambrian Basement Complex has irregularly formed, isolated bodies of granitoid rocks that are part of the Older Granite suite in the northern Obudu area. However, the ascent of magmas found zones of weakness in the N-S trending stress zones and other features, which caused the rocks to align with the N-S to NE-SW structural pattern of the pre-existing rocks (Ephraim, 2012).

Basic Theory, Data Acquisition And Processing

The magnetic and the gravity methods both have the same first-order approximation as their theoretical foundation. The magnetic approach examines the entire magnetic field (x, y, and z components), whereas the gravity method typically measures only the z component (Ives & Mickus, 2019). These are the primary distinctions between the two procedures.

A simple magnetic bar can be used to explain the primary concept of the theory underlying the geological application of the magnetic technique, known as the magnetic dipole. Figure 2 illustrates the force (F) that exists between two magnetic poles of strength (p_1) and (p_2) that are separated by a distance (r). Assuming equal polarity, the force would push the poles apart. Alternatively, because of attraction forces, magnets with opposite polarities would pull their poles together. Equation 1 offers a mathematical depiction of this.

$$F = \left(K\frac{p_1 p_2}{r^2}\right)_{r_1} \qquad (1)$$

Where K is the constant of proportionality which is define to be dimensionless (Lowrie, 2007), r_1 is a unit vector directed from p_1 towards p_2 (Telford, *et al.*, 1990).

It is possible to characterize a wide range of a substance's magnetic properties and use hypothetical poles to solve magnetic problems. Accordingly, a magnetic induction B is the force that a pole of strength P applies to a unit pole at a distance r (Telford *et al.*, 1990).

$$B(r) = \frac{F}{p_2} = \left(K\frac{p_1}{r^2}\right)_{r_1} \qquad (2)$$

However, the constant of proportionality K is not dimensionless in the modern Système Internationale (SI) units. It's value is $\frac{\mu_0}{4\pi}$ where μ_0 is called the permeability constant equals to $4\pi \times 10^{-7}\, NA^{-2}$, (or henry/meter, Hm^{-1} , equivalent to NA^{-2}).

If $K = \frac{\mu_0}{4\pi}$ is used, and the magnetic potential at r is given by eqn 3 and the pole strength, p, expressed in SI units.

$$W = -\int_r^\infty B\, dr = \frac{\mu_0 p}{4\pi r} \qquad (3)$$

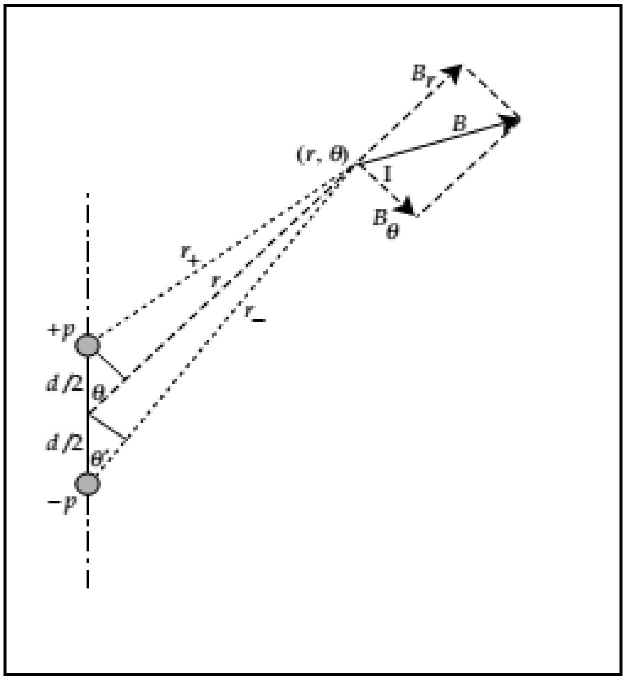

Figure 2: An example of calculating the potential between two magnetic poles [(Lowrie, 2007)

The dipole potential at the location (r, θ) is expressed as the potential W, which is the sum of the potentials of the positive and negative poles at a distance r from the middle of each set of poles, in an orientation which forms an angle to the axis.

$$W = \frac{\mu_0}{4\pi}\frac{dp\cos\theta}{r^2} = \frac{\mu_0}{4\pi}\frac{m\cos\theta}{r^2} \qquad (4)$$

$m(dp)$ is the magnetic moment of the dipole.

