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INTERPRETATION OF MAGNETIC FIELD INTENSITY OVER REGION OF MANGANESE ORE DEPOSIT AT BAKIN-RUWA AND DARANNA COMMUNITY, KEBBI STATE NORTHWEST NIGERIA.

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ABSTRACT
Aeromagnetic data that covers part of Northwestern Nigeria was processed and qualitatively interpreted with the aim of determining the magnetic field intensity associated with regions where manganese ore deposits are exposed. The study was undertaken to determine the possible continuity of the deposits beyond the current exposures. The characteristics and continuity of associated magnetic field intensity beyond the locations where used for this purpose. To achieve the above, four quarter degree sheets of high-resolution aeromagnetic data that covers the region was acquired and processed. The acquired data were combined into a composite data and then upward continued. Regional residual separation of the upward continued data was used to produce magnetic field intensity map of the area. The variations in the magnetic field intensity around the area was attributed to different geological units around the area and region where manganese ore deposits are located. The location of manganese ore deposits was found to correspond to part and edge of region which shows high magnetic field intensity. This region extends beyond the known exposures of manganese ore deposits hence suggest possible continuation of the deposits beyond the area.

Keywords: Manganese, magnetic-field, susceptibility, regional, residual, intensity.

INTRODUCTION

In a reconnaissance exploration for mineral resources in Nigeria, Fugro Airborne Survey limited carried out aeromagnetic survey for Nigeria Geological Survey Agency (NGSA) in the year 2006. This airborne data are available for research purposes and can be acquired from NGSA. In this study, Aeromagnetic data of part of Northwestern Nigeria was processed and qualitatively interpreted to view magnetic anomaly associated with surface expression of manganese ore deposit at Bakin-Ruwa and Daranna community. The occurrence of the deposit in an environment close to the sedimentary basin necessitates the investigation to determine the continuity of associated anomaly into the sedimentary (Basin) environment. Manganese ores deposits at Bakin-Ruwa and Daranna are hosted by schist and exposed as hills ("Tsauni" as it is called by the locals) at different locations while some are relatively close. Mining activities by a Chinese company called Sino Minmetals Co. Ltd and some local companies involve only excavation of shallow deposits that could be easily identified. The region still holds high potentials for undiscovered manganese ore deposits in view it proximity to sedimentary basin (Nnabo *et al.*, 2018). This is because sedimentary manganese ore deposits accounts for about 95% of commercial manganese ore explored worldwide (Cannon *et al.*, 2017)

Manganese ore deposits at Bakin-Ruwa and Daranna has been classified as Pyrolusite (MnO_2) (Nnabo *et al.*, 2018). They are expected to give rise to detectable magnetic anomaly. Where the percentage of iron in manganese ore is high, greater magnetic susceptibility can be conceptually expected. The paramagnetic nature of manganese entails that the ore gives positive magnetic susceptibility (Nave, 2008). In an environment where highly magnetic minerals exist, the manganese ore is expected to manifest as intermediate magnetic zone. However, in an environment with expectedly low magnetic susceptibility such as sedimentary basin, manganese ore can manifest relatively as zones with high magnetic field intensity. This can results in a visible magnetic anomaly especially in regions where there exists a significant contrast in susceptibility value between manganese ore and its host rock such as the study area. The probable presence and distribution of mineral deposits can therefore be deduced from anomaly patterns in magnetic field intensity maps. In these maps, low magnetic susceptibility minerals are revealed as regions with low valued corresponding colors (contours). Intermediate susceptibility rocks are respectively revealed with corresponding colors likewise the high susceptibility valued minerals. In view of these, magnetic method has expanded from its initial use solely as a tool for finding iron ore which is associated with high magnetic susceptibility to a common tool used in exploration for minerals and other resources.

Location of the study area

The study area is situated at Bakin-ruwa and Daranna villages in Kaoje district of Bagudo Local government area, Kebbi state Northwest Nigeria. It lies within Longitude 3^0 30' 0" E to 4^0 30'

0"E and Latitude 10º 30' 0"N to 11^0 30' 0"N. The location is as shown in figure 1.

