

## Geophysical Verification of Minor Fault Mechanics using Vertical Electrical Sounding survey in Ibadan and Ijebu-Ode, Southwestern Nigeria.

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### ABSTRACT

Understanding and mapping minor fault systems is essential for tectonic hazard assessment and sustainable subsurface resource management. This study applies the Vertical Electrical Sounding (VES) method to identify and characterize minor faults in Ibadan and Ijebu-Ode, southwestern Nigeria, regions previously underexplored in this context despite their proximity to known major fault zones from the Atlantic Ocean. Using the Schlumberger electrode array along four profiles in Ibadan and five in Ijebu-Ode, resistivity data were acquired and interpreted through geophysical inversion. The results revealed two main subsurface terrains: sedimentary and crystalline rocks. Specific curve types (KH, HKH, KHKH) indicated fractured or faulted basement zones, with fault-related resistivity anomalies detected at depths ranging from 1.0 to 53.1 m. These findings highlight the tectonic sensitivity of the study areas and underscore the importance of integrating such data into regional seismic risk mapping and groundwater development plans. Further multi-method geophysical validation is recommended to confirm the structural interpretations.

**KEYWORDS:** Vertical Electrical Sounding, Minor Fault, Resistivity, Ibadan, Ijebu-Ode, subsurface structures.

### I. INTRODUCTION

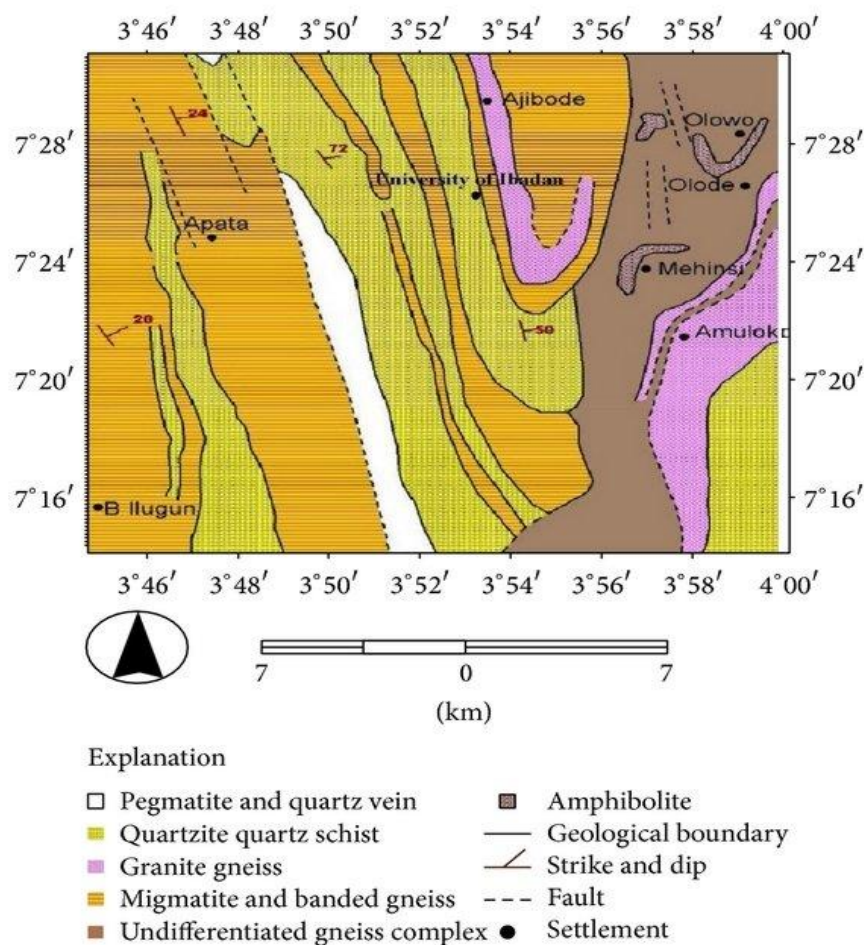
Minor faults, though often overlooked in regional tectonic assessments, play a critical role in groundwater flow, structural stability, and local seismicity. In southwestern Nigeria, particularly around Ibadan and Ijebu-Ode, the geological landscape includes both sedimentary rocks of the Eastern Dahomey Basin and crystalline rocks of the Basement Complex—terrains highly susceptible to fracturing and faulting (Ganiyu et al., 2021). Despite historical records of tremors in these areas (Ananaba, 1991; Ajakaiye et al., 1987; Ojo, 1995; Akpan and Yakubu, 2010), limited geophysical investigations have been conducted specifically to delineate minor fault systems. This study addresses a notable gap in the regional geophysical literature by applying Vertical Electrical Sounding (VES) to systematically investigate and map these minor faults. VES is a method that involves measuring the Earth's subsurface electrical resistivity variations at different depths, which in turn can provide insights into the geology and potential presence of fault zones. This non-intrusive method has been widely utilized to delineate subsurface structures, understand groundwater dynamics, and identify geological discontinuities such as fault zones (Abdulbari et al., 2023; El Makrini et al., 2022; Ghanem et al., 2022; Akingboye & Osazuwa, 2021; Akingboye & Oguntimehin, 2019; Binley et al., 2015; Bery & Saad, 2012). Farhang and Asadi (2019) adopted the VES to identify hidden faults with high accuracy in Fars, Iran identifying two fault zones along east-southwest and northwest-southeast lines and some sub faults and fractures along the Zagros flow. Previous research in Nigeria (Akingboye & Osazuwa, 2021; Akingboye & Oguntimehin, 2019) has predominantly focused on aquifer characterization or major fault structures, with limited emphasis on the detection of concealed or localized fault zones that may be linked to recent microseismic activity. The novelty of this study lies in its site-specific focus and use of resistivity profiling to infer fault mechanics in two geologically complex zones that have experienced tremor-related activity. VES is favored for its cost-effectiveness and depth penetration, offering a practical approach to subsurface fault detection in areas where seismic or borehole data are scarce. By identifying

