Journal of the Nigerian Association of Mathematical Physics
***Volume 30, (May, 2015*), pp161 – 168**
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A Qualitative Interpretation of Residual Magnetic Anomaly using Ground Magnetic Data

[1]Layade G.O., [2]Adebo B.A. and [3]Onyechefu O. C.

[1,3]Department of Physics, Federal University of Agriculture, Abeokuta Nigeria
[2]Department of Physics, Lead City University, Ibadan.

Abstract

This research aims at analyzing and interpreting residual magnetic anomalies for the determination of subsurface geology of the area under study. We employed the use of ground magnetic survey method for the subsurface delineation of a location within Federal University of Agriculture, Abeokuta, an area of 6600 m^2 with geographical coordinates of latitude 7.23707°N to 7.23777°N and longitude 3.43693°E to 3.43858°E. The magnetic data was collected using a G816 proton precision magnetometer. A total of 21 profiles were established along traverses. From these profiles it was seen that the intensities and characteristics nature of the magnetic anomalies, are indicative of the different rocks producing them. Analysis of residual anomaly graph reveals the existence of some structural features such as fault, fractures and contact between rocks and any other subsurface structure of the study area. When the anomaly is higher than the IGRF value, there is said to be a near surface magnetic material (igneous intrusion), but when the anomaly is below the IGRF value, then there is said to be a non-magnetic material such as fault, fracture, etc (sedimentary basin).

Keywords: Proton precession magnetometer, residual, anomaly, qualitative, IGRF

1.0 Introduction

The purpose of a magnetic survey is to locate rocks or materials in the Earth's subsurface, having unusual magnetic properties which reveal themselves as anomalies in the earth's magnetic field intensity[1]. The Earth's magnetic field is generated by the subsequent generation of an induction current by the generation of convection current which is generated by the movement of liquid metallic matter through a weak cosmic magnetic field. This study is meant for detailed mapping in order to understand the subsurface geology of the area of interest. This technique requires measurement of the amplitude of magnetic component at discrete points (stations) throughout the survey area of interest using a proton-precision magnetometer[2]. In acquiring the magnetic data, three components are measured, which are horizontal, vertical and total component, of which the vertical and total component are used to delineate faults, fractures, depth to magnetic basement, and other geological structures. Geophysicists have been able to develop mathematical model for the earth's magnetic field i.e its shape and intensity across the earth's subsurface[3]. Magnetic survey indicates that there are many unexpected variations in this model which are called "magnetic anomalies". A magnetic high anomaly is where the measured field strength is higher than the value predicted by the global model, and magnetic low is where the measured field strength is lower than the value predicted by the global model [4]. The magnetic susceptibility of rocks is extremely variable depending on the type of rock and the environment where it is found.

1.2 Objectives

1. Search for subsurface material and where they are located in the Earth.
2. Obtain the residual magnetic anomalies from the ground magnetic data of the area of study.
3. Analyse and interpret qualitatively the residual magnetic anomalies obtained.
4. Determine the materials responsible for these anomalies of these magnetic sources from the earth surface.

2.0 Materials and Methods

2.1 Location and Geology of the Study Area

Federal University of Agriculture, Abeokuta is located in sub-locality, locality and district, Ogun State of Nigeria.

Corresponding author: Layade, G.O., E-mail: layadeoluyinka018@gmail.com, Tel.: +2348139437356

The area of study lies within an area of 6600$m^2$and falls between latitude ranging from 7.23707^{o}N to 7.23777^{o}Nand a longitude of 3.43693^{o}E to 3.43858^o N, situated north-west of Abeokuta township. It is bounded to the west by Abeokuta – Opeji Eruwa road and to the east by Osiele-Alabata road. The site falls within the geographical region of Odeda local government.Abeokuta falls within the basement complex of the geological setting of south-western Nigeria. The basement complex rocks of Pre-Cambrian age are made up of older and younger granites, with the younger and older sedimentary rocks of the both tertiary and secondary ages. The area is underlain by basement rocks, which cover about 40% of landmass in Nigeria [5].

