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Research Article

Geological factors in civil engineering construction: the perspective of engineering geophysics using case histories from basement complex terrain of Nigeria

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Abstract

Acknowledged factors of premature failure of most civil engineering construction include poor construction materials, bad design, drainage problems and usage factor. However, the foundation of civil engineering projects and its routes requires pre-knowledge of the subsurface geology that carries the load and hence the need for engineers to have adequate predesigned idea of the subsurface geology. While direct exploratory borehole drill for sample collection and insitu engineering tests are considered ultimate in this respect, the rich opportunities of geophysical tools in giving needed subsurface information cannot be over emphasized due to the combine high speed, relatively cheap and appreciable accuracy of the latter. Therefore, theoretical

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background of engineering geophysics and case histories from basement complex terrains of Nigeria are presented and discussed with respect to civil engineering constructions.

Keywords: geological factors, engineering geophysics, civil engineering construction, basement complex

1. Introduction

Optimal design of civil engineering constructions essentially depends on the nature of the subsurface geology. Geological material could be a supporter or barrier to the integrity of civil engineering works depending on the competency of the former. Categorizing geological materials between these two extreme becomes very important to prevent failure of such structure before their design age. Construction of civil engineering structures such as high rising buildings, dams, roads, tunnels among others are done according to the requirements of certain design and from specific construction materials. Geological factors such as rock type, nature of the weathered material, subsurface structural disposition involving fractures, faults, sheared zones, joints, cracks among others constitute the essential determinant of ground quality upon which civil engineering foundation are placed [1]. This information particularly enables location of areas of bad ground so that correct excavation and support techniques are incorporated in the design and construction stage. Geophysical methods provides good prospect in this field as they are capable of surveying large areas of ground with relatively few problem of access. The combine high speed and relatively cheap nature of the geophysical survey enable data acquisition with a reasonable spread of control information from borehole or other sources [2]. Engineering geophysics are known to provide information such as the determination of the subsurface structural defect, determination of depth to bedrock, assessing nature of superficial deposit and rock mechanics/dynamic elastic constant evaluation among others. The present work hope to examine the theoretical background of the engineering geophysics and its application in identifying geological factors normally consider in civil engineering construction.

2. Theatrical background

Engineering geophysics involves application of physical principles to obtain geometry and nature of subsurface information for civil engineering construction. To achieve this, geophysical instruments are used to take measurement at or near the earth surface and obtain data that are direct consequence of vertical/ or lateral variation of the distribution of subsurface rocks and minerals. The electrical resistivity and seismic refraction method are known to have found a common used in most civil engineering site investigation [3]. The magnetic and gravity methods are equally known to serve as complementary techniques.

3. Field and Interpretational Procedure of Electrical Resistivity Method

The electrical resistivity method involve the introduction of artificially generated current into the subsurface ground through two current electrodes and measurement of the developed potential through another pair of electrodes as shown in Figure 2. The essential aim of any dc electrical survey is the determination of the subsurface resistivity distribution of the ground, which is a function of the lithology, porosity, the degree of water saturation and the presence or absence of voids in the rock etc. Resistance (R) of any object measured in ohms is the result of an electrical measurement which according to Ohm's Law is given as:

$$V = IR \text{ or } R = V/I$$

Where V = voltage in volts and I = current in amps.

Resistivity of a material is a fundamental physical property related to the ability of a material to conduct electricity. For a block of conductive material, If R and L are its resistance and length respectively with the cross-sectional area denoted by A (Fig. 1), then its resistivity is given as:

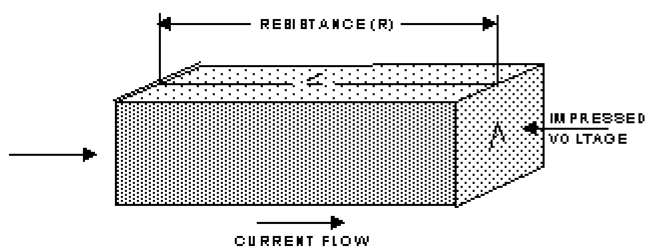

Figure 1. Diagrammatic Illustration of Resistivity Measurement in a Block of Conductive Material

$$\rho = RA/L$$

From the current (I) and voltage (V) values, an apparent resistivity (ρ_a) value is calculated.

$$\rho_a = kV/I$$

Where k is the geometric factor known to depend on the arrangement of the four electrodes. The "k" value can be calculated for any four-electrode configuration according to the generic formula:

$$k = 2\pi[1/(1/r_1 - 1/r_2 - 1/r_3 + 1/r_4)]$$

Where the subscripted "r" values represent distances as shown in (Fig. 2).

