INTEGRATED GEOPHYSICAL INVESTIGATION OF REMOTELY SENSED SUSPECTED FAULT ZONES AROUND IWARAJA-IJEBU IJESA AREA OF OSUN STATE, NIGERIA.

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ABSTRACT

Magnetic profiling, electrical resistivity 2-D Dipole Dipole imaging and 1-D Vertical Electrical Sounding (VES) were carried out over two suspected remotely sensed delineated mega lineaments in the area around Iwaraja – Ijebu Ijesa in Osun State, Southwest Nigeria. This was with a view to establishing the existence of the mega structures. Total field magnetic and electrical resistivity measurements were carried out along geophysical traverses established across the suspected fault zones. The magnetic measurements, carried out at 10 m interval, were corrected for diurnal variation and offset. The 2-D magnetic models generated along the traverses, delineated uneven magnetic basement relief with overburden thicknesses varying from 3.0 to 90.0 m and suspected steeply dipping magnetic dykes (suspected fault zones) with widths varying between 60 and 200 m. Inverted 2-D Dipole Dipole images and geoelectric sections along the geophysical traverses delineated five geologic layers comprising the topsoil, laterite, weathered layer, weathered/fractured basement and fresh basement. The 2-D Dipole Dipole images identified major low resistivity near vertical discontinuities typical of fault zones that correlated with the magnetic anomalous zones. The widths of the anomalous zones varied between 60 and < 200 m. The study concluded that the suspected mega lineaments are fault zones which were displaced slightly north of the present locations.

Keywords: Geophysical Traverses, Magnetic Profiling, Electrical Resistivity, Suspected Fault Zones

INTRODUCTION

The understanding of subsurface sequence and the structural setting of an area is important in the siting of infrastructures such as highways, schools, industrial buildings, hospitals, residential houses, and rail roads. Siting of infrastructures on geological structures make them prone to high structural damages. Although serious geotechnical problems are generated by fault zones, nevertheless faulted rock strata commonly form reservoir for the accumulation of groundwater, hydrothermal fluid and also for base and precious metal ore deposits. Faults exert important impact on regional system of fluid flow (Emst and De Ridder, 1960, England *et al.*, 1987, Knipe, 1997, Stuurman and Atari, 1997). Geological methods for mapping structures include aerial photograph interpretation, field mapping and borehole logging on both the down- and up-thrown sides of the fault. Geological mapping for structures is limited by vegetation coverage and anthropogenic activities while borehole logging is capital intensive and gives only vertical information at a location. Most geophysical methods on the other hand are relatively cheaper, quicker and give both vertical and horizontal information of the subsurface.

Different geophysical methods such as Resistivity, Magnetic, Gravity, Ground Penetrating Radar (GPR), Electromagnetic and Seismic methods are used for mapping geologic structures (Ganerød *et al.*, 2006). Geophysical measurements have been used by several workers to map the subsurface to elucidate spatial distribution of rock units as well as the underlying structures such as faults, folds and intrusive rocks. Oluwafemi and Oladunjoye (2013) mapped basement topography and overburden structure using Resistivity and Electromagnetic methods in a typical basement complex terrain in southwestern Nigeria while Adelusi *et al.* (2009), Bayode and Akpoarede (2011) and Ojo *et al.* (2011) mapped fractured zones in crystalline basement rocks using the Resistivity, Very Low Frequency Electromagnetic (VLF-EM) and Magnetic methods.

Remote Sensing (RS) data such as satellite imagery can also be processed and interpreted for lineaments. Such lineaments which may include faults, fractured and shear zones could be relevant in hydrogeology and mineral exploration. However, certain features other than geologic structures may also appear as lineaments on lineament maps generated from remote sensing data, hence it is necessary to verify lineaments of interest using other method(s). Also, RS delineated lineaments suffer spatial distortion which can be corrected through ground truthing with geophysical surveys.

The interpretation of remotely sensed data of the area around Iwaraja – Ijebu Ijesa in Osun State Southwestern Nigeria delineated two mega lineaments A and B suspected to be regional faults (Fig. 1). This study investigates the existence of the suspected fault zones using integrated magnetic and electrical geophysical methods.

Description of the Project Environment

Geographic Location, Relief, Drainage and Climate

The study area cuts across Ilesa and Oriade Local Government Area of Osun State (Fig. 1b). It covers an areal extent of 26.3 km^2. The area covers Ilo-Aiyegunle, Ilo-Ile, Iloko-Ijesa and Iwaraja and is bounded by Latitudes $7^\circ 37' 28''$ and $7^\circ 40' 18''$ N and Longitudes $4^\circ 46' 42''$ and $4^\circ 49' 37''$ E (Fig. 1c). The topography of the study area is gently undulating with an elevation ranging between 358 and 420 m above sea level (a. s. l.). On the western part of the study area is a NNE-SSW flat topped ridge whose altitude is over 550 m.