The total magnetic moment of a volume V of the substance is determined by the degree of synchronization of each atomic magnetic moment. It is the entire vector sum of the magnetic moments of the atoms in the substance. The magnetic moment per unit of volume of the material is its magnetization, denoted by the letter M.

$$M = \sum \frac{m_i}{v} \qquad (5)$$

Magnetic moment (Am^2) divided by volume (m^3) is the measure of magnetization. One can express the magnetic field H as

$$H = \frac{B}{\mu_0} - M \qquad (6)$$

In a vacuum, B and H are parallel and proportionate ($B = \mu_0 H$). and there is no magnetization (M=0). There are two origins of the magnetic B-field within a magnetizable substance. According to Lowrie (2007), the magnetization M is the outcome of an internal set of atomic currents that induce atomic magnetic moments, whose complete synchronization is represented by the magnetization. The magnetizing field H is generated by an external system of real current

A magnetizable body, such as iron or magnetite, will get magnetized and produce a secondary magnetic field when exposed to an outer magnetic field, such as the Earth's magnetic field. This secondary magnetic field will be defined by the magnetic polarization M of the material (Ives & Mickus, 2019). The magnetic susceptibility, or k, of the body is the measure of its degree of magnetization and is described as

$$M = kH \qquad (7)$$

Magnetic susceptibility is the basic physical attribute utilized in the magnetic technique. It is a non-dimensional quantity. The magnetic induction (B) is the measurement of the total magnetic field, which takes into account both the magnetization and the external magnetic field. It is expressed as follows in equation 3 (Kearey, *et al.*, 2002).

$$B = \mu_0(1 + k)H \qquad (8)$$

where, μ_0 is the magnetic permeability of free space. The unit of (B) is gammas (10-9 Tesla), which is more frequently used because Tesla is typically too big a number for applied magnetic work. Additionally, keep in mind that B is a vector quantity. In the majority of magnetic work done today, B's amplitude is measured and referred to as the total magnetic field.

The Earth's outer core is the primary source of the geomagnetic field that exists close to or on the surface. The declination, d; inclination, I; and total force vector, F, can be used to characterize the geomagnetic field. From a lower limit of about 3,000 nT at the magnetic equator to 60,000 nT at the magnetic poles, the vertical component of the Earth's magnetic field's intensity varies with latitude.

The Earth functions as a weak magnetic body, with a magnetic field that is similar to those of an evenly polarized magnetic dipole oriented at an angle of around 11.5° as regards to the axis in its center (Kearey, *et al.*, 2002). Although the exact cause of the geomagnetic field is unknown, convection currents carrying conducting materials through the outer fluid, a region of the earth's core, are thought to be the source (Telford, *et al.*, 1990). Because of the preponderance of these conducting materials, this field experiences periodic polarity changes (Adagunodo, *et al.*, 2015).

Different physical properties such as susceptibility, radioactivity, resistivity, colour density and more can be used to study rocks (Kearey, *et al.*, 2002). Since magnetic minerals are unevenly distributed in rocks, magnetic survey can be used to map out magnetic rocks thanks to the sensitivity of minerals to magnetic fields. This distortion of the Planet's magnetic field is caused by magnetic materials found in rocks. The many rock mineralogy features are displayed by this characteristic of the various rock mineral types.

Rocks contain minerals that are either naturally occurring (from lithogenesis or pedogenesis) or man-made. Magnetic susceptibility is a measure of a rock's magnetic mineral content. In magnetic modeling, it is claimed that determining the magnetic susceptibility is helpful, sensitive, and quick. (Ojo. *et al.*,2014).

The Earth's field may be enhanced by the induced field, leading to a high anomaly. Magnetization varies from point to point and is location-dependent. (Ojo. *et al.*,2014). All materials have been categorized as diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism based on their magnetic properties (Adagunodo, *et al.*, 2015).

Data was acquired through field exercises which include reconnaissance survey and the geological field work. During this exercise, the advanced GSM 19T Proton Precision Magnetometer was used to read and record the magnetic variations at predominant points on the study area as shown in the Magnetic data map of Figure 3. Field operations logically involved the removal of cultural noise, base station establishment, creation of a uniformly spaced Cartesian grid, measurement of first magnetic intensity reading at the base station, advancement of measurement to other points on the grid, hourly repetition of basement station measurements for diurnal variation check until the last measurement was taken.

Quantitative analysis of data involves the derivation and transformation of magnetic signal, based on mathematically defined algorithms to highlight significant and subtle structures which resulted from the signal. A set of carefully chosen derivatives then sheds light on the structural trend, tectonics and the igneous bodies present. Qualitative data include the Total Magnetic Intensity (TMI), Regional Magnetic Intensity (RMI), Residual Anomaly (RA), Tilt Derivative (TD), HTD, Euler Deconvolution, Analytical Signal (AS), Pseudo-gravity data, 2-D Power Spectrum.