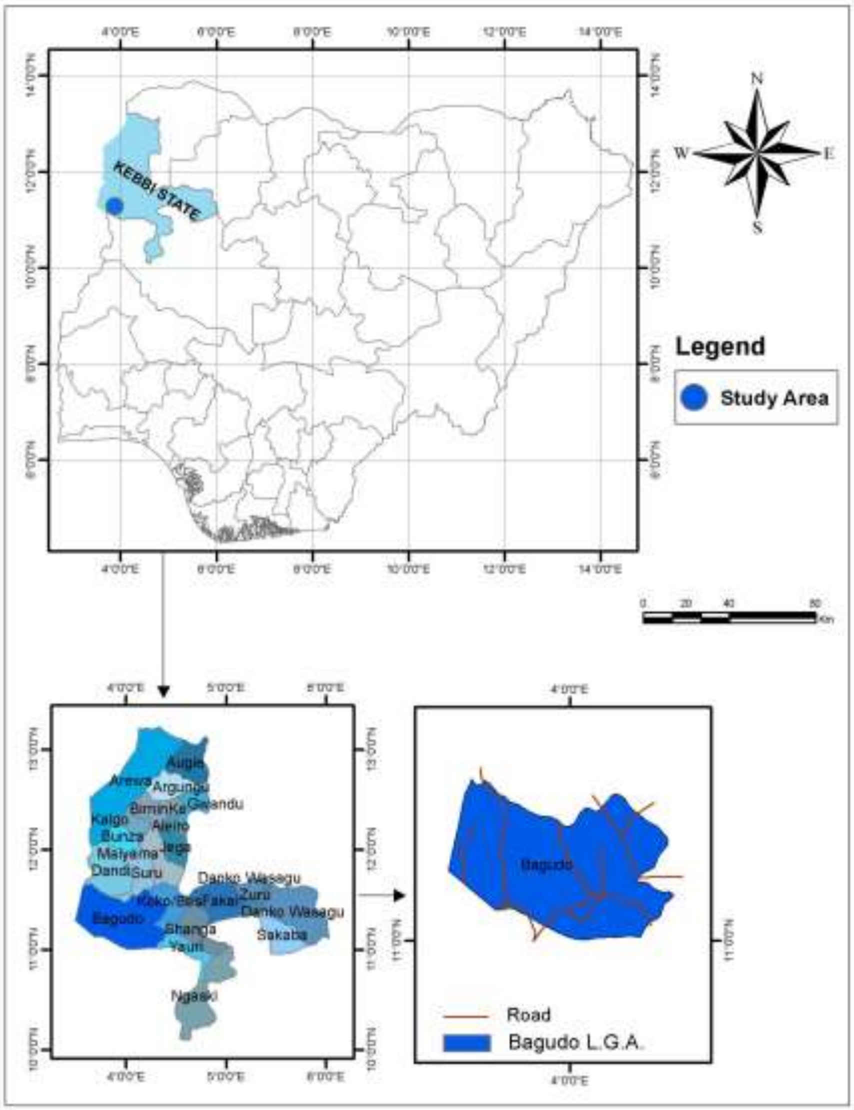

Fig. 1: Map of Nigeria showing the location of the study area

Geology of the Study Area

The geology of Kebbi State is dominated by two rock formations. Pre Cambrian basement complex and younger sedimentary rocks. The Basement Complex region consists of very old volcanic and metamorphic rocks that are made up of granites, migmatites gneisses, and quartzite. In addition to these are; narrow and tightly folded north-south trending schist belts. Schist belts are more prominent in the northwestern half of Nigeria. They contain some igneous rocks, pelitic schists, phyllites, and banded Iron-stones. Obaje (2009), Adelana *et al.*, (2008).

Migmatite-Gneiss Complex is reported to be the most widespread component unit of the Nigerian basement. They have heterogeneous assemblage comprising migmatites, orthogneiss, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. These rocks are confirmed to record some major geological events. Some of these events include initiation and crust forming processes, crustal growth by sedimentation and orogeny. The gneiss complex of Nigeria in time has a close analogy with the development of the Birrimian of the West African Craton. Although gold, manganese, and iron mineral deposits are associated with Birrimian rocks, the same aged rocks in Nigeria are very sparsely, if at all, mineralized (Rahaman 1988), (Obaje, 2009).

The Schist Belts comprise low grade, metasedimentary dominated belts trending North-South which are best developed in the western half of Nigeria. These belts are considered to be folded into the migmatite-gneiss-quartzite complex. The lithological variations of the schist belts include coarse to fine-grained clastic, pelitic schists, phyllites, banded iron formation, carbonate rocks and mafic meta-volcanic (amphibolite). Some may include fragments of ocean floor material from small back-arc basins. Obaje (2009) reported that "Ajayi (1980), Rahaman (1981) and Egbuniwe (1982)" have stressed that some schist belts include oceanic materials which led to the conclusion that some metallogenic features of the schist belts are relevant to the presence of oceanic materials.

The sedimentary basin constitutes a large percentage of the area covered by the aeromagnetic data. Sokoto Basin on the north-western outskirts of Nigeria is part of the large Iullemmeden Basin that extends far to the north. The basin's maximal depth is about 1km on the north-western margin of the country (Kogbe, 1979; Bonde *et al.*, 2014) but exceeds 2km in Niger republic and Mali part of the basin (Kogbe, 1979). The basin interpreted partially as troughs and rifts, was subjected to sync-sedimentary tectonic deformations during Cretaceous to Neogene and affected by magmatic volcanic episodes; which resulted in the present structural pattern (undulating planes) (Obaje 2009).

The Mesozoic and Tertiary strata, of the Sokoto part of the lullemmeden Basin comprise of interbedded sandstones, clays, and limestones that dip northwest. It consists predominantly of a gently undulating plain with an average elevation varying from 250m to 400m above sea-level (Kogbe. 1979).

Formations of the basin are capped by laterite. The sedimentary sequence includes; the late Jurassic to early Cretaceous Illo and Gudumi Formations, the Maastrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formations. These formations were deposited during a series of overlapping marine transgressions (Adelana *et al.*, 2008).The map in figure 2 presents the geological map of the area covered by Aeromagnetic data.