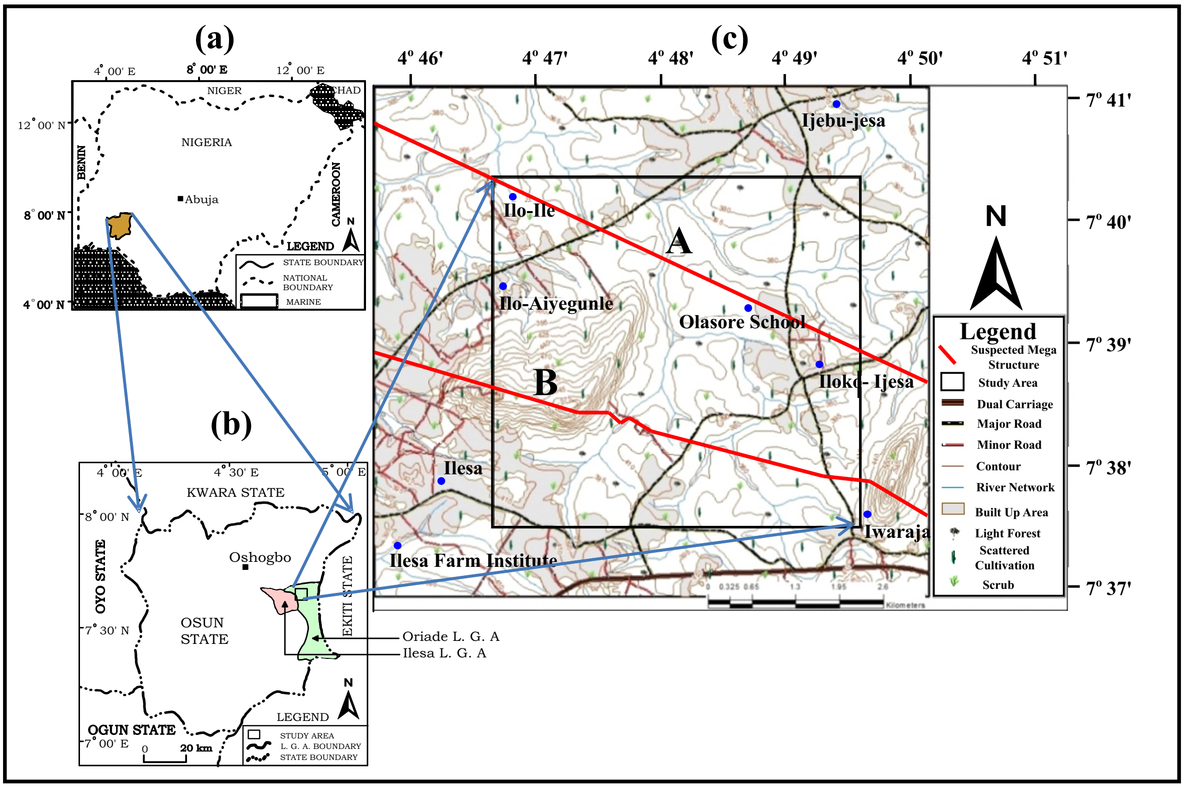

Figure 1: Topographical Map of the Study Area (Generated Using ArcGIS)

There are also low laying outcrops within the study area. The study area is drained by many seasonal streams flowing in the N-S direction. The drainage pattern is dendritic. The study area lies within the tropical climatic region marked by alternating wet and dry seasons. Temperature is moderately high during the day and also varies from season to season. The average daily temperature varies between about 20°C (for a very cold day) and about 35°C (for a very hot day).

Geological Setting of the Study Area

The study area is located within the Basement Complex of Southwestern Nigeria. It is underlain entirely by the rocks of the Ilesha Schist Belt composed of quartz schist, quartzite and amphibolite schist (Fig. 2c). A hilly outcrop of quartz schist which is over 550 m high is emplaced on the western flank of the study area while many low-lying outcrops are also found within the study area. The topsoil within the study area is heavily lateralized.

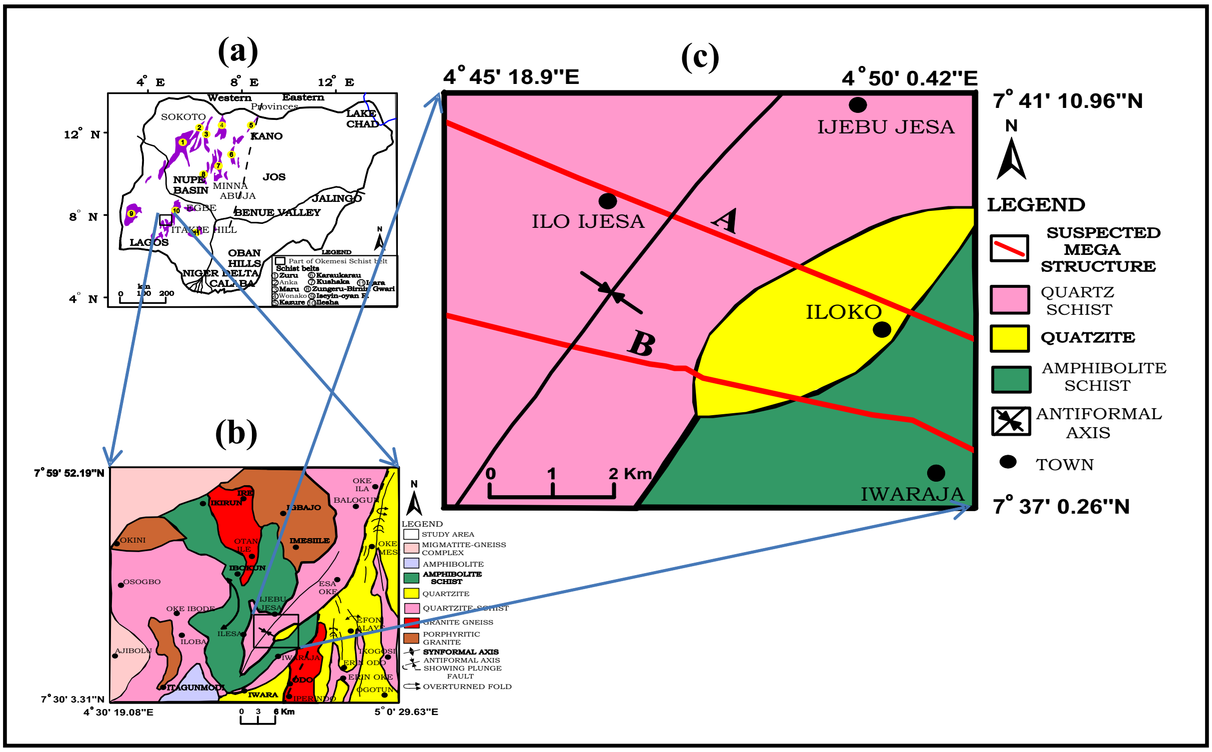

Figure 2: (a) Schist Belt localities within Nigeria (Woakes *et al.*, 1987); (b) Geological Map of Area Around Ilesha (Adapted from Odeyemi, 1993); (c) Geological Map of the Study Area (Adapted from Odeyemi, 1993)

The lineament map (Fig. 3) of the study area revealed N-S, NNE-SSW, NE-SW, NEE-SWW and E-W trending lineaments including the two mega lineaments A and B trending approximately WNW-ESE.

MATERIALS AND METHODS

Magnetic Method

Total field magnetic measurements, with Proton Precession Magnetometer (GSM-9) GEM Model, were carried out along four geophysical traverses varying in length between 1 and 4.55 km, trending approximately N-S, NNE-SSW and NE-SW and established near-orthogonal to the suspected mega structures (Fig. 4). The measurements were carried out progressively at 10 m interval facing northward with the magnetometer's sensor oriented approximately S-N, along all the traverses. Magnetic measurements were also carried out at corresponding base-stations. The raw field data were corrected for diurnal variation and offset by subtracting the base station reading from the traverse station reading at synchronized time. The resulting residual total field data were subjected to three points running average filtering to eliminate spikes. The filtered residual total field data were presented as profiles. The magnetic profiles were interpreted both qualitatively and semi-quantitatively using visual inspection and Oasis Montaj Software respectively.

