FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 3, June, (Special Issue) 2024, pp 9 - 18
DOI: https://doi.org/10.33003/fjs-2024-0803-2513

GROUND MAGNETIC STUDY OF GEOLOGICAL STRUCTURES AND MINERALIZATION IN AWO AREA, NEAR EDE, SOUTH WESTERN NIGERIA

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ABSTRACT

Ground magnetic study was carried out in Awo area, Osun State, Nigeria. The area lies within latitudes 7^0 44′N and 7^0 48′N and longitudes $4^0$20′E and $4^0$24′E in Southwestern part of Nigeria. The study focused on delineation of geological structures like: faults, fractures and possible minerals in the area. GM122 Proton Precession magnetometer was employed and 16 traverses were executed along roads and pathways for ease of labour and adequate coverage at spacing interval of 10 m between station points. Isolation of residuals was carried out to get magnetic residual intensity values that were plotted against station points using Microsoft excel. The quantitative interpretation was done using "half-slope" and "straight-slope" methods, as they are easy to use, fast and cost effective. The range of overburden thickness to the top of magnetized body obtained was between 2.50 and 30.00 metres. Qualitatively, the results obtained were used to delineate inflection points, contacts, fractures and faults by plotting 2-D and 3-D contour maps using Sufer applications. The graphs indicate geological structures, rock types and magnetic characteristics of minerals. The low magnetic values suggest presence of faults and fractures in the area while the high relative intensity values indicate deep structures, which may be due to block faulting. These findings have significant implications for mineral exploration in the region, particularly for identifying structurally controlled deposits. Rock types including banded gneiss and granite gneiss with pegmatite veins and economically valuable minerals such as tantalite, barite, quartz, mica and gravel were found in the area.

Keywords: Magnetic Intensity, Total component, Basement Depth, Residual, Fault

INTRODUCTION

Anomalies observed in the earth's magnetic field, stem from induced or remanent magnetism (Mariita, 2007). Induced magnetic anomalies arise when a ferrous body develops secondary magnetization due to the earth's magnetic field. The presence of rocks with magnetic charge beneath the surface leads to magnetic highs. Consequently, magnetic prospecting, aims to detect fluctuations in the earth's magnetic field caused by changes in subsurface geologic structures or variations in magnetic properties of surface rocks (Telford *et al*., 2001). Generally, the magnetic susceptibility of rocks varies greatly depending on their type and environmental context. Common sources of magnetic anomalies include dykes, faults and lava flows. The magnetic susceptibility of rocks is directly proportional to the strength of the local magnetic field; hence, rocks with high magnetic susceptibility strengthen the local magnetic field, while those with low susceptibility weaken it thus rock units with higher susceptibility manifest as areas of elevated magnetic field strength.

The objective of a magnetic survey is to explore subsurface geology by analyzing anomalies in the earth's magnetic field, which arise from the magnetic characteristics of underlying rocks (Mariita, 2007: Philip, *et al*., 2002). The intensity of the earth's magnetic field is assessed through magnetic methods, typically involving measurements of the total magnetic field and/or vertical magnetic gradient (Benson, 2006). Total field measurements capture the overall magnetic field of the earth, encompassing natural and man-made magnetic influences, including changes induced by specific targets (Olona, *et al*., 2010; Lan, *et al*., 2003 and Goudie, *et al*., 2002). The resolution of the variation in the total intensity showed light to the structural and mineralization of the study area. In addition, measurements of the horizontal or vertical magnetic components or horizontal gradient of the magnetic field may be conducted, as was implemented in this research work.

The magnetic survey of anomalies can be done on land, at sea and in the air. This survey whether on the land, in the sea or in the air intends to investigate subsurface geology based on the anomalies causing magnetic field emanating from magnetic properties of the underlying rocks (Philip, *et al*., 2002). Ground magnetic measurements provide more detailed information on sub-surface structures than aeromagnetic data but are less useful for exploring large geological features. Hence, ground magnetic survey has been applied by some researchers to study areas of smaller dimensions either investigating the geological structures, mineral locations, deposition and potentiality. Among these include: Layade, et al., 2023; Adegoke, and Layade, 2019; Adebisi, 2018; Akintayo *et al.*, 2014; Kayode *et al.*, 2013. Also, Nwankwo, *et al*., 2005, carried out a ground magnetic survey using a digital fluxgate magnetometer, and gradient analysis of the residual magnetic data was found to yield basement thickness of the study area. A similar study by (Fasunwon, *et al*., 2007) adopted ground magnetic method to delineate undifferentiated older granite, charnockite and gnesiss. The delineation of subsurface structures is very imperative as it reveals detailed analysis of areas, hence, the adoption of this method to delineate the fractures, faults and rock types in Awo area, Osun State, Nigeria. Awo area is located in Osun State, and the region is part of the basement complex terrain, of southwestern Nigeria. The choice of Awo as the study area is due to the illegal mining of tantalite that took place in the area about a decade ago while the deployment of Ground magnetic method is because of its sensitivity to magnetic minerals, high resolution, cost-effectiveness, non-invasive nature, and the ability to provide valuable data on geological structures and lithological boundaries (Telford, *et al*., 2001; Reynolds, 2011; Hinze, *et al*., 2013; Clark, 2014). Its practicality and adaptability to various terrains make it an indispensable tool in the exploration of basement complex regions.