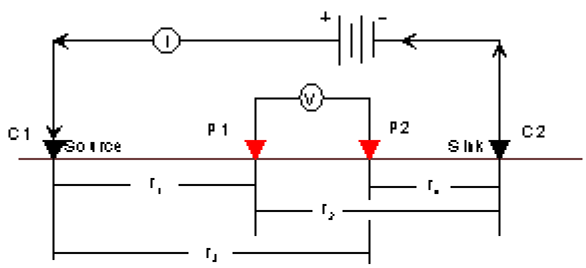

Figure 2. Typical Four Electrode Array

Two basic survey techniques involving vertical electrical sounding (VES) and horizontal profiling are commonly employed. The VES technique involves successive measurement of apparent resistivity of the subsurface downward by successive increase in the current spacing C_1C_2 while the horizontal profiling involve measurement of the lateral variation in the resistivity of the earth using a fixed electrode set up. Common ambiguities and field operational problems arise due to suppression, equivalence, lateral inhomogeneity, contact problems at the current electrode etc.

4. Field and Interpretational Procedure of Seismic Refraction Method

The general principle underlying this method is that seismic wave are generated at the earth's surface from an energy source, S (hammer, explosives, weight drop etc) and propagated through the subsurface and refracted along interface where acoustic impedance contrast exist. This interface may or may not coincide with geological interface. The refracted waves return back to the surface and are detected by the geophones, G or the seismometers located at a fixed distance from the source along established traverses. Both horizontal and dipping subsurface interface may be encountered and hence the usual practice is to carry out forward and reverse seismic refraction shooting. The obtained results are values of arrival time in millisecond recorded by the seismometer and can be directly read. The recorded travel time are plotted against source-geophone distances to obtain the time-distance graph that are interpreted in terms of formation velocities and depth to the interfaces (Fig.3).

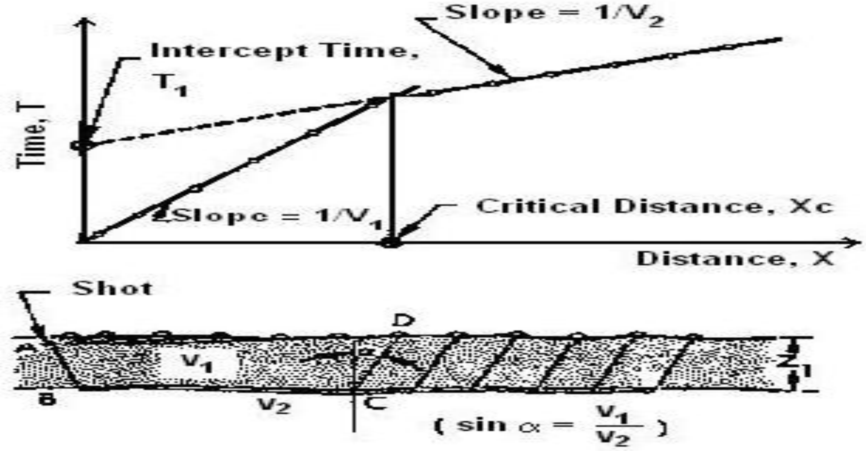

Figure 3. Simplified Two Layer Case with Plane, Parallel Boundaries and Corresponding Time-Distance Curve [4]

Once the condition of reciprocity is satisfied, the following can be measured from the time-distance graph.

(1) The seismic velocity of the first layer (V1). This is determining from the reciprocal slope of the first line segment from S and G ends. Obtained values are expected to agree to within <10% to confirm the uniformity of the materials near S and G or otherwise.

(2) The second layer seismic velocity (V2) is computed from the reciprocal slope of the second line segment. Note that V2S and V2G are unequal only when the interface is dipping.

(3) The critical distances: By analysing the arrival time of P-wave (T) as a function of distance (X) from the source point, the seismic velocity (V) of the underlying soil or rock unit and the depth to geological contact can be determined and written as:

$$V = \frac{X}{T}$$

The depth of the top layer in the profile (Fig. 3) determined as thus:

$$Z_1 = \frac{Ti\, V_1 V_2}{2\left(V_2^2 - V_1^2\right)^{1/2}}$$

where,

Z1 = depth of the top layer

Ti = intercept time for i layer
V1 = P-waves velocity in the first layer
V2 = P-waves velocity in the second layer

The other method to determine the depth of layer is the critical distance method as shown below.

$$Z_1 = \frac{X_c}{2}\frac{(1 - V_1/V_2)}{\cos(\sin^{-1} V_1/V_2)}$$

Where Xc is the critical distance.

