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GEOPHYSICS: AN ESSENTIAL TOOL IN GEOTECHNICAL AND ENVIRONMENTAL SITE INVESTIGATION

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ABSTRACT

The role of geophysics as a tool for geotechnical and environmental engineering site investigation at Igarra, Akoko Edo Area of Edo State, Nigeria was studied using integrated geophysical method involving electromagnetic (Very Low Frequency, VLF) and electrical resistivity (dipole - dipole) methods. The study is aimed at providing a cost effective, fast, and accurate and a holistic information of the subsurface on which proposed structures would be built for future development. Three traverses of length 205m each were laid to establish the orientation and consistency of the subsurface geological structures (faults and fractures). The traverses were laid in South-North direction perpendicular to the orientation of the geological structure (faults and fractures). The VLF method identified the conductive zones along the profile which is indicative of geological structure. Positive peak points on the VLF profile indicate high conductive zones that coincide with low resistivity zones on the dipole-dipole pseudo-section. The results obtained from the two methods show consistency of result which is indicative of geological structure (faults/fractures). High conductivity 23%, 9%, 24%, 28.4% and 27% at stations 20 m, 60 m, 80 m, 140 m and145 m were observed along traverse 1 which showed consistency with low resistivity values 21.9-46.7 Ωm, 47.3-29.1Ωm and 56.9-39.8Ωm at stations 20 – 60 m, 80 – 90 m and 120 – 130 m. Conductivity values 5%, 25.7%, 19.1%, 14%, 25.7%, 19.1% and 4.4% at stations 15m, 35m, 65m, 80m, 105m, 165m and 185m were observed along traverse 2 which coincides with 27.7-12Ωm, 17.67Ωm, 15.27 and 14.47 for stations 80m to 90m and 120m to150m. Along traverse 3, the conductivity values 4.3%, 13.2%, 22.4%, 7.8%, 10.7%, 6.2%, 11.7% and 7% were observed at stations 10m, 55m, 75m, 90m, 110m, 125m, 160m, 170m and 185m. Low resistivity values were observed at stations 70m to 90 m and 110m to150m. The high conductivity VLF values and low resistivity values overlap suggest the presence of geologic structure that showed consistency across the three traverses. The resistivity (dipole-dipole) pseudo-section shows the depth of the competent formation to be around 0 to 5m and about 10m deep in some stations. The pseudo section also revealed the geologic structures (faults and fractures). However, for geotechnical and structural construction purposes, the competent formation/bed should be confirmed with vertical electrical sounding (VES) before laying engineering foundation while the areas identified as structures could be reserved for groundwater/hydro-geophysical development because groundwater accumulation is favoured in faulted, fractured, jointed, and weathered rocks, hence the relevance of geophysics in geotechnical and environmental engineering site investigation.

KEYWORDS: Dipole-Dipole; Environmental; Geologic structure; Geotechnical; Site investigation; VLF

INTRODUCTION

The spate of structural (building, road, and rail) failure in recent years is becoming a global concern. Huge financial loss, loss of lives, loss of materials and time of investment occasioned by faulty site investigation had been reported. Causes like deficient structural drawing, absence of proper supervision, alteration of approved drawings, use of substandard materials, inefficient workmanship (labour) among others are attributed (Dimuna, 2010). Although, several material integrity tests are carried out and building code compliant. Seasoned professionals like geologist, civil engineers and builders vet some of the designs that were later executed. Several soil tests, like California bearing ratio (CBR), standard penetration test (SPT), cone penetration test (CPT), Atterberg limit test, liquid limit test, plasticity index test, AASHO test are carried out. In many cases, the standard organization of Nigeria (SON) must certify the integrity of the materials deployed to site. At the beginning of October 2020, a case was reported of building collapse at Obalende, Lagos Nigeria, while a seven storey building collapse was reported in Ikoyi few months earlier (Premium Times, 12th October, 2020). All these would have been avoided if the right tools for site investigation had been adopted. Majority of the site investigation methods are point based tests and do not provide a holistic view of the subsurface.

