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Post Foundation Geophysical Investigation of the Former Faculty of Arts Building, Ekiti State University, Ado-Ekiti, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author HYM wrote the abstract, part of the introduction and the ground magnetic section. Author IJT wrote the methodology and the Impact method of electromagnetics. Both authors made inputs in the conclusion, read and approved the final manuscript.

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ABSTRACT

Aims: This study entails the geophysical approach for the post foundation investigation using magnetic prospecting and impact method of electromagnetism.
Study Design: Traverses and GPS stations of the area were taken.
Place and Duration of Study: The former Faculty of Arts building at Ekiti State University. Ekiti State University is located along Ado-Iworoko road in Ado-Ekiti, Ekiti State which is located in southwestern Nigeria. The work was on 3rd of October 2019.
Methodology: The instrument used in the ground magnetic data acquisition was the proton precession magnetometer. The study area was divided into four traverses that are 100 m long perpendicular to the strike line i.e. the traverse runs from east to west of the study area. A spacing of 5 m serving as stations were maintained on each traverse making a total of eighty stations was accumulated for the four traverses. The impact method of electromagnetics was carried out immediately after the ground magnetic method, the only alteration was the establishment of sub-stations immediately after each station at 2.5 m away from the main station at each traverse. The creation of sub-stations is to comb the study area and obtain a concise data so as to delineate each of the subsurface structures.

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Results: The generated geomagnetic contour map of the study area indicates that the central region with high magnetic value implies competent formation, while the extreme North West has low magnetic values suggesting unstable formation. Electromagnetic Profiles of Traverse EFA-1 is a very conductive zone from top to bottom and can be classified as a very weak zone. It cannot bear the load of the structure that was placed on it and thus not a safe site. The weakness of the zone may lead to differential settlement. Traverse EFA-2 defines a fairly competent zone of weathered or a fractured bedrock typically a weathered zone of intermediate value; it can still bear the load of a structure. Traverse EFA-3 is a zone of weathered/fractured bedrock. It has an intermediate potential and evidence of a linear fracture. In traverse EFA-4 is not a competent zone of low to intermediate value. The low value zones may be seasonally wet and dry which can affect the stability of the foundation.

Conclusion: Data analysis delineated suspected fractured, shear or faulted zones and also revealed that the collapsed Faculty of Arts building was sited within the incompetent clayey weathered layer; these weak zones were detrimental to the integrity and stability of the structure.

Keywords: Building failure; differential settlement; fracture; post foundation; traverse.

1. INTRODUCTION

Building Failure is the inability or insufficiency of the building components to perform their expected functions as specified in the design and construction requirements [1]. According to [2], building failures can be categorized into the two broad groups of physical (structural) failures (which result in the loss of certain characteristics, e.g., strength) and performance failures (which means a reduction in function below an established acceptable limit). Reference [3] classified building collapse as either total or partial; total collapse occurs when some or many primary structural members of a building have fallen down completely, while partial collapse occurs when only some of the primary structural members of the building components have fallen down. The rate of failed structures in Nigeria have increased in recent times [4]. Several probable reasons speculated to have been responsible for this ugly incidence have been highlighted: inadequate supervision, poor construction materials, non-compliance to specification etc. Unfortunately, one distinct point that has always not been given serious attention is inadequate information on the nature of subsurface conditions prior to construction exercise [5]. The nature (i.e. competence, strength and load capacity) of the soil supporting the super structure becomes a particularly important issue for safety, structural integrity assessment and durability of the super structure [6]. This assertion can be attributed to the minimal attention towards the use of geophysics in foundation studies [7]. Unfortunately, building collapse incidences are common in southwestern part of Nigeria despite the development of proactive, non-destructive, time saving, low cost and effective idea of applying geophysical methods to delineate the subsurface condition [8]. Rocks normally deform (by expansion, contraction, shear or combination of them) in response to an applied load, changes in temperature or water content (swelling and shrinkage) and growth of secondary minerals (such as Zeolite, Chromite and Calcite) filling cracks and pores, which poses negative effect on the overall strength of the rock [9]. Engineering Geophysics offers a wide spectrum of methods that can be used for post foundation investigation [5].

Ekiti State University is witnessing rapid structural development. Hence, what caused the collapse of the former Faculty of Arts has to be unravelled so that existing and future structures won’t go the same way. This study entails the geophysical approach for the post foundation investigation using magnetic prospecting and impact method of electromagnetism. The ground magnetic survey detects anomalous magnetization of parts of the solid earth’s surface and estimates the magnetic susceptibility of rock formations which might be associated with local mineralization or the amount of magnetite that the formation contains to delineate the subsurface structure; because rock materials and layers contain small amount of magnetite. Magnetic survey data have been used to provide information on the nature and form of the crystalline basement in the subsurface. Magnetite produces a secondary magnetic field that is superimposed on, and distorts, the Earth’s magnetic field [10]. During interpretation of low-altitude aeromagnetic and ground magnetic measurements linear magnetic minima are frequently observed and are often attributed to

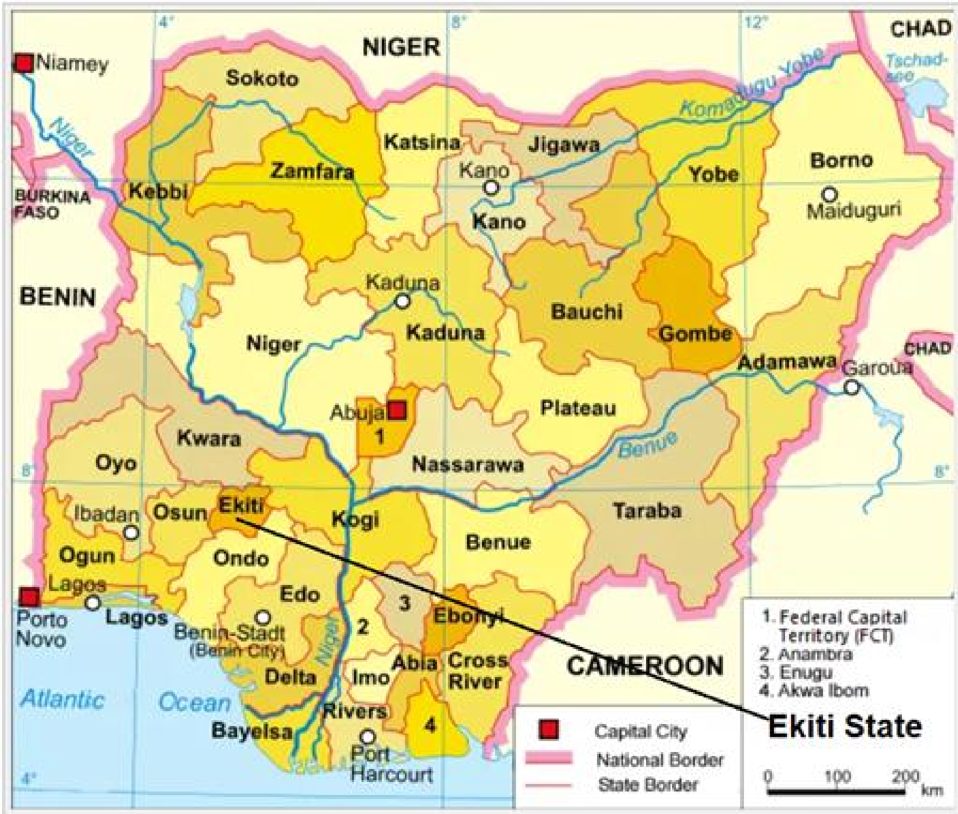

Fig. 1. Map of Nigeria showing Ekiti State, modified from [20]