The general formulation for depth calculation can be written as:

$$Z_D = \frac{\Delta T_D V_1}{\cos\left(\sin^{-1} V_1/V_2\right)}$$

Where ΔT_D is the delay time at geophone (detector) and Z_D is the layer thickness at D geophone point (Figure 4).

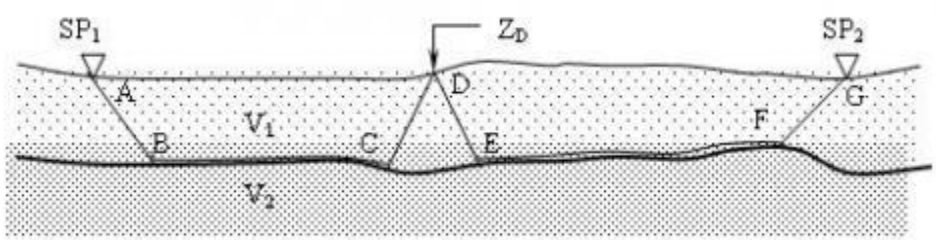

Figure 4. The Time Delay Analysis for Depth Determination in the Two Layer Cases [4]

5. The Magnetic Method

The magnetic survey involves detecting magnetic anomalies within the Earth's magnetic field, which are caused by the magnetic properties of the underlying rocks. Most rock-forming minerals are non-magnetic but a few rock types contain sufficient amount of magnetic minerals, which can impart magnetism to their host rocks and thus produce detectable magnetic anomalies [1]. Such magnetic minerals include ferromagnetic minerals (iron, cobalt and nickel), ferrimagnetic minerals (magnetite, pyrrhotite, maghemite and pyrite), antiferromagnetic minerals (ilmenite) and parasitic ferromagnetic minerals (haematite).

6. Selected case histories

6.1. Case study from oau international school, south-western nigeria

Obafemi Awolowo University (OAU) Campus is among the well-known universities in Nigeria that has continued to expand to accommodate her over 40,000 teeming populace. To this end, the OAU international school came on board recently as secondary school to cater for the need of the university community and the surrounding towns. A fault zone within the premises of OAU international school was suspected from contour map of the basement depression carried out by Olorunfemi and Okhue, 1992 within the area demarcated in Figure 1 as the study area. The need to therefore carry out detail investigation within the premises of the school cannot be overemphasized. The OAU campus is underlined by rocks of the Precambrian Basement Complex with banded gneiss, mica schist and granite gneiss constituting the major lithologies (Fig.1). As shown by Figure 1, the study area is underlined by Banded gneiss and mica schist.