Although, earlier deployed for oil and gas exploration by Schlumberger brothers in early 1920s, geophysics mainly involves ground investigations, the search for engineering materials and the investigation of engineering structures. Geophysics has been used on a wide variety of engineering projects, from high-rise buildings and major dams, to the disposal of nuclear and other toxic wastes. Geophysical techniques have been applied to structural engineering problems and they now form a significant component of non-destructive testing (NDT) (McDowell et al., 2002). In most of these applications, the geophysical techniques are intended to supplement direct methods. They are not a substitute for direct methods of site assessment such as drilling or trenching, etc. They may be thought of as a means of interpolating between, and extrapolating from, borehole data. By careful planning, the number of boreholes required for adequate definition of subsurface conditions can be greatly reduced if the proper geophysical methods are chosen to supplement the direct investigation program. There are some situations in which the interpretation of geological conditions from borehole data alone could be very misleading, such as faulted ground or areas where buried channels are present, and the use of an appropriate geophysical method to aid the correlation between boreholes is vital. Some of the strength of geophysics include; determination of depth to the bedrock, mapping the bedrock structure such as faults, fractured zones, deep measurements (hundreds of feet) etc. In the developing era since 60's in Japan, geophysics has mainly contributed to investigation of new constructions such as tunnels, dams and high-rise buildings. Geophysics is considered for predicting earthquake ground motion. It has been actively used for investigation of active faults and deep subsurface structure for earthquake disaster prevention, to investigate a wide area very efficiently, to investigate non-destructively, and to image invisible underground (McDowell et al., 2002). Different methods of geophysics used for site investigation includes electromagnetics, electrical resistivity method, gravity and magnetics, seismic refraction and seismic reflection method.

Several factors are responsible for structural failures, which include geological, geomorphological, geotechnical, road usage, construction practices, and maintenance (Adegoke et al., 1980; Ajayi, 1987). Field observations and laboratory experiments carried out by Adegoke et al., (1980), Mesida (1981), and Ajayi (1987) showed that structural failures are not primarily due to usage or design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behaviour of residual soils on which the structures are built and non-recognition of the influence of geology and geomorphology during the design and construction phases. The geological factors influencing structural failures include the nature of soils (laterites) and the near surface geologic sequence, existence of geological structures such as fractures and faults, presences of laterites, existence of ancient stream channels, and shear zones. The collapse of concealed subsurface geological structures and other zones of weakness controlled by regional fractures and joint systems along with silica leaching which has led to rock deficiency are known to contribute to failures of highways and rail tracks (Nelson & Haigh, 1990). The geomorphological factors are related to topography and surface/subsurface drainage system.

For the past two decades, geophysics has proved quite relevant in highway site investigations (Nelson and Haigh, 1990), geophysical methods like electrical resistivity has been used in mapping subsurface geologic sequence and concealed geological structures (Olorunfemi et al., 2015). The electromagnetic prospecting method was used in highway investigation along Akure - Ilesha road, Southwestern Nigeria (Akintorinwa, 2008) including geophysical investigation of Ilesha - Owena highway failure in the basement complex area of southwestern Nigeria (Momoh et al., 2008). Osinowo et al., (2011) identified features which correspond to major and minor linear fractures within the basement rocks as the root cause of incessant road failure along Ijebu – Ode – Erunwon road, Southwest Nigeria using combined electromagnetics and electrical resistivity method. They identified high current density >30 and low resistivity <10 Ω m delineated rock units underlying the failed pavement to be water saturated. Oladunjoye et al., (2019) mapped the subsurface lithology in order to delineate its peat stratigraphy that has been causing foundation failure at Medina Estate Lagos using integrated GPR and vertical electrical sounding and concluded that soils at shallow depth are organic soils which are difficult foundation materials because they exhibit very high compressibility, as such shallow foundation are not recommended except some form of soil improvement is carried out. They suggested alternative approach of deep foundations in form of piles in the area. Adiat et al., (2009) evaluated causes of road failures along Igbara Oke-Ibuji road southwestern Nigeria. They identified geologic sequence and structures as the controlling factor of the failure. The aim of the this study is to provide cost effective, fast, accurate, and holistic subsurface geologic information for proposed engineering structures in the study area while the objectives are to:

i. Carry out geophysical investigation in order to obtain subsurface geologic variation
ii. Classify the subsurface according to engineering competence based on information obtained in (i) above
iii. Categorize and recommend the site appropriately for various purposes based on degrees of competence as obtained in (ii) above.