linear fracture zones [11]. Detailed petrophysical studies were made on an outcropping fracture zone showing a negative magnetic anomaly and it was found that the observed linear magnetic minima are caused by a combination of a fault graben and the oxidation of magnetite to hematite [11]. The degree of martitization and hydration is the cause of the variation of susceptibility, both processes indicate (near-surface) alterations at low temperature, high oxygen pressure and the presence of water; the linear magnetic minima may therefore be ascribed to oxidation and hydration along linear fault zones [11]. Measurements of the magnetic field strength made on the ground surface can be used to determine the depth of the layer containing the magnetite and estimate its magnetic susceptibility [12]. Impact method of electromagnetism uses low frequency time varying primary magnetic field as a source to excite the ground with electrical current and by induction send back a secondary magnetic field to the surface. This particular EM-method utilizes two electrodes to stimulate the subsurface in other to delineate how conductive it is [13]. Several authors have used integrated geophysical methods in the detection of groundwater in fractured media e.g. [5,14,15] [16,17]. Ekiti State is located between latitudes 7°15′N to 8°5′N and longitudes 4°44′E to 5°45′E in southwestern Nigeria and covering an approximate area of about 6353 km^2 (Fig. 1). Ekiti State University is located along Ado-Iworoko road in Ado-Ekiti. Ado-Ekiti lies within latitudes 07°41'N – 07°4'N and longitudes 05°15'E – 05°18'E, respectively (Fig. 2); covering an approximate surface area of 242.6 km^2. The former Faculty of Arts building at Ekiti State University lies between longitudes 8°52'861"E and 8°52'824"E and latitudes 7°48'509"N and 7°48'413"N, covering a total area of 100 m^2 (Fig. 3). Nigeria lies to the rest of the West African Craton in the region of late Precambrian to early Paleozoic orogenesis (Fig. 4). The Basement complex is made up of Precambrian rocks and these rocks consist of the schist belt infolded in them [18]. The study area is accessible through major and minor roads within the university and the area is a Migmatite-Gneiss terrain which is part of the Precambrian Basement Complex [18] made up of the Migmatite Gneiss Quartzite Complex; the Slightly Migmatised to

Unmigmatised Metasedimentary Schists and Metaigneous rocks; the Charnockitic, Gabbroic and Dioritic rocks; and the members of the Older Granite Suite (Fig. 5). The topography of the area is plain and slightly slopping towards the west. Most of the rocks in the study area are not exposed and are below sea level. The drainage system in the area is usually marked with the proliferation of many smaller streams which are dry for many months, especially from Nov – May [19]. The drainage pattern typical of the study area is trellis which is structure-controlled.

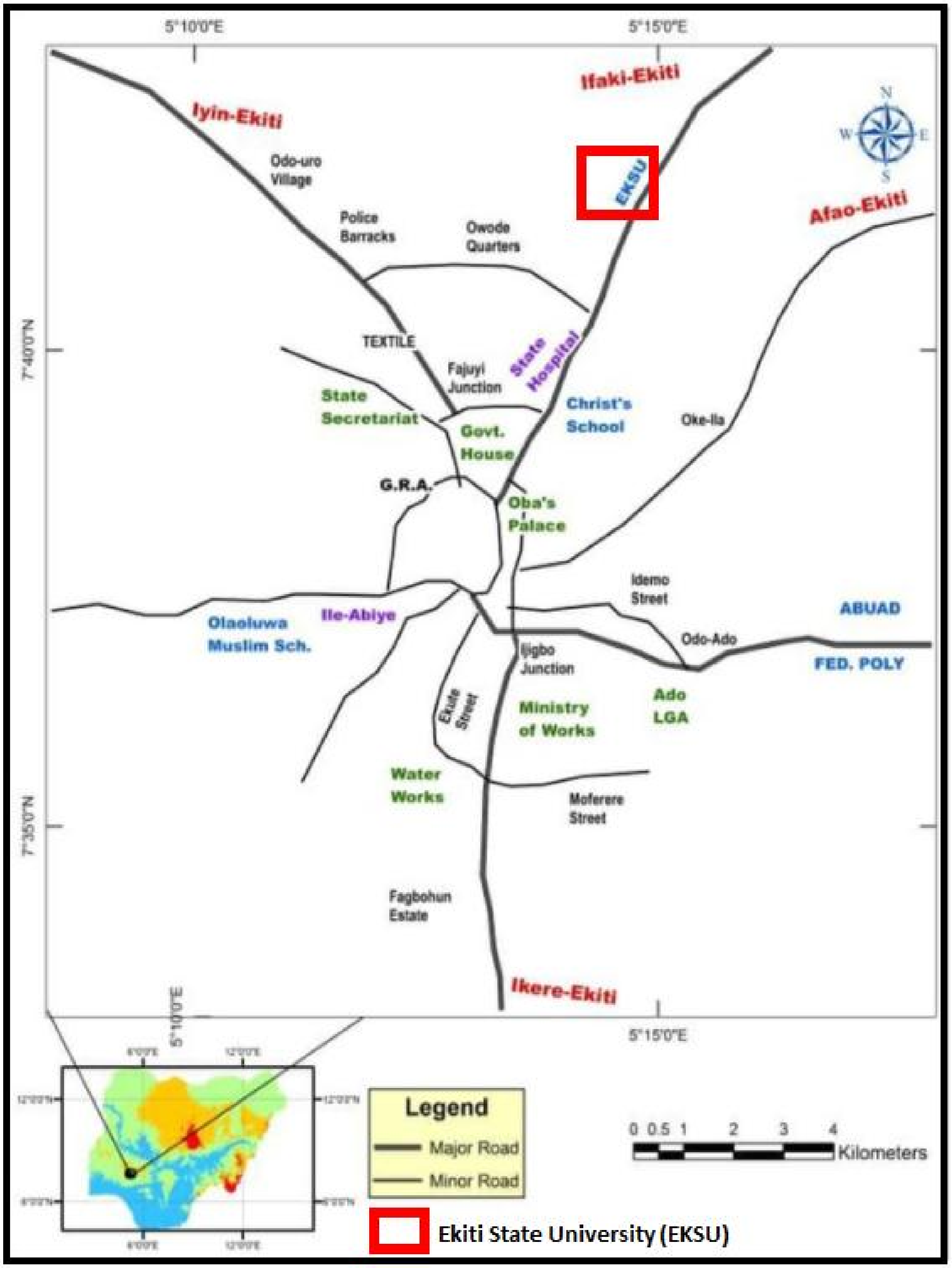

Fig. 2. Map of Ado-Ekiti showing Ekiti State University Ado-Ekiti modified from [21]

