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Exploit of Ground Magnetic Survey Data for Solid Mineral Exploration

Kesyton Oyamenda Ozegin[1]*, Owens Monday Alile[2]

[1]*Department of Physics, Ambrose Alli University, Ekpoma Edo State, Nigeria*
[2]*Department of Physics, University of Benin, Benin City, Nigeria*

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Contact
*Kesyton Oyamenda Ozegin
ozeginkess@yahoo.com

ABSTRACT

Solid minerals are natural resources that forms part of the earth resources which beckon on humankind for exploration, extraction, exploitation and growth. The high global demand for solid mineral produce has led to growing applications of geophysical scientific knowledge of prospecting to a wide range of solid mineral deposits. In this study, ground magnetic survey was used to investigate and delineate the presence of subsurface magnetic features for possible solid mineral exploration. Ground magnetic field survey carried out with a hand-held magnetometer were taken in Igarra along Six (6) traverses at 20 m interval each and in Ososo along two (2) traverses were surveyed at 20 m and 5 m interval each respectively. It involves establishing traverses in an approximately W – E direction in the study area. The GSM-19T Systems utilities software was used to perform the diurnal corrections. The total magnetic intensity values at various station positions were processed to obtain the relative magnetic intensity values. These were plotted against station positions as magnetic profiles using Grapher 11 to produce the magnetic profile along the traverses while Surfer 13.0 Software was also used to produce relative magnetic intensity map, 2D Contour and 3D Surface distribution Maps which aided the qualitatively interpretation. The obtained magnetic signature showed substantial varying amplitude from a minimum value of -750 nT to a maximum value of 1000 nT, indicative of different magnetic susceptibilities or distinction in solid mineral contents of the rock types. It also showed that there are magnetic mineral rocks with high magnetic susceptibility values from the centre towards the northeastern and low magnetic susceptibility values at the southwestern of the study area. The findings showed that the study area had vast occurrence of the solid mineral deposits, which would be of economic importance, if exploited.

1. Introduction

The quest for diversification of the national financial system and high global demand for solid mineral commodities has placed on the potential importance of the solid minerals sub-sector of the economy. Solid mineral resources are considered a critical component in boosting socio-economic development of a country. It can provide gainful employment and capable of enriching national income and earning foreign exchange. Besides, solid minerals can provide funds for investment in other sectors of the economy, also important, it provide locally raw materials for the building and construction industries while expanding the productive horizon of the national economy and conveying infrastructural facilities to otherwise rural areas. The minerals sector is no less linked to advances in knowledge and technological capabilities in the modern world. Indeed, it is one of the high-tech industries of the global economy (Wright and Czelusta, 2003). Human development has depended heavily on resources obtained from both near surface (as in construction materials) and hundreds to thousands of meters deep (as in metalliferous ores and petroleum-based products) (Akintayo et al., 2014).