fault-related anomalies, this research contributes to hazard assessment and groundwater exploration models for regions where infrastructure development continues to expand despite underlying geotechnical risks.

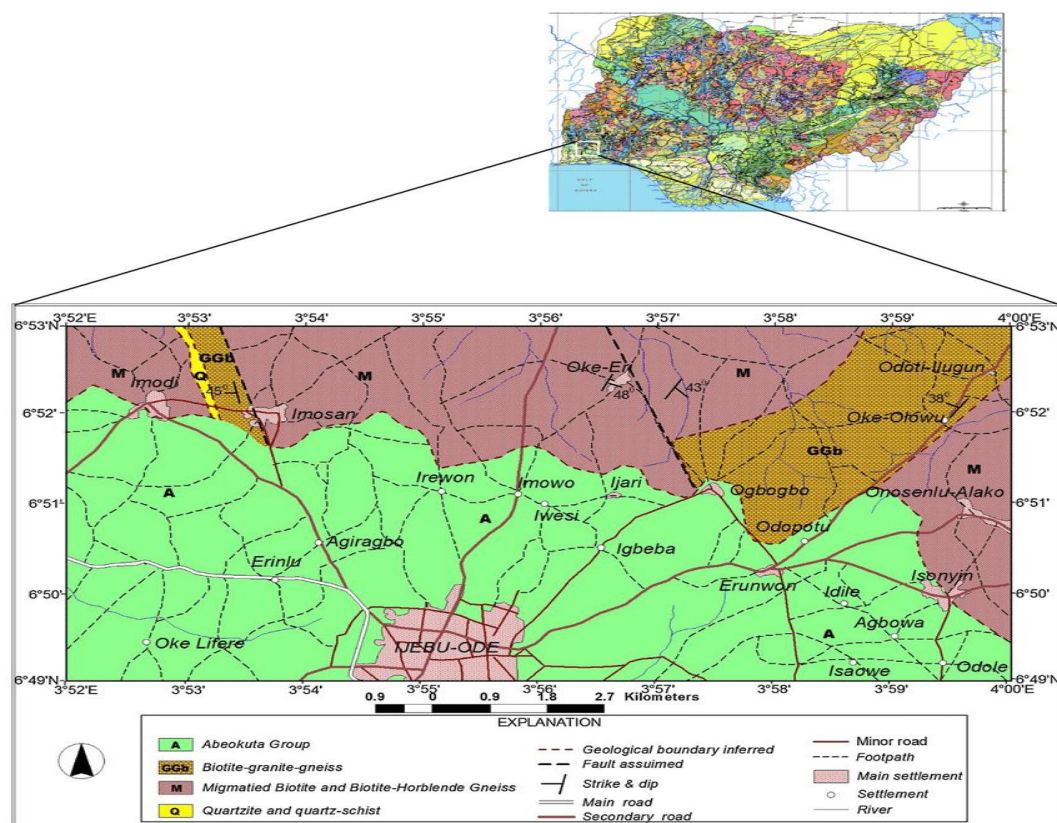
## II. METHODOLOGY

### A. STUDY AREA

The study areas, Ibadan and Ijebu-Ode are located within southwestern Nigeria, between latitudes  $7^{\circ}23'$  and  $6^{\circ}49'$  N and longitudes  $3^{\circ}55'$  and  $4^{\circ}24'$  E. Ibadan is situated within the Oyo State, while Ijebu-Ode lies in Ogun State. The two areas are characterized by similar geology dominated by the Precambrian Basement Complex rocks, with substantial granite, gneiss, and schist formations. They also exhibit similar topographical features of gently undulating terrain interspersed with minor hill ranges.



**Figure 1:** Geological Map of Ibadan

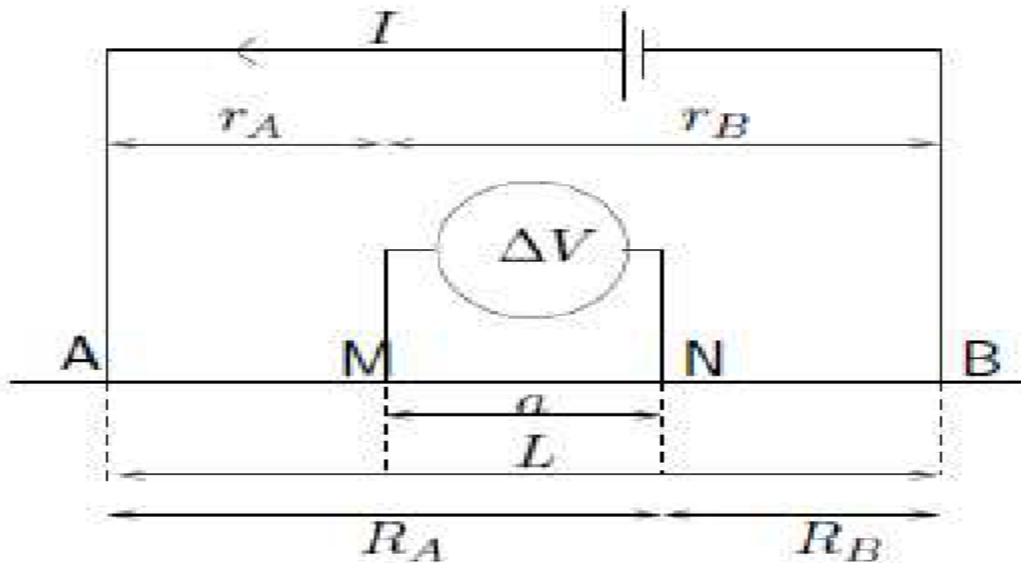


**Figure 2:** Geological Map of Ijebu Ode and its environment

Geologically, these regions are susceptible to faulting due to the tectonic evolution of the West African Craton, which has undergone multiple deformation events. The local hydrology is also heavily influenced by these fault lines, with fractures often serving as conduits for groundwater movement.