MATERIALS AND METHODS

Study Area

Three communities: Awo, Iragberi and Iwoye in Osun state of Nigeria were covered in this study. The study area lies within latitudes 7^0 44′N and 7^0 48′N and longitudes $4^0$20′E and $4^0$24′E in the Southwestern part of Nigeria, where unauthorized mining of tantalite was carried out about a decade ago. The area of study is about 15 km from Osogbo, the state capital in the Northeast direction. The area is easily accessible with a network of roads. The study area shares borders on the East with Ara; on the South with Ede, on the Northeast with Ido-Osun and on the West with Songbe. The study area covers approximately an area of 18.0 km^2. The vegetation in the area is of rain forest type and it is characterized by dense evergreen forest. The climatic setting of the area is also characterized by two seasons. The wet season lasts from April to November with a peak in June and July. During these two months, rainfall is usually high; at times rainfall in excess of 46 mm is recorded in a single day while the average annual rainfall is about 1300 mm. The dry season spans from November to March, with December and January being the driest months (NiMet, (2016). Throughout the year, temperatures remain consistently between 25°C and 30°C, except during the peak of the dry season when temperatures rise to 34°C. The topography of the area features exposed granite and banded gneiss rocks. Research indicates that Southwestern Nigeria is underlain by Precambrian crystalline rocks (commonly known as the Basement complex) overlain unconformably by sedimentary rocks dating back to the Cretaceous and earlier periods (Oyinloye, 2011), as illustrated in Figure 1.

Geology of the Study Area

In the Nigerian basement complex four major lithological groups are usually distinguished as: a polycyclic migmatite-gneis-quartzite complex, schist belts which have also been described as newer metasediments (Adekoya, *et al*., 2003), younger metasediment and non-migmatised to slightly migmatised paraschists and metaigneous rocks (Ojo, *et al*., 2011). Osun state lies wholly in the Precambrian basement complex terrain of Southwestern Nigeria. Hence, the area being investigated Awo, Iragberi and Iwoye fall within Southwestern Nigeria basement complex. The study area, is basically covered by basement rock types, such as migmatite meta sedimentary and meta-igneous rocks, and granite rocks (Figure 1). Outcrops of banded gneiss and granite boulders were easily seen in the survey area. Banded gneiss is a coarse-grained strongly foliated rock. Mineralogical banding marks the foliation, which is flat-lying. Pegmatite veins composed of crystals of feldspar, quartz, and mica were observed during the geological mapping. The composition of the topsoil is made up of sandy clay to dark loamy soil and gravel aggregates.

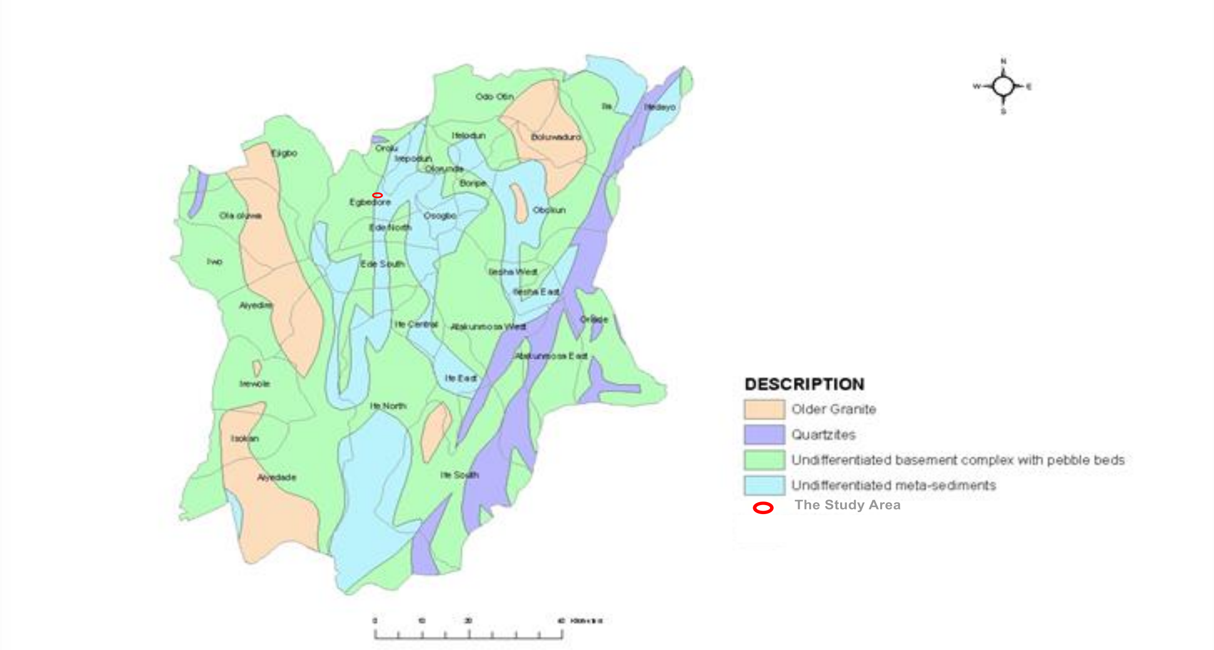

Figure 1: Geological Map of Osun State (modified after NGS 2014)

Data collection and drift correction

Traverses were established perpendicular to the strike direction. The choice of orientation was based on strike direction, topography and accessibility. Most of the traverses were taken either along the roads or footpaths and very few through the bush. The lines were staked at station interval of 10 meters apart. Three local base stations were marked for this study where the local field gradient is relatively flat. Magnetic data were collected using a Geometrics GM122 Proton Precession magnetometer.

