Integrated Geophysical Investigation of Suspected Structurally Controlled Valleys within the Basement Complex Underlain Federal University Oye-Ekiti, Southwestern Nigeria

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ABSTRACT

Integrated geophysical investigation was carried out across series of parallel valleys within the Federal University Oye-Ekiti, Ekiti State, Southwestern Nigeria with a view to establishing if the features are structurally controlled or are mere geomorphological features. Total field magnetic intensity and 1D Vertical Electrical Sounding (VES) data were acquired along three traverses that were established approximately normal to the strike of the valleys. The magnetic data were corrected for diurnal variation and offset and presented as residual magnetic profiles and map. The residual data were reduced to the magnetic equator (RTE) and series of data enhancement filters such as the Second Vertical Derivative (SVD) and Total Horizontal Derivative (THD) were applied to the data set.

Fifteen Schlumberger VES, whose locations were constrained by the results of the magnetic survey, were occupied. The VES data were presented as VES curves and interpreted quantitatively by partial curve matching and computer assisted 1-D forward modeling using the WinResist software. The VES interpretation results were used to generate geoelectric sections. The magnetic field intensities varied between -10.6 and 111.1 nT with series of low (negative) magnetic peaks, typical of thin and thick dykes, suspected to be geologic structures. These anomalies showed on the residual and RTE maps as isolated and short wavelength signatures whose locations were often displayed away from the valley sites. The general NW-SE anomaly trend was discordant to the strikes of the investigated valleys.

Contact enhancement SVD and THD maps revealed discontinuous and isolated contact locations along segments of some of the valley courses. The 2-D geoelectric sections revealed that the study area is underlain by four (4) geologic layers. These include the topsoil, weathered layer, partly weathered/fractured basement and the fresh basement. The partly weathered/ fractured basement rocks are isolated and localized and most time outside the valley axes. This study therefore concluded that the series of parallel valleys are not structurally controlled but mere geomorphological features.

(Keywords: integrated geophysics, geomorphic valleys, structure control, basement complex terrain)

INTRODUCTION

Faults, lithological contacts/boundaries, network of joints, fractures/fissures and shear zones are structural features in crystalline basement complex rocks that create inhomogenities in the earth upper crust. These features are host for many precious minerals, aquifer for groundwater and sometime inimical to foundation of civil engineering structures. Some valleys are known to be associated with these features because geologic structures sometime control topography, the size, spacing, orientation and shape of hills, ridges, valleys, basins and drainage system (Olorunfemi *et al*., 2001).

Geological and geophysical studies play an important role in the investigation of structural features (Olorunfemi and Okhue, 1992 and Oyeniyi *et al*., 2016). Geophysical investigation involves taking measurements at or near the earth's surface as a means of delineating subsurface features. It involves the study of those parts of the earth hidden from direct view by measuring their physical properties with appropriate instruments usually on or above the surface. It also includes interpretation of the measurements (data) to obtain useful information on the structures and the composition of concealed zones (Kearey *et al*., 2003).

Several geophysical methods have been used successfully either singly or in combination to delineate lithologies, identify structurally controlled valleys in various geologic environments and map some major geological structures (Olorunfemi et al., 1986; Olorunfemi and Okhue, 1992; Okunubi and Olorunfemi, 2016). Oyeniyi *et al*. (2016) used magnetic method to study the structural disposition of the lithologies within Obafemi Awolowo University Campus in Ile-Ife, Southwestern Nigeria while Isife and Obasi (2012) applied Radial Vertical Electrical Sounding around Ifon, Southwestern Nigeria to determine the electrical anisotropy and map the trend of concealed structures.

Within the Federal University Oye–Ekiti (FUOYE) Campus, the present study area, series of parallel valleys have been identified. These geomorphological features have approximately the same orientation which could suggest that their emplacement might be structurally controlled. Structure controlled valleys, in basement complex environment, are prime target for groundwater development due to high storativity and transmissivity capacities arising from secondary porosity. FUOYE, a new generation university, has witnessed increased human population and infrastructural development in recent time leading to inadequate water supply. This study therefore adopted the ground magnetic and electrical resistivity methods of geophysical prospecting to investigate if the valleys are structurally controlled and hence viable targets for groundwater development through borehole drilling.

Description of the Study Area

The Federal University Oye-Ekiti (FUOYE) Campus is located in Oye Local Government Area of Ekiti State (Figure 1a). The University is situated along Oye-Are-Afao Road. It lies between the geographic coordinates of Eastings 754900 and 756500 mE and Nothings 859700 and 860900 mN of Zone 31N (Minna datum) in the Universal Traverse Mercator (UTM) coordinate system. The investigated site is situated within the FUOYE campus and is accessible through an E-W major road (Figure 1b).

The study area is underlain by the Precambrian Basement Complex rocks of Southwestern Nigeria. The major rock type is the migmatite-gneiss complex that is concealed in places by variably thick overburden (Figure 2). The lithologic unit within the study area is granite whose outcrops are found at the northern and southern parts of the study area (Figure 1b). The topography is gently undulating with elevations ranging between 502 m and 547 m. However, some parts are characterized by relatively flat terrain. The prominent geomorphological features include the three (3) valleys being investigated in this study.

The drainage pattern in Oye area is dendritic (Figure 2). The study area enjoys tropical climate with high rainfall of up to 1600 mm and is characterized by two distinct seasons (Ayoade, 1988). These are the rainy season (April-May) and the dry season (November-March). Temperature ranges between 21^{o}C and 28^{o}C. The vegetation of the area is the rain forest type with dense evergreen forest of tall trees with thick vegetation.

MATERIALS AND METHODS OF STUDY

Preliminary investigation involved acquisition of geographical coordinates used for the generation of a base map of the study area. Important features such as the investigated valleys, outcrop locations, buildings, roads and other features were properly geo-referenced on the base map (Figure 1b). This map aided the establishment and cutting of three geophysical traverses (TR 1-3) each 600 m long and at high angle to the strike of the valleys (Figure 3). The magnetic and electrical resistivity methods of prospecting were adopted for the study.