## B. DATA ACQUISITION

The geophysical survey employed the Schlumberger array configuration for Vertical Electrical Sounding (VES), as shown in *Figure 3* below. A total of 9 VES stations were strategically established across Ibadan and Ijebu-Ode, targeting areas of suspected minor faulting based on geological maps, satellite imagery, and remote sensing interpretations. The electrode spacing (AB/2) ranged from 1.5 m to 200 m, allowing for the investigation of subsurface structures at varying depths. At each station, two current electrodes and two potential electrodes were placed collinearly in a straight line. The electrode separation was systematically adjusted to increase the depth of investigation. The resistivity meter was connected to a data logger and calibrated to predefined parameters, including current injection level and duration. GPS coordinates were recorded at each station to ensure spatial referencing and reproducibility.



**Figure 3:** Schlumberger-Configuration

### C. DATA QUALITY CONTROL AND PROCESSING

To ensure data accuracy, the following steps were taken:

- Pre-measurement checks were conducted to confirm electrode contact resistance was within acceptable limits.
- Spurious readings caused by poor contact or environmental noise were filtered out.
- Multiple readings were taken for each configuration, and outliers were removed before final averaging. The measured potential differences were processed using the IPI2Win software (version 4.0), a well-established tool for one-dimensional geoelectrical inversion. The inversion algorithm employed a smoothness-constrained least squares approach to convert apparent resistivity values into true resistivity-depth models.