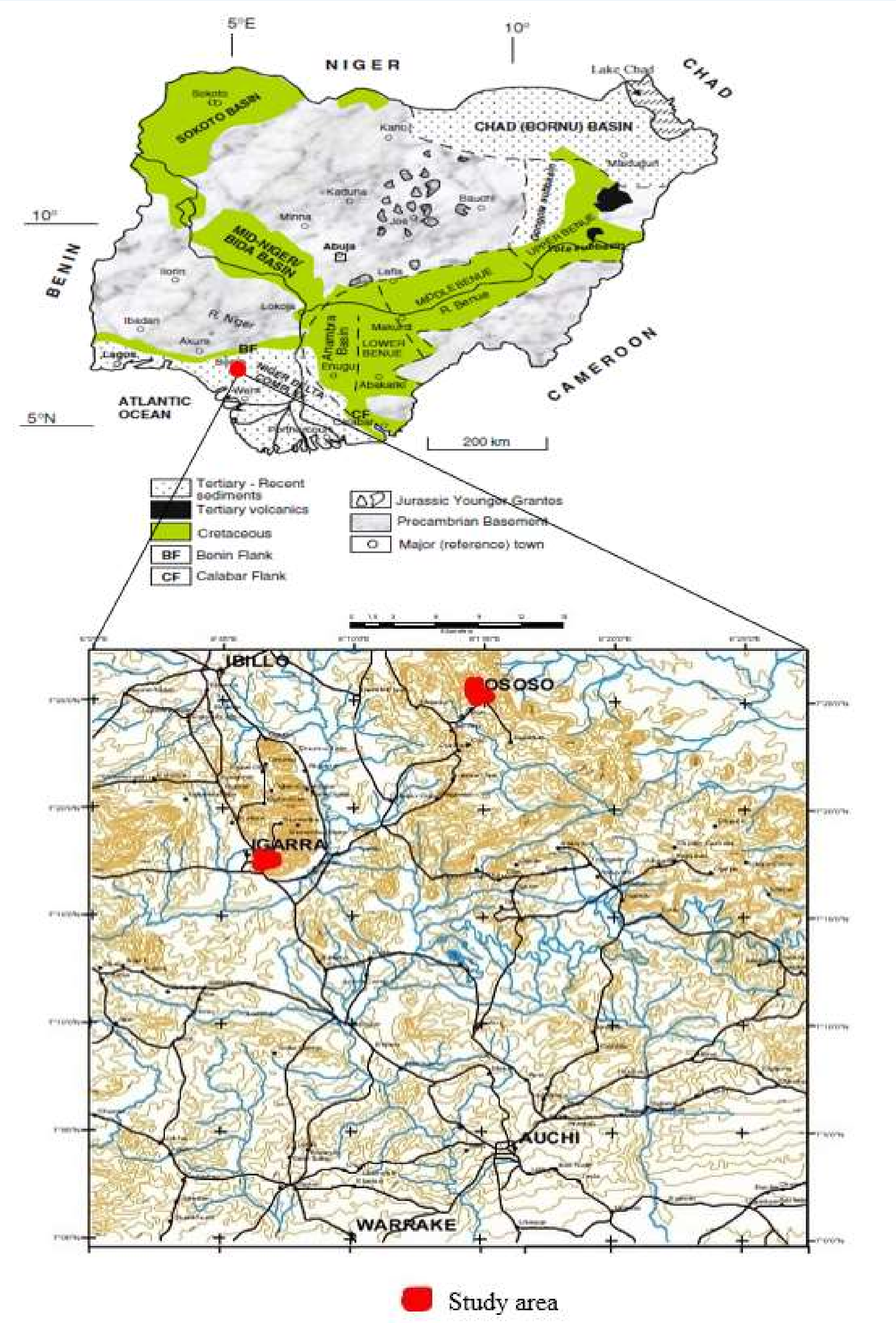

Fig. 1. Map of Nigeria showing study area

Solid mineral exploration is the process of finding ores to mine. Accordingly, ore is a mineral deposit that has commercially feasible concentrations and value to be mined at a profit. Essentially mineral resources can be categorized into two main groups in accordance with their form of occurrence, viz; (a) Solid Minerals and (b) Liquid Fuels (oil and gas). The solid minerals are further divided into three types, namely; metallic, non-metallic and energy minerals. The metallic minerals are Precious (Gold, silver, and the platinum group metals), Ferrous (iron ore, manganese, molybdenum and tungsten) and Base metals (Copper, lead, tin and zinc). The non-metallic minerals (and rocks) can be considered as Industrial and manufacturing minerals (asbestos, mica, talc, barite and salt), Metallurgical and refractory (dolomite, marble, fluorspar, refractory clays, graphite and limestone) and Gemstones (topaz, tourmaline, sapphire, diamonds, and emerald). Energy minerals are fundamentally solid substances used for fuel, for instance, thorium, coal, bitumen, lignite and uranium. Mineral exploration is significantly more intensive, organized and professional form of mineral prospecting and, though it often uses the services of prospecting, the process of mineral exploration on the whole is much more involved. Sedimentary rocks have the lowest magnetic susceptibility, whereas metamorphic and acidic igneous rocks intermediate and basic igneous rocks have the highest magnetic susceptibility (Kearey et al., 2002). Therefore, the largest proportion of a magnetic signal or anomaly is thus generated at crystalline (igneous or metamorphic) basement level (GETECH, 2007). Magnetic anomalies are caused by magnetic minerals contained in rocks; such anomalies are usually caused by underlying basement (igneous and/or metamorphic) rocks or by igneous features such as intrusive plugs, dykes, sills, lava flows and volcanic centers when magnetic anomalies are observed over sedimentary terrain (Gunn, 1997).

In the exploration for subsurface resources, magnetic methods are capable of identifying, mapping and delineating local features of likely interest that could not be revealed by any practical drilling programme. Magnetic surveying is perhaps the oldest of geophysical methods. However, it saw its full potential in the advent of airborne surveys after the Second World War (Reford and Sumner, 1964; Hanna, 1990). Magnetic field survey is to some extent cheap and can rapidly cover large areas of ground. It's also non-invasive and non-destructive to the environment under study. The ground magnetic prospecting is a geophysical technique that measures variations in the magnetic field to determine the geometry, anomaly's depth and magnetic susceptibility of subsurface features. It is a passive geophysical method that uses the contrast in the magnetic properties of rock-forming minerals. The technique requires measurements of the amplitude of magnetic components at discrete points along traverses distributed regularly throughout the survey area of interest. In ground magnetic study, three components are measured which are horizontal, vertical, and total components. The magnetic method is very suitable for locating buried magnetite ore bodies because of their high magnetic susceptibility (Young and Droege, 1986). Magnetic methods are sensitive to the susceptibility within the subsurface geology and so are ideal for exploring in the basement complex regions (Folami, 1998). Magnetic susceptibility of rocks is primarily dependent on the presence of ferromagnetic minerals, of which magnetite and members of the titanomagnetite series are most common in the earth's crust (Grant, 1985; Clark, 1997; Babu, et al., 2007). Several minerals containing iron and nickel display the property of ferromagnetism. Rocks containing these minerals can have strong magnetization and as a result can produce significant local magnetic fields (Nwankwo et al., 2006). The magnetic method is firmly established as an investigative procedure in applied geophysics and it is increasingly recognized as an understanding of the elements of magnetic petrophysics that assists in optimizing field data interpretation (Clark and Emerson, 1991). Magnetic surveys have had successes as an airborne tool, on ground and on sea. It has also been used for planetary studies. Igarra and Ososo are endowed with abundant solid mineral resources many of which have not even been mapped fully for the purpose of further exploitation. Hence there is the need to generate geophysical data to delineate and locate the solid mineral deposit in the study area. To achieve these, inversion from ground magnetic geophysical data was used to map solid mineral deposits in the study area.