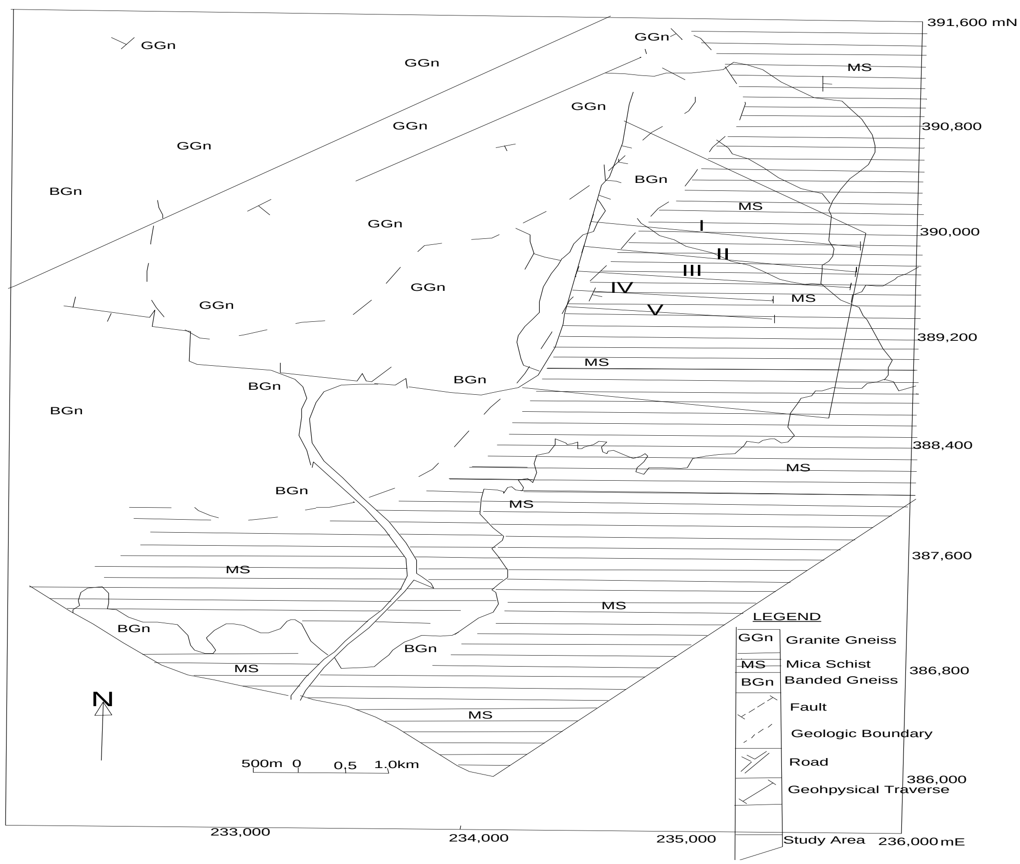

Figure 5. Generalised Geological Map of the Obafemi Awolowo University [5]

A geophysical survey involving the magnetic and vertical electrical sounding (VES) were carried out to assess the subsurface geoelectrical configurations and ascertain the competent of the subsurface that is essential for further expansion of the school. Five geophysical traverses were established for this survey perpendicular to the strike of the suspected fault and axis of the basement depression (Fig. 1). Traverses I, II and III were taken along road 23, 7c and 7 of OAU staff quarter road respectively and were approximately 800m long except traverse III that was 850m long. Traverse IV and V were 225 and 330m respectively and were adopted for the magnetic method only within the premises of OAU international school to intercept and confirm the suspected fault zone (Fig. 1). The ground magnetic survey involved measurement of total field component of the earth's magnetic field along the five established traverses. These measurements were made with the GSM-8 Proton Precession Magnetometer in the unit of nanotesla at 5.0 m interval. The closely spaced stations adopted for the magnetic survey allow high resolution of near surface sources. Two readings of the magnetic field were recorded at each station with the sensor at about 1.5 m above the ground and the mean determined. The time of each reading was recorded while it was ensured that the observer was magnetically clean. The traverses have a total length of 2980 m (2.98km) with 601 magnetic stations. A base station was established for the three traverses. Base station readings were taken before commencement of measurement and immediately after all the traverses had been occupied to enable diurnal and offset corrections. Eight base point readings were taken at interval of three seconds and an average was taken in each case. The base station values obtained above were plotted against the corresponding time. A smooth curve was drawn through the points, which peak around 1.00p.m. Magnetic values were read from the curve at each time of data point along each traverse. Each value was then subtracted from the mean values obtained from the field at the corresponding time. This way, diurnal (which account for the temporal variation of the geomagnetic field that are caused mainly by the solar effect on the ionosphere) and offset corrections were made. The resultant values give the residual (local) anomalies for the stations as presented in Appendix IV. The corrected magnetic data were plotted against station positions and presented as magnetic profiles along the five traverses. These profiles were then qualitatively and quantitatively interpreted using thin sheet and thick dyke models. A total of seventeen (17) VES data points uniformly distributed along traverses I, II and III were carried out for the study. ABEM Terrameter SAS 300C unit was used for the VES data acquisition with electrode spacings AB/2 varying from 1 to 150m to successively probe the depth. The VES data were plotted to obtain sounding curve and curve matched segment by segment to obtain the geoelectric parameters (layer resistivities and thicknesses) used as the starting parameters for the 1D modelling using RESIST software. The final interpretation results were as shown in table 1 below.