The data collected were drift corrected before interpretation. This was done by using the relation that:

$$\frac{Final\ base\ station\ reading - Initial\ base\ station\ reading}{Final\ time - initial\ time}\frac{nT}{s} = Y\left(\frac{nT}{s}\right)$$

$$Drift = Y\left(\frac{nT}{s}\right)X\ (Instantaneous\ time - Initial\ time)$$

$$Drift\ Corrected = Average\ Magnetic\ value + Drift$$

Note: $nT\ means\ nanotesla$

The drift calculated is either added or subtracted from the average magnetic value. The causes of cultural effects were avoided during field survey and the ones that could not be avoided were mitigated by using various forms of averages or weighted averages (Folami and Ojo, 1991).

At the end of the survey, 16 traverses with a sampling step of 10 m along each line were executed which resulted in 54 profiles comprising of the total field, vertical and horizontal components. On the whole, about 3978 measurements were made. The magnetic profiles were quantitatively interpreted and analyzed using half slope and straight-slope methods, (Igboama, 2005; Li, 2003; Peters, 1949).

RESULTS AND DISCUSSION

Profile Analysis and Interpretation

Potential errors due to cultural effects, diurnal variations were dealt with by employing various forms of averages or weighted averages (Folami and Ojo, 1991). Drift correction was equally carried out to ensure the reliability of the results obtained. The findings were analyzed using both qualitative and quantitative approaches. Magnetic data are displayed as profiles with geomagnetic sections for different total magnetic fields. These profiles were created by plotting relative magnetic intensity values against their respective station points. For qualitative interpretation, 2-D geo-sections and 3-D contour maps of the data were generated using Surfer software. Ground magnetic profiles were examined to ensure trend consistency. Quantitative analysis of the magnetic profiles employed the half slope and straight slope methods.

The profile analyses of the data obtained showed different anomaly signatures, indicating variation in susceptibility among different rock types and to certain extent, the effects of intrusions, fissures and rock contacts (Kayode, *et al.*, 2010). Generally, in this area, the ground magnetic residual intensity varies from negative 1200-900 nanoteslas, which is a measure of the geomagnetic variation due to the underlying rock units and on conditions near and/or far beneath the surface. Large-scale rocks can be recognized by characteristic anomaly patterns. Although 16 traverses were covered in the survey, traverses with significant results to the work at hand will be discussed here.

Traverse1 has its profile in the East to West direction, presenting the total magnetic component, and its corresponding geomagnetic section. The total magnetic component (Figure 2) has some pronounced anomaly signatures occurring at 130-170 m from the origin with a magnetic relative intensity of about 75 nanotesla, also at a distance of 640-720 m, with a relative magnetic intensity of 25-125 nanotesla and at a distance of 870-960 m, with relative intensity of 50-135 nanotesla. There was an interesting signature at about 1240-1300 m, which indicated a high and a low magnetic value which may be associated with intrusion. This profile revealed a total of twelve anomalies. Figure 2 shows two rock units as delineated from the corresponding geomagnetic section of the traverse.

Banded and Granite Gneiss

The initial segment of the profile consists of banded gneiss, beginning at the first station and extending approximately 900 meters along the profile. The depth to the magnetic basement in is section varies from roughly 5 to 14 meters. The second rock unit identified along the profile extends from about 900 meters to the end of the traverse, with the depth to the magnetic basement ranging from approximately 7 to 15 meters.