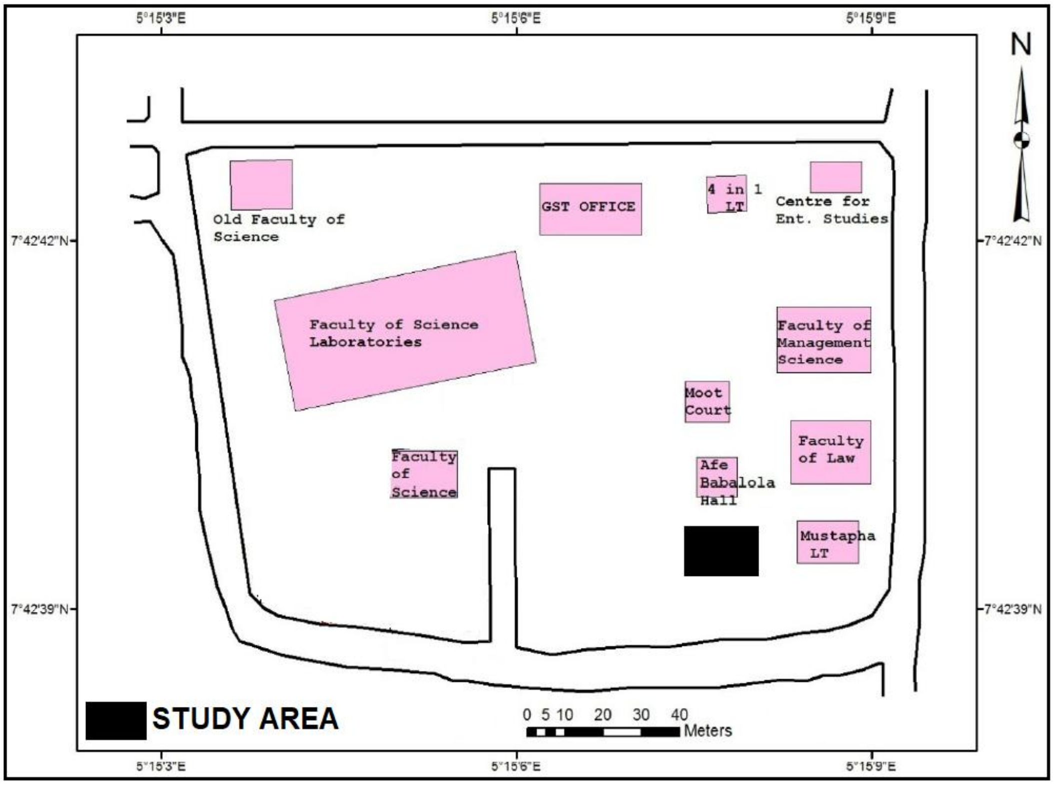

Fig. 3. Map of Ekiti State University showing the study area, modified from [22]

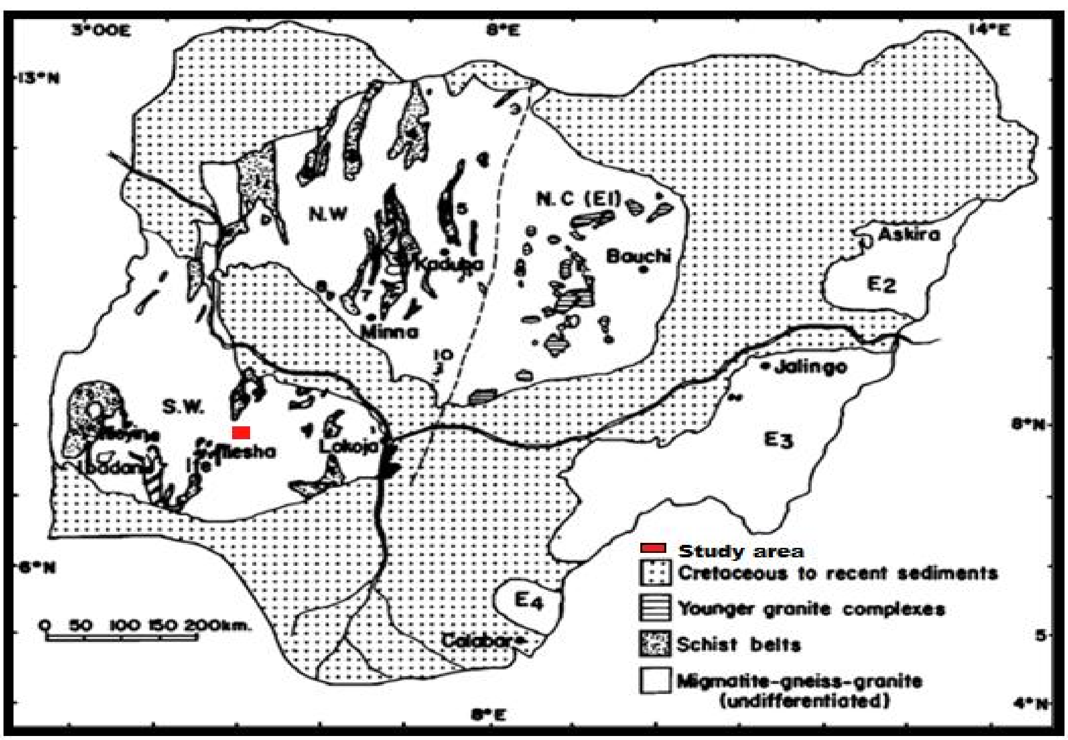

Fig. 4. Geological map of Nigeria showing the study area, modified from [23]