7. Results and discussion

Table 1. Resistivity, Thickness and Type Curve of the Obtained Resistivity Data

VES NO	Maximum Electrode Separation	Thickness (m) // Resistivity (ohm-m)	Type Curve
1	100	0.4/5.5/23.7//262/554/68/∞	KH
2	100	0.2/5.5/13.4/37.5//487/192/774/211/∞	HKH
3	100	1.0/3.1/93.9//112/1948/319/∞	KH
4	100	0.3/7.3/36.4//109/869/74/∞	KH
5	100	0.3/1.6/4.9/35.1//649/192/348/158/∞	HKH
6	65	0.3/0.5/2.9/13.1//276/184/252/53/∞	KH
7	100	0.7/1.3/6.1/24.2//230/109/212/86/∞	HKH
8	100	0.4/10.1/44.1//67/303/117/∞	KH
9	100	1.6/7.5/27.5//160/117/25/148	QH
10	100	1.5/5.4/12.2//219/111/6.2/∞	QH
11	100	0.6/3.8/11.2/57.2//215/143/180/73/∞	HKH
12	100	4.0/15.2/61.6//480/206/147/∞	QH
13	100	0.7/1.6/29.7//133/386/94/∞	KH
14	100	0.4/6.6/37.3//198/286/67/678	KH
15	100	3.1/16.7/28.5//350/132/45/1041	QH
16	100	0.4/6.2/28.0//141/714/95/∞	KH
17	100	0.6/10.7//185/463/214	K

The geoelectric sections shown in Figure 6 revealed four subsurface layers including the topsoil, the clay/clayey sand/sandy layer/laterite, the weathered basement and the fresh bedrock. The topsoil is made up of sandy clay/clayey sand that are lateritic at station 15 and 12 and with resistivity values varying between 67 to 649 Ωm. The layer thicknesses generally vary from 0.2 to 4.0m.

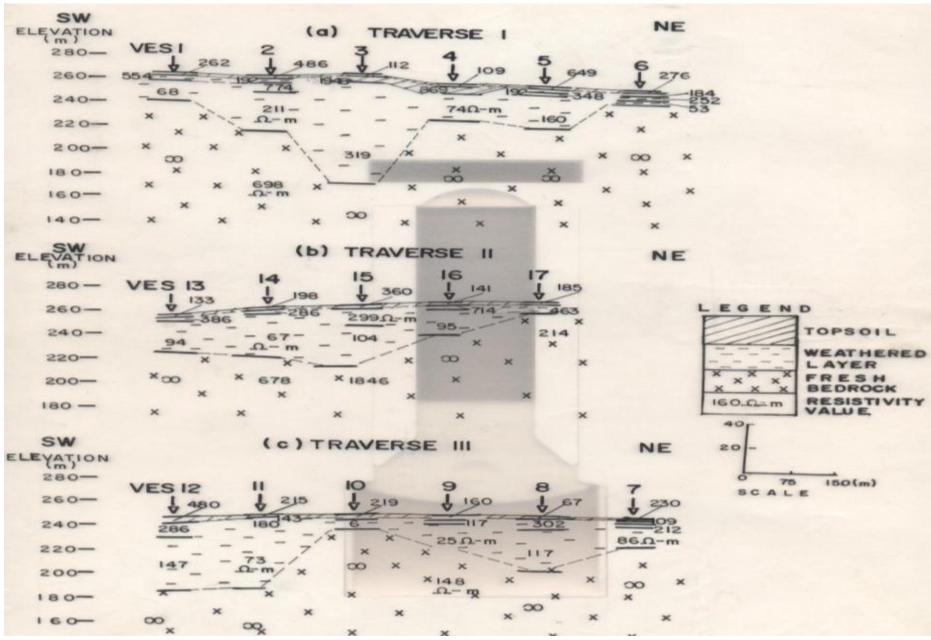

Figure 6. Geoelectric Section Along Traverses I, II and III

The second layer which has resistivity values varying from 109 to 1948 presumably indicating clay/clayey sand/sand/laterite. The layer thicknesses vary from 0.2 to 13.6m. The weathered layer which constitutes the third layer has resistivity values varying from 6 to 319 Ωm with layer thickness ranging from 6.8 to 46.6m. The bedrock constitutes the fourth layer and is infinitely resistive in most places. The depth to bedrock varies from 0.2 to 93.9m. The geoelectric section shows alternation of bedrock ridges and depressions. Basement depression in the geoelectric section form the most significant structural feature beneath stations 2&4 along traverse 1, stations 9&7 and 11&12 along traverse 3 and finally beneath stations 13&15 along traverse 2. A basement depression correlated over a significantly long distance could be diagnostic of a buried river channel [6]. The prominent negative magnetic anomaly along traverse 3 (between station 140 and 159) coincides with the basement depression between stations 7 and 9 along the same traverse further confirming the fault (Fig. 6). Figures 7-11 show the magnetic profiles along the five traverses. Qualitatively, traverse I show no defined anomaly since there is no well-defined peak or trough. The magnetic profiles along traverses II, III, IV and V show some significant values.