Electrical Resistivity Method

The resistivity survey involved 2-D imaging with the Dipole-Dipole array and 1-D Vertical Electrical Sounding (VES) with the Schlumberger array. The Dipole Dipole data were acquired along three profiles established along two geophysical traverses (TR 1b) (and TR 2a & b) (Fig. 4).The Dipole Dipole profiles whose locations were constrained by the magnetic profiles were 500, 600 and 600 m long.

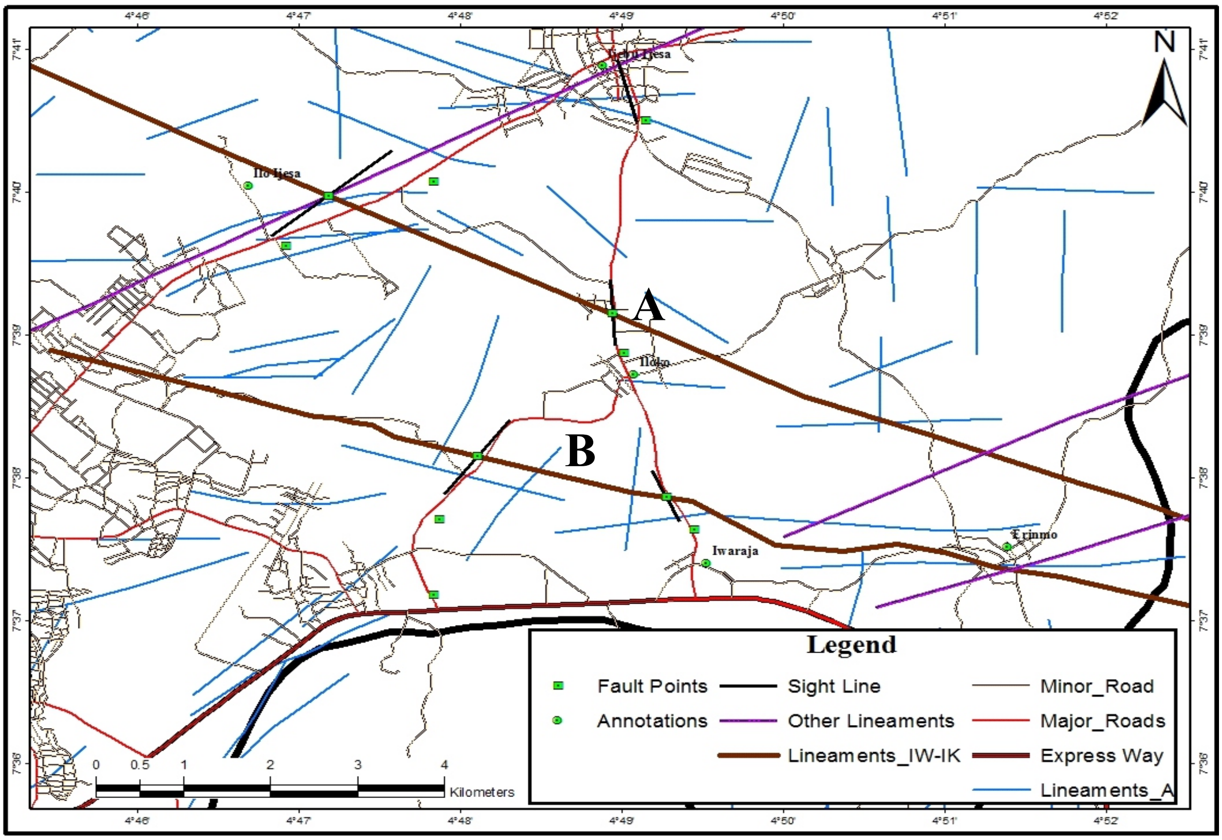

Figure 3: Lineament Map of the Study Area (Generated Using ArcGIS)

A dipole length of 20 m was adopted while the inter dipole expansion factor, n, was varied from 1 – 5. The profiling data were presented as pseudo sections and quantitatively interpreted by 2-D inversion using the DIPRO for Windows (2001) Software. The number of layers obtained from the VES data interpretation was used to constrain the 2-D inversion.

Fifteen (15) VES stations were occupied with the Schlumberger array along traverses TR 1b, 2a and 2b (Fig. 4) at locations constrained by the Dipole Dipole images. Five VES stations, one separated from another by a distance varying between 60 and 120 m were established along each of traverses TR 1b, 2a and 2b. The half current electrode spacing (AB/2) was varied from 1 to a maximum of 225 m. The VES data were presented as sounding curves. The VES curves were quantitatively interpreted using partial curve matching and computer assisted 1-D forward modeling with the WinRESIST software (Vander Velper, 2004) technique. The resulting interpretation results (layer resistivities and thicknesses) were used to generate geoelectric sections. Figure 5 shows the typical VES type curves and the interpretation models. The PASI Digital Resistivity Meter was used for the resistivity data acquisition while the Global Positioning System (GPS) GARMIN 12 model type was used to geo-reference the Dipole Dipole and VES stations.

RESULTS AND DISCUSSION

The magnetic profile, 2-D magnetic model, 2-D resistivity structure and 2-D geoelectric section along traverse TR 1b are presented on Figure 6. The magnetic profile (Fig. 6a) shows a minor anomaly between distance 230 and 360 m probably due to topographic variation of the magnetic basement and a major anomaly (over 100 m wide) between distance 390 and 550 m which is characterized by double peak negative (–176