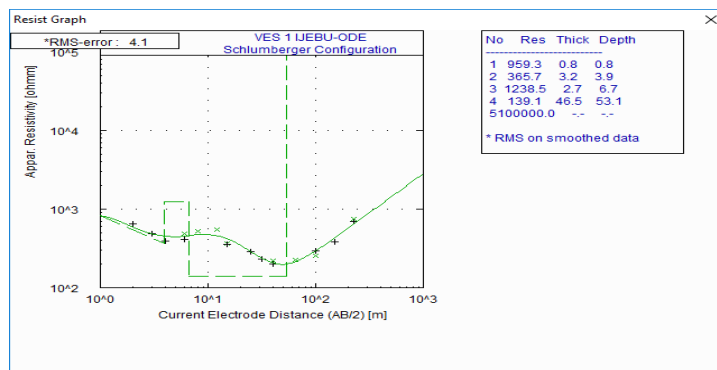
### D. DATA VALIDATION

While borehole logs were not directly available within the immediate vicinity of all stations, regional lithological data and prior hydrogeological borehole records from existing geological surveys were used for cross-validation. In regions with known borehole profiles, the interpreted geoelectric layers showed strong agreement with documented lithologic sequences (e.g., clay, sand, laterite, and weathered basement layers), lending credence to the resistivity interpretations.

## III. RESULTS AND DISCUSSION

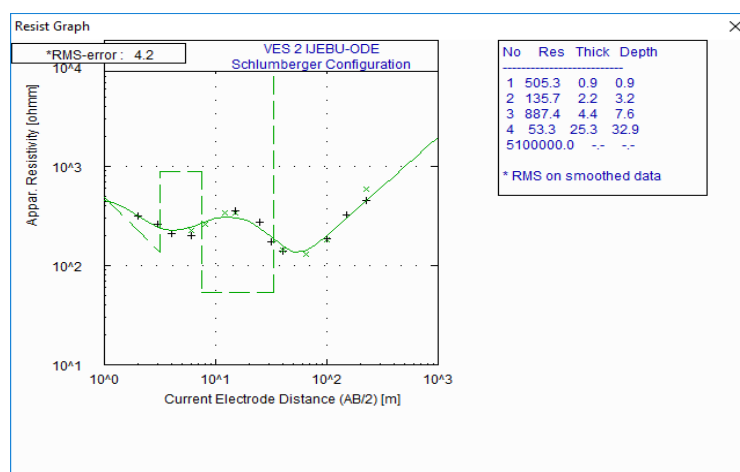
The resistivity data obtained were processed using an inversion algorithm to produce resistivity-depth models for each VES station. The processed data were interpreted using both qualitative and quantitative techniques, with the results are presented as sounding curves, tables and geo-electric sections. Figure 4(a) – (f) and Figure 5(a) – (c) below, show the sounding curves obtained from Ijebu-Ode and Ibadan respectively.

(a)

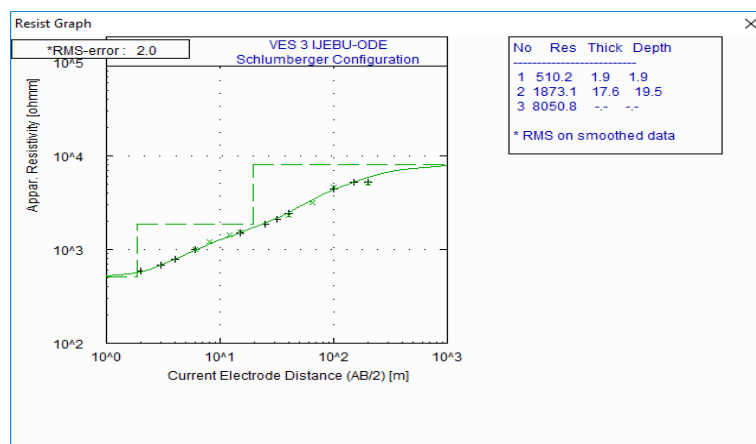


The A, and K- type curves reflect thin weathered layers while the other type curves such as KH, HKH and KHKH etc. contain fractured/fault basement (Olorunfemi and Meshida, 1987). Field curves often mirror-image, geoelectrically, the nature of the successive lithologic sequence in a place.