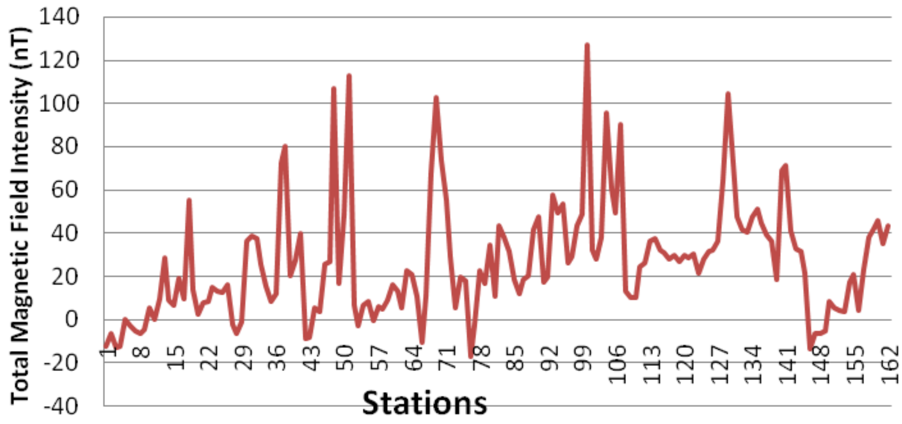

Figure 7. Total Magnetic Field Intensity Profile Obtained Along Traverse I

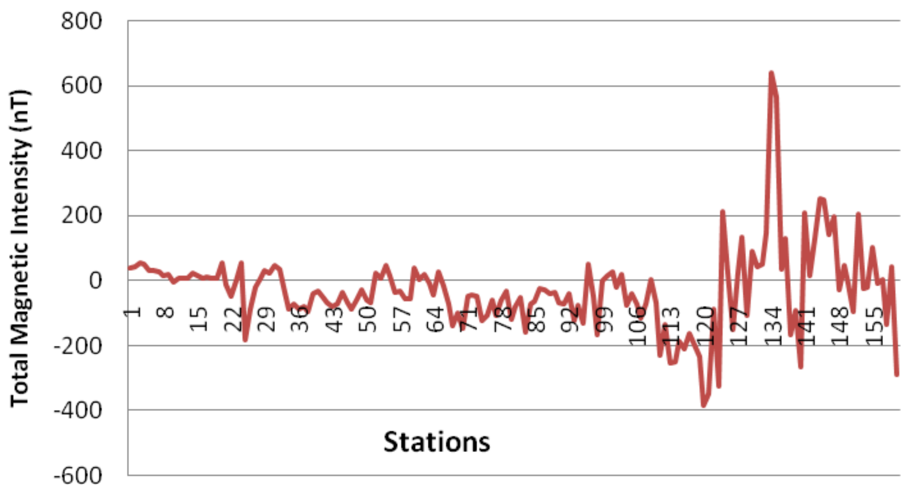

Figure 8. Total Magnetic Field Intensity Profile Obtained Along Traverse II

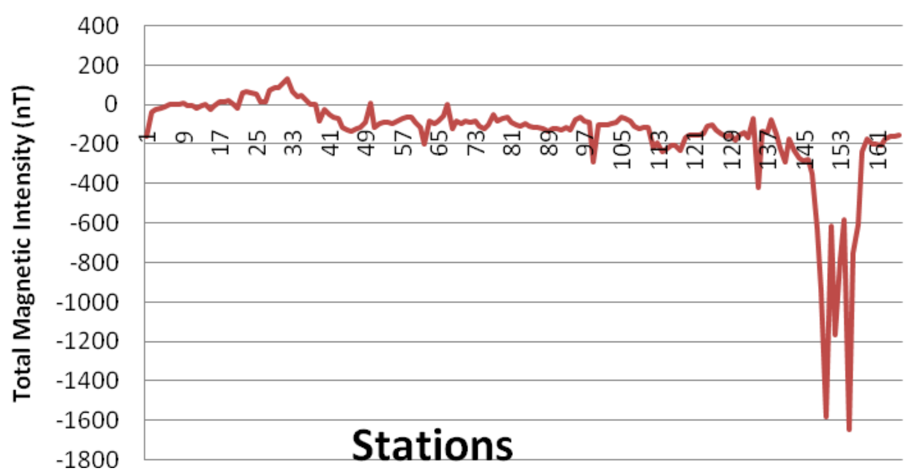

Figure 9. Total Magnetic Field Intensity Profile Obtained Along Traverse III

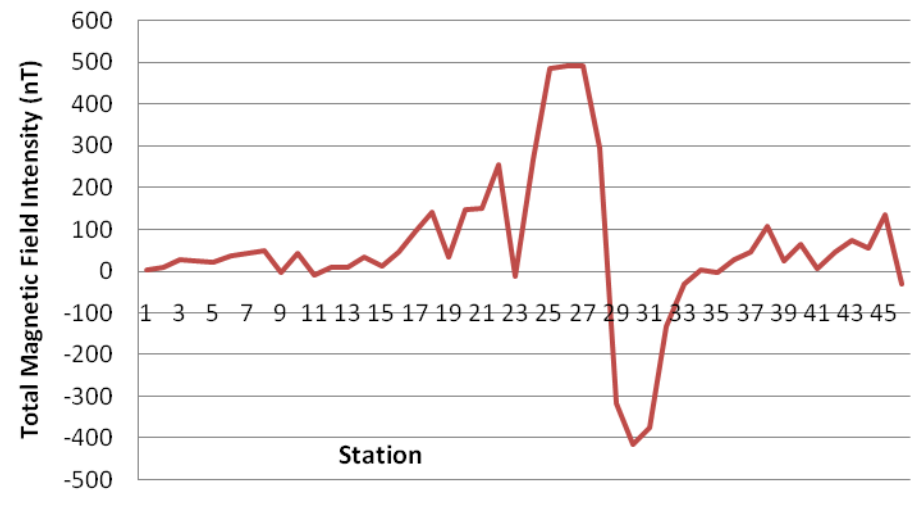

Figure 10. Total Magnetic Field Intensity Profile Obtained Along Traverse IV

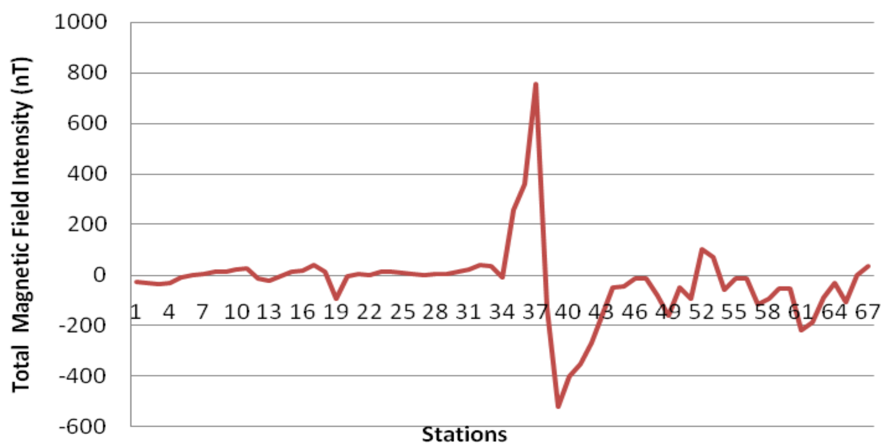

Figure 11. Total Magnetic Field Intensity Profile Obtained Along Traverse V

Of particular interest is the prominent magnetic trough (anomaly) between stations 112 and 146, 140 and 159, 24 and 33, 35 and 43 along traverses II, III, IV and V respectively with the most striking anomaly values obtained along traverses III, IV and V. The maximum peak negative anomaly of about 35m in length observes along traverse III is diagnostic signature over linear subsurface structural defect. The observed anomaly along traverses IV and V covering about 40m in length reveals typical magnetic signature over thin dyke. A close examination of profiles IV and V shows that maximum positive and negative background anomaly of 489 and 457nT, and -368 and -426nT respectively, the former being greater than the latter characterised the two traverses. This shows that the fault is possibly trending in NW-SE direction. Quantitatively, lateral position of the top edge, depth of the edge/to the centre and dip of the fault can be estimated. Using half-width rule given as $z = x_{1/2}$ for the edge of sheet [7] enable the depth to the centre of the fault to be estimated. Where z = depth, x = half-width defined as the horizontal distance between the principal maximum (or minimum) of the anomaly (assume to be over the centre of the source and the point where the value is exactly one-half the maximum value. The results along traverses IV and V were as tabulated in table 2 below using the horizontal distance between the principal minimum of the anomaly and the zero anomaly point.

Table 2. Results of Quantitative Interpretation of the Magnetic Data using Half-Width Method

Traverse No	Station Values	Stations	$X_{1/2}$ (m)	Z (m)	
IV	28-30		135-145	10	10
V	38-40		185-195	10	10

Using Parasnis method enable lateral position of top edge, depth and dip of the fault to be determine. This method was adopted for anomalies along traverses IV and V only since their profiles are at right angle to the strike of the fault.