Abeokuta lies within the Basement Complex rocks. The gneiss-migmatite complex is the most widespread rock formation within the study area. It comprises gneisses, quartzite, calcsilicate, biotite-hornblende schist and amphibolites [6]. These rocks are of Precambrian age to early Paleozoic age and they extend from the north-eastern part of the Ogun state (which Abeokuta belongs) running southwest ward and dipping towards the coast. The older granites and around the Abeokuta, are of late Precambrian to early Paleozoic in age and are magmatic in the origin [7].

The basement complex metamorphic rocks are characterized by various folds, structures of various degree of complexity, faults, foliation and many more. These structural features have a predominant North-South or North-North-East-South-South-West orientation which is particularly strong within the low grade metamorphic. The common metamorphic rocks encountered are gneiss, schist, quartzite and amphiboles. Abeokuta belongs to the stable plate which was not subjected to intense tectonics in the past. The terrain of Abeokuta is characterized by two types of landforms; sparsely distributed low hills and knolls of granite, other rocks of the basement complex and nearly flat topography[8]. The rugged rock-strewn relief is prominent towards the north, in the central and south-eastern parts of the city.

2.2 Magnetic Field Measurement and Data Correction

The entire area was gridded and delineated into profiles in both North-South and East-West directions with a total number of twenty-one (21) profiles of length 110 m and 60 m respectively. A G-816 proton precision magnetometer was used to measure the magnetic variation of the area. A direct current flowing in a solenoid creates a strong magnetic field around a hydrogen-rich fluid, causing some of the protons to align themselves with that field. The current is then interrupted, and as protons realign themselves with the ambient magnetic field, they precess at a frequency that is directly proportional to the magnetic field. This produces a weak rotating magnetic field that is picked up by a (sometimes separate) inductor, amplified electronically, and fed to a digital frequency counter whose output is typically scaled and displayed directly as field strength or output as digital data.

The relationship between the frequency of the induced current and the strength of the magnetic field is called the proton gyromagnetic ratio, and is equal to 0.042576 Hz nT^{-1}. Thegyromagnetic ratio, symbol γ, of a particle or system is the ratio of its magnetic moment to its spin angular momentum,

$$\boldsymbol{\mu} = \gamma \boldsymbol{I} \qquad \text{……………..} \qquad (1)$$

where $\boldsymbol{\mu}$ is the intrinsic magnetic moment of the nucleon, $\boldsymbol{I}$ is the nuclear spin angular momentum, and g is the effective g-factor. For the proton, $\boldsymbol{I}$ is $1/2\,\hbar$, so the proton's g-factor, symbol g_p, is 5.585694713(46). For nucleons, the ratio is conventionally written in terms of the proton mass and charge, by the formula

$$\gamma = \frac{g\mu_N}{\hbar} = g\frac{e}{2m_p} \qquad \text{…………….} \qquad (2)$$

Because the precession frequency depends only on atomic constants and the strength of the ambient magnetic field, the accuracy of this type of magnetometer can reach 1 ppm

The frequency of Earth's field NMR for protons varies between approximately 900 Hz near the equator to 4.2 kHz near the geomagnetic poles. These magnetometers can be moderately sensitive if several tens of watts are available to power the aligning process. If measurements are taken once per second, standard deviations in the readings is in the 0.01 nT to 0.1 nT range, and variations of about 0.1 nT can be detected.

A Global Positioning system (GPS) was used to measure the longitude, latitude, and elevation along the profiles. The position and size of an anomaly depends on the position and size of the magnetic body. Consequently, the generated profile map in 2D plot of the residual anomaly and the horizontal distance is used for the analysis and the interpretation of the anomaly for the location of magnetic bodies and nature of geological structures such as faults, fractures, etc, are inferred.