2. Geological Settings of the Study Area

The study area constitutes part of the Precambrian Basement Complex of Southwestern Nigeria which lies East of the West African Craton in a mobile belt that has been affected by Pan-African thermo tectonic events. It is located between Latitudes 7° 15' N-7° 28' N and Longitudes 6° 05' E - 6°25' E (Fig. 1). Basement complex rocks are subdivided into migmatite-gneiss complexes; the older metasediments; the younger metasediments; the older granites; and the younger granite alkaline ring complexes and volcanic rocks. The Migmatised Gneiss complexes are the most widespread and occupy about 60% of the total surface area of Nigeria (Rahaman and Ocan, 1978). The migmatites and gneisses occur as a polycyclic basement, on which the rocks of Igarra Schist belt were unconformably deposited. The metasediments, comprising phyllite schists, quartz-muscovite-biotite schists, calc-silicate gneiss, quartzites, marbles, metaconglomerates are structurally overlying the mica schist unit and probably have been deformed at least twice during the Pan African Orogeny 550 ± 50 my (Odeyemi, 1982). In Ososo, deposition of rocks for processing into crushed rocks and dimension stone are largely associated with internal processes which take place at variable depth within the Earth at high temperature high pressure and low-pressure high temperature and are largely associated with igneous and metamorphic rocks being, gradually exposed to the surface by the processes of denudation Egesi and Tse (2011).

3. Theory of Magnetic Method

For past two centuries, it has been showed that the force of attraction or repulsion between electrically charged bodies and between magnetic poles also obeys an inverse square law like that derived for gravity by Newton. Accordingly, Magnetic Force is defined in terms of monopoles: If two magnetic poles of strength say m_1 and m_2 are separated by a distance r, hence the magnitude of force between them is given by:

$$F = K\frac{m_1 m_2}{\mu r^2} \tag{1}$$

where μ is magnetic permeability of medium and K is a constant. This depends on the magnetic properties of the medium in which the poles are situated. The force is repulsive if the poles have the same sign, attractive if they are of opposite sign. Magnetic field strength (magnetizing field) vector, H is defined as force per unit pole strength which would be exerted upon a small pole of strength m, if placed at that point.

$$H = \frac{F}{m_1} = \frac{m_2}{\mu r^2} \tag{2}$$

The units related with magnetic field strength are Newton's per Ampere-meter; it is referred to as a Tesla (T) named after Nikola Tesla. When describing the magnetic field strength of the earth for geophysical work, it is common to use the units, nanoTeslas (nT). A nT also commonly referred to as a gamma.

Rocks or rock forming minerals may have an inherent property to be magnetised in the presence of an applied magnetic field. This property of the rock forming mineral is its susceptibility. It's the fundamental parameter controlling the magnetic field variations of interest which is caused by changes in the subsurface geologic structures. Placing a magnetiseable body in the influence of a magnetizing force tends to align the dipole moment within the body in the direction of the magnetising force. The body thus takes on a degree of magnetisation which is proportional to the magnetising force and also depends on the cause of magnetisation of the body. Most rocks of the earth's crust contain crystals with magnetic minerals; thus, most rocks have a certain amount of magnetism which usually has two components: induced by the magnetic field present while taken measurement, and remnant which formed during geologic history (Telford et al., 1990).

The susceptibility is a measure of the number of elementary magnets per unit volume of the material and of their mobility or the ease with which they can be oriented. i.e quantitative measure of the extent to which a material may be magnetized in relation to a given applied magnetic field. The Magnetic susceptibility of a material is the ratio of magnetization (i.e., magnetic moment per unit volume) in a substance to the corresponding magnetic force H. It is mathematically expressed as:

$$k = \frac{I}{H} \tag{3}$$

where; I = intensity of magnetization, H = magnetizing force. The factor k is the magnetic susceptibility. In SI units, k is "dimensionless", since I and H have the same unit (A/m). Magnetic susceptibility values are important in interpreting regional magnetic anomalies and in crustal modelling (Kjetil, 2012; Ajayi et al., 2019). With the exception of rare monomineralic rocks, magnetic materials generally may be classified as diamagnetic, paramagnetic, or ferromagnetic on the basis of their susceptibilities. Diamagnetic materials are characterized by constant, weak, negative susceptibilities, only slightly affected by changes in temperature. Paramagnetic materials have constant, small positive susceptibilities, less than 1/1,000 at room temperature, which means that the enhancement of the magnetic field caused by the alignment of magnetic dipoles is relatively small compared with the applied field. Measured ferromagnetic susceptibilities have relatively large positive values, sometimes in excess of 1,000. Accordingly, Positive susceptibilities are either paramagnetic or ferromagnetic (aligned with the field). And negative susceptibilities are diamagnetic (aligned oppositely with the field). Diamagnetic materials are Copper, Zinc, Bismuth, Silver, Gold, Antimony, Marble, Water, Glass, and NACL. Paramagnetic materials include magnesium, molybdenum, lithium, and tantalum. Ferromagnetic materials are Iron, Cobalt, and Nickel Besides, metallic alloys and rare earth magnets are also classified as ferromagnetic materials. Magnetite is a ferromagnetic material which is formed by the oxidation of iron into an oxide. In fact, most of the ferromagnetic materials are metals.