The total field magnetic intensity data were acquired with the Proton Precession Magnetometer (GSM-19T) GEM model along the established traverses at 10 m interval. The observed magnetic data were corrected for diurnal variation and offset. The resulting Residual Magnetic Intensity (RMI) data were presented as profiles and map. Further processing involving the Reduction to the Magnetic Equator (RTE) to remove the asymmetry associated with low latitude magnetic anomalies, was applied to the RMI data using the geomagnetic parameters including Inclination, I = -10.190º, Declination, D = -1.622º and Total Field, F = 33,231 nT at the center of the study area (X = 5.319ºE or 755793 mE; Y = 7.779ºN or 860397 mN), with the aid of the Geosoft package software, Oasis montajTM V.6.4.2. The RTE magnetic data were subsequently subjected to data enhancement techniques including the Total Horizontal Derivative (THD) and Second Vertical Derivative (SVD) for structure identification. The THD was used to estimate contact (fault, fracture, geologic boundaries) locations as peaks of the horizontal gradient (Ndougsa – Mbarga *et al*., 2012). The derivative map enhances shallow features (Telford *et al*., 1990) while the 0 nT/m^2 contour lines of the SVD map delineates edges of geological features (faults, fractures and geological boundaries).

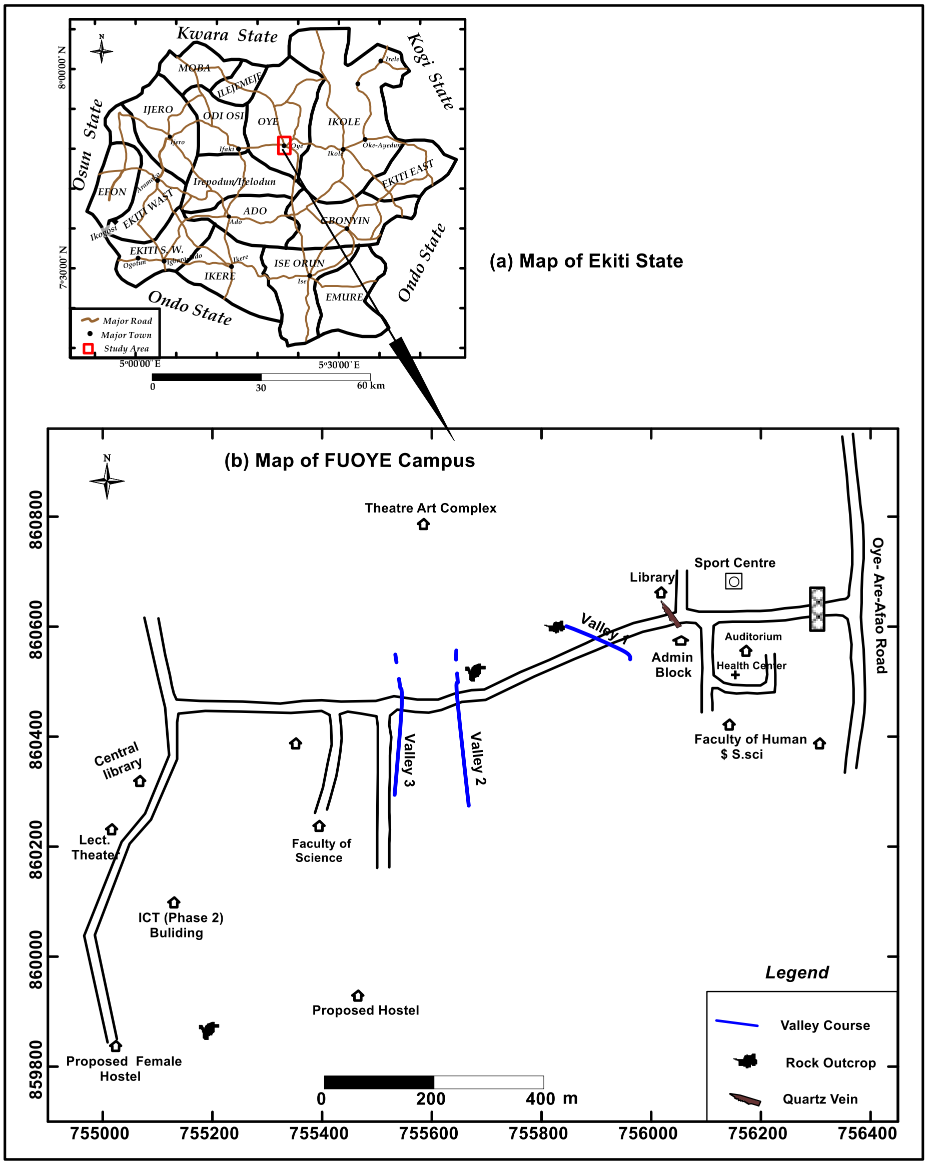


Figure 1: (a) Administrative Map of Ekiti State Showing Oye Local Government Area and (b) Map of FUOYE Campus Showing the Location of the Investigated Valleys.