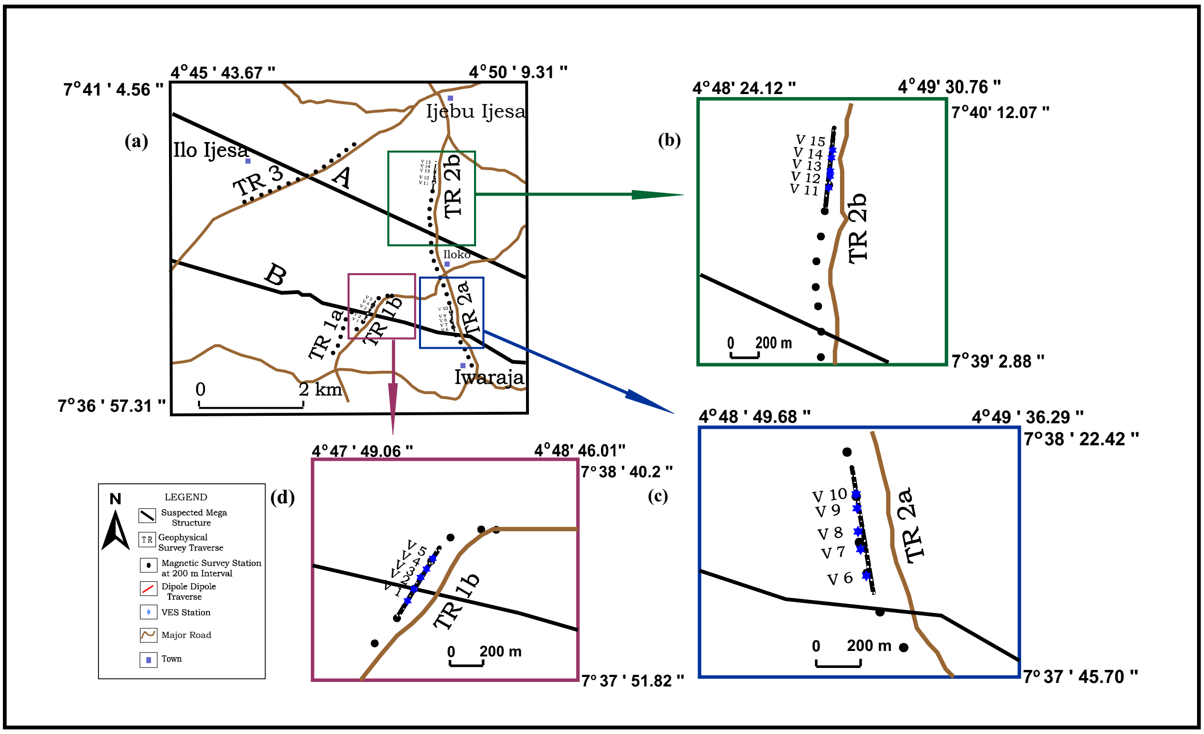

Figure 4: Geophysical Data Acquisition Map

and – 143 nT) amplitudes. The major anomaly is indicative of a thick dyke in low magnetic latitude. Figure 6b displays the subsurface 2-D magnetic interpretation model generated from the magnetic profile. The model shows susceptibility and depth to the top of the magnetic basement varying from – 0.059 to 0.024 cgs (indicating relatively high degree of mineralization) and < 1 m to about 50 m respectively. The major magnetic anomaly was interpreted as a thick dyke suspected to be a fault/shear/fractured zone. The depth to the top of the steeply dipping thick dyke ranges from about 30 – 45 m.

The 2-D resistivity structure (Fig. 6c) imaged the subsurface stratigraphic sequence beneath traverse TR 1b. The structure identifies three geologic layers composing the topsoil, weathered layer and fractured/fresh basement. The topsoil may have merged with the underlying lateritic/weathered layer because of its small thickness (< 1.0 m) and overlapping resistivity values. The colour code (green/yellow/brown) of this layer presents layer resistivity values varying from 215 to 1566 Ωm. The weathered layer with green/blue colour code underlies the topsoil. The resistivity and thickness values for the weathered layer vary between 67 and 573 Ωm and 10 and about 40 m respectively. The fractured/fresh basement (with yellow/brownish red/purple colour code) displays resistivity values of between 707 and 4993 Ωm. Within the high resistivity basement bedrock, there exists a relatively low resistivity (518 – 697 Ωm) near – vertical discontinuity suspected to be fractured/fault zone. The ground surface manifestation of the steeply dipping structure with center at around distance 480 m (Fig. 6c) correlates significantly with the center of the thick dyke interpretation model (Fig. 6b).