The data was corrected for local variations with reduction to equator being at lower latitude. The residual magnetic field which is the difference of total magnetic field(TMI) and the expected field(IGRF) was calculated and plotted against horizontal distance to obtain the magnetic profile plot [9]. These residual anomalies are subjected to qualitative interpretation for the determination of all subsurface structure of the study area as related to the Earth's magnetic field.

2.3 Qualitative Interpretation Technique

The term qualitative interpretation' (visual inspection) of magnetic surveys is usually undertaken as an aid to geological mapping, often using the property of magnetic surveys to reveal the magnetic signature of the crystalline bedrock, even where it is covered by superficial deposits and thus invisible to the conventional field or photogeologist [10].

The process involves two stages; the first stage of this process is simply to prepare the geophysical data and the best available geological data at the same scale and projection that allows geological deductions to be made from the geophysical data in the areas lacking in outcrop. This leads naturally into the process known as 'zoning' of the map, zoning involves the outlining of those areas of well-defined physical expression on the magnetic map that appear to the interpreter as distinct geological units. However, the zoning process is, of course, subjective. In order to capture essential geological information of the bedrock the map is divided into geophysically similar units based on the physical description of anomaly patterns; and geological names are ascribed to the geophysical units with due reference to the
information on any available geological map.

3.0 Result and Discussion

The results obtained from visual inspection of the anomaly maps for each profile formed the basis for the qualitative interpretation. The presence of magnetic materials and non-magnetic material in the Earth's subsurface is what causes the variation or sinusoidal movement in the residual magnetic field [11]. Therefore, the result below reveals the causative materials responsible for the sinusoidal movement in the residual anomaly for each profile. The results of the analysis and interpretation of the residual anomaly is presented as follows for selected profiles:

3.1 North-South Trend

The profile map in Figure 1 has a total length of 110m and trends North-Southward. The magnetic signature reveals both high and low residual as shown by spikes and hollow. Spikes A, B and Cshows positive residual anomaly which signifies near surface magnetic material such as crystalline rocks, that is, porous sediments with magnetic grains, while the magnetic lows T, U, V, are indicative of the fact that there is a presence of non-magnetic zone which is the consequence of fault, fracture, crack or contact, between two rocks. However, the anomalies in this profile all lie above the positive x-axis. Equally Figure 2, the magnetic points A and B shows the presence of magnetic material within a sedimentary zone far from the surface, while the point Cc shows an inflection at B which means there is a contact between two rocks that forms the rock under which the magnetic material is suspected to be. The areas T, U, and V indicates the presence of non-magnetic materials such as faults, fracture, cracks or contact between two rocks which are also far from the crustal surface as they all fall into the negative x-axis.

In addition, Figure 3 reveals a high magnetic anomaly at point A which signifies the presence of an intrusive magnetic material as an outcrop very close to the surface. However, point B is near zero anomalies because the field measured is practically the ambient earth magnetic field without external influence while magnetic points T and U indicates the presence of moderate non-magnetic zone or metamorphic grains. The residual magnetic traverse in Figure 4 reveals magnetic highs at point A and B, which is an indication of the near surface magnetic material, while the areas T, U and V is as a result of weathered rock that produced faults, fracture, cracks or contact between two rocks. The area labeled Cc is an inflection point where there is a contact between two rocks, and the extension towards the y-axis is suspected to form a signal for broad anomaly, i.e. a broad magnetic high.

In Figure 5, the profile map suggests that the magnetic materials present are found a bit farther below the earth surface. It is characterized by sedimentary zone with low residual value which resulted from faults, fracture, cracks or contact between two rocks as indicated by point U with a wide gap in the region. On the other hand, the profile map in Figure 6 presents a sinusoidal magnetic profile with magnetic highs and lows respectively. The magnetic material spread along the profile, though there is a region where the magnetization is found below the reference level. Howbeit, the profile reveals some points with good prospect for magnetic mineral exploration.