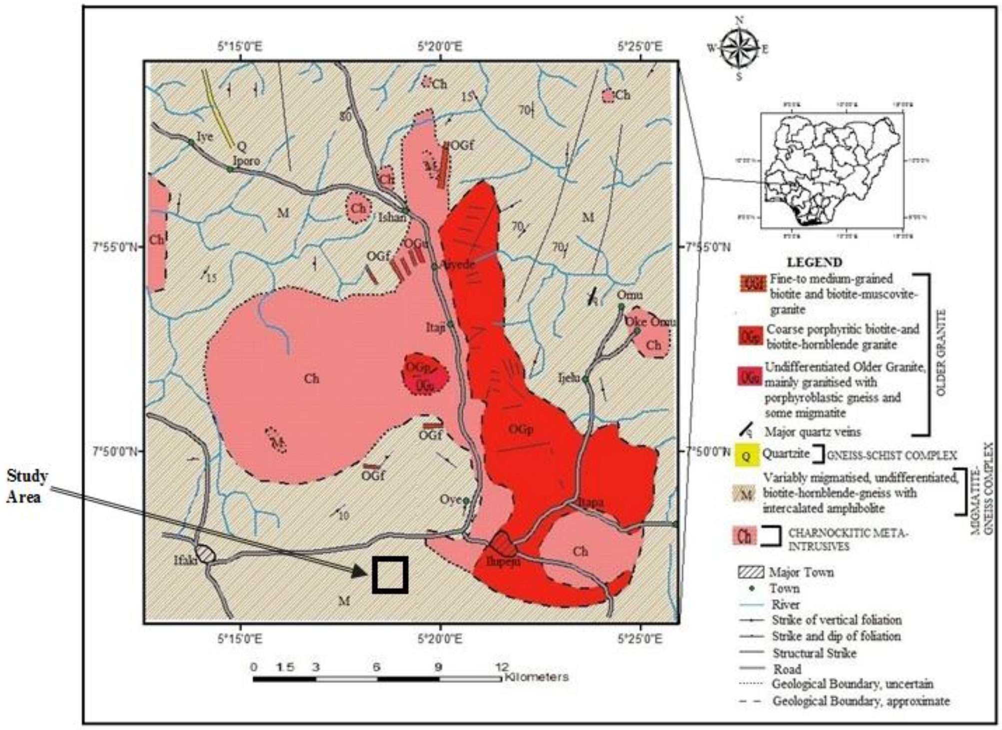


Figure 2: Geological Map of Oye and Its Environs Showing the Study Area.

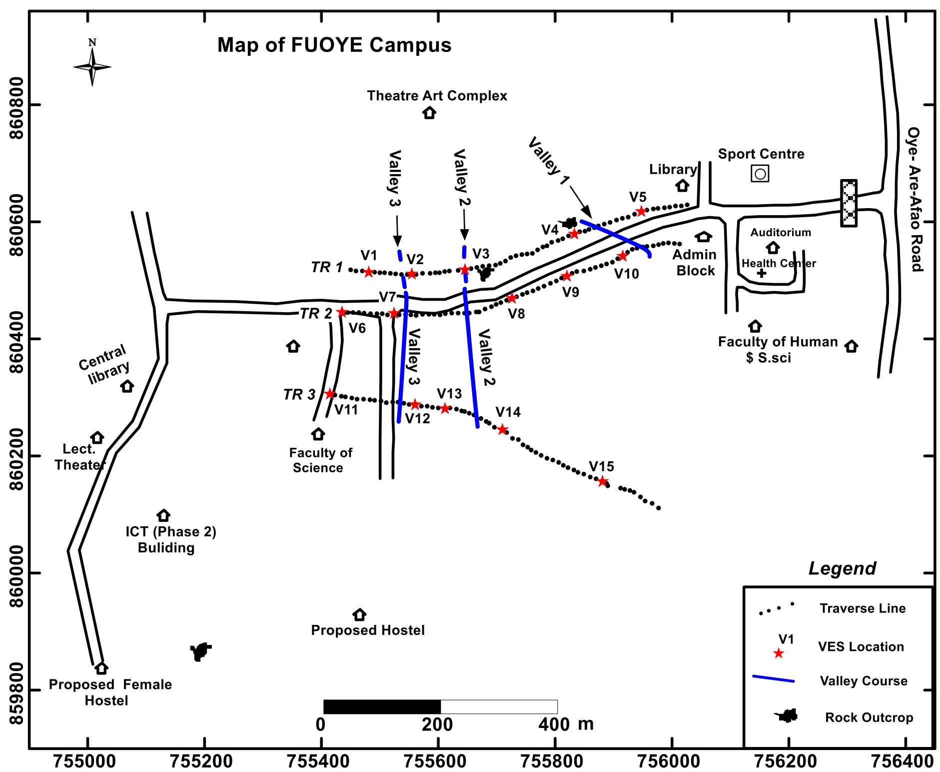


Figure 3: Geophysical Data Acquisition Map of the Study Area Showing the Magnetic Traverse Lines and the VES Locations.

Fifteen (15) VES locations were constrained by the results of the magnetic survey (Figure 3).

The 1D VES utilized the Schlumberger array with half current electrodes spread (AB/2) varying between 1 and 65 m. The VES data were acquired using the ABEM SAS 300C Resistivity Meter and presented as VES curves. The VES curves were interpreted quantitatively by partial curve matching and 1-D computer assisted forward modeling using the WinRESIST version 1.0 software. The VES interpretation results (layer resistivities and thicknesses) were used to generate geoelectric sections. The magnetic profiles and maps and the geoelectric sections were integrated and used to investigate whether the investigated valleys are structurally controlled.

RESULTS AND DISCUSSION

Residual Magnetic Profiles along the Traverses

The magnetic data are presented as profiles of residual magnetic anomaly (Figures 4a-c) along all the traverses. Figure 4a shows the residual magnetic profile along Traverse 1. The anomaly amplitude varies from -9.8 nT to 1.4 nT with series of positive and negative peaks. Three (3) significant low (negative peak) magnetic anomalies, typical of thin and thick dykes, were observed along the profile. These anomalous zones are located between stations 0 – 9, 13 – 27 and 41 – 54 and labeled as F1, F2 and F3 respectively. The magnetic anomalies denoted as F2 and F3 are typical of thick dykes and dip easterly while the one denoted as F1 is typical of a thin dyke, in a low magnetic latitude region like the study area. The identified anomalous zones are suspected to be fractured/faulted or shear basement columns.

Along Traverse 2, Figure 4b presents the residual magnetic anomaly profile. The amplitudes of the magnetic field range between -10.6 and 8.2 nT. Two (2) major anomalous zones were observed. These zones are denoted as F4 and F5. The first anomaly, F4, is an anomaly of a thin dyke located between stations 5 and 13 while the anomaly between stations 14 and 24, labeled as F5, is typical of a thick dyke. Other stations along this profile show limited variations in amplitude that are not significant and hence considered to be relatively magnetically quiet. Observed variations in the residual magnetic field intensities along Traverse 3 (Figure 4c) range from -3.0 to 111.1 nT. Anomalous zones F6 and F7 constitute the major anomalies identified along this traverse and are suspected to be due to buried geologic structures.