4. Methodology

Ground magnetic study is used for detail mapping in order to understand the subsurface geology of an area. The technique requires measurements of the amplitude of magnetic components at discrete points along traverses distributed regularly throughout the survey area of interest. In ground magnetic study, three components are measured which are horizontal, vertical and total components. The vertical components were used for this study. Among a variety of applications of portable magnetometers, especially the total proton (nuclear precession) magnetometers are their uses in mineral and petroleum exploration, geological mapping, search for buried or sunken objects, magnetic field mapping, geophysical research, magnetic observatory use, measurement of magnetic properties of rocks or ferromagnetic object, paleomagnetism, archaeological prospecting, conductivity mapping, gradiometer surveying, and magnetic modeling.

The model GSM-19T portable proton magnetometer was used for the field survey. The instrument measures total field intensity, the accuracy of each measurement is independent of sensor levelling. Furthermore, the measurement is based upon an atomic constant and is independent of temperature, humidity and battery conditions. The inherent simplicity of the GSM-19T proton magnetometer allows rapid, accurate, high resolution measurements of the field to be obtained from a rugged, compact field instrument. To make sure optimum results, the sensor is marked with an arrow and the letter "N". The arrow should be roughly pointed north or south. In the field, the North direction for sensor in all traverses was used. This procedure will allow the sensor axis to be placed perpendicular to the earth's field and produce optimum Signal. Measurements are made at regular intervals along the pathways or other accessible routes. At each station, the time, magnetic readings, altitude and coordinates of the location is noted. The pacing for Igarra along six (6) traverses were taken at 20 m intervals each measuring 1,560 m, 740 m, 720 m, 540 m, 620 m and 980 m while at Ososo along two (2) traverses were surveyed at 20 m and 5 m measuring 2,340 m and 155 m respectively. The traverses were established in approximately W–E direction in the study area. The built-up nature of the study area and the presence of thick vegetation, rivers and settlement (linear) in Ososo did not allow the establishment of more than two traverses.