For the analysis, the 2D profile modelling of magnetic depth estimation and inversion to revise the qualitative interpretation, test plate tectonics models, basement depth and other significant subsurface horizon. These include profiles that highlight the tiny magnetic anomalies caused by the variations in rock type across basement unit boundaries, as well as the radially average power spectrum (Billings, 2013).

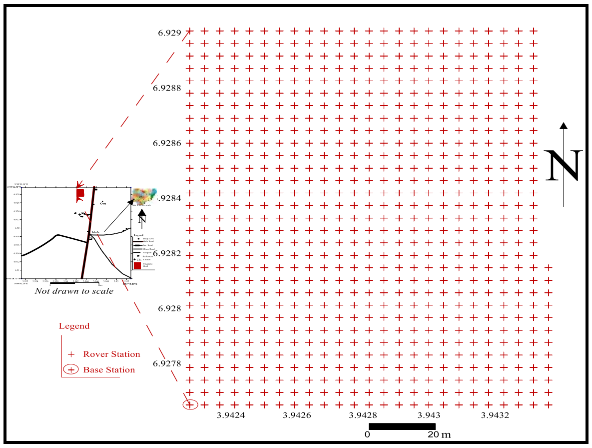

Figure 3: Field data acquisition map

RESULTS AND DISCUSSION

Total Magnetic Intensity (TMI) map of the study is presented in Figure 4. The map shows the ground over shallow magnetized bodies which is the vector that results from the strength of the Earth's magnetic field's vertical and horizontal components at a particular location in the area (Rao, *et al.*, 1981; MacLeod & Ellis, 2013). The anomalous field of the magnetized feature varies significantly with the direction of the Earth's normal field within the locality of the magnetized granitoid content (Roest, *et al.*, 1992). It is highly variable in shape and amplitude, and appears complex.

The map portrays the combination effects of several sources. It fundamentally shows variation of resultant strength of the Earth’s magnetic field, comprising both the long and the short wavelengths. The blue coloured area indicate areas with low magnetic intensity, areas with green colour indicate the background magnetic intensity, while areas with pink and violent colour indicate high and very high magnetic intensity respectively. It ranges from 32939nT – 33319nT.

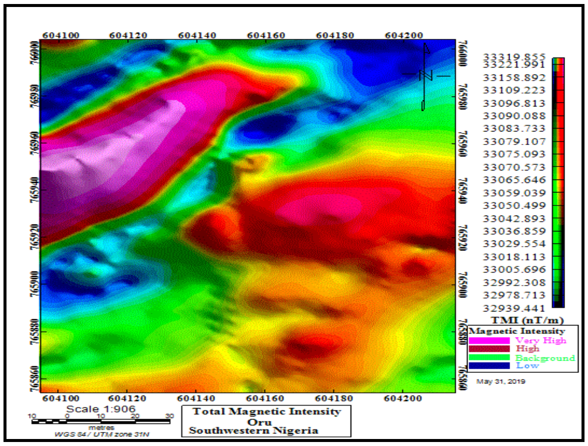

Figure 4: The Total Magnetic Intensity map of the study area

The Regional Magnetic Intensity (RMI) removes the regional effect caused by the imperfect sphericity of the earth (Blakely, 1996). It shows only long wavelength displayed in a regional anomalies map as shown in Figure 5. The regional anomaly ranges from 32996.84nT to 33111.711nT, suggesting an intrusive lower deeper magnetic body, which trends structurally in the NE –SW direction.