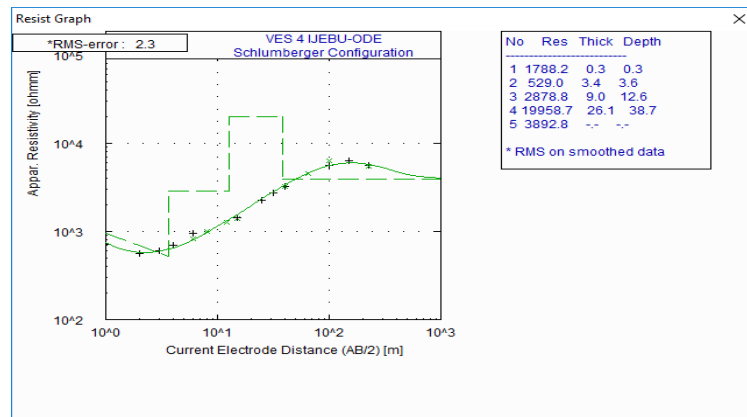
(b)



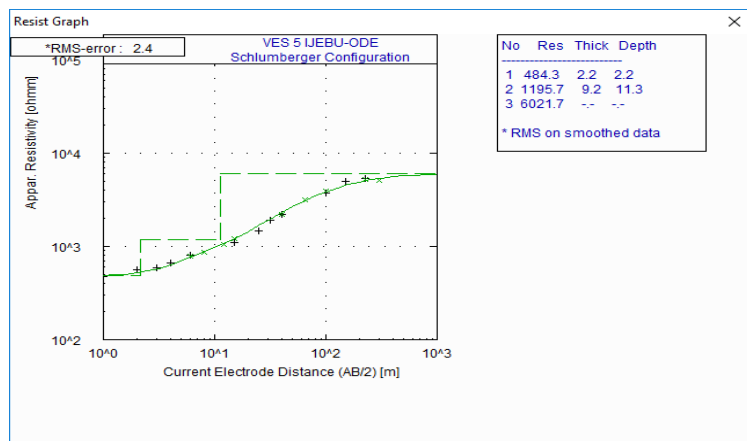
(c)



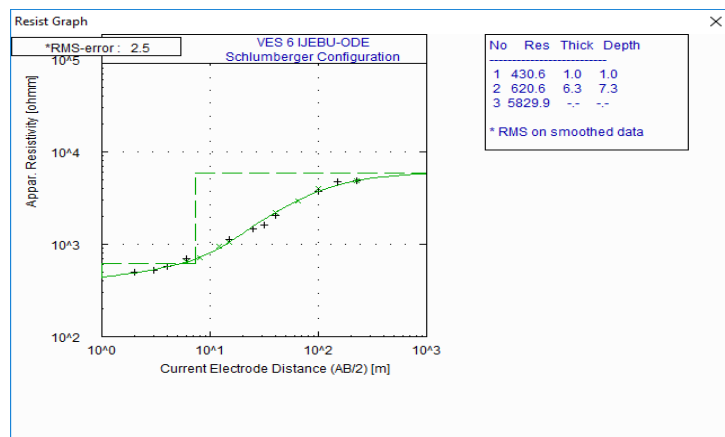
(d)



(e)



(f)