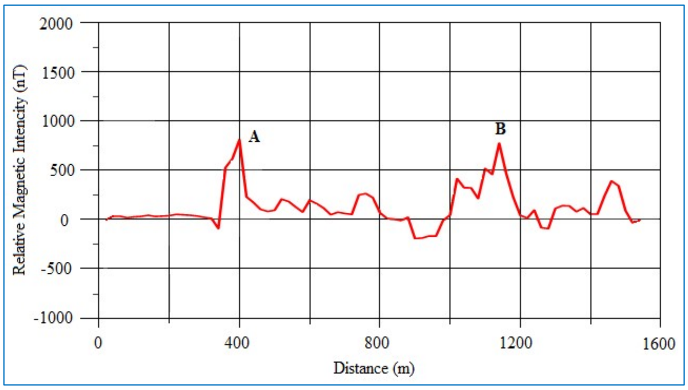

Fig. 2a. Magnetic curve at Igarra in traverse 1

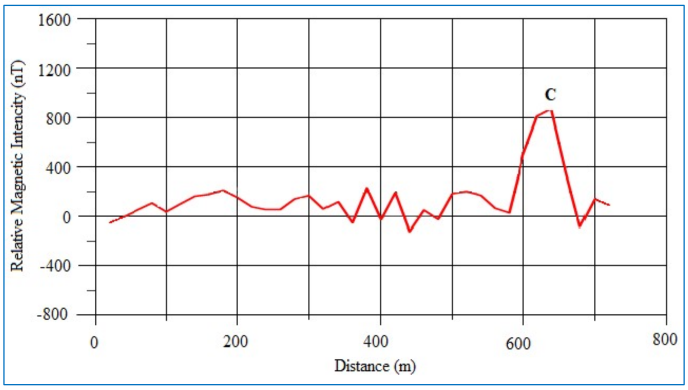

Fig. 2b. Magnetic curve at Igarra in traverse 2

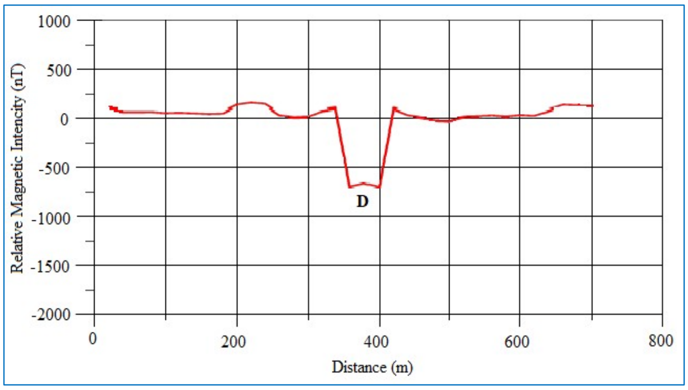

Fig. 2c. Magnetic curve at Igarra in traverse 3

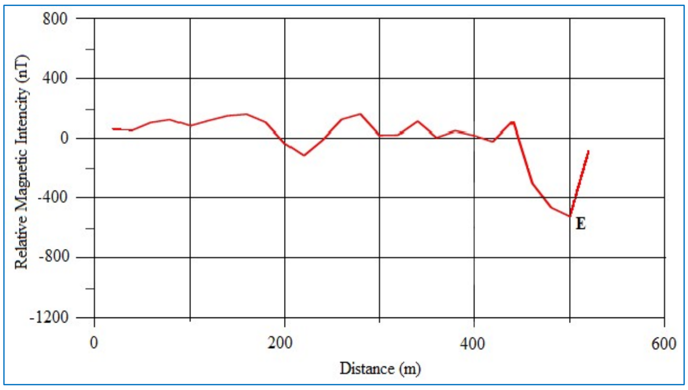

Fig. 2d. Magnetic curve at Igarra in traverse 4

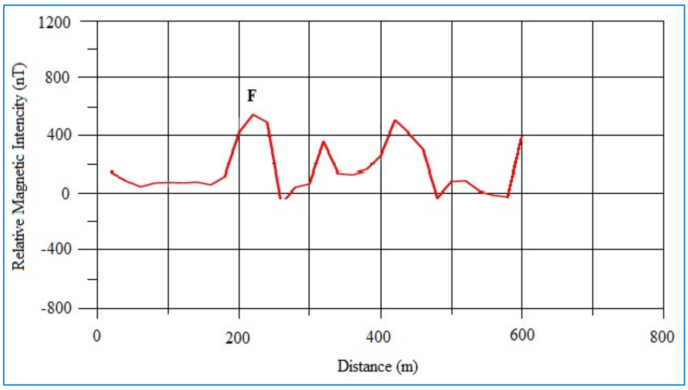

Fig. 2e. Magnetic curve at Igarra in traverse 5

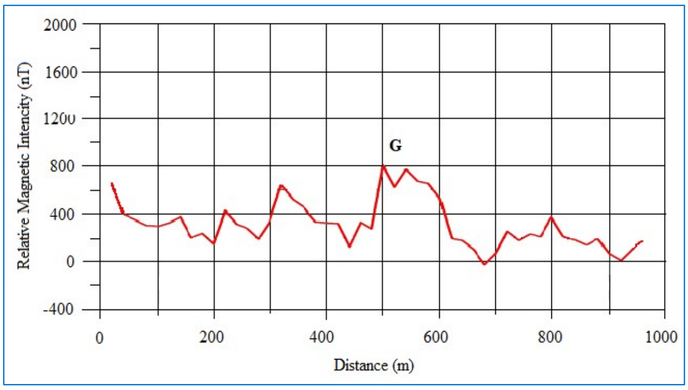

Fig. 2f. Magnetic curve at Igarra in traverse 6

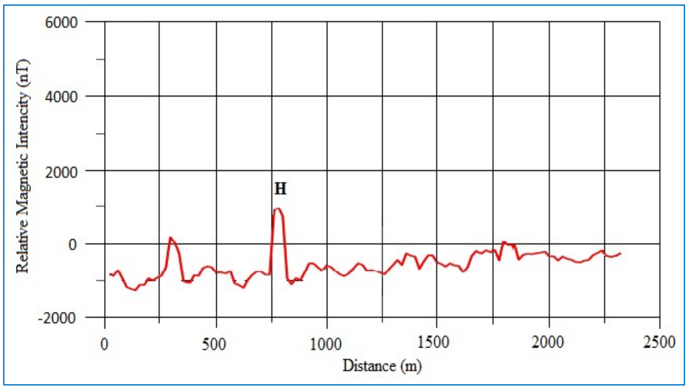

Fig. 2g. Magnetic curve at Ososo in Profile 11

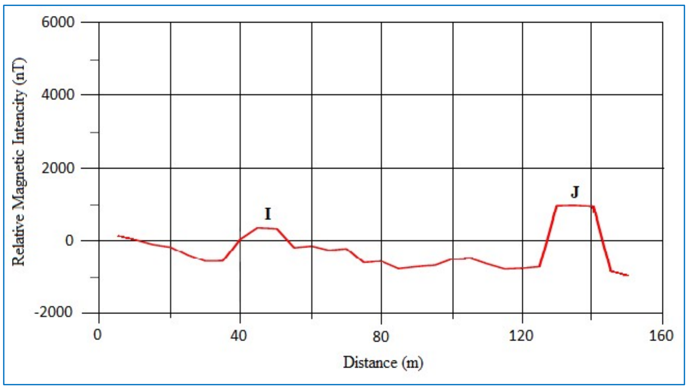

Fig. 2h. Magnetic curve at Ososo in Profile 12

In all, the distance occupied in the study was 7.655 m (7,655 km). The obtained ground magnetic data were drift corrected using base station readings that were taken before the commencement of the measurement and immediately after each traverse have been occupied to enable diurnal and offset corrections. The GSM-19T Systems utilities software was used to perform the diurnal corrections. In profiles and 3D maps, magnetic anomalies are indicated by peaks, and in the case of the contour maps, close and high contour values indicate magnetic minerals (Kearey et al., 2002).

The total magnetic intensity values at various station positions were processed to obtain the relative magnetic intensity values. These were plotted against station positions as magnetic profiles using Grapher 11 to produce the magnetic profile along the traverses while Surfer 13.0 Software was also used to generate relative magnetic intensity map, 2D Contour and 3D Surface distribution Maps for Igarra and not for Ososo because of limited traverses.

5. Results and Discussion

In most cases, to carry out geophysical investigation of the earth's subsurface, signals are sent into the earth and measurements taken. As the signals transmit through the earth's interior, they will be influenced by the internal distribution of the earth's physical properties. These physical properties include; elasticity, density, permeability, magnetic susceptibility, resistivity and conductivity. It also entails the interpretation of the measured parameters in order obtain information about the structure and composition of the concealled layers both in vertical and lateral directions (Ozegin and Oseghale, 2012a).

In this study, we are concerned with magnetic susceptibility. The results of the ground magnetic surveys were presented as Profiles (the oldest form of data presentation and it has the benefit of being able to show features that cannot be shown in grid-based presentations), Relative magnetic intensity map, 2D Contour and 3D Surface distribution maps.