Residual Magnetic Intensity (RMI) Map

Figure 5 displays the Residual Magnetic Intensity (RMI) map of the study area. The amplitude of the magnetic field varies from -10.6 to 111.1 nT. The map shows series of magnetic lows (negative peak anomalies) labeled A to E, at the north, south, northwestern and northeastern parts of the study area. These negative peak anomalies are zones of interest in low magnetic latitude region such as the study area and are typical of zone of mineralization and/or location of geological structure (faulted/fractured/shear zones) (Kayode *et al.*, 2010).

The southwestern end of the study area is characterized by relatively high positive magnetic anomaly denoted as F. However, the study area is located within the geographical (UTM) coordinates X (755400 mE and 756000 mE) and Y (860100 mN and 860650 mN) and is characterized by Inclination and Declination values of $I = -10.190^o$ and $D = -1.622^o$ respectively. Magnetic anomalies are asymmetrical and target position distorted due to the non- zero value of the magnetic inclination. To correct for this spatial distribution error and the anomaly asymmetry there is need to reduce the residual magnetic data to what are obtainable at the magnetic equator ($I = 0^o$).

Reduced to the Magnetic Equator (RTE) Map

Figure 6 presents the Reduced to the Magnetic Equator (RTE) map. The anomaly patterns are generally similar to the map presented in Figure 5 with the exception of the northern part of the study area where some of the previously identified anomalous zones (A, B and C) in Figure 5 seem to have disappeared. The magnetic anomalies which trend generally in the northwest-southeastern (NW-SE) direction are discordant with the strike of the prominent Valleys 2 and 3 (Figure 6) that strike approximately north-south (N-S). However the magnetic anomaly in the northeastern part of the study area where Valley 1 is located partly trend in the same direction as the strike of the valley.

The contrasting trends of the magnetic anomalies to the strike of the major Valleys 2 and 3 suggest that the valleys may not have been structurally controlled.

Magnetic Derivative Maps

In order to clearly map the locations and orientations of geologic structures (fault/fracture/shear zones) within the study area, the RTE data were subjected to suite of structure enhancement techniques which include the Second Vertical Derivative (SVD) and the Total Horizontal Derivative (THD).

Figure 7 displays the SVD map of the study area. Overlain on this map are the 0 nT/m²contour lines which give the probable locations of contact (geological structure or lithological boundary) (Oyeniyi *et al*., 2016). The 0 nT/m² contour lines displayed in this map did not show any significant correlation with the strike of the valleys with the exception of the northern segment of Valley 2.

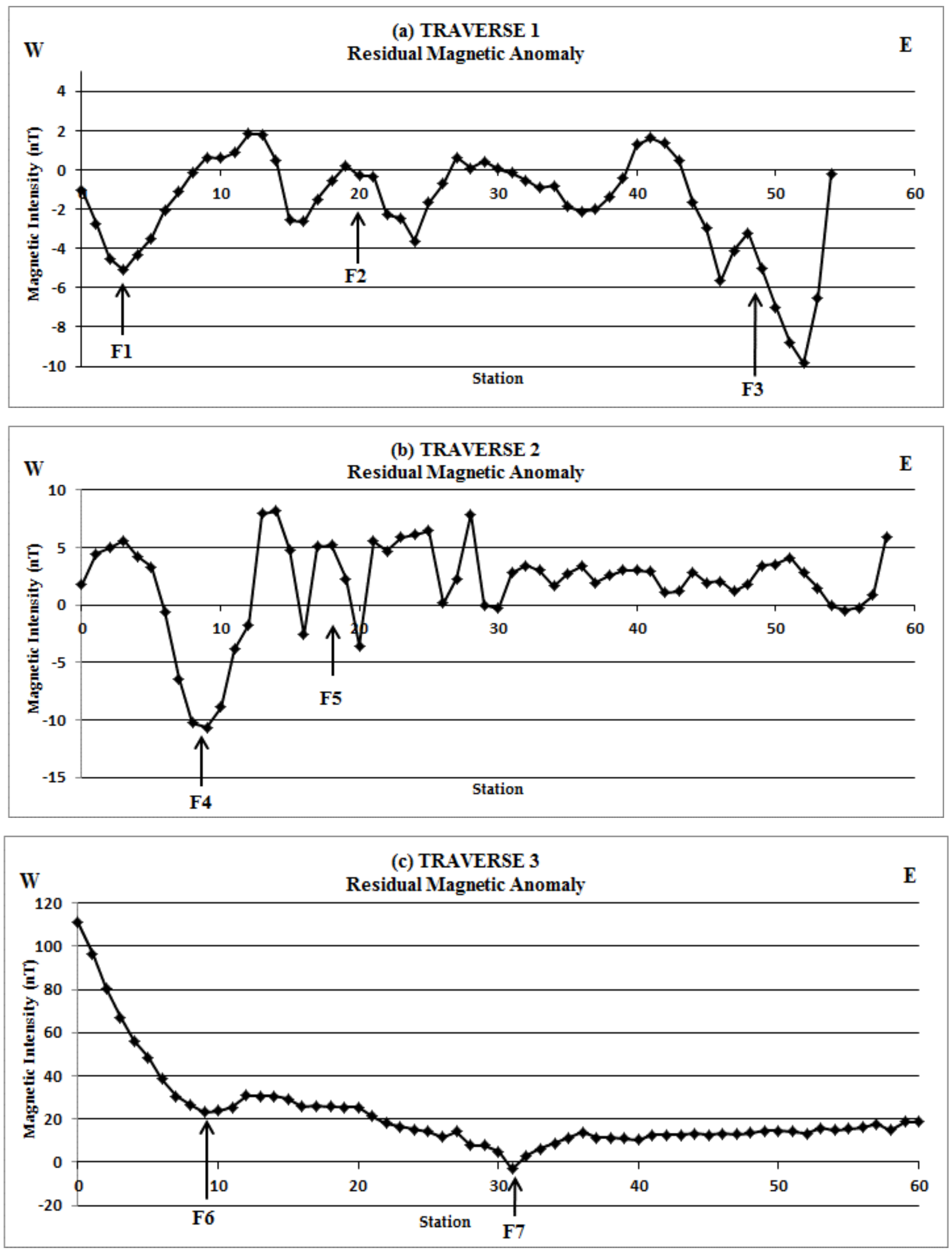


Figure 4: Residual Magnetic Profiles along (a) Traverse 1 (b) Traverse 2 and (c) Traverse 3.