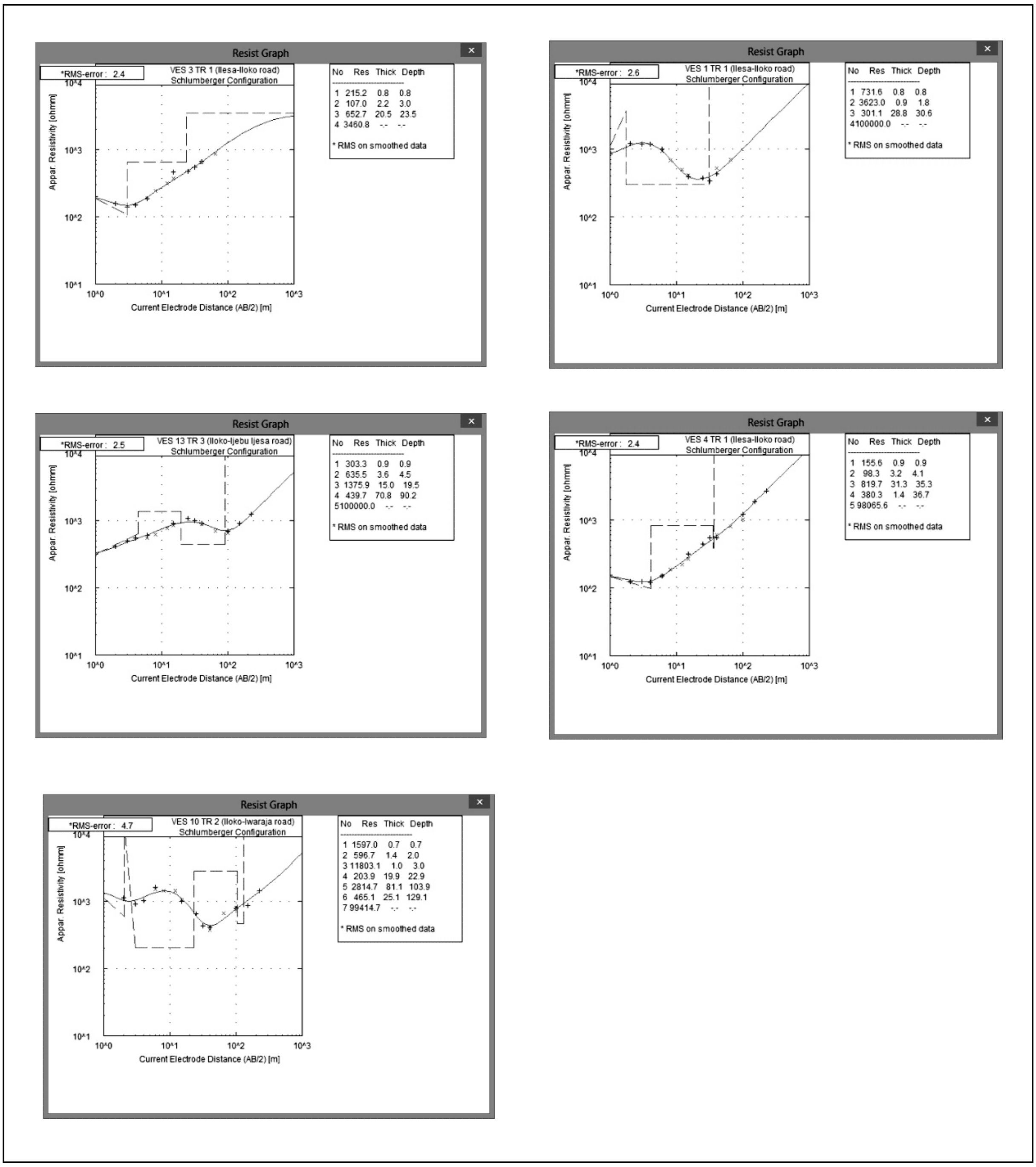

Figure 5: Typical Resistivity Sounding Type Curves and Interpretation Models

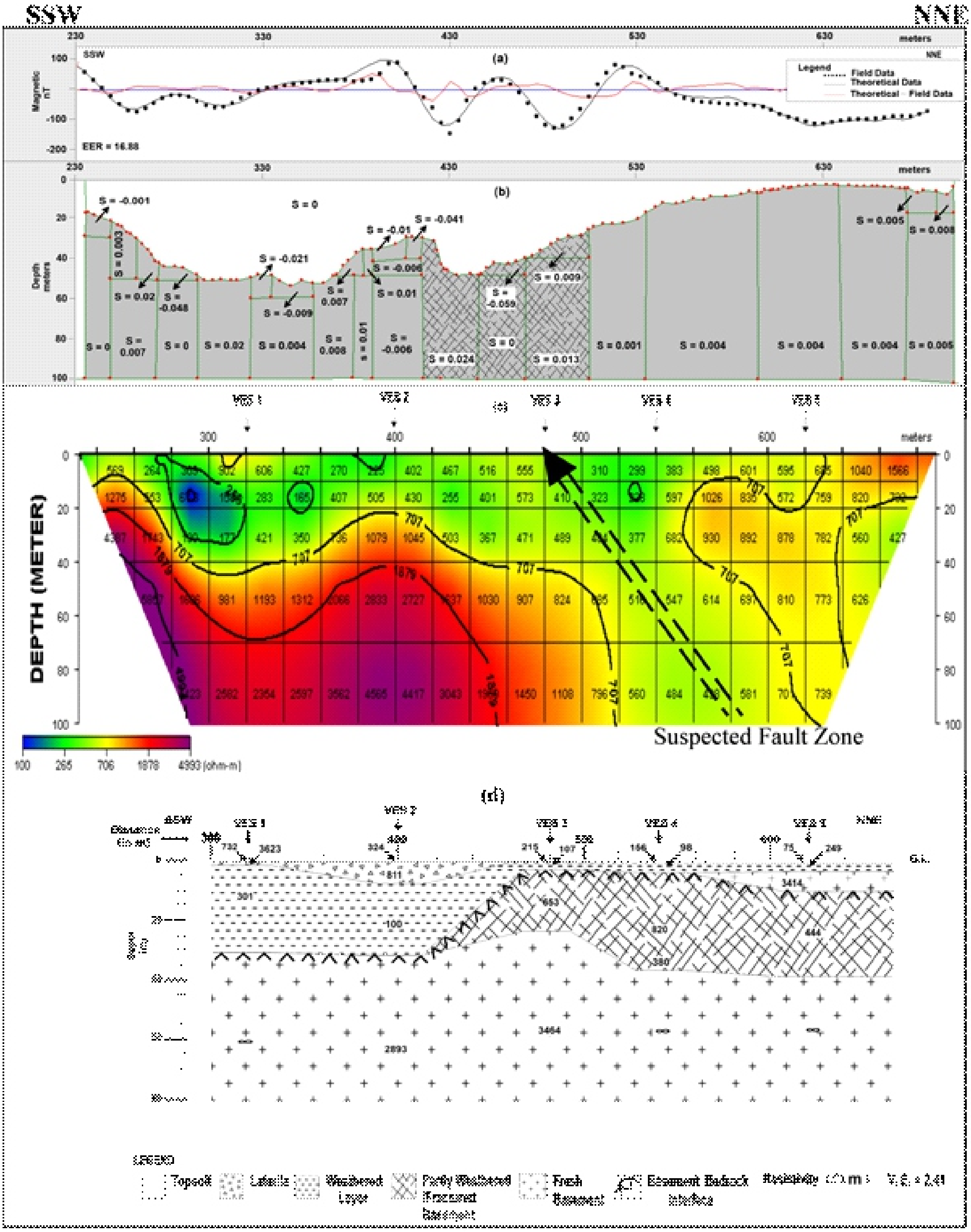

Figure 6: Correlation of (a) Magnetic Profile (b) Magnetic Model (c) 2-D Resistivity Structure and (d) 2-D Geoelectric Section along Traverse TR 1

The 2-D geoelectric section (Fig. 6d) relating VES 1-5 imaged the geological layers beneath traverse TR 1b. The subsurface layers comprise the topsoil, lateritic layer, weathered layer, partly weathered/fractured basement and the fresh basement. The topsoil is composed of clay, sandy clay, clayey sand and sand and has resistivity and thickness values of 75 to 732 Ωm and 0.5 to 1.0 m respectively. The lateritic layer underlying the topsoil at some places ranges in resistivity from 811 to 3623 Ωm and thickness from 0.9 to 7.4 m. The weathered layer underlies the lateritic layer/topsoil. The resistivity and thickness values range from 98 to 301 Ωm and 2.2 to 28.8 m respectively. The partly weathered/fractured basement underlies the weathered layer beneath VES 3 – 5 has resistivity values of between 380 and 820 Ωm and thickness of between 20.5 and 32.7 m. The resistivity values of the underlying fresh basement rock range between 2893 and ∞ Ωm. Partly weathered/fractured basement was delineated within the magnetic/2-D resistivity structure delineated suspected fault/shear zone.