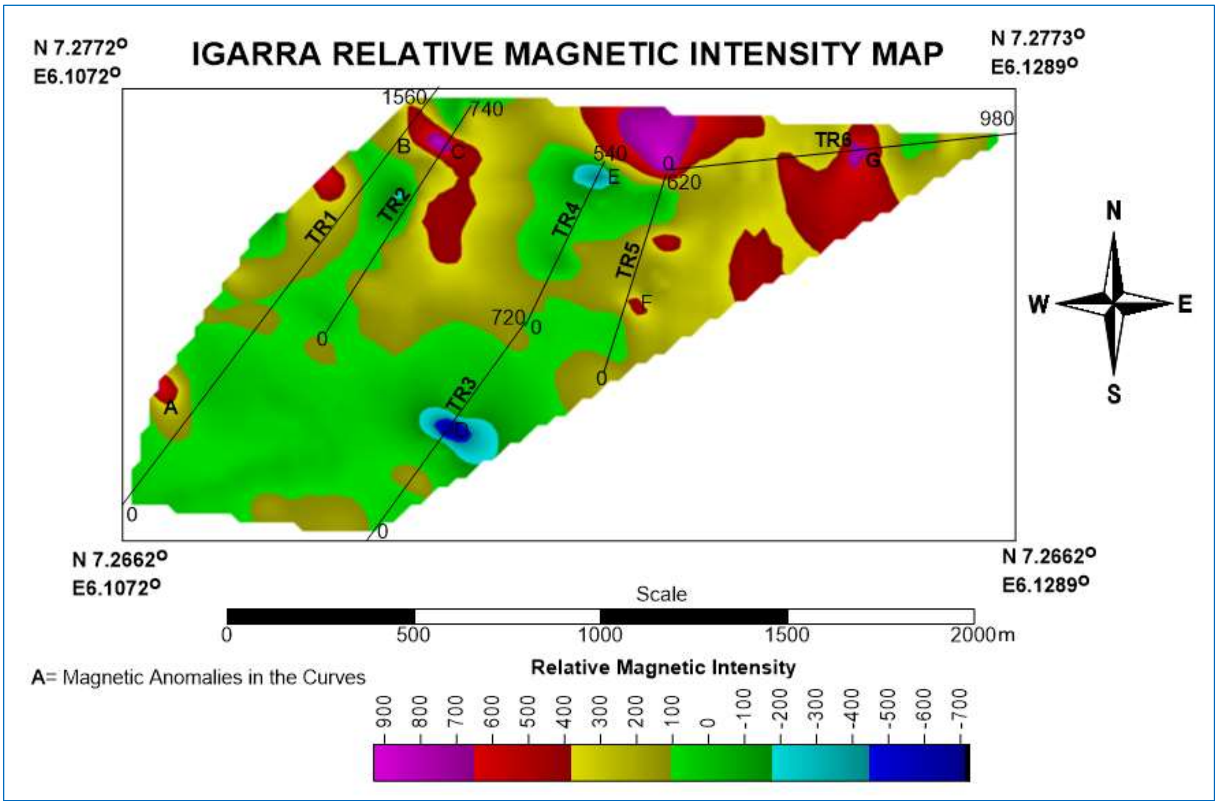

Fig. 3. Ground magnetic intensity map at Igarra

5.1. Profiles along the traverses

Relative Magnetic Intensity (nT) of the total magnetic fields are various plotted against distance (Figs. 2a-h). The magnetic anomalies show no uniformities in the profiles. It shows lots of magnetic lows and highs which is an indication of the nature of the basement and the extent of inhomogeneity of the subsurface, which could be as a result of basement structural feature. The magnetic lows are characterized by low amplitude and low intensity and vice versa. The magnetic anomalies, labelled A, B, C, F, G, H, I and J in Figs. 2a–b and Figs. 2e-h are positive anomalies, which probably reflect igneous intrusions within the bedrock or ferromagnetic mineral accumulation. This is evidenced by increase in magnetic signal from minimum values to maximum and then finally decreases to a minimum value.

The host rock is non-magnetic or has little magnetization. A (occurs between 350 and 450 m marks) has a relative magnetic intensity and width of about 760 nT and 100 m respectively while B (occurs between 1000 and 1200 m marks) is about 750 nT and 200 m. C (occurs between 580 and 670 m marks) has a relative magnetic intensity and width of about 840 nT and 90 m respectively. F (occurs between 180 and 250 m marks) has a relative magnetic intensity and width of about 580 nT and 70 m, respectively. G (occurs between 475 and 620 m marks) has a relative magnetic intensity and width of about 800 nT and 145 m, respectively. H occurs between 750 and 850 m marks and has a relative magnetic intensity and width of about 1000 nT and 100 m respectively. M occurs between 40 and 80 m marks and has a relative magnetic intensity and width of about 450 nT and 20 m respectively while N occurs between 125 and 140 m marks and has a relative magnetic intensity and width of about 1000 nT and 15 m, respectively.

The magnetic anomalies, labelled D and E in Figs. 2c and d are negative anomalies, which likely indicates fairly magnetic bed rock of which its fracture or depressed zone with non-magnetic material possibly sand, gravel clay or chemically formed sediment. The inflection points are indicative of geologic boundaries or contacts between two rock types, structural changes within the same rock type and the presence of lineaments such as network of joints, fractures and or faults (Ozegin et al., 2012b). This is evidenced by increase in magnetic signal from low positive value to negative value and then finally increases to a relatively low positive value. The host weathered sediment or rock has magnetization higher than the discrete body located. D (occurs between 340 and 420 m marks) has a relative magnetic intensity and width of about -750 nT and 80 m respectively. E (occurs between 450 and 530 m marks) has a relative magnetic intensity and width of about -500 nT and 80 m respectively.