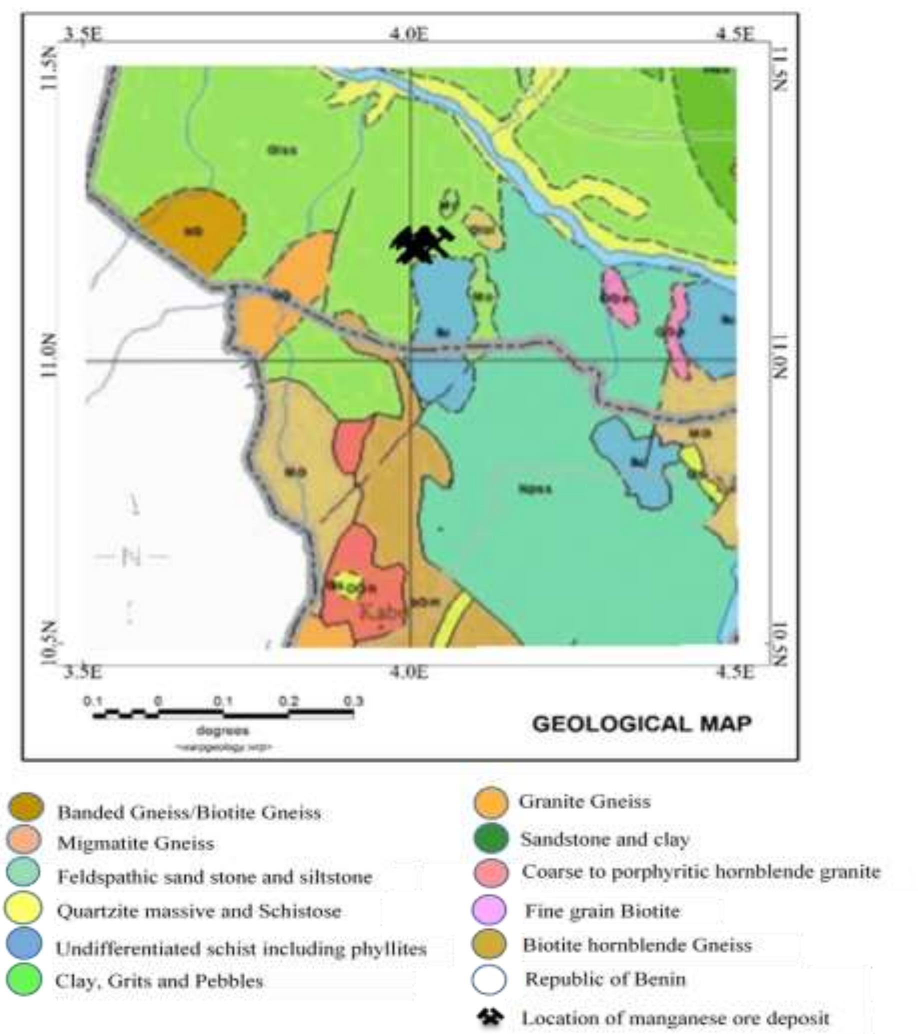

Fig. 2: Geological map of the study area

Basic Princi

The Earth's magnetic field is generated predominantly in the Earth's core. It is complex in structure but can be simply approximated to a dipole field like that of a bar magnet. A large percentage (80 – 90 %) of the earth's field is believed to originate from the convection of liquid iron in the earth's outer core. This convection occurs between the outer mantle and the inner core (Campbell, 1997). This magnetic field penetrates materials (rocks and minerals) that make up the earth's crust and further envelopes the earth. Some materials (rocks and minerals) when placed within an external magnetic field, become magnetized. These materials develop an induced magnetic field while others can possess their own intrinsic magnetic fields. The interaction of such fields with the Earth's primary field gives rise to varying field at the Earth's surface and beyond. Some parts of these measurable earth's varying fields are also considered to be 'background'. They emanate from deeper sources having a characteristic long wavelength. Some are considered to be signals derived from magnetic anomalous sources within the crust. Some of these sources can be reached while some are sourced from outer space as a result of solar activities. The part of the field regarded as a signal depends on the survey target. Any signal from a body which is not the target of exploration can be regarded as noise. Corrections are carried out on acquired data in order to remove such signals.

Two types of magnetization exist namely, induced magnetization and remnant magnetization. Induced magnetization is proportional to the susceptibility of the material. It has the same direction as the Earth's field as such, it yields a positive magnetic anomaly. Manganese oxide found in the study area are also characterized (as paramagnetic) to exhibit induced magnetization (Walid *et al.*, 2013). The second type of magnetization is remnant magnetization also called permanent magnetization. This can have any direction depending on the Figure (3) is a vector representation of the earth's main field, anomalous field and total magnetic field measured by an instrument during a magnetic survey.

orientation of the earth's main field during rocks or minerals crystallization. As a result of this, rocks with permanent magnetization can yield both positive and negative anomalous effects on the measured magnetic field. The influence of permanent magnetization is however classified to be negligible. Induced magnetization is far more common than remnant magnetization. In certain cases, remnant magnetization can be of orders of magnitude greater than induced magnetization. In either of the above cases, the magnetic response of a magnetic body is directly proportional to the magnitude of its magnetization both induced and remnant (Clark, 1997).

Magnetization of a rock can be directly related to the volume concentration of magnetic minerals in the body.

Earth's magnetic field measured during the survey is composed of three parts:

1. The main field, which varies relatively slowly and is believed to originate from the earth's outer core.
2. An external field that varies rather rapidly and originates outside the Earth but interact with the earth's magnetic field which as a result, leaves an influence on the measured field
3. Spatial variations of the total field, which are usually smaller than the main field, and nearly constant in time and place. They are caused by local magnetic sources (either induced or permanent) within the crust which represent the targets in magnetic prospecting (Telford *et al*., 1990).

The total magnetic field measured during the survey is the resultant of the Earth's magnetic field, the anomaly field either remnant or induced field and the external interference or noise. The regional (earth's main field) magnetic field must be determined and removed. The external interfering field must also be corrected for in order to get the residual (anomalous) magnetic field that likely results from our targets.

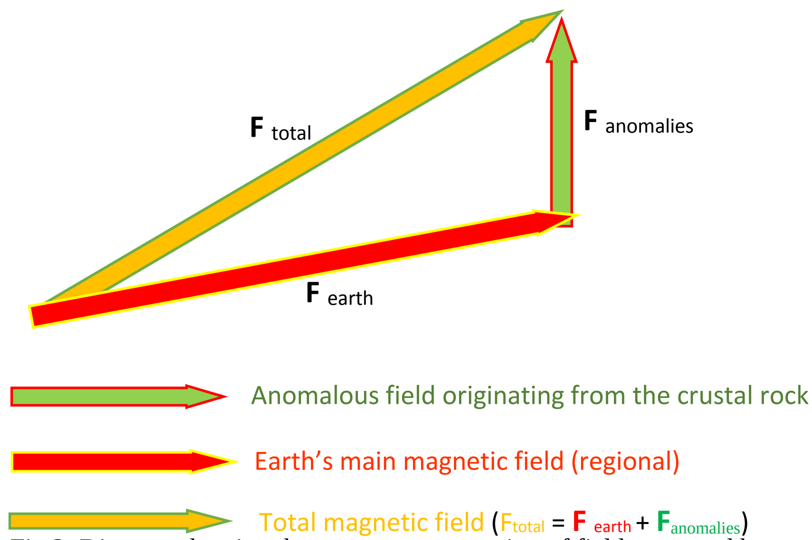

Fig 3: Diagram showing the vector representation of field measured by a magnetometer

The distributions of magnetization reflect geologically significant features whose interpretation can yield important three-dimensional information about the distribution and structure of these features. The interpretation can also provide complementary information if there is a magnetic contrast between the host rock and mineral of interest, which is commonly the case (Watson *et al.*, 2001).