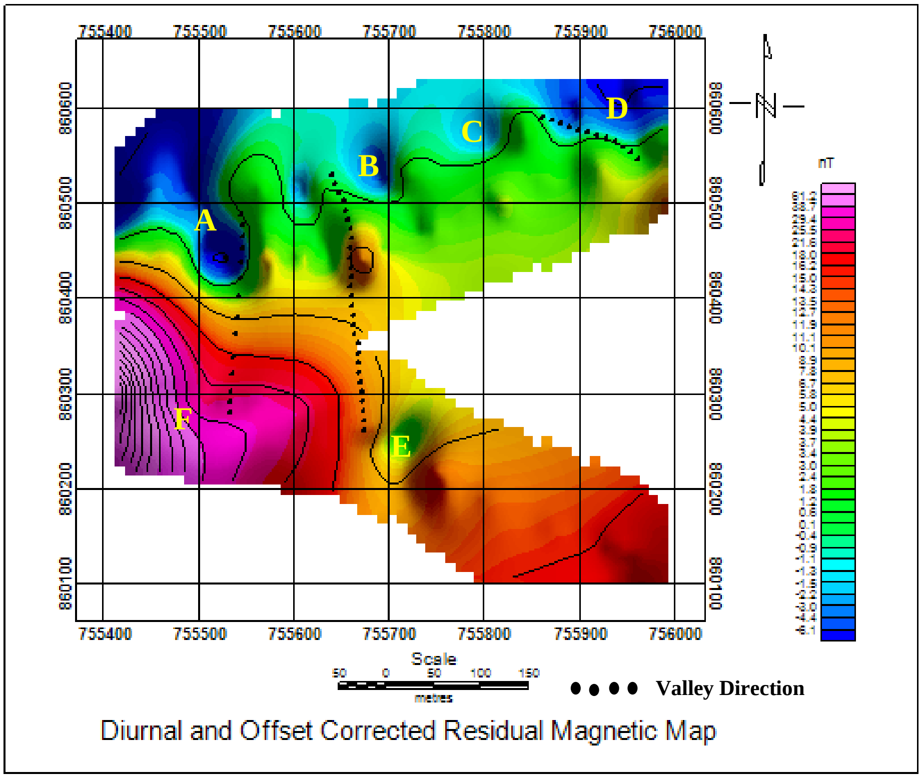


Figure 5: Residual Magnetic Intensity (RMI) Map of the Study Area.

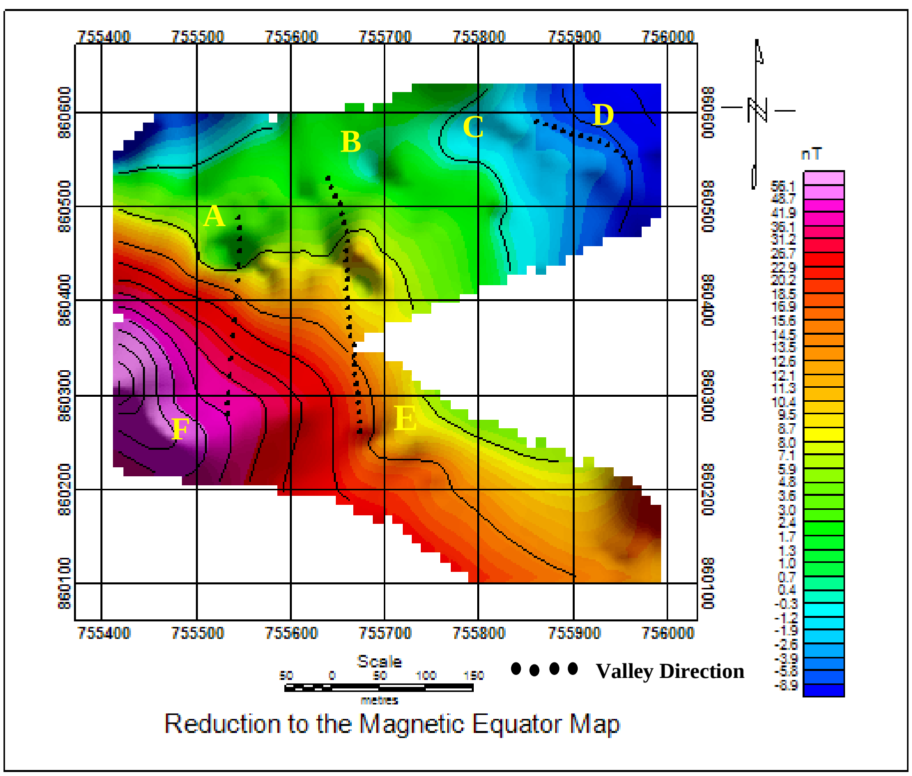


Figure 6: Reduction to the Magnetic Equator (RTE) Map of the Study Area.