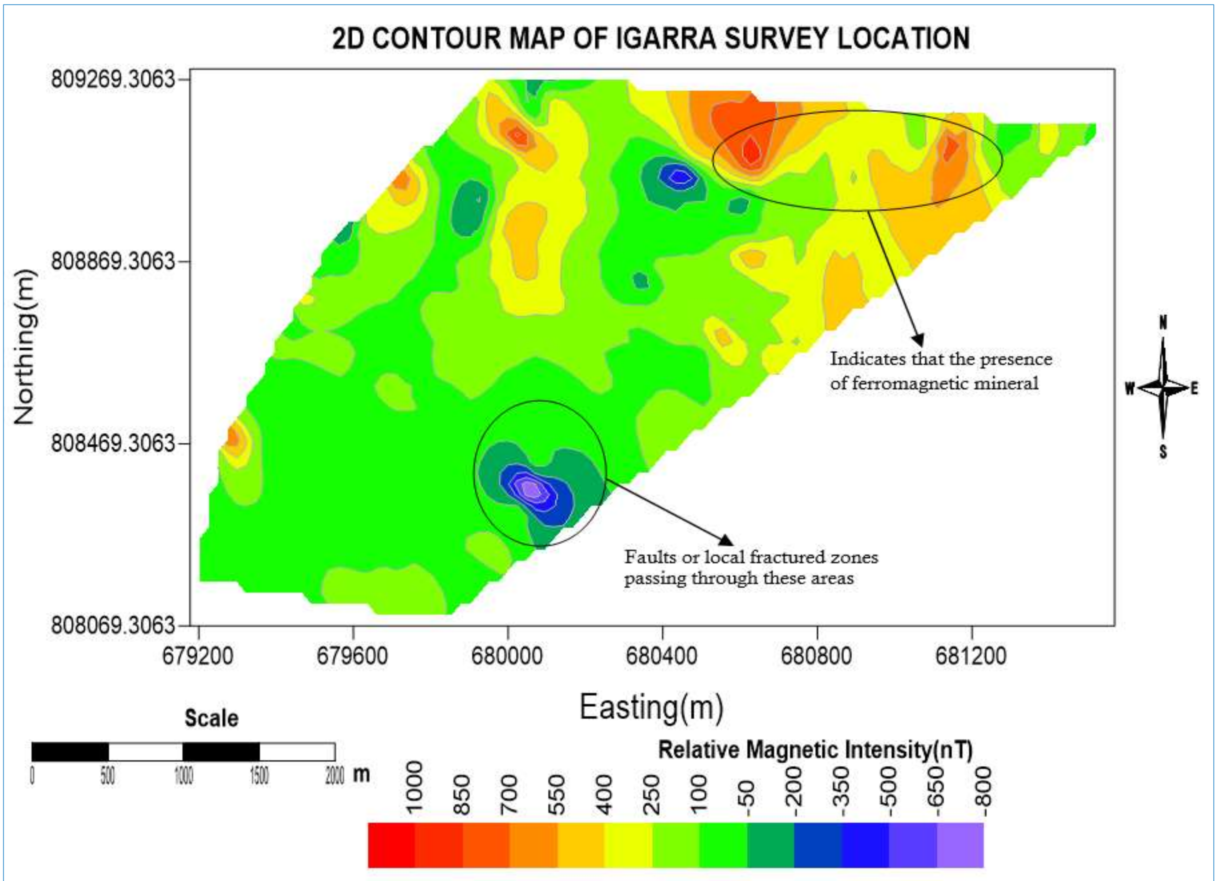

Fig. 4a. 2D contour map of the study at Igarra

5.2. Relative magnetic intensity map

Relative magnetic intensity map was plotted using surfer 13.0. The data was gridded and then re-processed by subjecting it to Wavelength Filtering (Moving Averaging Filter) operation to attenuated deep regional magnetic anomalies and enhance shallow anomalies which are of interest. Two major magnetic zones were recognized based on the magnetic intensity discrepancy over the study area (Fig. 3). The NE parts are dominated by high amplitude magnetic anomalies values between 100 nT and 900 nT. On the other hand, at the SW part of map, the area is characterised by relative low amplitude magnetic intensity values between -100 nT and -700 nT marked with greenish to blue colour suggests areas typified by geological structures (fracture/fault) with low magnetic contents possibly with capability to serve as hosts to minerals.

High anomalies observed may be attributed to the presence of basic rocks and rocks rich in iron oxide such as Garnet-Schist and Migmatite-Quartzite. Also, negative anomalies observed in the area may be due to the presence of low magnetic rocks such as sandstone, weathered sediments in the area, that are well-known for low magnetic signatures. The result of qualitative interpretation showed that the area is intensely fractured with major fractures trending NE-SW directions using visual inspection of magnetic intensity map.