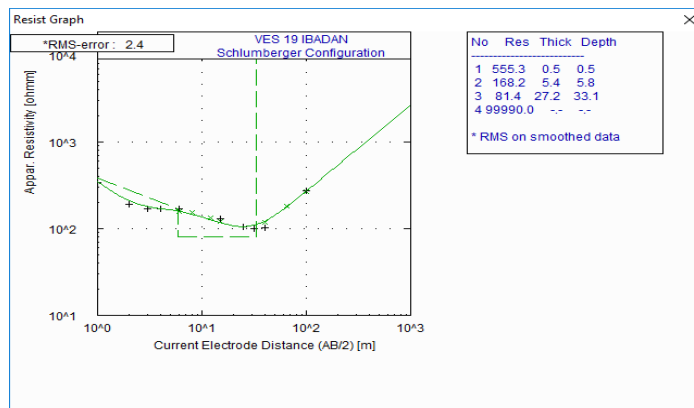


**Figure 4:** Typical Sounding Curve along Profile AA1 (Ijebu Ode) (a) KH (b) HKH (c) A (d) HAK (e) K (f) A

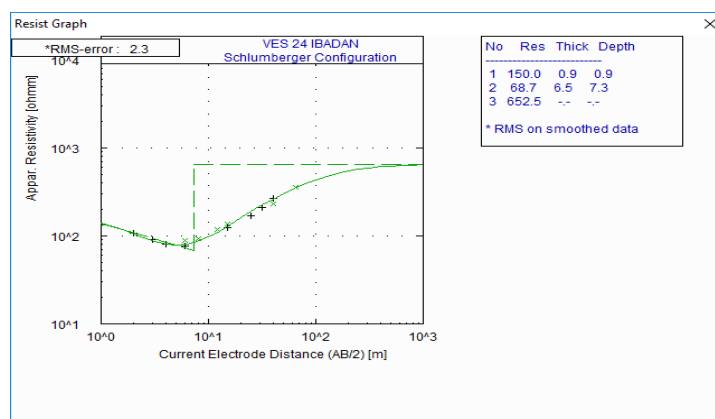


Typical curve types are shown in Figures 4, while the summary of the results i.e. the geo-electric parameters obtained from the VES curves interpretations is presented in Figure 5.

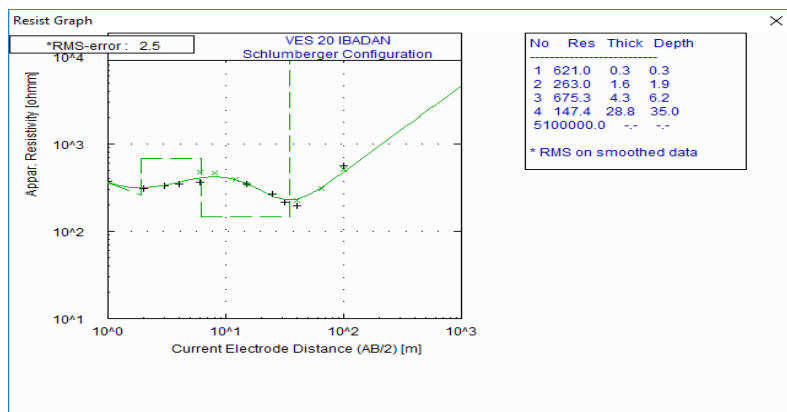
(a)



(b)



(c)



**Figure 5:** Typical Sounding Curve along Ibadan (a) QH (b) H (c) HKH

The resistivity profiles obtained from both Ibadan and Ijebu-Ode, as seen in the sounding curves of Figure 4(a)-(f) and Figure 5(a)-(c) above, indicate the presence of minor fault structures. These are interpreted from sudden drops in resistivity values typically associated with fractured or weak subsurface zones. These

discontinuities were most pronounced in HKH and KH-type curves, which are characteristic of faulted or fractured basement rocks (Olorunfemi and Meshida, 1987). The consistency of these signatures across several profiles reinforces the reliability of the VES method for subsurface fault detection in basement terrains.

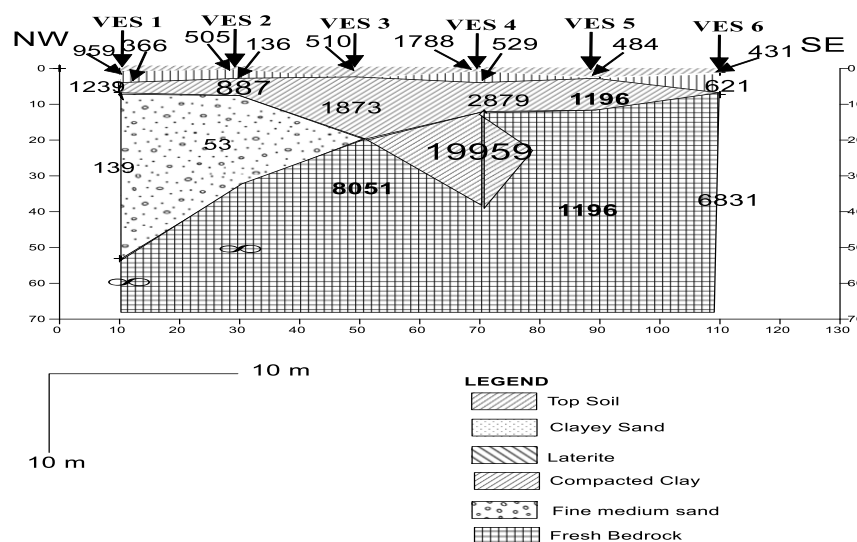
In Ibadan, the resistivity values ranged from 214 to 555  $\Omega$ -m depending on the subsurface material. Several profiles showed resistivity drops to as low as 50–100 ohm-m at depths between 20 and 50 meters, interpreted as faulted zones. These faults were likely caused by localized stress within the basement complex. The identified faults were found to correlate with known fracture zones and stream alignments in the area, indicating that these minor faults might play a role in groundwater movement.