In magnetics exploration, since we are only interested in magnetic anomaly resulting from the Earth's crust, the ideal data set is a 'snap-shot' of the magnetic field at all required locations at the same instant of time, but with the Earth's regional magnetic field removed (Luyendyk 1997).

The shape and amplitude of a magnetic anomaly depends on the location, shape, size, strike, burial depth, magnetic susceptibility and intrinsic magnetization of the causative body, and the angle at which the survey lies relative to both the Earth's magnetic field and to the causative body (Reynolds 2011).

The magnetic method is able to describe the typical geometric distribution of magnetic minerals in a variety of mineral deposit types in their original undisturbed forms. The application of this knowledge to the detection of mineralization requires an appreciation of how such magnetic accumulations will manifest themselves at different localities.

There are no fixed anomaly forms that can be regarded as giving standard universal responses for mineral deposits

Upward Continuation

Upward continuation has been a tool for the interpretation of potential field data for over six decades. It is a perspective view of potential field data at different elevations as a result, giving an opportunity to vary the data between deeper and shallow features (long and short wavelength). Edwin Robinson (1970) recognized upward continuation as a tool widely used in interpreting subsurface anomalous sources of potential field geophysical data.

Several theories have been employed to explain the concept of upward continuation. Foss (2011), indicates that the detectable amplitude of a magnetic field above a source varies with elevation at which measurement is taken as an exponential function of wavelength. This results in small wavelength signals fading out into the larger ones as altitude of measurement is increased. In recent years, this relationship has been exploited with fast Fourier transform (FFT) filters in different software to re-compute the field at different levels of higher elevation (upward continuation) or lower elevations (downward continuation).

The most common method of upward continuation is presented in Edwin Robinson (1970). It involves evaluation of equation 1

$$T(x,y,z) = \frac{|Z|}{2\pi}\iint_{\infty}^{\infty}\frac{F(x',y',0)}{R^3}\,dx'dy', \qquad 1$$

Where $T(x,y,z)$ is the field component on the new surface at height z, $F(x',y',0)$ is the field value on the surface $z = 0$before upward continuation and

$$R = (|x - x'|^2 + |y - y'|^2 + z^2)^{1/2} \qquad 2$$

Therefore,

$$R^3 = (|x - x'|^2 + |y - y'|^2 + z^2)^{3/2} \qquad 3$$

Hence,

$$T(x,y,z) = \frac{|Z|}{2\pi}.\iint_{\infty}^{\infty}\frac{F(x',y',0)}{(|x-x'|^2+|y-y'|^2+z^2)^{3/2}}\,dx'dy', \qquad 4$$

Regional Residual Separation:

The data usually collected as total magnetic intensity (T. M. I.) comprises both the deep and shallow sourced signals. The shallow sourced signals are superimposed on the later. In exploration activities, the anomalies of interest are usually the relatively shallow seated anomalies that could be within reach. Hence, there is a need to separate the low-frequency signals belonging to large and deep-seated features from high-frequency signals of shallow features.

There exist different techniques for regional residual separation. Some common ones include the Polynomial fitting method, Fast Fourier Transformation (Upward continuation) method, Moving Average method, Minimum curvature method, Kriging interpolation method (Martınez-Moreno *et al.*, 2014). All techniques here mentioned are based on the fact that the spectrum of the regional field is dominated by relatively low frequencies (Basiliki *et al*. 2003). For the sake of this work, polynomial fitting was considered.

Polynomial fitting method for Regional Residual Separation

Polynomial fitting can be employed to define large-scale trends and patterns over a potential field data in order to obtain the regional field trend (Martín *et al.*, 2011). This technique is a popular method used to produce anomaly that fits regional geological information. This geological information corresponds strictly to the area of interest or area covered by the data (Martınez-Moreno *et al.*, 2014).

Least-square polynomial approximation is a low pass digital filtering procedure that can be used to extract regional fields from potential field data. It is generally performed with a function of the form;

$$Z(x, y) = \sum_{r=0}^{n}\sum_{s=0}^{n} k_{rs}\, x^r y^s \quad 5$$

Where

k_{rs} = coefficients of the polynomial.

Assuming that a potential field data, denoted by T(x,y,z) have been sampled on a rectangular grid with spatial dimension (m-l)dx by (p-1)dy where dx and dy are the grid intervals in the x and y directions. If $R_g(x,y)$ represents the polynomial that best fits the data, then it has the form of equation 2.12a such that:

$$R_g(x, y) = \sum_{r=0}^{n}\sum_{s=0}^{n} k_{rs}\, x^r y^s \quad 6$$

Once the regional field id determined from equation 12b, it is subtracted from the total magnetic intensity data to give residual data such that; residual data is given by T(x,y,z) – $R_g(x,y,z)$ (Jeffrey and Brown, 1992)

The residual field $F(x, y, z)$ can be expressed in term of the best fit polynomial plane and the observed data as:

$$F(x, y, z) = T(x, y, z) - R_g(x, y, z) \quad 7$$

Where:

F(x,y,z) = Residual field

T(x,y,z) = Total magnetic field data (observed data)

$R_g(x,y,z)$ = Regional magnetic field (fitted polynomial plane

MATERIALS AND METHODOLOGY

Data Acquisition.