5.3. 2D contour and 3D surface distribution maps

Contour maps are grid-based presentation used to generate scaled 2D Contour and 3D Surface Distribution Maps. An inspection of the contour map (Fig. 4a) showed that the contour lines of the northeastern part of the contour map are widely spaced indicating that the depth to magnetic basement in these areas is relatively large, the magnetic intensities in this area is also high, which indicates that the presence of ferromagnetic mineral at this part of the study area. However, at the southwestern part of the contour map, the contour lines are relatively closed spaced indicating that the depth to the basement is shallow in these regions. The closely spaced contours at the southwestern part suggest shallow subsurface geologic structures and the prospect of faults or local fractured zones passing through these areas. Fig. 4b showed the 3D surface distribution of the anomaly for the survey area which visibly depict positions and area of magnetic mineral concentration. Magnetic anomaly was visible approximately at the centre to the north edge of the map. However, the southwestern part is almost plain and there are no points at all signifying that there is a minute or no presence of magnetic mineral rocks.

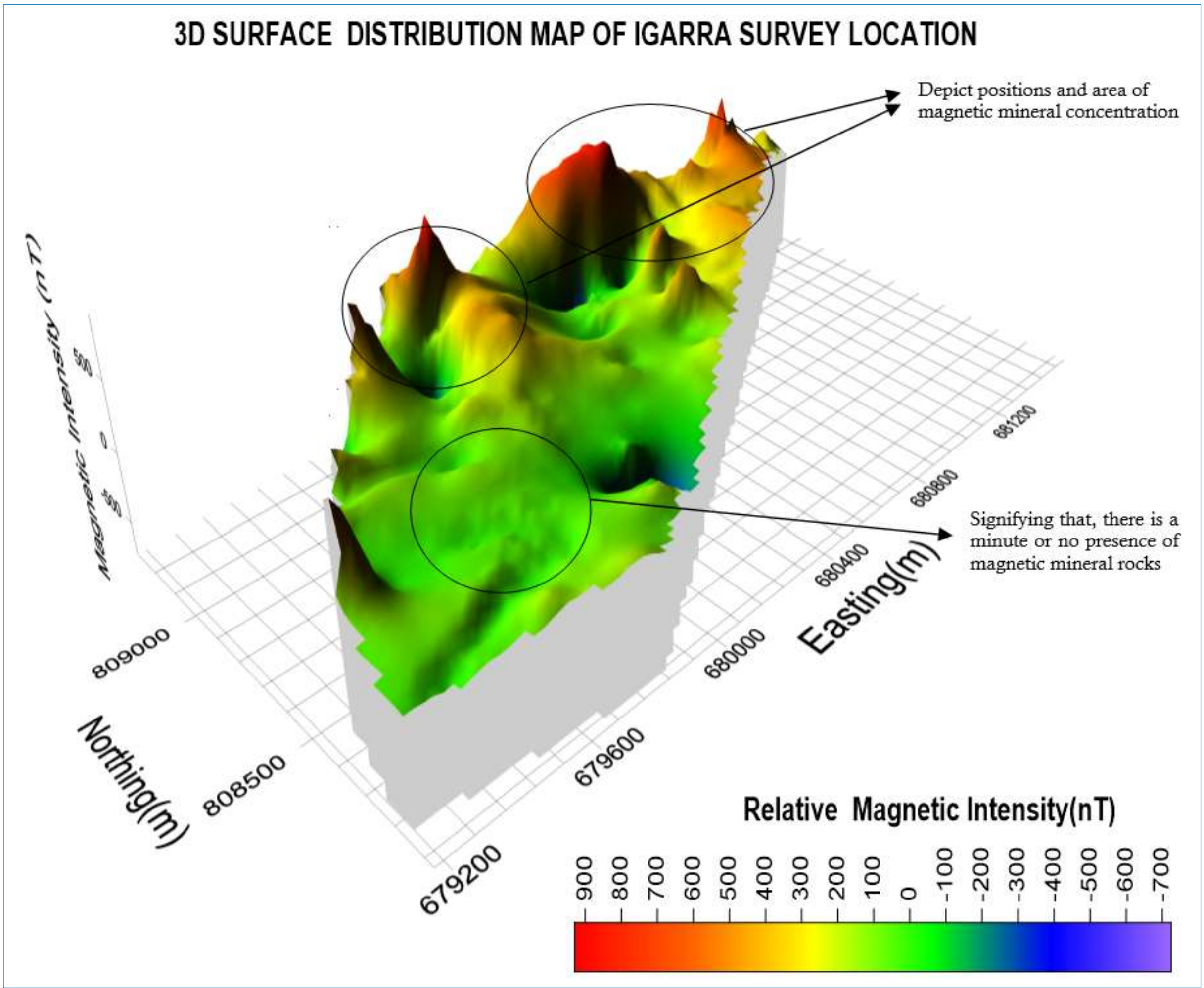

Fig. 4b.3D Surface distribution map of the study at Igarra

6. Conclusion

Quantitative evaluation of solid mineral resource is an important part of geophysical research and national economy. A significant progress has been made using geomagnetic technique in mapping solid mineral potential. The ground magnetic survey carried out in this study using high resolution proton precision magnetometer the GSM-19T has been helpful in successfully predicting the presence of the solid mineral deposit across the study area. The interpretation of the magnetic data obtained in the study area showed the varying amplitudes of the anomaly signature. This implies that the magnetic features are not evenly distributed along the respective traverse across the study area. The area of low magnetic intensity on the magnetic traverses suggests possible discontinuity or faults or fracture zones while the region with high magnetic intensity indicates that the area is underlain with solid deposited mineral. The diverse application of solid mineral resources would promote economic growth in the area of occurrence and the national economy at large. Government should therefore encourage and fund geophysical investigation for solid mineral resources.

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