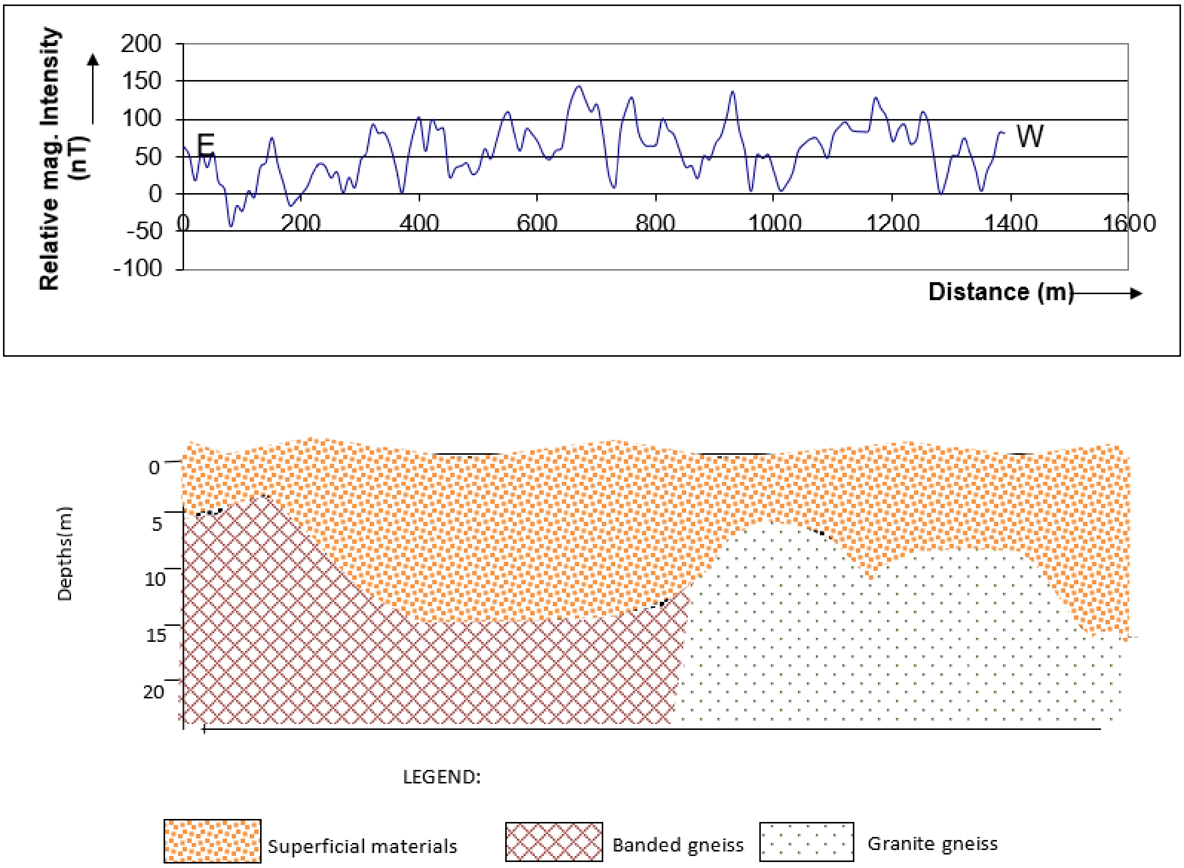

Figure 2: Total ground magnetic profile and its corresponding geomagnetic section along Traverse 1

Traverse 4 covers a distance of 790 m and trends in a south - to- north direction. A broad and pronounced anomaly signature of low magnetic intensity value was shown at a distance of 200-310 m with an intensity value of negative 1100 nanotesla. Another low magnetic value was shown at 680-790m with relative magnetic value of negative 500 to 700 nanotesla. The broad anomaly shapes of the curve suggest the depth of burial of the underlying rocks, while the magnetic lows may indicate faults or fractures.

The quartz vein is likely to have very low magnetic susceptibility, which explains the observed negative magnetic values (Drivenes and Leppe, 2011). Granite-gneisses typically contain minor amounts of magnetite and paramagnetic minerals such as biotite and hornblende. Consequently, it is reasonable to infer that the host rock is more magnetic than the quartz vein. This difference in magnetism could cause the quartz vein to appear as a negative anomaly in the magnetic data, or it might be due to the presence of other minerals with low magnetic values in the study area.

Banded Gneiss and Pegmatite Veins:

The rock units established within this area were banded gneiss with pegmatite veins. This traverse showed three anomalies. The magnetic basement depth within the rock unit varies between 5 meters and 20 meters.

Traverse 5 covers a distance of 1400 m and trends in the East to West direction. This traverse also showed a magnetic low of negative 1200 nanotesla, which covers a distance of 410-750 m. This suspected anomaly has an extent of about 340 m. The geomagnetic depth of this anomaly using 'straight-slope' method was obtained to be between 16-18.8 m. The profile on this traverse indicated a trace of intrusion at a distance of 580-600 m. The occurrence of the magnetic low is an indication of a geological structure. Hence, the influence of a fracture or fault cannot be ruled out. The geomagnetic section showed two rock types, banded gneiss and granite gneiss with pegmatite veins.

Banded gneiss

This rock unit was delineated from the initial position of the traverse to about 1200 m of the traverse. This rock unit was embedded with pegmatite veins. The rock to basement depth was between 20 to 30 meters.

Granite gneiss

This rock type was identified starting at approximately 1200 meters from the beginning of the profile and extending to around 1400 meters towards the profile's end. The depth to the magnetic basement for this rock unit was approximately 30 meters.

Traverse 6 was mapped from behind the Egbedore Local Government Secretariat, Awo to the front of the Corper's lodge in the East to West direction. Traverse 6, revealed two prominent magnetic low values along the profile. The first one was located at a distance of 180-220 m with a relative intensity value of zero to negative 200 nanotesla and the second one was at 230-300 m with an intensity of minus 50 to 500 nanotesla. Two rock units characterize the traverse. The inflection at 180 m along the traverse was indication of rock contact. The distance of 180 m from the origin of the traverse was occupied by granite gneiss with little high magnetic values. While from the inflection point at 180-310 m was occupied by banded gneiss. The geomagnetic section of the profile under the traverse further exhibited this.

Banded Gneiss

This rock unit was delineated from the initial position of the traverse to about 180 m of the traverse. The rock to basement depth was about 10 m.

Granite gneiss

Granite gneiss was delineated at about 180 m away from the starting point and ends at about 310 m towards the end of the profile. The magnetic basement depth for the rock unit was between 10 to 20 meters.

Traverse 7 spans a distance of 540 meters and runs from north to south. All the stations along the profile showed high magnetic values, which could be due to basement ridge or shallow causative bodies (Al-Zoubi, et al., 2003: Igboama, 2005). These high values were particularly noticed from the zero station point of the profile to 240 and 280-540 m with magnetic values of 1430-1650 nanotesla and 1400-1650 nanotesla, respectively.

Granite gneiss

This was the only rock type delineated along the traverse. The magnetic basement depth for this rock unit was between 7 to 18 meters.

Traverse 9, equally portrayed high magnetic values of about 1100-1450 nanotesla, which agreed with the adjacent, traverses 7 and 8. This implies that this traverse has associated geological properties with traverse 7 and 8. Traverse 9 also indicated a low magnetic value between 550-880 m with a negative value of 750-1000 nanotesla. This anomalous low is associated with a fracture/fault and should be of hydrogeological interest. The traverse has an overburden thickness of between 13.8-15 m. The possibility of having an accumulation of mineral deposit with low magnetization is very likely here. The geomagnetic section showed granite gneiss covering the entire traverse.