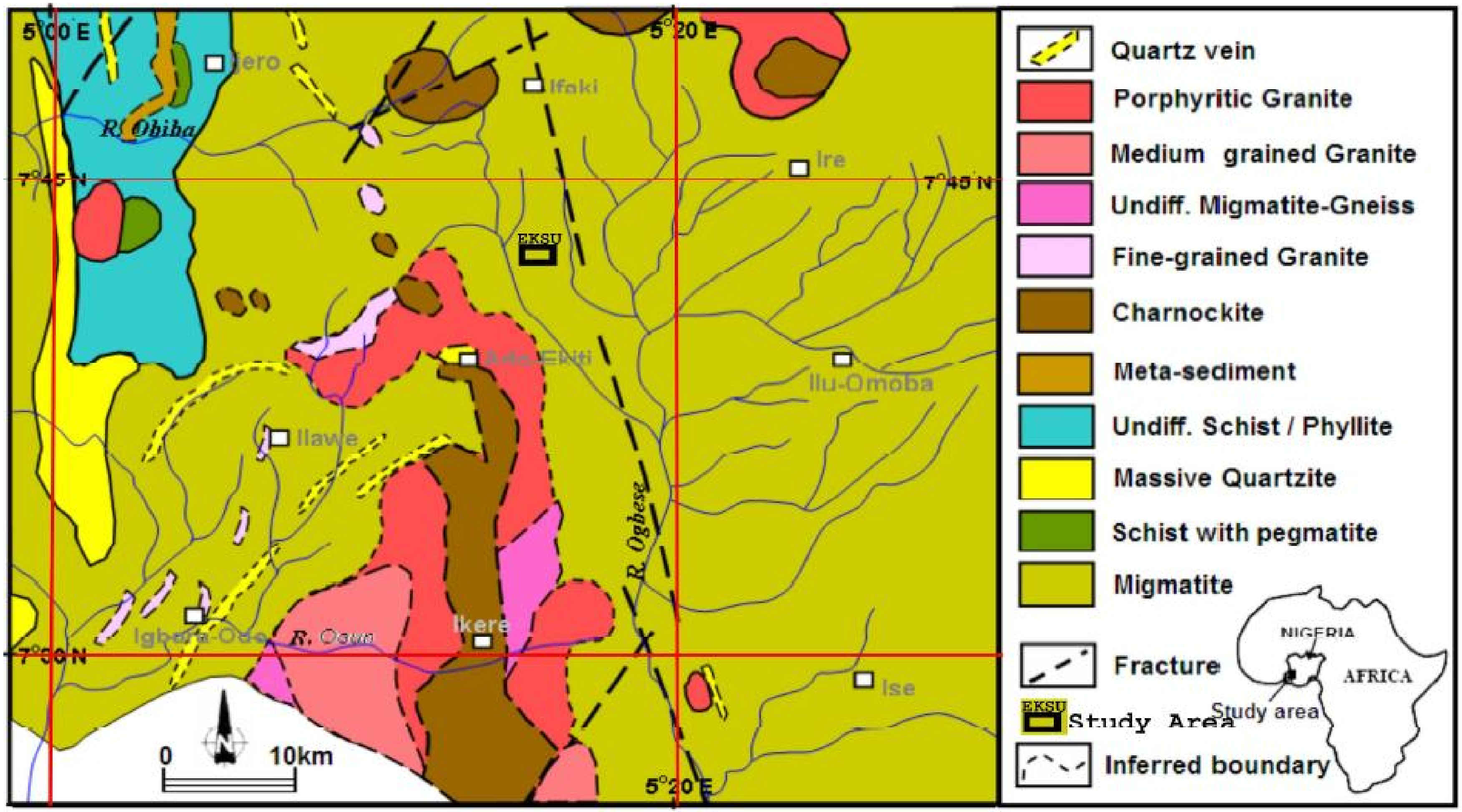

Fig. 5. Geological Map of Ado-Ekiti and its environs showing the study area modified from [22]

2. METHODOLOGY

2.1 Ground Magnetic Survey

The instrument used in the ground magnetic data acquisition was the GEM 8 proton precession magnetometer. The study area was divided into four traverses that are 100 m long perpendicular to the strike line i.e. the traverse runs from east to west of the study area (Fig. 6). A spacing of 5 m serving as stations were maintained on each traverse making a total of eighty stations was accumulated for the four traverses. The GPS readings and time at each station were taken before acquiring data at each station starting from the base station. At the end of end each traverse, the reading was closed by taking the base station reading again before moving the next traverse starting from its base station. Large belt buckles, etc., were removed when operating the unit. The compass was placed more than 3 m away from the magnetometer when measuring the field. A final test was to immobilize the magnetometer and take readings while the operator moved around the sensor. To make accurate magnetic anomaly maps, temporal changes in the earth's magnetic field during the period of the survey was considered. After all corrections have been made, magnetic survey data were displayed as individual profiles, contour maps and graphs. All of the magnetic readings and time were inserted into surfer 10 to generate a graph; this graph was attained using the Peter's Half-slope method to get the probable depth to basement and subsurface features and obtain a 2-D image of the subsurface structures.

2.2 Impact Method of Electromagnetic

The impact method of electromagnetics was carried out immediately after the ground magnetic method, the only alteration was the establishment of sub-stations immediately after each station at 2.5 m away from the main station at each traverse. The creation of sub-stations is to comb the study area and obtain a concise data so as to delineate each of the subsurface structures. The Electromagnetic method is an electrical method of geophysical prospecting that utilizes the magnetic effect of electric current. One rods was used for the transmission of electric current, while the second rod was used to receive the resultant field. The electromagnetic source (receiver) used in this study is the magnetic component of the electromagnetic field generated in the high frequency band at 15-30 kHz by powerful battery serving as the major power source. The equipment used for the impact method of electromagnetics was the PQWT- S150•150 Meters; it exploits the natural electric field as electromagnetic field work source, based on the resistivity difference of underground rock, minerals or groundwater and measures the natural electric field in the soil of different components of electric field. After collection of data, the in-built computing functions of the instrument automatically drew curves, chart and profile map, indicating the geological structures and features as 2D electromagnetic profiles.