Figure 7 presents the magnetic profile, 2-D magnetic model, 2-D resistivity structure and 2-D geoelectric section along traverse TR 2a. The magnetic profile (Fig. 7a) with amplitude ranging from – 740 to 297 nT displays a single anomaly between distance 1230 and 1460 m. The W-shaped anomaly, typical of a thick dyke, is about 200 m wide. The2-D model (Fig. 7b) generated from the magnetic profile displays an uneven magnetic basement relief with susceptibility of – 0.019 to 0.013 cgs and depth to the top of the magnetic basement of < 5.0 m to about 30 m. The modeled thick dyke has a depth to top that varies from 20 – 30 m and a center at around distance 1335 m.

The 2-D resistivity structure (Fig. 7c) identifies the topsoil, weathered layer, fractured basement and fresh basement. The topsoil (in blue/green/yellow and red colour band) has resistivity values of 95 to 1120 Ωm. Due to small thicknesses (generally < 1 m) and overlapping resistivity values, the topsoil merges with the weathered layer in places. The weathered layer, in blue/green colour band, underlies the topsoil. The resistivity values range from 154 to 650 Ωm and thicknesses of < 1.0 to 10 m. The basement bedrock (in yellow/reddish brown/purple colour) has resistivity values ranging from 766 to 4993 Ωm. The resistivity structure identifies, between distance 1320 and 1400 m, a low resistivity (497 to 902 Ωm) near vertical discontinuities suspected to be a fractured/fault zone within the high resistivity basement bedrock. The ground surface manifestation of this structure occurs at about distance 1360 m which coincides with the center of the interpreted magnetic dyke (Fig. 7b).

The 2-D geoelectric section (Fig. 7d) along traverse TR 2a relates VES 6 - 10. The 2-D geoelectric section delineates four subsurface geologic layers which include the topsoil, weathered layer, partly weathered/fractured basement and the fresh basement. The topsoil consists of sandy clay, clayey sand and sand with layer resistivity and thickness values varying from 160 to 1597 Ωm and 0.6 to 1.0 m respectively. The weathered layer which is composed of clay, sandy clay and laterite underlies the topsoil directly with resistivity and thickness values of 74 to 597 Ωm and 1.4 to 9.2 m respectively. The partly weathered/fractured basement is localized beneath VES 6 and 10 with resistivity values varying from 465 to 600 Ωm. The fresh basement resistivity values vary between 907 and ∞ Ωm.

The magnetic profile, 2-D magnetic model, 2-D resistivity structure and 2-D geoelectric section along traverse TR 2b are presented on Figure 8. The magnetic profile shows amplitude varying from – 205 to 47 nT. Only one magnetic anomaly was identified along this profile. The single negative peak (with maximum amplitude of – 205 nT), large wavelength (low frequency) anomaly occurs between distance 4380 and 4540 m with its center at 4460 m. This anomaly is suspected to be due to a geologic structure (faulted basement). The symmetry of the anomaly depicts a vertically or steeply dipping causative body.

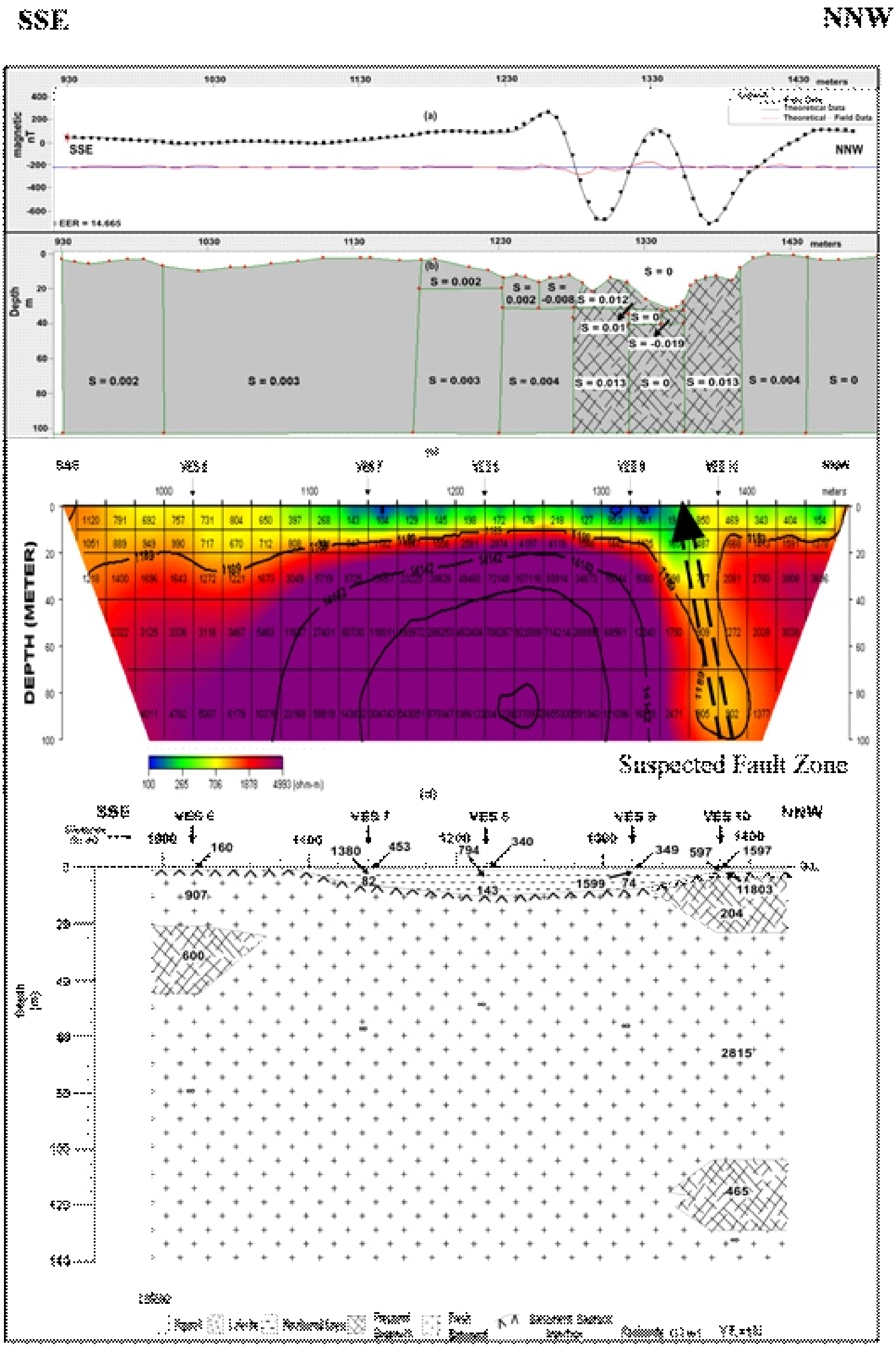

Figure 7: Correlation of (a) Magnetic Profile (b) Magnetic Model (c) 2-D Resistivity Structure and (d) 2-D Geoelectric Section along Traverse TR 2a