Granite Gneiss

The geomagnetic section of this traverse delineated only one rock unit, granite gneiss along the entire traverse. The traverse has magnetic basement depth ranging from about 6 to 15 m.

Traverse 10, runs from South to North and spans a distance of 940 metres (Figure 3). The broad low on this traverse was equally associated with a fault. The magnetic anomaly of this low has an extent of 450 metres and a top surface to magnetized body depth of 12.5 metres. The source of this anomaly is either wide compared to its depth of burial or it could be due to complex sources consisting of several closely spaced anomalous bodies whose effect merged to give a single broad anomaly (Cassidy and Locke, 2010; Telford, *et al*., 2001: Adelusi and Folami, 2001). A magnetic high was also identified along this traverse. These areas of high values were due to basement ridge. These values were obtained between the origin and 10th station point and also 110-350 m and 870- 920 m respectively with magnetic values of 350-800 nanotesla. The observed magnetic intensity range and over burden thicknesses are consistent with previous studies in similar Precambrian terrains, indicating substantial subsurface heterogeneity (Adagunodo and Sunmonu, 2012).

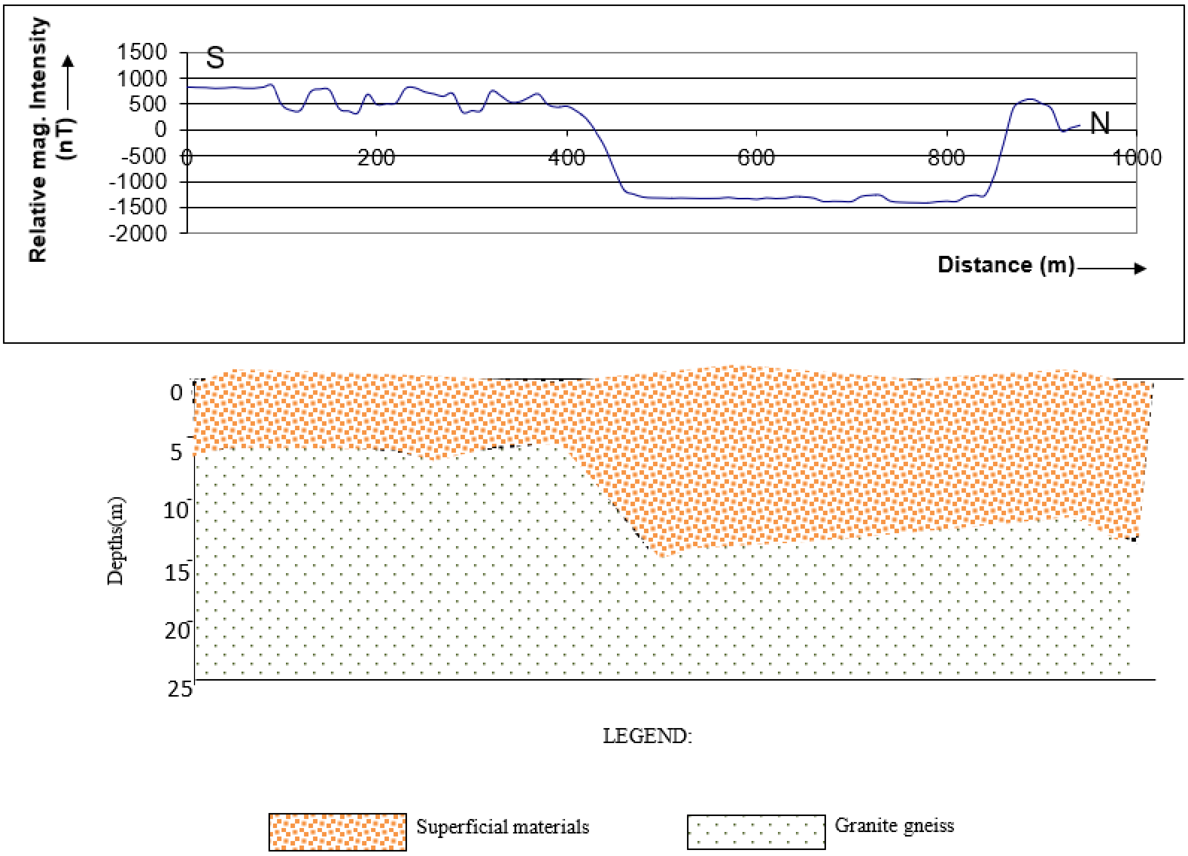

Figure 3: Total ground magnetic profile and its corresponding geomagnetic section along Traverse 10

Ground Magnetic Contoured Map and Its 3D Perspective View of the Total Field Component

Figure 4a is the ground magnetic contoured map of the total magnetic field of the study area. Close examination of this map revealed that the North – Eastern part, A, North – Western, B, and the extreme of South West, C, were characterized as very low relative magnetic intensity values of negative 1400 – 1600 nanotesla, which suggest the presence of linear structures relevant for mineralization and hydrological study. These linear geologic structures could be faults/fractures/and/or joints. The map displays dipolar magnetic anomalies, characterized by both positive and negative components, with an overall east-west orientation (Mansouri, et al., 2015). The tightly spaced contours in the eastern part of the map indicate the presence of shallow subsurface geological structures and suggest the potential for faults or local fractured zones. The presence of large positive relative magnetic intensity values, of about 1400 nanotesla, characterized the central, D, Northern and the Western, E, portions of the ground magnetic map. This high relative magnetic intensity values may indicate deep (Odeyemi, *et al*., 1997: Igboama, 2005), which may be due to block faulting. The contours at the central portion of the map, trend in the North to South direction.