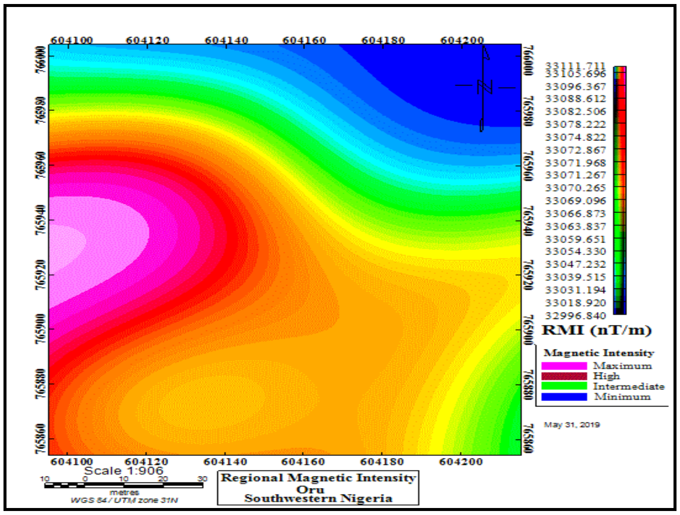

Figure 5: The Residual Magnetic Intensity map of the study area

Figure 6 is a Residual Anomaly (RA) map obtained by subtraction of regional component from that of the total magnetic field. It depicts the short wavelength anomalies, and presents a better understanding of the response of the geological structures, with the surface - subsurface lithological relationship (Rao, *et al.*, 1981). It is 126nT along the fractured host, and 247nT over the concealed intrusive bodies across the study area.

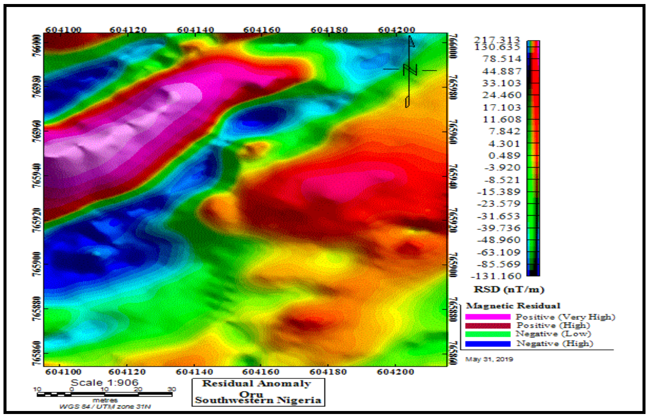

Figure 6: The Residual Anomaly map of the study area

It has been established that magnetic anomalies are frequently distraught by the direction of magnetization (MacLeod & Ellis, 2013). As such, the precise location and configuration of the source cannot be ascertained directly from the original magnetic anomaly. Nonetheless, a technique for the analysis of magnetic anomalies has been developed that is based on the analytic signal derivatives (Ma, *et al.*, 2012). The depth to magnetic sources is determined via the Analytical Signal (AS) map, as seen in Figure 7. The predicted depths of the buried magnetic body in the study area have magnetic fields range from 0.180nT to 49.588nT.

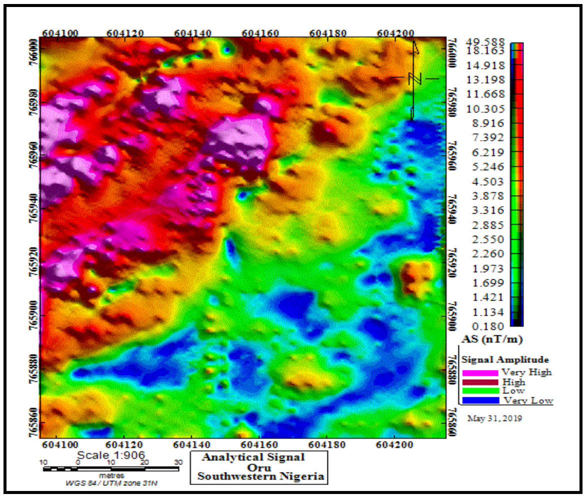

Figure 7: The Analytical Signal map of the study area

Figure 8's tilt derivative map is intended to help identify structure boundaries and provide important details about both shallow and deep structures. The ratio of the potential field's vertical derivative to its horizontal derivative, represented as the Arc tan value, is used to express the tilt angle. Tilt angle derivative of the area ranges between 1.556nT and 1.566nT. The amplitude distribution on the tilt angle map indicates the presence of parallel NE – SW trending structural (discontinuities) feature within the gneisses known as fracture, along which the igneous intrusive emplacements were brought about (Rao, *et al.*, 1981). The igneous intrusive bodies (anomalies) are well defined in the Horizontal Tilt Derivative Map shown in Figure 8 whose value ranges between 0.001nT – 1.491nT.