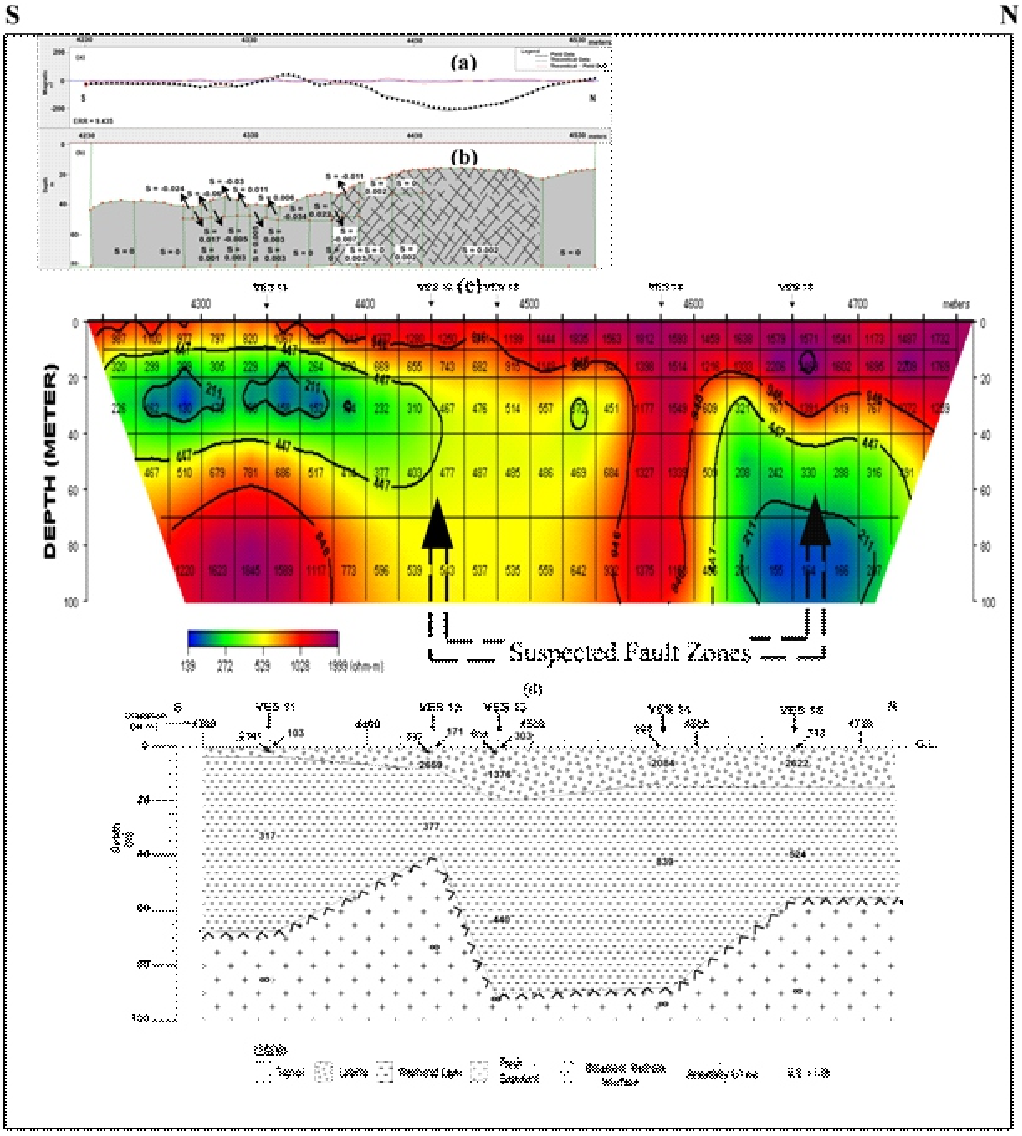

Figure 8: Correlation of (a) Magnetic Profile (b) Magnetic Model (c) 2-D Resistivity Structure and (d) 2-D Geoelectric Section along Traverse TR 2b

The magnetic anomaly was modeled as a thick dyke (Fig. 8b). The depth to the magnetic basement ranges from 20 – 40 m with susceptibility values ranging from – 0.06 to 0.022 cgs.

The 2-D resistivity structure (Fig. 8c) beneath traverse TR 2b delineates a sequence comprising topsoil/lateritic layer (in brownish and red colour), weathered layer (in blue/green colour) and basement bedrock (in yellow/brownish red colour). The topsoil/lateritic layer resistivity and thickness range from 797 to 2469 Ωm and 5 to 20 m respectively. The resistivity and thickness of the weathered layer vary between 130 and 684 Ωm and 30 and > 60 m respectively. The basement bedrock underlies the weathered layer. The resistivity of the basement bedrock varies between 535 and 1999 Ωm. Low resistivity (451 – 642 Ωm and 156 – 447 Ωm) near vertical discontinuities between distance 4400 and 4540 m and 4620 and 4740 m respectively were imaged by the resistivity structure. The former discontinuity was also identified by the magnetic profile and 2-D magnetic model. The depth to the top (about 20 m), width extent (160 m) and center (4465 m) of the vertically dipping discontinuity correlate significantly with those of the magnetic thick dyke interpretation model.