Figure 4b is the three-dimensional view of the total field component of the study area. A strong negative anomaly appeared on the eastern part A^1 of the map. These low magnetic values were also shown on southwest C^1 and north central B^1. The blue colour is an indication of magnetic lows with values of negative 800-1600 nanotesla. Positive anomalies are seen with pink colour and these are areas with magnetic highs. These values are obtained on areas immediately above the central portion, D^1 of the map and northwestern E^1, areas.

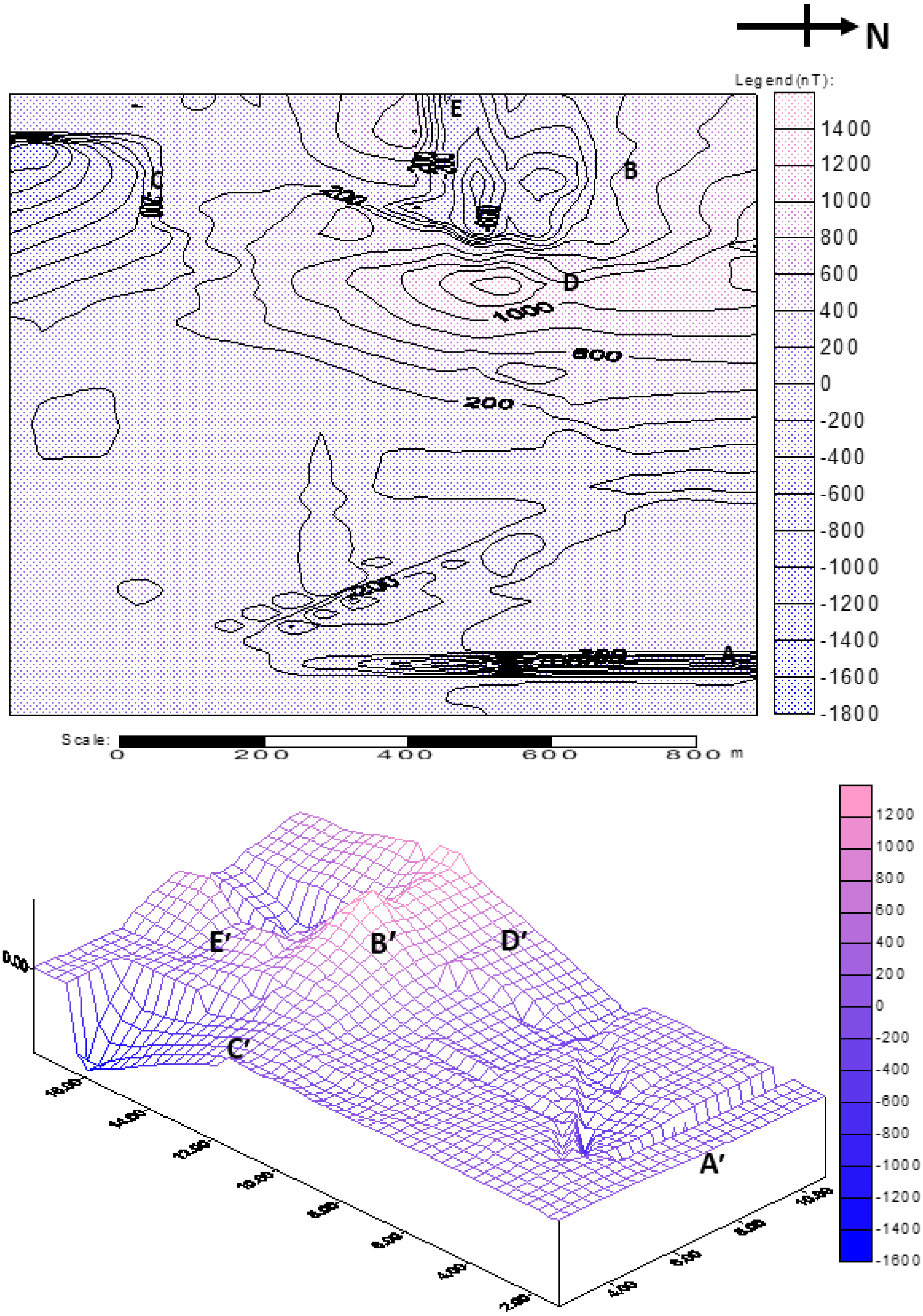

Figure 4(a): Ground magnetic contour map of the total field component (b) 3D Perspective view of the total field component

Depth Distribution Contour Map

The overburden depths obtained from the depth estimates were contoured to obtain the depth distribution map of the total field component (Figure 5a), of the study area. Figure 5a shows areas of overburden thickness of about 4-8 m on the spots marked P. These are found in the South, Eastern, North Western, South Western and central portions of the depth distribution map. All these areas show blue colour. The areas with high overburden thickness are marked Q and they all showed pink colour. These are obtained around Northeast, Southeast, with values of 18-24m and 18-30m around the North-South area of the map.