3.2 East-West Trends

Each profile along this trend covers a total length of 60m with magnetic highs and lows but significantly prosperous for magnetic mineral survey. In Figure 7, points A, B, and C signifies near surface magnetic material, while the areas T and U indicates the presence of non-magnetic materials such as faults, fracture, cracks or contact between two rocks. At Cc there is an inflection point which shows that there is a contact between two rocks. However, Figure 8 has magnetic highs A and C with an outcrop at B, while the fault delineation within the basement complex could be attributed to areas T, U and V with magnetic low.

The anomaly map in Figure 9 shows that points A and B have high residual anomaly, while at C the magnetic material covers more horizontal distance at very near surface. The point labeled EXT shows that there is an extension of magnetic material within the complex which is suspected to be a magnetic high. However, a point U, and V indicates the presence of non-magnetic materials such as faults, fracture, cracks or contact between two rocks.

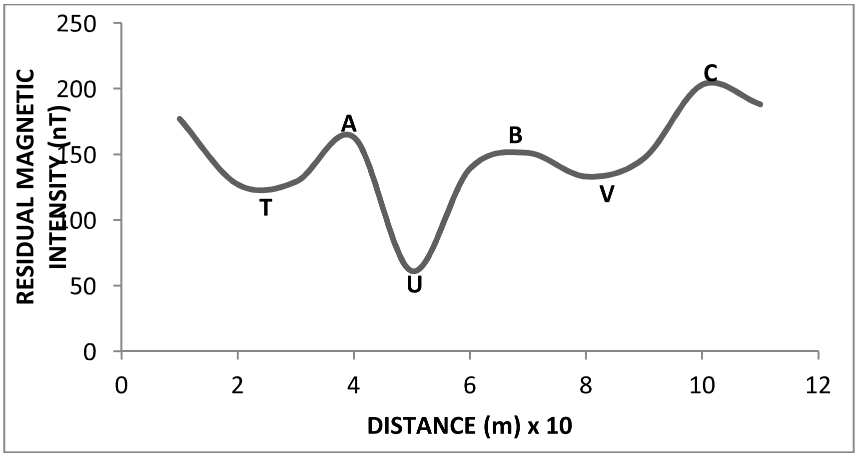

Figure 1: Graph Of Residual (nT) Against Distance (m) For Profile 1

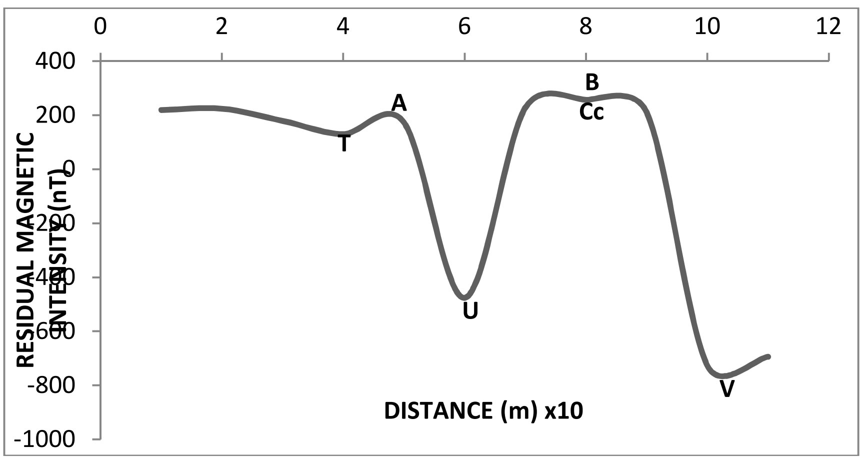

Figure 2: Graph Of Residual (nT) Against Distance (m) For Profile 2

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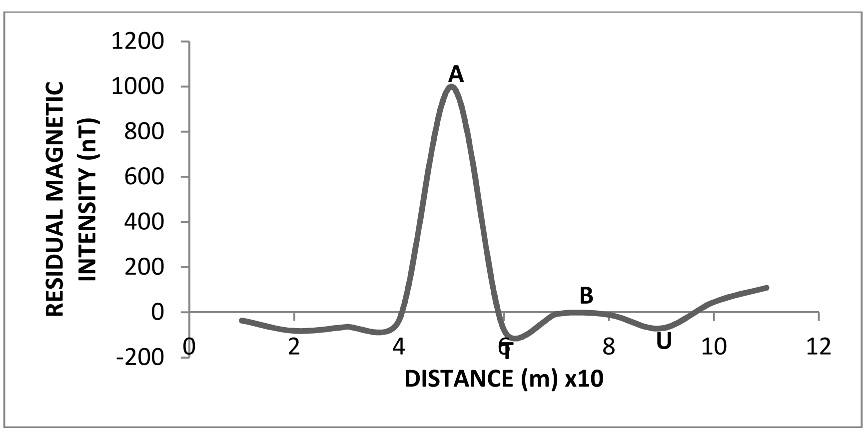