Total magnetic intensity (TMI) aeromagnetic data of the area was sourced from the Nigerian geological survey Agency (NGSA). Four adjacent quarter degree sheets of aeromagnetic data comprising of sheet 94, 95, 116 and 117 corresponding to Bani, Kaoje, Karengi, and Konkweso were used for the study. The magnetic data of the entire country was acquired by Fugro Airborne Survey limited on behalf of federal government of Nigeria between 7th December 2006 and 31st May 2007 with the under listed specifications

Magnetic Data Recording Interval 0.1 seconds or less

Sensor Mean Terrain Clearance 80 meter

Flight Line Spacing 500 meters

Tie Line Spacing 5000 meters

Flight Line Trend 135 degrees

Tie Line Trend 45 degrees.

This was an improvement on the first data acquired across the entire country between 1974 -1976. The earlier data were acquired at flight or profile spacing of 2000m (2km) and sensor mean terrain clearance of approximately 150m.

Upward Continuation of The Gridded Aeromagnetic Data

Upward continuation defined by equation (1) was applied to total magnetic intensity (TMI) data to reduce noise that could be originating from local and shallow features as well as the effects of rough terrain. Based on recommendations from geosoft (Oasis Montaj) user manual, the TMI grid data was upward continued to a height of 170m. This adds up to flight height of 80m to give elevation of 250m. From this, the elevation is now equivalent to the chosen grid cell size (250m). Figure 5 shows the result of upward continued TMI

Regional Residual Separation (RRS):

This is the process of removing the deep sourced magnetic field from the shallow ones which may be within reach. The residual field was separated from the TMI data leaving behind the regional field as a first-order polynomial given by equation 6. This fitted plane is then subtracted from the TMI data using equation 7. The outcome of the RRS procedure produced residual magnetic field grid and the regional magnetic field trends grid.

RESULTS AND INTERPRETATION

Total Magnetic Intensity (TMI)

TMI map (Figure 4) shows the variation of the total magnetic intensity across manganese ore exposures and beyond.

The distribution of total magnetic field intensity can be attributed to three prominent lithology on the geological map of the area covered. These include the northern half of the map corresponding to region mapped geologically as clay, grits, and pebbles. This region exhibit relatively high magnetic field intensity.

The southern part of the study area is generally characterized by relatively smooth low magnetic field intensity. The SE quarter of the map comprises majorly of feldspartic sandstone and siltstone. This lithology extends into the NE quarter of the map. It exhibits relatively lower magnetic field intensity with a patch of very low field at the eastern part of the corner. This can be attributed to Migmatite Gneiss as indicated by the geological map.

The mostly basement southwestern corner of the map shows alternating high and low magnetic field intensity value. This was cut through by a low magnetic field intensity again associated with Migmatite Gneiss in the area.

Northwestern corner of the map generally shows smooth high-intensity magnetic field with patches of low magnetic intensity. Banded biotite Gneiss which occurs as indicated at the edge of the geological map also has low magnetic field intensity associated with it.

The mapped schist zone which serves as host to manganese ore in the study did not exhibit any traceable magnetic anomaly. A visible high magnetic field intensity, however, cut across the schist extending beyond its boundary. This high TMI value corresponds to region where manganese ores are exposed hence, such intensity value can be attributed occurrence of manganese ore deposit particularly around the present deposits.