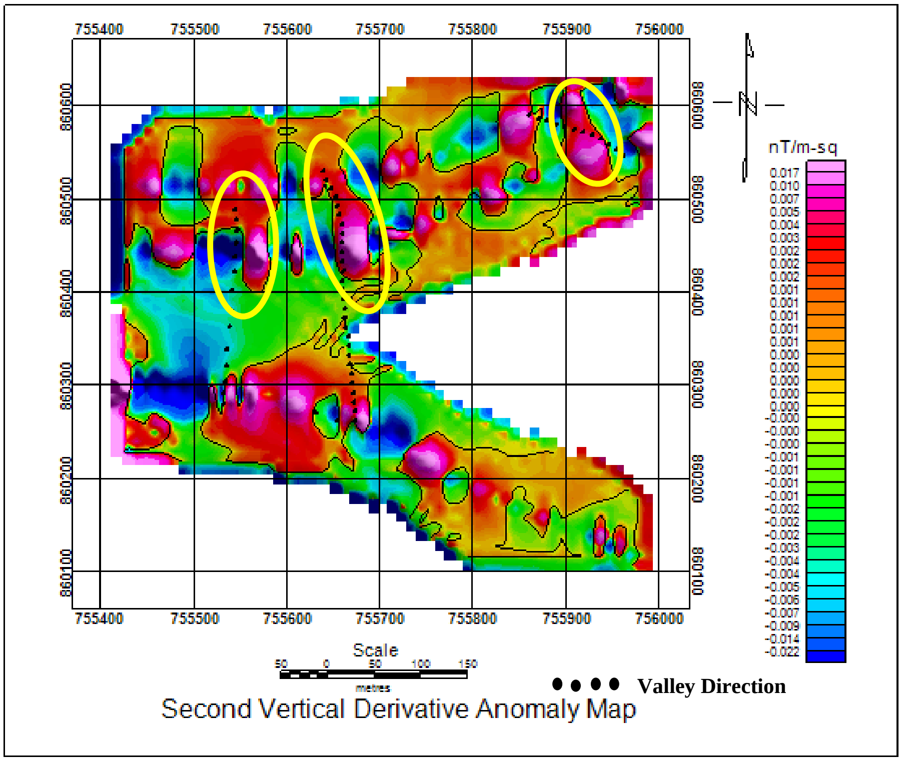


Figure 7: Second Vertical Derivative (SVD) Map of the Study Area.

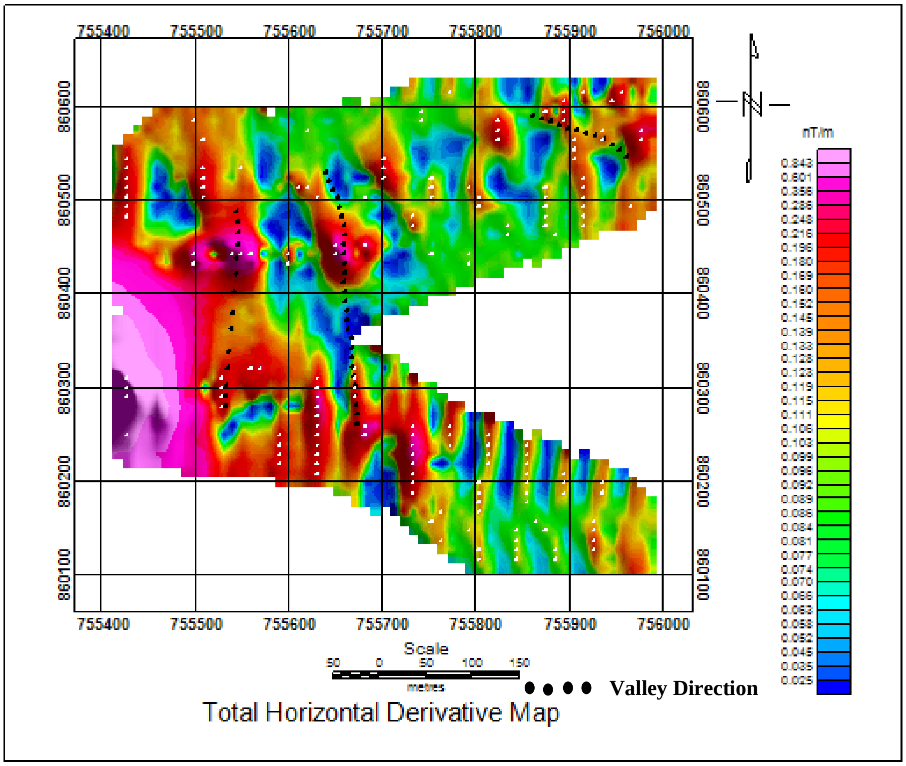


Figure 8: Total Horizontal Derivative (THD) Map of the Study Area.

The THD map is presented in Figure 8. The amplitudes of the gradient vary from 0.025 - 0.843 nT/m. In order to highlight the contact zones on this map, the maxima on the THD map were plotted as white dotted lines. The observed trends of the peak amplitudes are generally discordant with respect to the strike of the investigated valleys except at the lower segment of Valleys 2 and 3. There is generally no correlation amongst the RTE, SVD and THD maps as regards the delineated magnetic structure trends and the strike of the investigated valleys.

ELECTRICAL RESISTIVITY RESULTS

VES Type Curve

Five (5) VES type curves ranging from H, A, KH, HA to HKH (Figures 9a-e) were identified within the study area. The H type curve predominates with 60% of occurrence. The variability of the VES type curves suggests the heterogeneous nature and the complexity of the subsurface sequence underlying the study area. Three geoelectric sections were generated from the VES interpretation results along the traverses.

Geoelectric Section Along Traverse 1

The geoelectric section along Traverse 1 is presented in Figure 10. The section delineated four (4) geoelectric/geologic layers. The first layer is the topsoil with resistivities and thicknesses ranging between 296 and 695 Ωm and 0.6 and 2.3 m respectively. The second layer is the weathered layer with resistivities of between 76 and 289 Ωm and thicknesses between 1.8 and 6.7 m. The third layer is the fractured basement with resistivity values ranging between 270 and 287 Ωm and thicknesses of 10.3 – 20.9 m. The fractured basement is localized beneath VES 2 and 4 along the traverse. The fresh basement bedrock constitutes the last layer with resistivity values of between 801 and 9436 Ωm. The depth to the rock head/the overburden thickness varies from 0.6 – 7.2 m. The bedrock topography is gently undulating.