Let ΔB (1) and ΔB (2) denotes the extreme values of ΔB Figs. 11 and 12.

1. The lateral position of the top edge was determine using $\Delta B = \Delta B(1) + \Delta B(2)$ where ΔB(1) and ΔB(2) were peak negative and positive anomaly field respectively in this case. ΔB (2) is normally greater. The top edge will exactly be below the corresponding observation point which will be the origin of the fault coordinate denoted by $X_O = 0$ in both Figures and. The positive and negative X with respect to Xo were denoted as X_1 and X_2 respectively from ΔB(1) and ΔB(2)

2. Therefore, the depth (a) of the edge of the fault is given as

   $a= -(-X_2X_1)^{1/2}$

   Where $X_2 = X_2\text{-}X_O$

   $X_1 = X_1\text{-}X_O$

   Then, the constant $K= 2a/X_1+X_2$

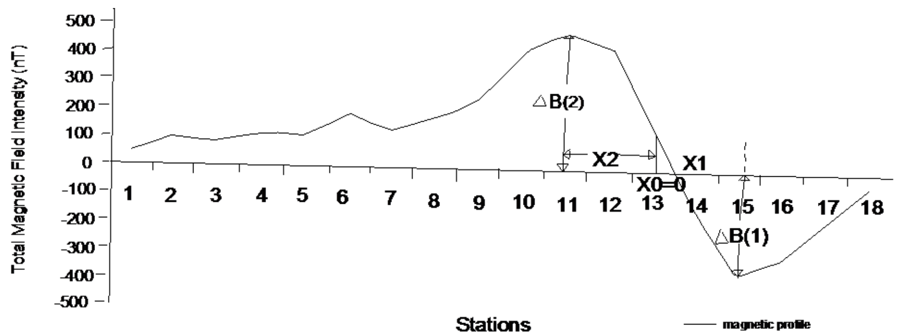

Figure 12. Quantitative Interpretation of the Magnetic Data along Traverse 10 using Parasnis Technique

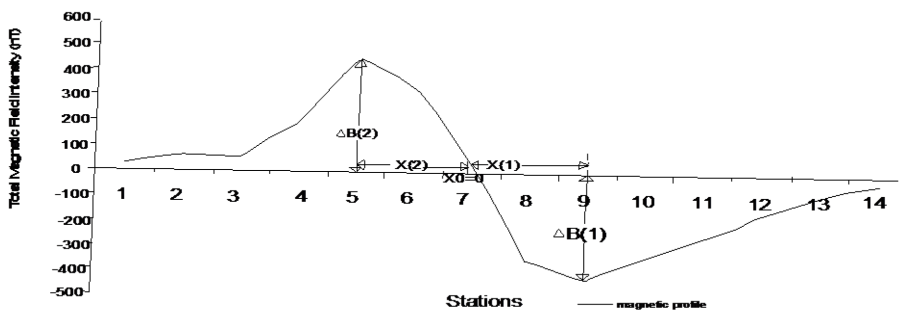

Figure 13. Quantitative Interpretation of the Magnetic Data along Traverse 11 using Parasnis Technique

c. The dip of the fault was estimated using $2I^1-\theta = Cot^{-1}(k) = tan^{-1}(1/k)$. Where I^1 = tan I/strike of the fault. But I = 0 along the magnetic equator where Ife area is located. Applying the above, the results were as tabulated below:

Table 3. Results of the Quantitative Interpretation of the Magnetic Data using Parasnis Method

Tvs No	ΔB(1)	ΔB(2)	ΔB	X1	X2 K=2a/X1+X2 (nT)	XO	a=	-(-X2X1)1/2 θ=Cot-1	(nT)	(nT)	(m)	(m)	(m)	(degree)
IV	-368	489	121	10.5	-9.5					10		20	3º	
V	-426	457	30	10.5	-9.5					10		20	3º	

ΔB(2) and ΔB(1) exist at station length of 125 and 145m respectively along traverse IV while traverse V has values for ΔB(2) and ΔB(1) at station length 175 and 195 respectively. Traverses IV and V has depth to the centre/edge of the fault to be approximately 10m in each case. The general magnetic effect of range 15 to 920 nT above the background along the fault zone indicate mineralisation. In addition, the near equal values obtained along traverse IV and V account for the similar symmetry of the anomalies and are typical of vertical sheet.

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