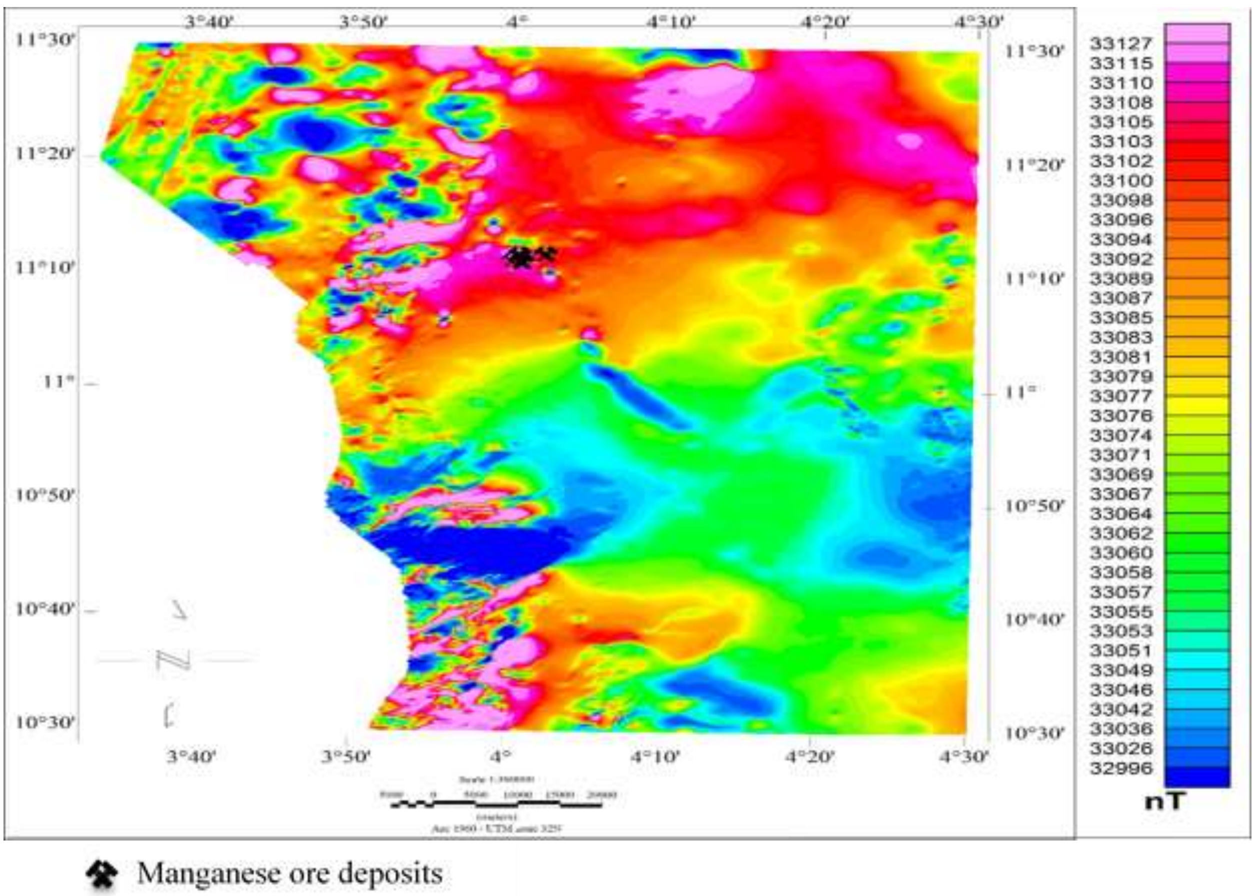

Fig. 4: Total Magnetic field Intensity map

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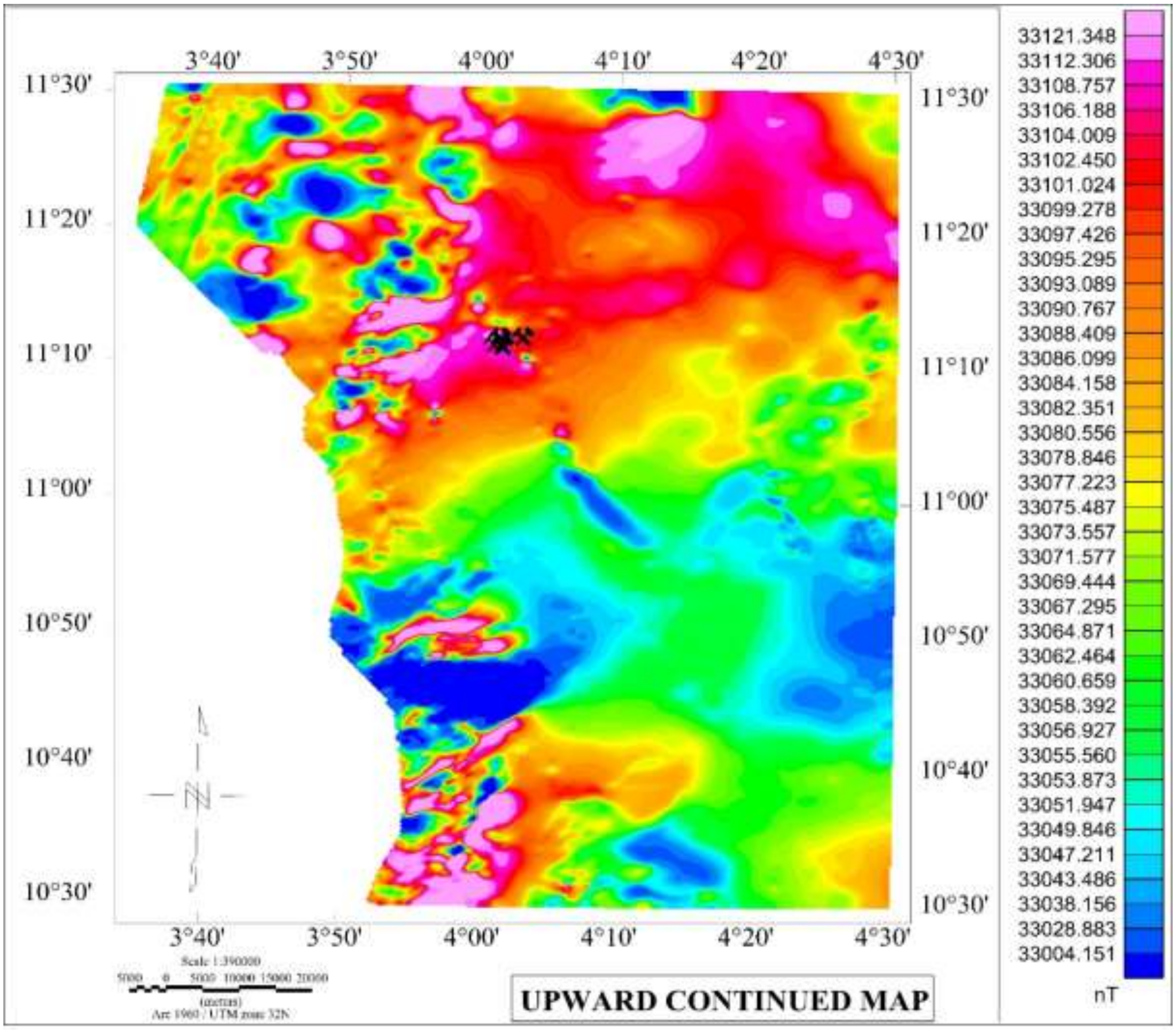
The upward continued map produced a magnetic anomaly view of the study area with some slightly visible features from the total magnetic intensity (TMI) map removed. These features are likely noise emanating from high-frequency shallow sources. This becomes necessary because it helps to smoothen high-frequency anomalies relative to low-frequency anomalies. Figure (5) shows the upward continued map of the TMI to a height of 170m.