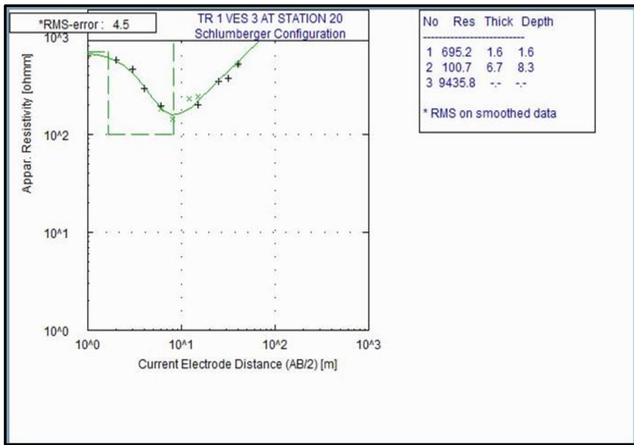
As indicated on this section, Valley 1 is the only valley whose physical expression was observed along this traverse. The locations of Valleys 2 and 3 were inferred. Observation from this section shows that no geological feature (fault/fracture) was visible beneath Valley 2 while the fractured basement column delineated close to the other Valley 1 and Valley 3 could be suspected structures beneath these valleys.

Geoelectric Section Along Traverse 2

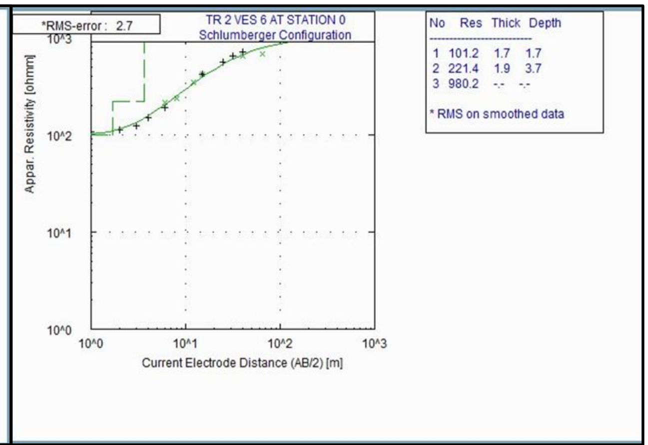
The geoelectric section along Traverse 2 (Figure 11) delineated four (4) geologic layers. The first layer is the topsoil with resistivities and thicknesses ranging between 101 and 353 Ωm and 1.7 and 1.9 m respectively. The second layer is the weathered layer with resistivities of between 90 and 221 Ωm and thicknesses of 1.9 and 10.4 m. The third layer is the partly weathered/fractured basement with resistivity value of 157 Ωm and thickness of 15 m. This layer is localized beneath VES 7. The fresh basement constitutes the bedrock with resistivity values of between 980 Ωm and infinity. The depth to the rock head varies from 3.7 – 12.3 m. The section shows a gently undulating bedrock topography. It also shows that a fractured basement was delineated beneath VES 7 close to Valley 3 while Valleys 2 and 3 are devoid of subsurface fractured basement.

Geoelectric Section Along Traverse 3

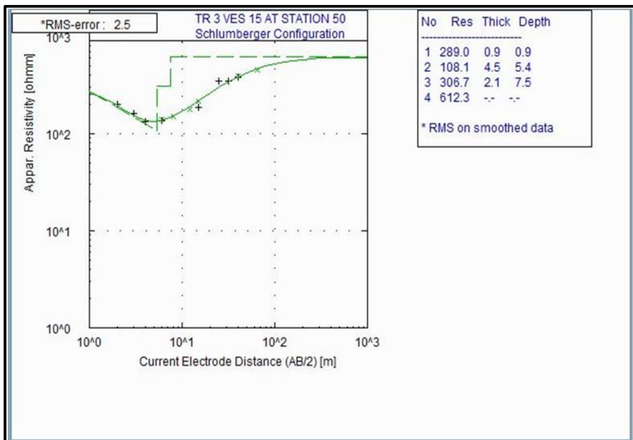
The geoelectric section along Traverse 3 is presented in Figure 12. The section delineated four (4) geoelectric layers beneath this traverse. The first layer is the topsoil with resistivities and thicknesses ranging between 113 and 438 Ωm and 0.5 and 0.9 m respectively. The second layer is the weathered layer with resistivities of 22 to 108 Ωm and thicknesses ranging between 2.7 and 7.7 m. The third layer is a partly weathered/fractured basement with resistivity and thickness values ranging from 213 - 307 Ωm and 2.1-14.8 m, respectively. The partly weathered/fractured basement is localized beneath VES 11 and 15 along this traverse. The fresh basement constitutes the last layer with resistivity values of 612 Ωm to infinity. The depth to the rock head/or overburden thickness varies from 2.1 – 7.7 m. The section also shows a gently undulating bedrock topography. No fractured basement column was delineated beneath/ or close to any of the identified and inferred valleys.



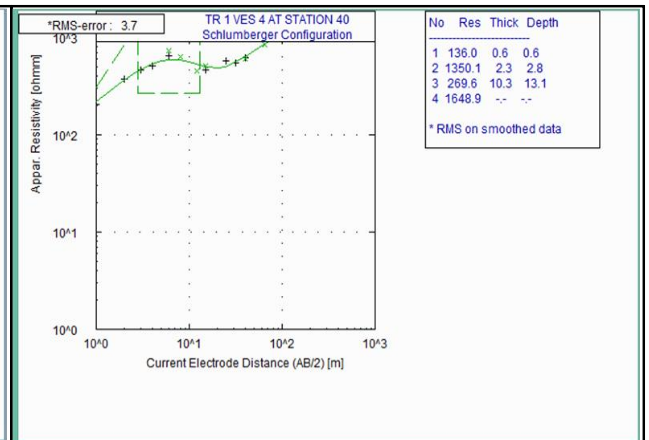
(a) H Type Curve



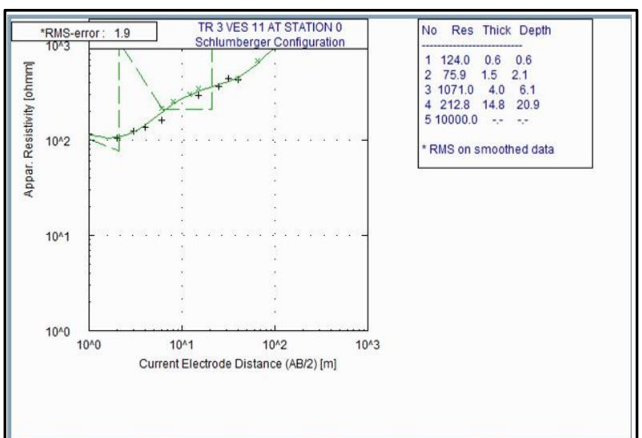
(b) AType Curve



(c) HA Type Curve



(d) KH Type Curve



(e) HKH Type Curve

Figure 9 (a - e): Typical VES Type Curves Identified within the Study Area.