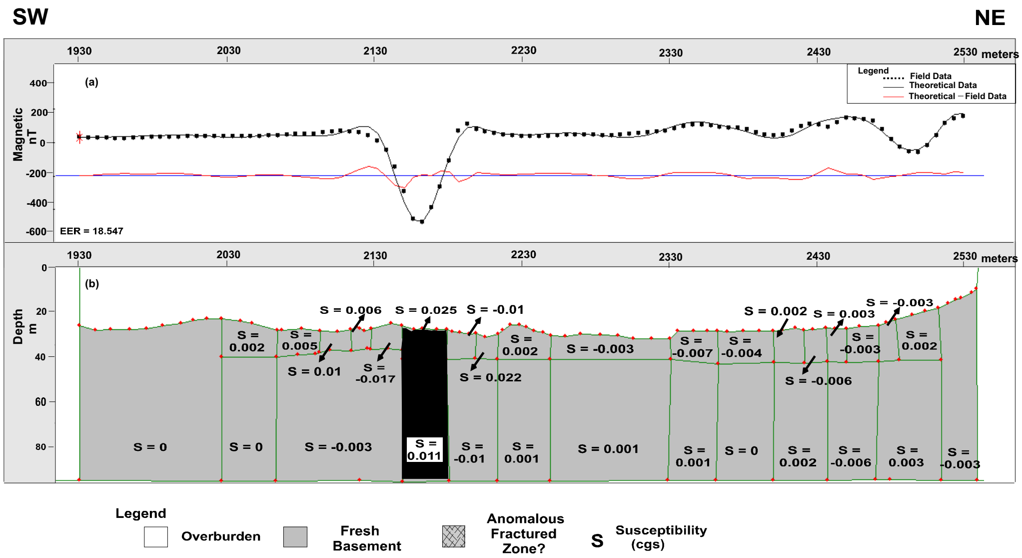

Figure 9: (a) Magnetic Profile and (b) 2-D Model along Traverse TR 3

The 2-D geoelectric section (Fig. 8d) relates VES 10 – 15 and identifies four geologic layer including the topsoil, lateritic layer, weathered layer and fresh basement. The topsoil is composed of sandy clay and sand with resistivity and thickness values that range from 103 to 303 Ωm and 0.8 to 1.2 m respectively. The lateritic layer with resistivity and thickness values varying from 537 to 2659 Ωm and 3.0 to 18.6 m respectively, underlies the topsoil. The weathered layer underlies the lateritic layer with resistivity and thickness values ranging from 317 to 839 Ωm and 39.7 to 73.7 m respectively. The fresh basement has infinite resistivity value.

The magnetic profile and 2-D model obtained along traverse TR 3 are presented in Fig. 9. The magnetic profile (Fig. 9a) with amplitudes varying from - 517 to 155 nT identifies one major magnetic anomaly between distance 2110 and 2200 m with peak negative amplitudes of – 517 nT. The magnetic anomaly is typical of a steeply dipping thin dyke (suspected to be a fault/shear zone). The center of the dyke is at about 2160 m. The 2-D magnetic model (Fig. 9b) images a magnetic basement that is 25 – 30 m deep. The modeled thin dyke is about 30 m deep.

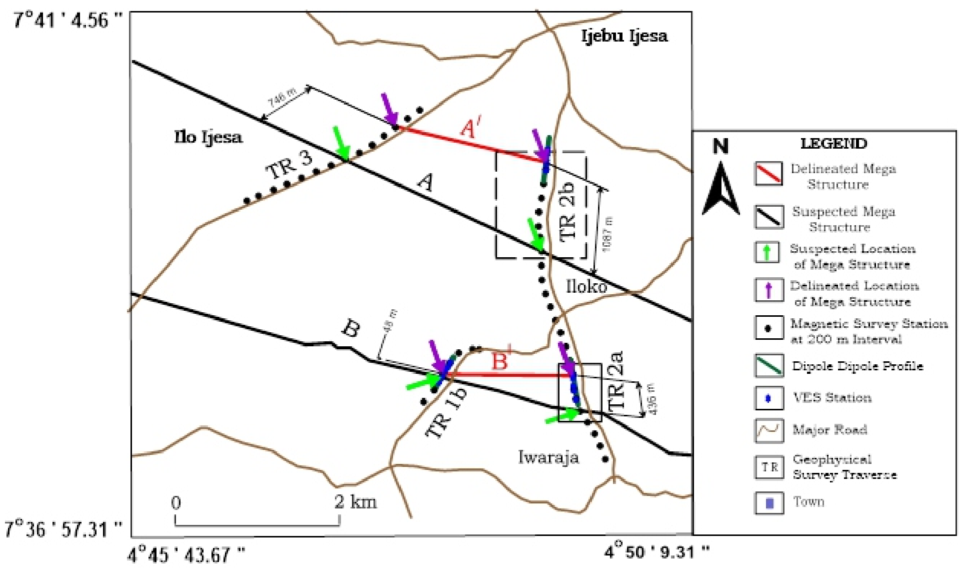

Figure 10: Spatial Relationship between Remote Sensing Suspected Mega Structures A and B and the Geophysically Delineated Equivalent Mega Structures A' and B'

Synthesis of Results

The centers of the modeled magnetic dykes and the surface manifestation of the steeply dipping low resistivity discontinuities within high resistivity basement bedrock on the resistivity structures correlated well across all the traverses investigated (see Figs. 6 – 8). These centers and the center of the thin dyke modeled along traverse TR 3 are considered as centers of the geophysically delineated suspected fault zones. These centers were correlated across traverses TR 1b and TR 2a as mega structure B' and across traverse TR 3 and TR 2b as structure A' (Fig. 10). The correlation shows that the remote sensing delineated mega lineaments A and B actually exist but are shifted slightly northwards with displacement of as small as 50 m along traverse TR 1b to as large as about 1100 m along traverse TR 2b (Fig. 10). The mega lineaments are suspected to be regional fault zones.

CONCLUSION

Integrated geophysical investigation involving the magnetic and resistivity (1-D VES and 2-D Dipole Dipole) methods was carried out to investigate the existence or otherwise of two remotely sensed mega lineaments (suspected fault zones) around Iwaraja – Ijebu Ijesa area of Osun State, Nigeria. Segments of magnetic profiles established across the suspected fault zones identified anomalous zones. These zones were modeled as thick and thin dykes characteristic of fracture/fault in a typical basement complex terrain. The centers of the model dykes correlate with surface manifestations of steeply dipping low resistivity discontinuity within high resistivity basement bedrock on the 2-D resistivity structures. The study concluded that the remote sensing delineated suspected mega lineaments A and B exist, but are shifted northwards by distances varying from 50 m – 1100 m. The mega lineaments are suspected to be regional fault zones.

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