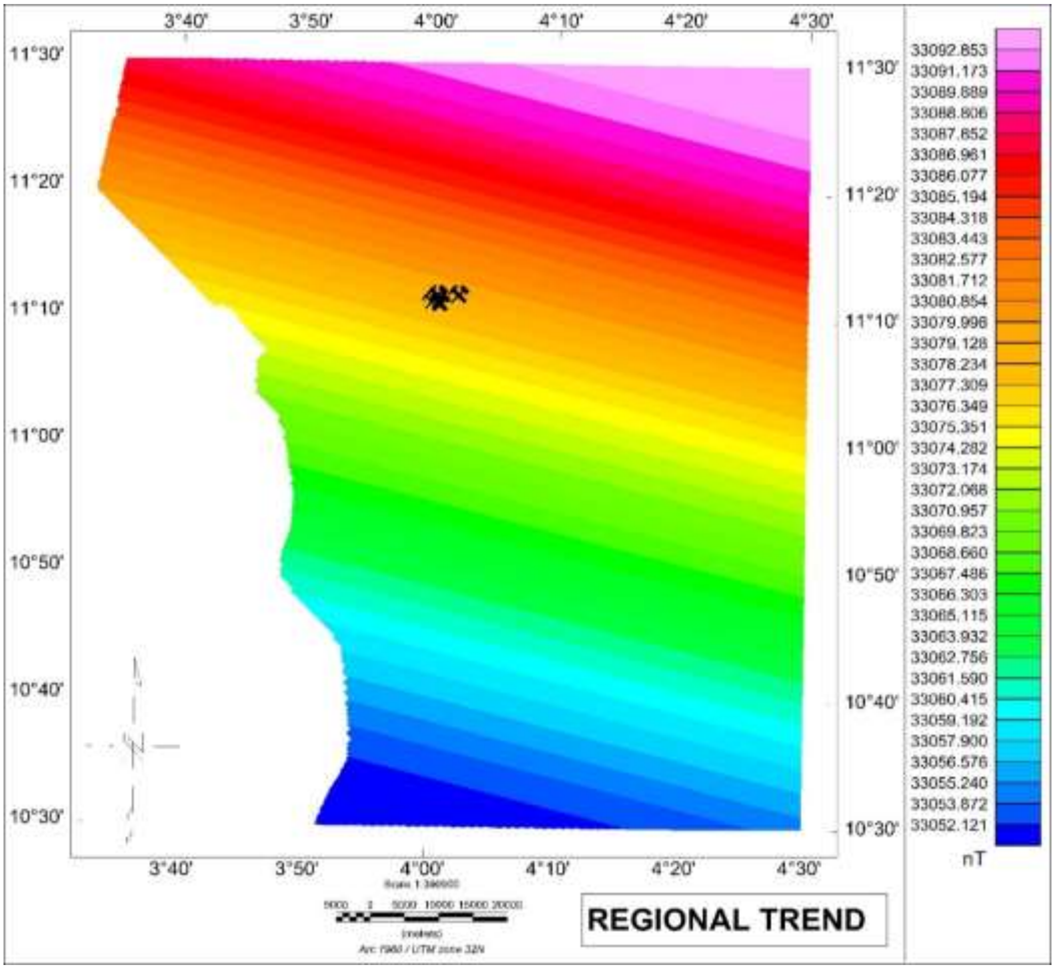


Manganese ore deposits

Fig. 5: upward continued Total Magnetic Intensity map

Regional and Residual Separation of Magnetic Anomalies

The regional magnetic field data was computed as first-order polynomial fitting subtracted from the total magnetic intensity to give residual magnetic intensity data. The technique considered residual magnetic field data to be deviations from a fitted plane of the total magnetic intensity. The result produced residual magnetic field and fitted plane of regional field. The regional magnetic field shows a linearly increasing field ranging from 33092.121nT to 33092.853nT between the north and south. These fields trend approximately NW-SE as shown in figure 6.



Manganese ore deposits

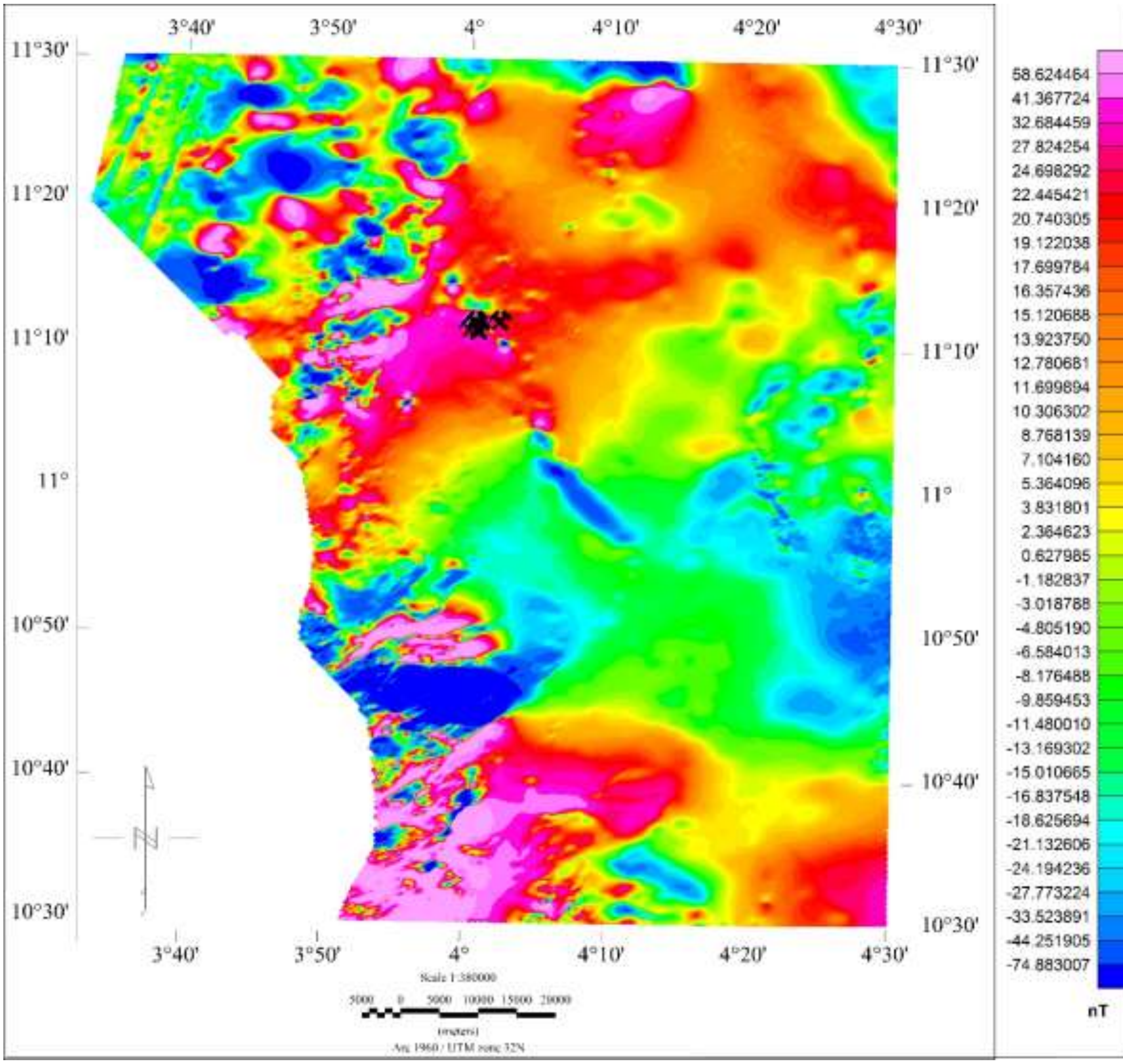
Fig. 6: Regional magnetic trend of the study area