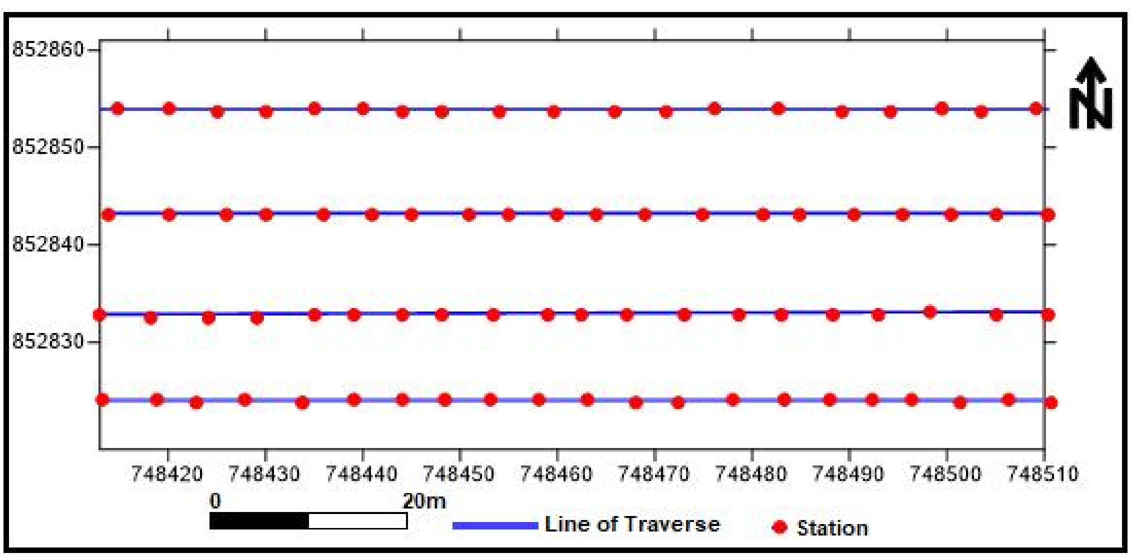

Fig. 6. Map of the traverse lines and stations employed in the study

3. RESULTS AND DISCUSSION

3.1 Magnetic Profiles

The generated geomagnetic contour map of the study area (Fig. 7) expressed in Universal Transverse Mercator (UTM) coordinates of zone 31, Minna datum as Northings 852830 - 852860 and Eastings 748420 - 748510 indicates that the central region (orange colour) with high magnetic value implies competent formation, while the extreme North West has low magnetic values suggesting unstable formation. The 2D modeling technique helps to understand the irregular pattern of the basement of varying depths reflecting uplifted basement (horsts) and down-faulted basins/sub-basins (grabens). The Magnetic profile and geomagnetic section along traverse EFA-1 (Fig. 8) displays undulating magnetic anomalies. The anomalies are typical of thin dipping dyke models suspected to be fractured, shear or faulted zones [24]. Two major magnetic anomalies between distances 35-45 m and 75 -100 m, which are indicative of probable fracture zones. The 2D geomagnetic section reveals overburden thickness ranging from 1 to 4 m. These are weak zones that could be inimical to the stability of foundation of any structure arising from differential settlement leading to cracks in the building and this must have contributed to the distress encountered on the removed structure. Along traverse EFA-2, two major magnetic anomalies with a distances of 0 to 22 m, due to overburden thickness and at a distance between 30 and 75 m (Fig. 9) which is probably a fractured zone. The overburden is shallow (eastern part) with thickness of about 0.5 m and deeper at the western part (thickness of about 5 m) and this would cause a differential settlement from the foundation to the structure erected on it. Along traverse EFA-3 (Fig. 10) the magnetic intensity contrast observed were at distances of 10-25 m; 60-75 m and 75-90 m, which are indicative of probable fractured zones; they are areas of weak zones. Traverse EFA-4 (Fig. 11) displays undulating magnetic anomalies. Four major magnetic anomalies between distances 35-40 m, 43-53 m, 55-65 m and 90-98 m, which are indicative of fracture zones. The magnetic anomalous zones are weak zones with shallow overburden (~1 to 1.5 m).

3.2 Electromagnetic Profiles

The profile maps (Figs. 12-15); the vertical axis is the depth from surface to the subsurface in meters, horizontal axis is the number of measured points in meters, the contours are values as per the local geological conditions in millivolts, the legend (values range) are values as per the rock characteristics. Traverse EFA-1 (Fig. 12) is a very conductive zone from top to bottom and can be classified as a very weak zone based on the decrease in the intensity of the colour from deep blue to greenish-blue; this typically indicates water saturated clayey top and sandy-clay at the bottom. It cannot bear the load of the structure that was placed on it and thus not a safe site. The weakness of the zone may lead to differential settlement. Traverse EFA-2 (Fig. 13) defines a fairly competent zone of weathered or a fractured bedrock typically a weathered zone of intermediate value; it can still bear the load of a structure. Traverse EFA-3 (Fig. 14), it is a zone of weathered/fractured bedrock. It has an

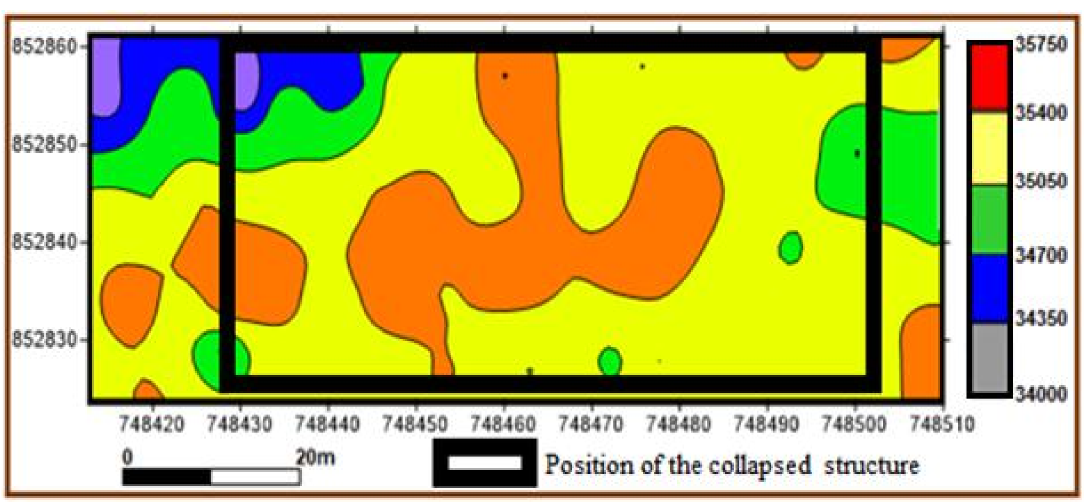

Fig. 7. Geomagnetic contour map (total magnetic field, in Tesla) of the study area

intermediate potential and evidence of a linear fracture. In traverse EFA-4 (Fig. 15), this zone is not competent i.e. a weathered/fractured rock of low to intermediate value. The low value zones may be seasonally wet and dry which can affect the stability of the foundation.