Figure 5b is the 3D perspective view of the depth distribution maps. The areas where blue colour is located have shallow bedrock and are marked P^1. They are found around the Eastern, Southwest, East Central and Northwestern portions of the study area. The pink colour that is associated with the peaks showed areas where the overburden thickness is high. These portions are labeled Q^1

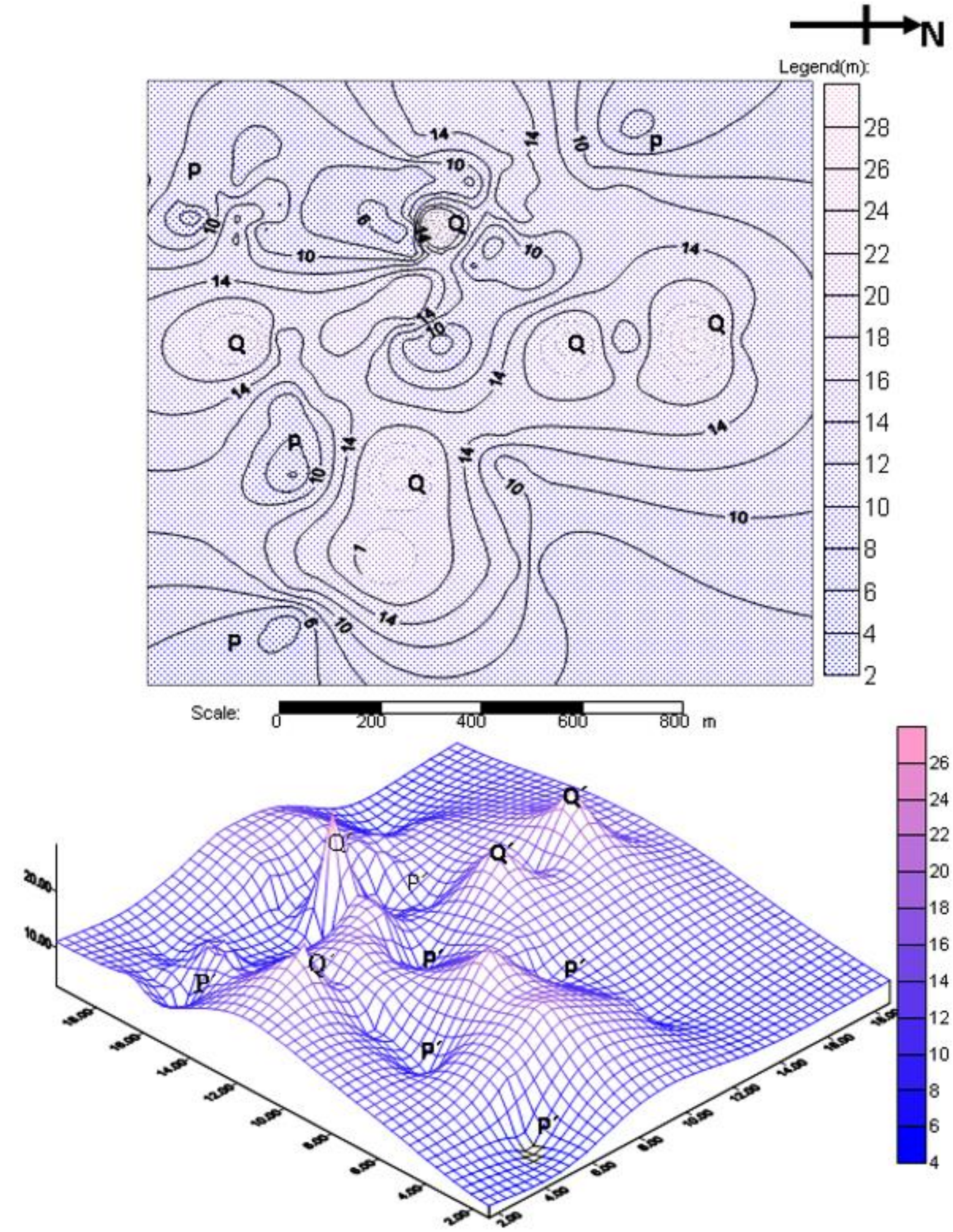

Figure 5 (a): Depth Distribution map of the study area from total field component (b) 3D Perspective view of the total field component

Isolation of Residuals Using Fourth Order Polynomial
One of the greatest tasks in inverse potential problem especially magnetic anomaly interpretation is the separation of regional background anomaly or trend from the data set. The least squares technique of regional-residual separation was used. The fitting surface which represents the regional is a surface that will have both positive and negative deflections from the observed data points with the residuals balanced between positive and negative areas (Nettleton, 1973).
The surface fitting technique was applied to the field data collected. This was done by fitting a trend to the observed (relative) magnetic profiles, using a personal computer. The trends obtained were digitized to obtain the expected regional effect. Hence the residualized data were obtained by deducting the regional values from the relative magnetic (observed) intensity values (Olowofela, *et al.,* 2006).
Fig.6a is the residual map of the study area using a trend of fourth order polynomial of the total component. The Figure revealed presence of faults/fracture at the north – eastern part, north – western, and the extreme of south west. Also noticed in the southeast direction were pockets of enclosures with a particular pattern and trend. This result suggests confirmation of the presence of thin, shallow dipping magnetic dykes. The map revealed the low at Iragberi which might be deposits of mineral of low magnetic content and geologic formation (fault). The residual map (Fig.6a) also showed the magnetic high at traverses 8 and 11, this could be due to regional effect. Thus, according to Odeyemi, *et al.*, (1997), high relative

intensity values may indicate deep structures, which may be due to block faulting.