The residual magnetic intensity map shows lateral and relative magnetic fields produced (likely by induction) from different geological units within the area. This field shows the response of target features which are assumed to be relatively shallow thus, making them the anomalies of geological interest.

The residual magnetic intensity map shows slight deviations from the total magnetic intensity map. The majority of features present on the TMI map are also present on the residual magnetic field map. This is because the regional field which was removed from the TMI field to give the residual field is fairly constant over large area.

The most prominent deviation of the residual magnetic field intensity map from TMI map occurs at the Southern flank of the map. This region shows significant increase in high magnetic anomaly covering a larger area when compared to TMI map. The region also corresponds to mapped basement rock mapped as coarse-porphyritic hornblende granite, Biotite hornblende gneiss, and Migmatite Gneiss. Migmatite Gneiss still appears to be associated with low magnetic field intensity in this region.

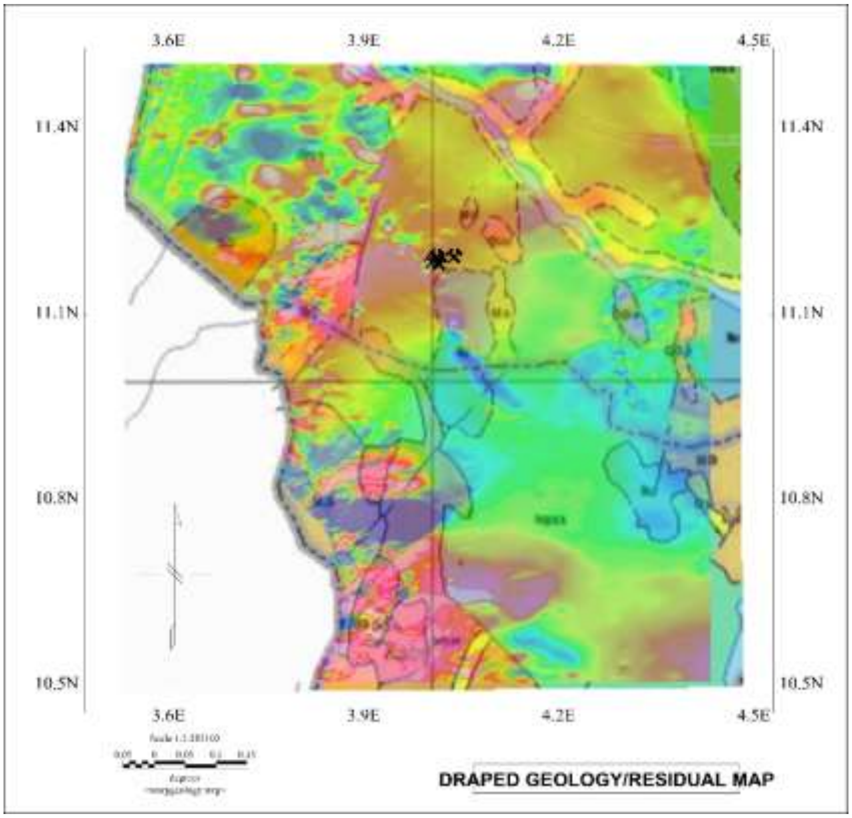
The residual magnetic map produced as a result of the separation process is shown in figure 7



Location of Manganese ore deposits

Fig. 7: Residual magnetic map of the study area

The residual magnetic intensity map was finally draped to the geological map of the study area to have a better view of the distribution of magnetic field intensity with respect to the geology of the area. The draped map is presented in the figure below



Location of Manganese ore deposits

Figure 8: Draped geological and Residual magnetic maps

CONCLUSION

The result of the processed aeromagnetic field data shows that manganese ore in the area is associated relatively with region which show high magnetic field intensity. This region extends well beyond the exposures of manganese ore. This characteristic high residual magnetic field intensity is clearly seen beyond the host of manganese ore into the sedimentary basin. Hence, it may suggest possible continuity of the deposit beyond the current exposures particularly, the extension of the associated high magnetic field intensity to the sedimentary zone could suggest possible continuity of the deposits into the sedimentary basin. This magnetic anomaly pattern, therefore, leads to the conclusion that the area have more prospect for manganese ore deposits than the presently discovered deposits.

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