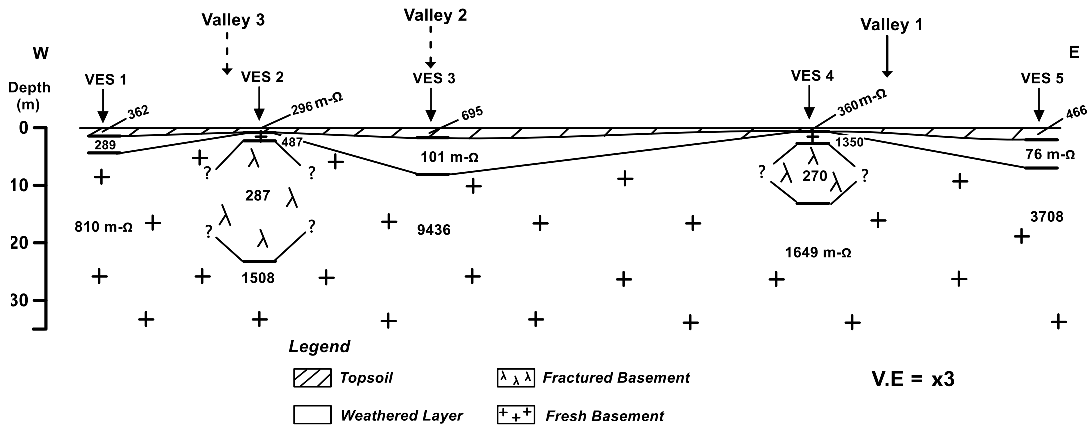


Figure 10: Geoelectric Section beneath Traverse 1.

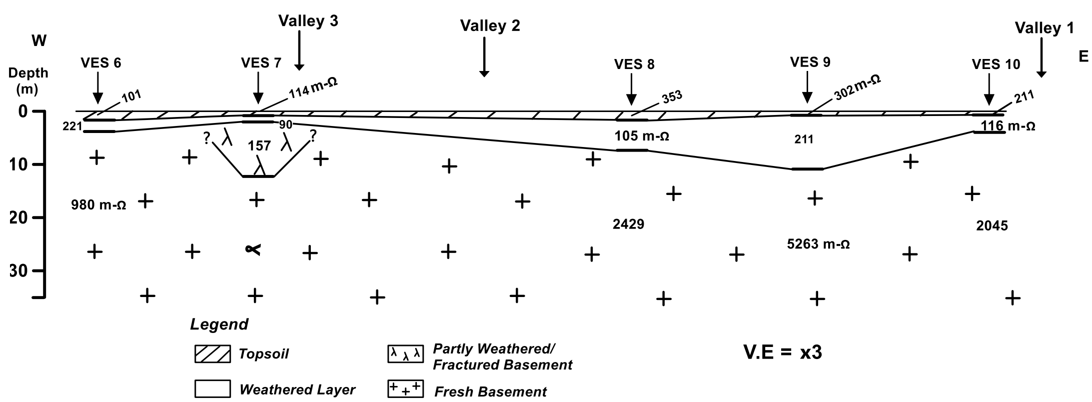


Figure 11: Geoelectric Section beneath Traverse 2.

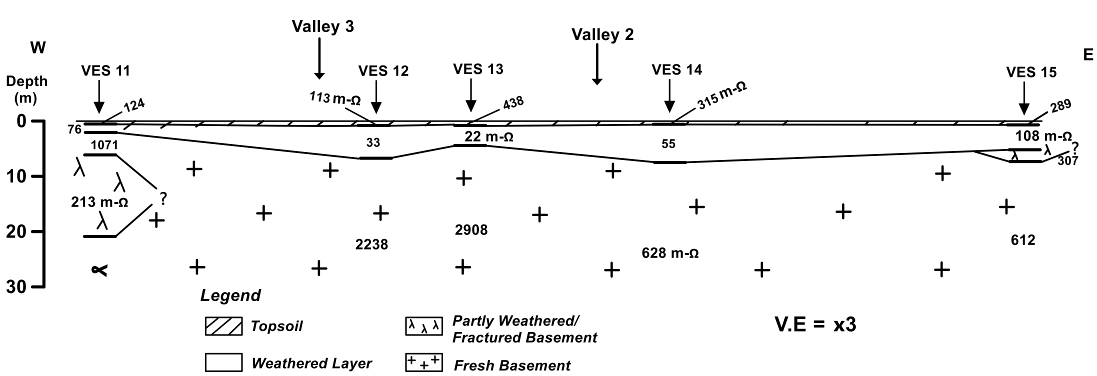


Figure 12: Geoelectric Section beneath Traverse 3.

SYNTHESIS AND CONCLUSION

The magnetic profiles within the study area showed characteristic anomalies typical of thin and thick dykes that are suspected faulted/fractured, sheared basement zones and lithologic boundaries. These anomalous zones are predominant along Traverses 1 and 2 at the northern and central part of the study area. The various magnetic anomaly maps showed that the identified anomalous zones are generally isolated with anomaly trends that are generally discordant with respect to the strike directions of the investigated valleys.

At shallow depths where fractured basement columns were identified, their locations except at few instances were not in line with the axes of the valleys. The geoelectric sections generated from the VES interpretation results showed that the study area is underlain by four (4) geologic layers namely the topsoil; weathered layer; partly weathered/fractured basement (at isolated locations) and the fresh basement. The depth to the rock head is relatively thin ranging from 0.6 to 12.3 m.

It can therefore be concluded from the results of the integrated geophysical investigation that the series of parallel valleys within the study area are not structurally controlled but mere geomorphological features

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