Fig.6b is the 3-D view of the residual anomaly of the total field component of the study area. The negative anomaly that appeared on the eastern part and southeastern part which trends towards northwest are suspected areas of fractures with mineral deposit. The low magnetic values observed at the west region of the map was due to regional effect suggesting possibility of a fault and the interference pattern of an anomaly. The positive highs at immediately above the central portion could be due to basement ridge.

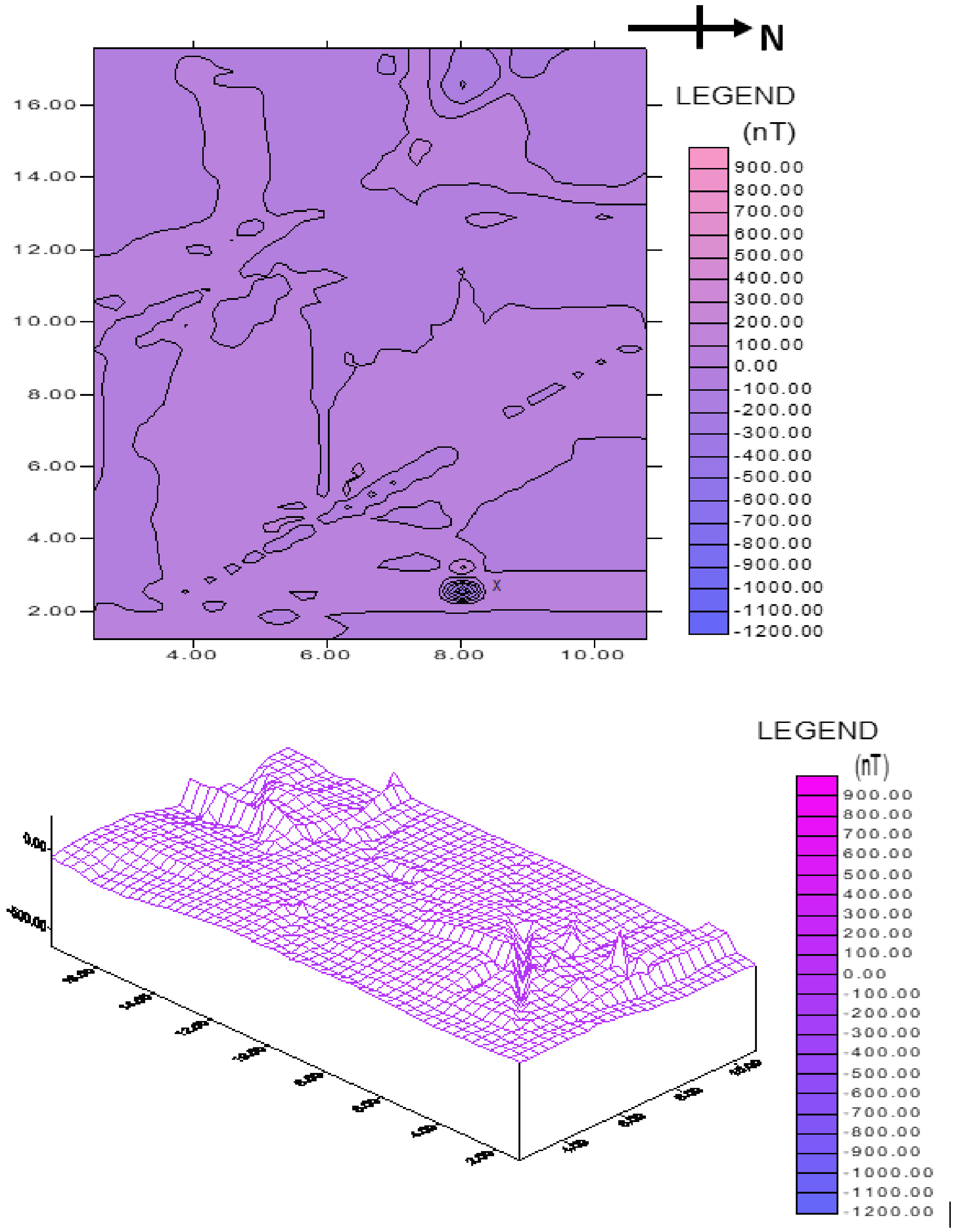

Figure 6(a): Residual map of the study area (Total component) (b) 3D Perspective View of the residual map

CONCLUSION

This paper presents the findings from the ground magnetic survey conducted by the authors in Awo area of Osun state, Southwestern Nigeria. The Peter's “half-slope” and “straight-slope” methods employed in this study effectively provided quick and preliminary depth estimates in the ground magnetic analysis. The methods revealed overburden thickness to range from 2.50-30.00 metres. The results generated enabled contact points, fractures and faults to be established. The primary rock formations identified in the area include banded gneiss and granite gneiss with pegmatite veins. The study area was found to be rich in valuable minerals such as tantalite, barite, quartz, mica, and gravel which if harnessed can add to the economic growth of the state and the country at large.

The very low relative magnetic intensity values obtained in some areas suggest the presence of linear structures relevant for mineralization and hydrological study while the high relative magnetic intensity values, indicate basement ridge, which could be due to block faulting. This anomaly suggests concentration of magnetic minerals in the elevated basement rock.

The result of this study adds valuable data to the existing knowledge base and in addition should serve as a reference point for further investigation of the area in terms of quantification and potentiality of the mineral resources. Other geophysical methods like electrical resistivity and induced polarization method should be integrated into the study for more reliable results

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