Figure 3: Graph of Residual (nT) Against Distance (m) For Profile 3

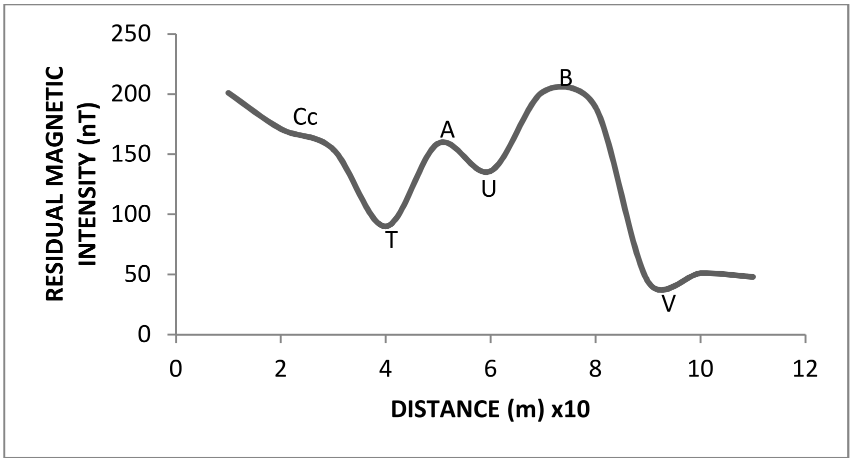

Figure 4: Graph Of Residual (nT) Against Distance (m) For Profile 4

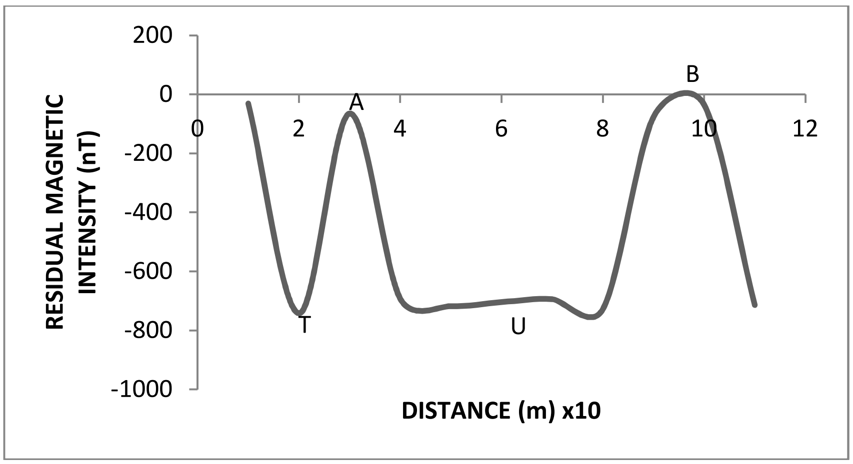

Figure 5: Graph of Residual (nT) Against Distance (m) For Profile 5

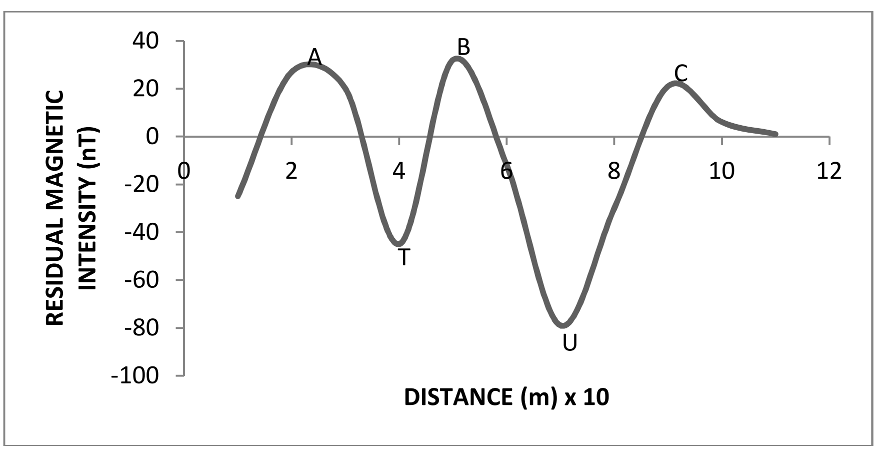

Figure 6: Graph Of Residual (nT) Against Distance (m) For Profile 6

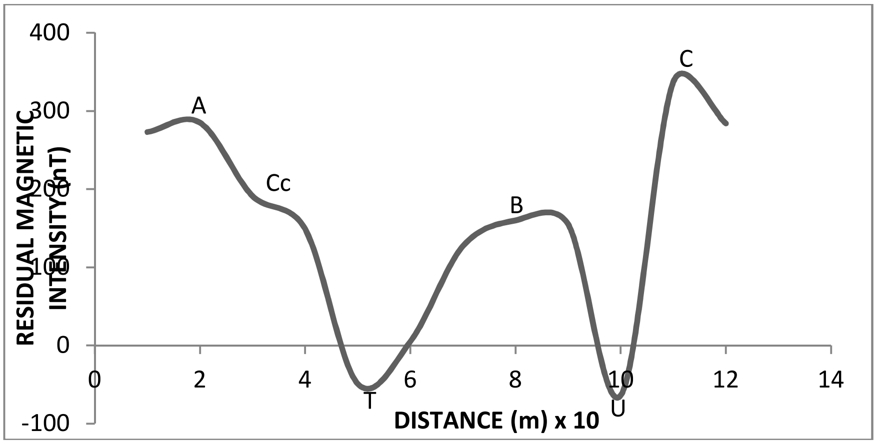

Figure 7: Graph of Residual (nT) Against Distance (m) For Profile 7

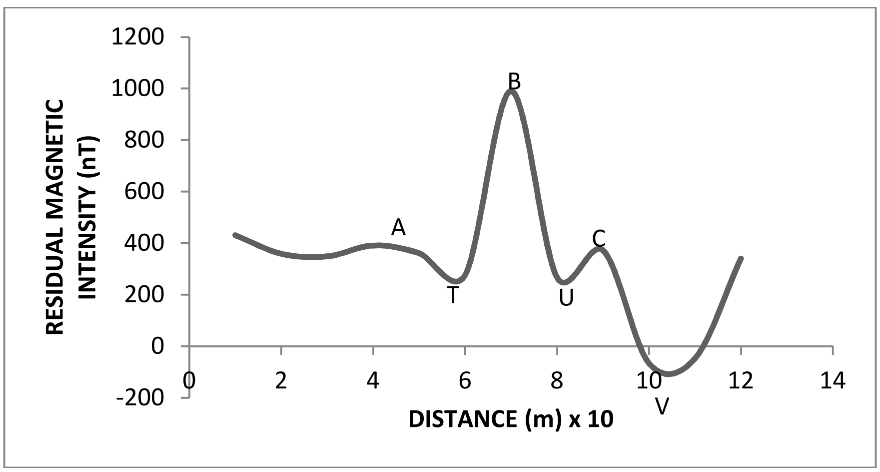