Similarly, in Ijebu-Ode, resistivity values varied between 136  $\Omega$ -m to 959  $\Omega$ -m. The geoelectric sections revealed that the faults are generally aligned in NE–SW and NW–SE orientations, which correlate with known tectonic trends within the southwestern Nigerian Basement Complex (Ajayi & Hassan, 2014; Ganiyu et al., 2021). These orientations are consistent with regional deformation patterns attributed to Pan-African tectonic reactivation, suggesting that the minor faults mapped in this study may be splays or secondary structures of deeper-seated major faults associated with crustal stress release mechanisms.

This interpretation is in line with earlier works by Olayinka and Olorunfemi (1992), who identified fault-induced resistivity anomalies in southwestern Nigeria using VES. Similarly, Farhang and Asadi (2019) detected hidden fault systems using resistivity contrasts in Iran's Zagros belt, emphasizing the method's robustness in characterizing subsurface discontinuities.

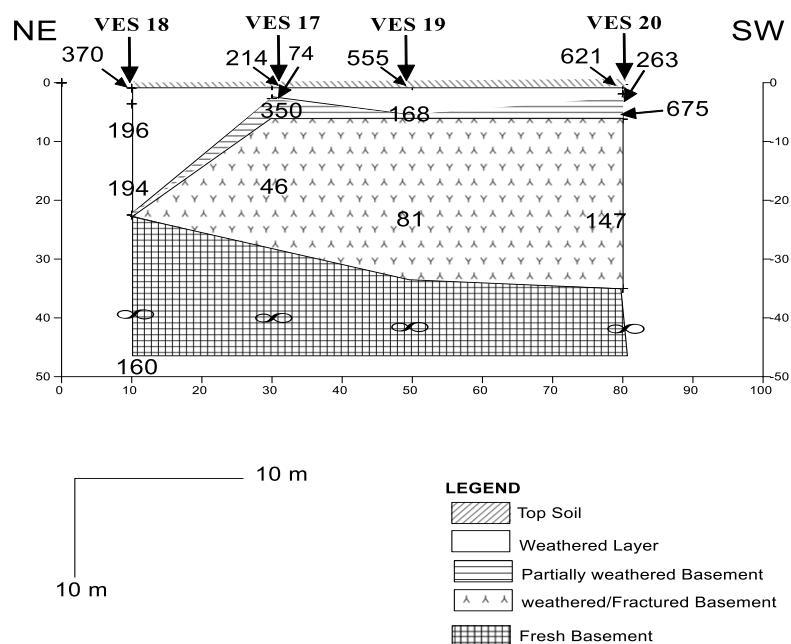
However, while prior studies have focused predominantly on major fault systems, this research provides new evidence of previously uncharacterized minor faults, especially in urban areas like Ijebu-Ode and Ibadan, which had been relatively underexplored despite recurring seismic tremors. Figure 6 shows the geoelectric-section along profile A-A1 (Ijebu-Ode). The section consists of VES 1, 2, 3, 4, 5 and 6. At Ijebu Ode area, the vertical electrical sounding data shows an asymptotic increase characteristic of the crystalline basement bedrock (see Figure 4(c)). In this section, four subsurface layers were delineated. In the first layer, (top soil) resistivity values range from 136 to 959  $\Omega$ -m, while thickness vary from 0.8 to 3.2 m. The second layer consist of highly resistive (887 to 19956  $\Omega$ -m) and highly compacted clay layer. The thickness varies from 4.4 to 26.1 m. The fairly thick and highly resistive compacted clay layer is suspected to be responsible for abortive or failure of hand dug well. The third geoelectric layer delineated composed of sandy clays and fine-medium sand with resistivity values ranging from 53 to 139  $\Omega$ -m and thickness of 32.9 to 46.5 m form aquifer units in this area which is a good potential for groundwater exploitation. The bedrock resistivity values vary from 8051 to  $\infty$   $\Omega$ -m, with depth to bedrock range of 7.3 and 53.1 m. The weathered layer thickness decreases in the southeast direction while VES points 1 and 2 shows fairly thick fault column in the northwest direction.