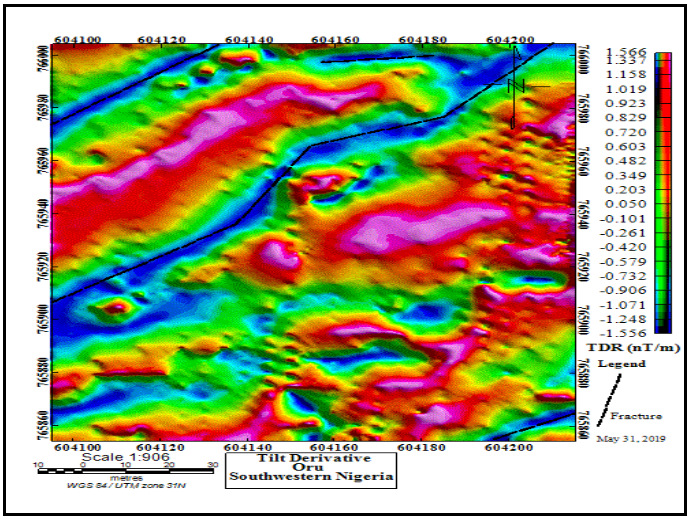

Figure 8: The Tilt Derivative map of the study area

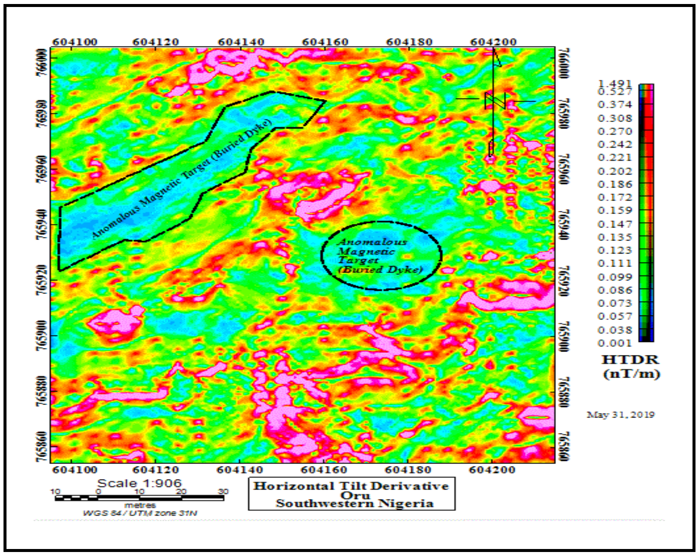

Figure 9: The Horizontal Tilt Derivative map of the study area

The 2D analytic signal is autonomous of the magnetization orientation. Nonetheless, an analysis tool that is helpful in transforming a picture into the spatial frequency domain is the 2-D Power Spectrum (Aydin, 2008). Features in the image may now be quantified thanks to the 2-D power spectrum that was produced, as seen in Figure 10. Using 1D power spectral density (PSD) graphs to summarize a 2D spectrum is frequently helpful. It displays the fluctuations' strength in relation to frequency.

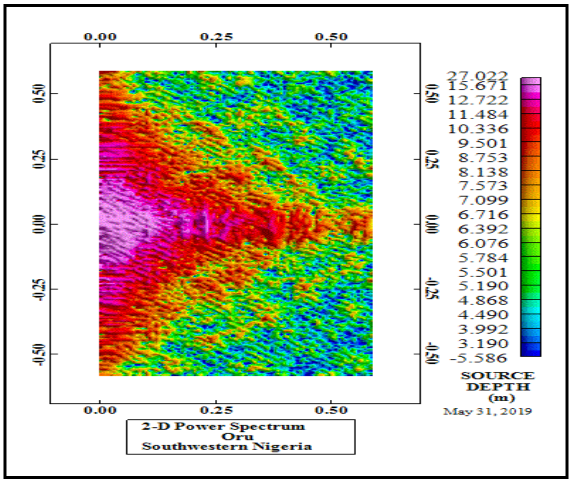

Figure 10: The 2D Power Spectrum map of the study area

CONCLUSION

Total intensity and residual maps are two methods used to study the magnetic fluctuation in a portion of southwest Nigeria. Series of map data that were processed, analysed and modelled showed improved subjective quality and detection of constituent of interest in the measured magnetic signal. The morphology and arrangement of each of the granitoid blocks, in particular, were revealed by the magnetic residual maps, which provided far more precise geologic features. The magnetic anomaly can be understood with the aid of the 2D analytical map, which was created using the analytic signal for both the horizontal and vertical derivatives. Moreover, it highlights the faint magnetic anomalies caused by the variations in rock type at basement block boundaries. Certain geologic characteristics resulting from anomalous rock types found in the basement are also displayed on the Total Intensity Map.

Without a doubt, the granitoid rocks in the research area cannot be linked to convergent boundaries because they underwent crustal thickening during the Pan African orogeny epoch. As a result, they do not correspond to the deepest origins of rift volcanism that have been revealed in areas where erosion has eliminated volcanic rocks and other rifting-related data. The physical and geometric characteristics of the causative granitoid bodies have been solved with the aid of the interpretation of the magnetic anomalies.

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