Figure 8: Graph Of Residual (nT) Against Distance (m) For Profile 8

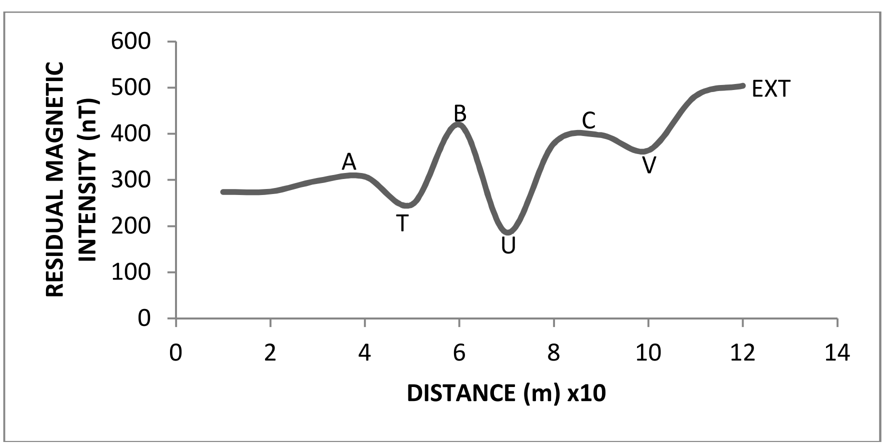

Figure 9: Graph Of Residual (nT) Against Distance (m) For Profile 9

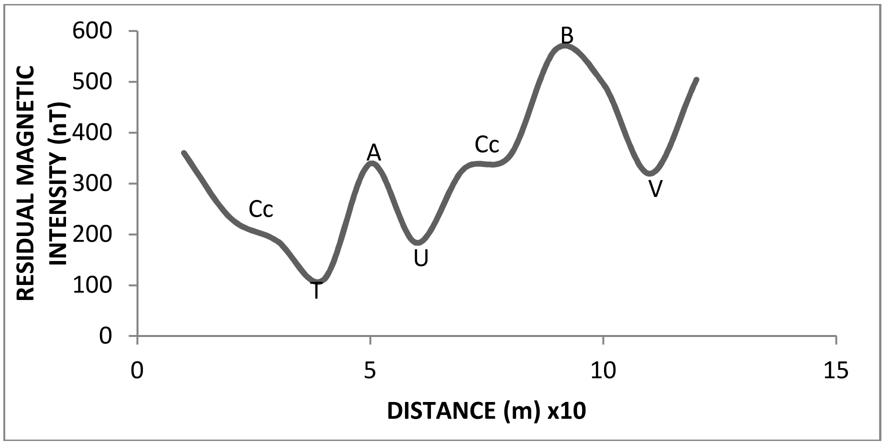

Figure 10: Graph Of Residual (nT) Against Distance (m) For Profile 10

4.0 Conclusion

Qualitative interpretation of ground magnetic data of a location in Federal University of Agriculture, Abeokuta revealed subsurface materials with magnetic properties and those areas with non-magnetic minerals like faults, fracture, rock contacts, and joints between rocks along each profile. This visual (inspection) interpretation method used for the interpretation has revealed magnetic structures within the basement complex, and also the state of the subsurface structure of the area under study. The method used in this survey readily provides hands-on geophysical information relevant to any survey area with fast, simple, easy to learn and implement processes of techniques in geophysical interpretation.

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