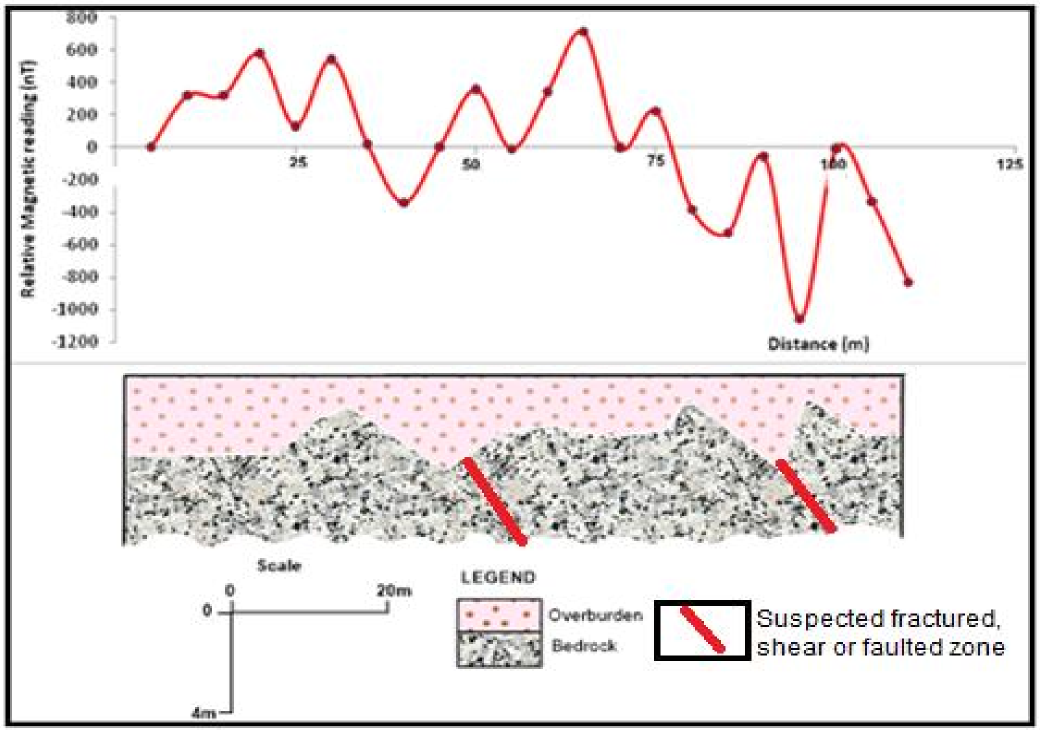

Fig. 8. Magnetic profile and 2D-Geomagnetic section of traverse EFA-1

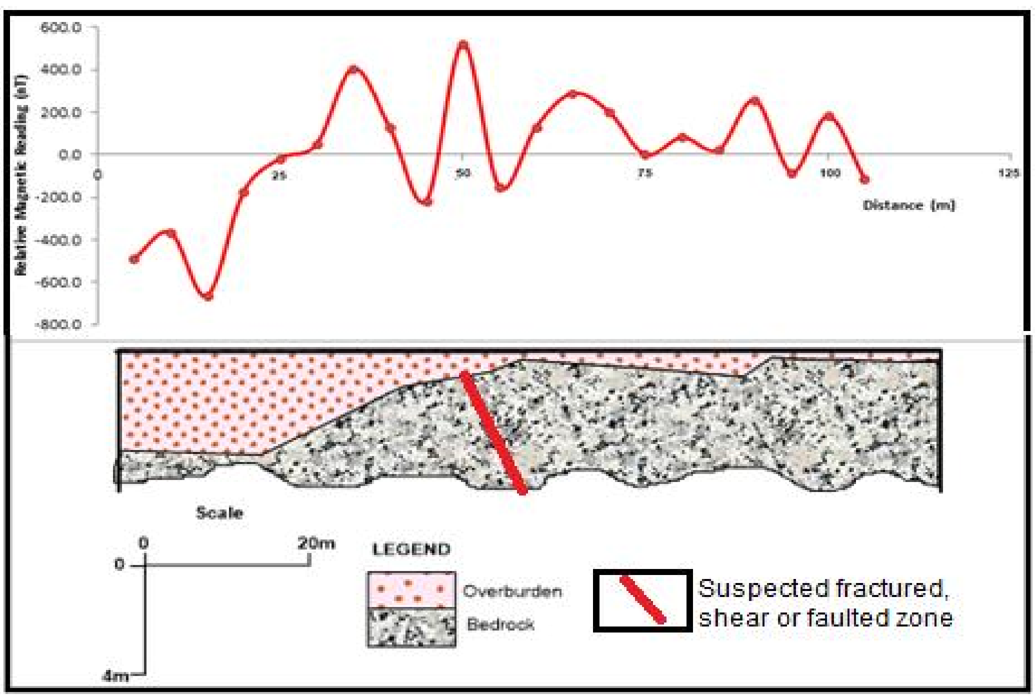

Fig. 9. Magnetic profile and 2D-Geomagnetic section of traverse EFA-2

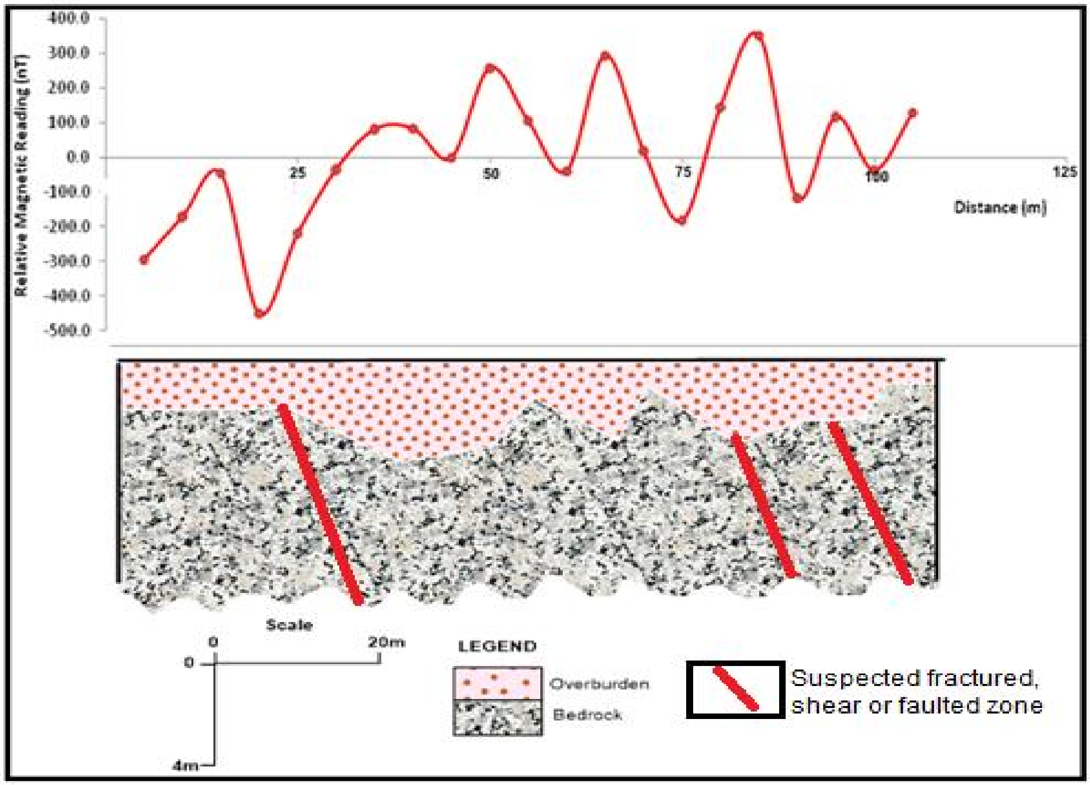

Fig. 10. Magnetic Profile and 2D-Geomagnetic section of traverse EFA-3

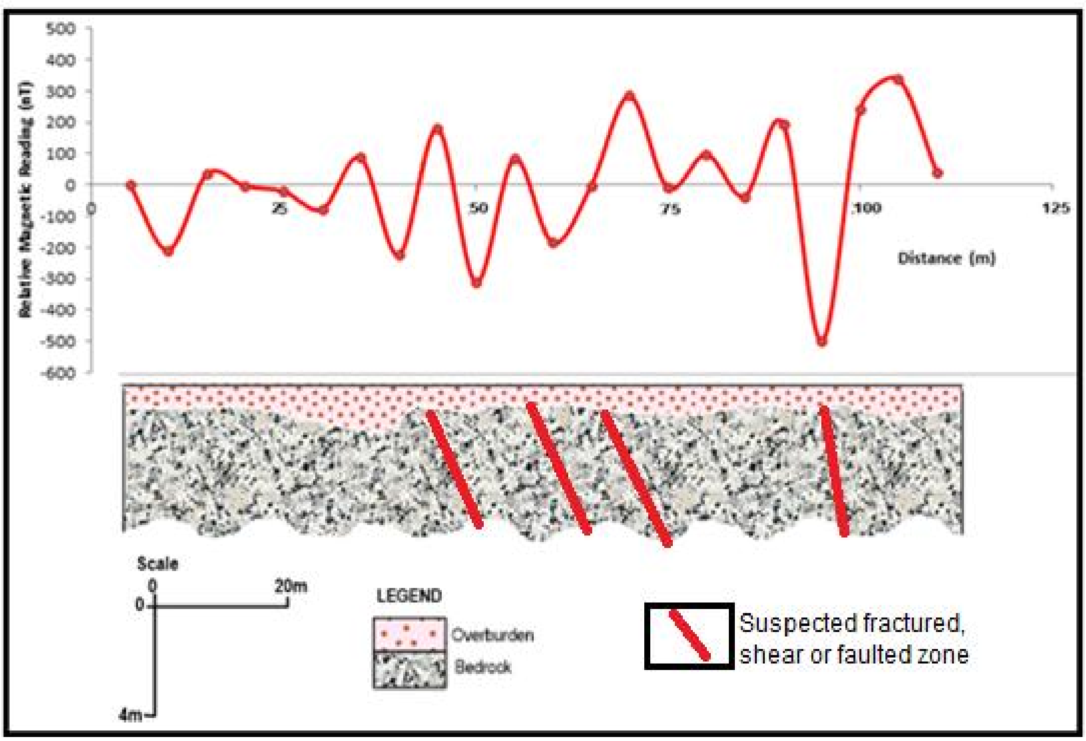

Fig. 11. Magnetic Profile and 2D-Geomagnetic section of traverse EFA-4

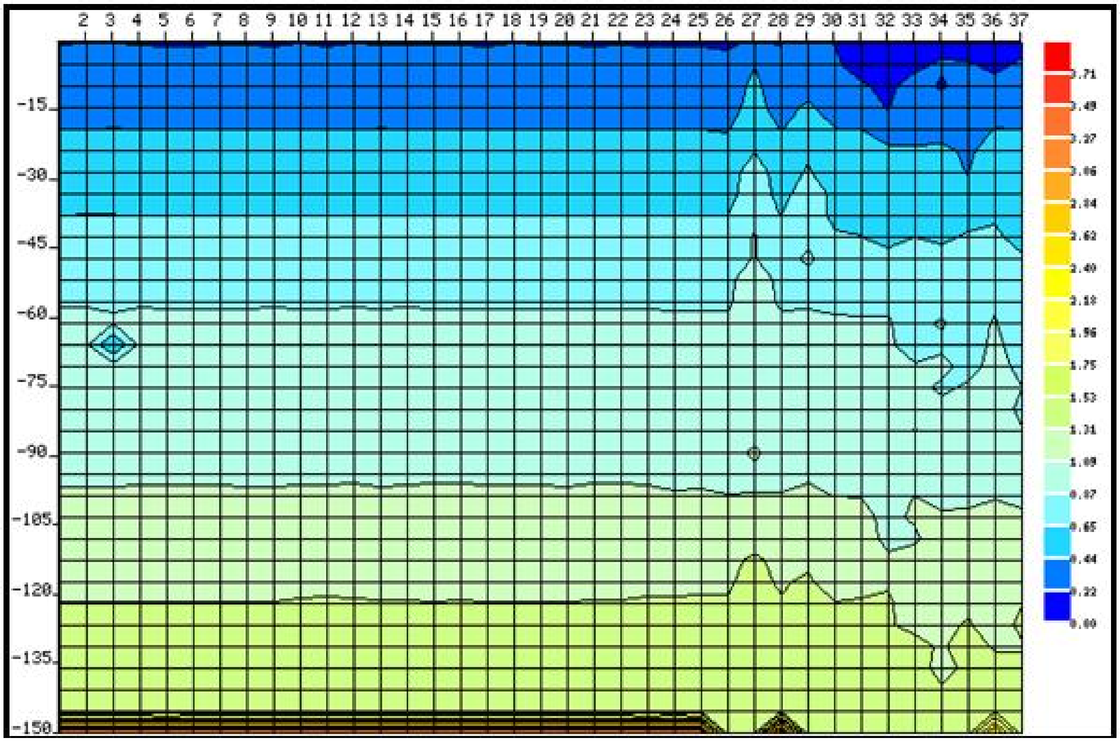

Fig. 12. 2D electromagnetic profile map of traverse EFA-1

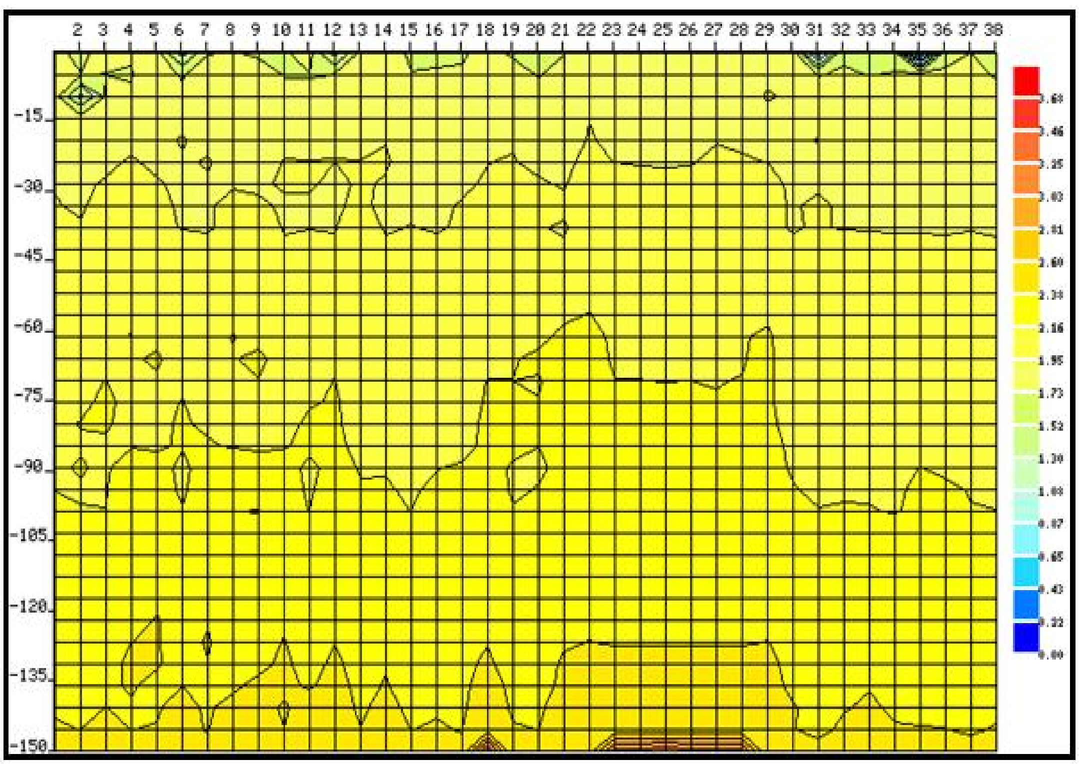

Fig. 13. 2D electromagnetic profile map of traverse EFA-2

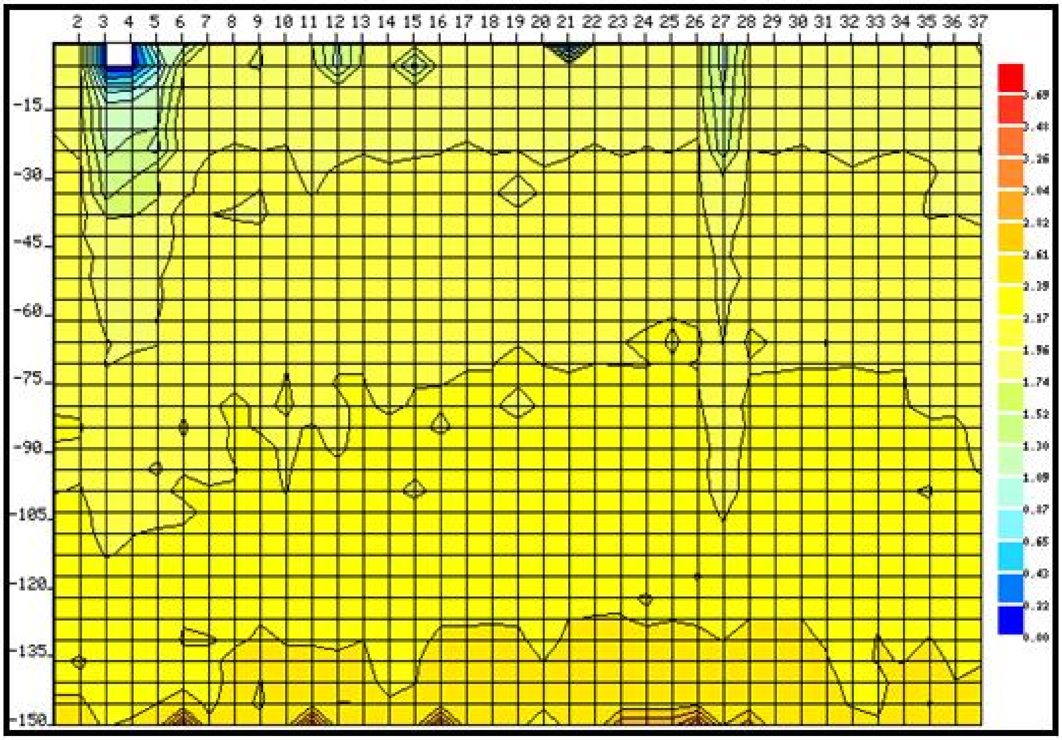