**Figure 6:** Goelectric Section along profile A-A1 Ijebu Ode

Figure 7 presents goelectric section along profile C-C' the section consists of VES 18, 17, 19 and 20. Five subsurface layers were identified in the section. The topsoil resistivity values range from 214 to 555  $\Omega$ -m and is presumed to be clayey sand/laterite material. The weathered layer resistivity values range from 74 to 196  $\Omega$ -m (sandy clay materials). The partially weathered basement resistivity values range from 350 to 675  $\Omega$ -m with thickness of 1.6 to 4.3 m, beyond this layer is weathered/fracture basement with resistivity of 46  $\Omega$ m to 147  $\Omega$ m (thickness of 23.8 m to 28.8 m). The bedrock resistivity value is  $\infty$   $\Omega$ -m, with depth to bedrock range of 22.5 to 35 m. The partially weathered/fractured basement delineated at VES 17, 19 and 20 along the southeastern part of the profile identified a major discontinuity suspected to be fault zone and characterized by low resistivity values which may be favorable to groundwater accumulation.



**Figure 7:** Goelectric Section along profile C-C' (Ibadan)

The geoelectrical data obtained from the VES surveys in both Ibadan and Ijebu-Ode revealed significant resistivity anomalies indicative of minor faults at several locations. The resistivity profiles demonstrated characteristic low-resistivity zones interspersed with higher resistivity regions, suggesting areas of weakness, likely associated with minor fault mechanics.

#### A. TECTONIC IMPLICATIONS

The identification of vertical or near-vertical faults at depths of 20–50 meters has important tectonic implications. Though categorized as “minor,” these faults could represent active or reactivated zones capable of accommodating strain from broader crustal movement. Historical tremors reported in these regions (e.g., 1939, 1984, 2009) may be linked to the activity along these minor fault zones. As such, this study contributes to the growing body of evidence that southwestern Nigeria is not as tectonically stable as previously assumed. These findings support the need for improved micro seismic monitoring and tectonic risk assessment, especially in growing urban centers.

#### B. HYDROGEOLOGICAL SIGNIFICANCE

Hydrogeologically, the delineated weathered and fractured basement units represent potential aquifers. The low-resistivity zones associated with faults suggest enhanced porosity and permeability, which are critical for groundwater storage and movement. This is especially evident in Ijebu-Ode, where the compacted clay layer may impede vertical infiltration, while faults may provide preferential flow paths, thus determining well yield variability across short distances. Similar observations have been noted by Shemang & Chaoka (2003) and Jha et al. (2008), who highlighted the importance of fault zones in groundwater exploration within crystalline terrains. These results underline the need for fault-aware hydrogeological mapping, especially in water-scarce rural communities that rely heavily on shallow boreholes and hand-dug wells. The thick fractured zones identified at some VES points, notably in the northwest of Ijebu-Ode and southeast of Ibadan, are promising targets for sustainable groundwater development.

### IV. CONCLUSION

The application of the Vertical Electrical Sounding (VES) technique in this study has successfully identified and characterized minor fault structures in Ibadan and Ijebu-Ode. The geoelectrical signatures, particularly resistivity lows associated with KH and HKH curve types, indicate zones of fracturing and potential faulting within the crystalline basement terrain. These findings not only enhance the understanding of local fault mechanics but also demonstrate the utility of VES in mapping concealed tectonic features in structurally complex regions. The results have practical implications for groundwater resource management, as the identified fractured zones likely serve as conduits for groundwater flow and potential aquifer units. For urban planners and engineers, the detection of near-surface faulting is critical in assessing the geotechnical stability of construction sites, particularly in rapidly expanding cities like Ibadan and Ijebu-Ode.

Based on the findings from this study, the following recommendations are made for future work:

- (a). Geographical Expansion: Future surveys should be extended to other tectonically sensitive areas in southwestern Nigeria such as Abeokuta, Shagamu, and Akure, which have also experienced historical tremors and share similar basement geology.
- (b). Integrated Methods: VES results should be corroborated with borehole data, seismic refraction, and ground penetrating radar (GPR) to improve subsurface interpretation accuracy.
- (c). Fault Hazard Mapping: A fault susceptibility map combining VES data, satellite imagery, and historical

seismic records should be developed to support regional hazard assessment and land-use zoning.

- (d). Water Resource Planning: Hydrogeologists can use the identified fault and fracture zones as target areas for sustainable groundwater development, particularly where conventional drilling has yielded dry or low-yield boreholes.
- (e). Infrastructure Development: Urban development authorities should consider resistivity-based subsurface data in site selection and foundation design, particularly in zones identified as structurally weak or fault-prone.

This study serves as a baseline for the application of electrical resistivity methods in regional tectonic and hydrogeological investigations and emphasizes the value of integrating geophysical techniques into spatial planning and resource management frameworks.

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