Fig. 14. 2D electromagnetic profile map of traverse EFA-3

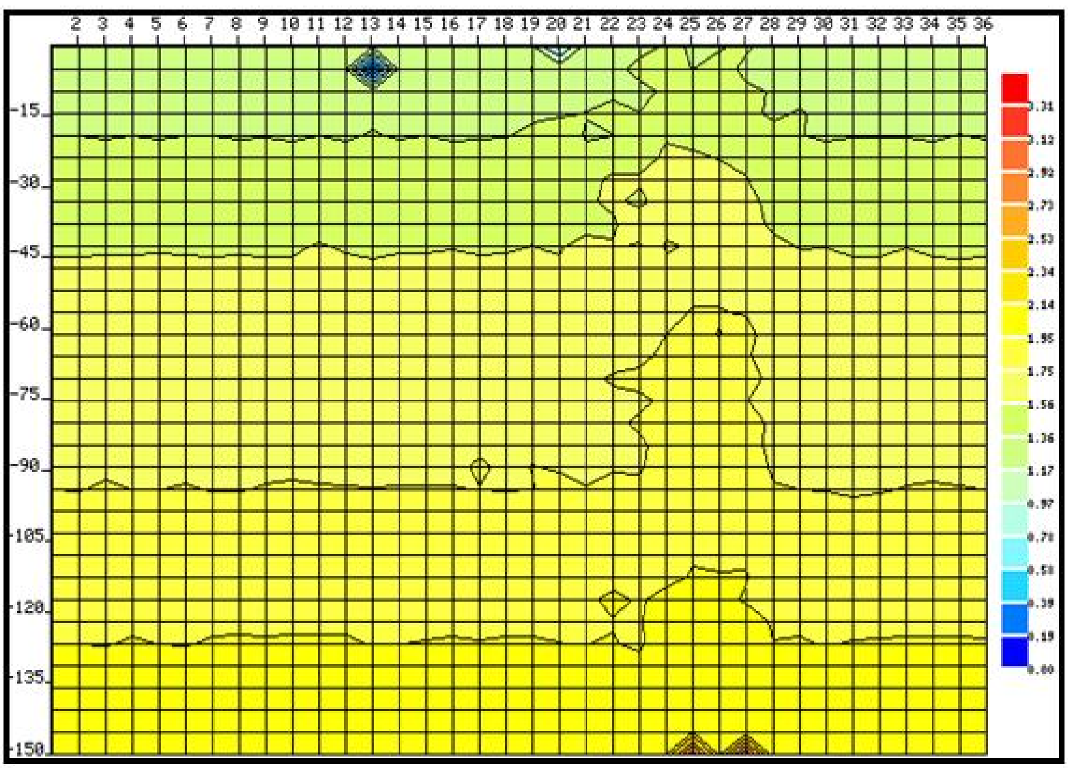

Fig. 15. 2D electromagnetic profile map of traverse EFA-4

4. CONCLUSION

Post foundation analysis of what initiated and caused the collapsed of the former Faculty of Arts building, Ekiti State University was embarked upon using ground magnetic and Impact–Electromagnetic geophysical methods. Qualitative and quantitative analyses were utilised to visualize and interpret the subsurface. Data analysis delineated suspected fractured, shear or faulted zones and also revealed that the collapsed Faculty of Arts building was sited within the incompetent clayey weathered layer; these weak zones were detrimental to the integrity and stability of the structure. Three major causes of potential failure in the area were also identified, these are: failure due to lateral inhomogeneity of the subsurface layers; failure precipitated by differential settlement and failure initiated by suspected linear geologic features. This study has revealed that thorough and detailed geophysical/geotechnical investigation is necessary before constructing any structure as it guarantees post construction stability to avoid structural failure of foundation itself and undue loss of lives and properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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