Site Description

The study area is located along the Igarra Akoko Edo roadway, Edo State, Southern Nigeria. It lies between longitudes $6^0$04'E and $6^0$08'E and latitudes $7^0$15'N and $7^0$20’N. The terrain in the study area is moderately undulating, with topographic elevation ranging from 340m to 377m above sea level. The area is traversed by the Oyami stream which flows approximately in the East-West direction (Figure 1)

The study area covered by the Southwestern Nigeria basement complex lies between latitudes $7^0$05’N and $7^0$30’N and longitudes $6^0$00’E and $6^0$30’E right in the equatorial rain forest region of Africa (Figure 2). The main lithologies include the amphibolites, migmatite gneisses, granites and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist talk-tremolite schist, and the muscovite schists. The crystalline rocks intruded into these schistose rocks. The area mapped is located in the southwestern part of Nigeria basement complex within the schist belt of the Igarra area and has the gneissic-schist-quartz complex. Six major rocks underlie the basement complex uncomformably in the area which are: Meta-conglomerate, Quartzite, Calc-gneiss, Marble, Schist, and Granite.

Methodology

Geophysical investigation involving the integration of Very Low Frequency Electromagnetic (VLF – EM) and Electrical Resistivity methods using dipole-dipole array were carried out in the study area to determine geological structures that may impair present and future structural development. Three traverses of 205m length were established. Traverses 1, 2 and 3were laid parallel to each other (Figure 3). ABEM WADI was used for the VLF EM data acquisition along the traverses. The VLF transmitter operating at frequency of 17.6 KHz was used for the investigation. The station to station interval of 10m was adopted for the survey. The Electrical Resistivity method utilized dipole-dipole array. The excel worksheet and Karous - Hjelt software were used for processing the VLF EM data and Dipro - Win software for the electrical resistivity (dipole-dipole) data.

Results and Discussion

The results of the integrated Geophysical methods carried out along the three traverses are displayed below (Figures 4-6). The results are displayed as profiles, curves, pseudo-sections.

Traverse 1

Very Low Frequency: Figure 4a presents the VLF profile and pseudo-section for traverse1. Stations distances of 15m, 35m, 65m, 80m, 105m, 165m, and 185m show high conductivity response of 5%, 25.7%, 19.1%, 14%, 25.7%, 19.1% and 4.2% respectively which indicates the presence of conductive body and suggestive of geological structure which could be fault or fracture.

Dipole-dipole: station 80m, 120 to150m (Figure 4b) show low resistivity value of 27.7Ωm to122Ωm and 17.67Ωm, 15.27Ωm and 14.47Ωm which reveals the presence of geological structures interpreted to be faults, or fractures. This result complements the result obtained from the electromagnetic method.

Traverse 2

Very low frequency (VLF): Stations 20m, 65m, 80m, 140m, 145mshow high conductivity response of 23.2%, 9.9%, 24%, 28.4%, 27.4% respectively which show possible presence of conductive bodies suggesting geological structures like fault and fractures (Figure 5a).

Dipole-dipole: Stations 20m to 60m, 80m to 90m and 120m to130m (Figure 5b) show low resistivity values of 21.9Ωm to 46.7Ωm, 41.3Ωm to 29.1Ωm and 56.9Ωm to 39.8Ωm respectively, which shows the presence of conductive bodies. The values also confirm the presence of faults, or fractures indicated by the obvious depression zones.

Traverse 3

Very low frequency (VLF): Stations 10m, 55m, 75m, 90m, 110m, 125m, 160m, 170m and 185m along the VLF profile and the pseudo section (Figure 6a) show high conductivity response of 4.3%, 13.2%, 22.4%, 7.8%, 10.7%, 6.2%, 11.7%, and 7% respectively which shows the presence of conductive bodies.

Dipole-dipole: Stations between 70m and 90m show low resistivity values of 26.4Ωm to 9.8Ωm, and 46.7Ωm to 24.8Ωm respectively, which may be an indication of the presence of faults and fractures (Figure 6b).

CONCLUSIONS

The investigation across the three established traverses revealed that the topsoil depth ranges from 0-5m and occasionally about 10m at some points along the traverses. Along traverse 1, slight depression is observed between stations 70m and 90m considered as the beginning of the geological structure, while stations between 110m and 150m revealed a larger geological structure. In traverse 2, depression is observed between station 70m and 90m, and station 110m-140m to deeper depths. In traverse 3, depression suggestive of geological structure is observed between station 70m and 90m, and stations 110m-150m. The information along the three traverses shows consistency of the identified geological structures in the study area. Depth 0 to 5m depicts the topsoil and subsequently competent formation suitable for engineering and constructions purposes. Siting structures on faulted/fractured zones could lead to degrees of distress, ranging from multiple cracks, sinking of building, and partial or complete differential settlement. The faulted zones between stations 70m to 90m and stations 110m to 150m could be considered weak zones usually suitable for groundwater development and hydrogeological purposes. The result of the investigation clearly shows the features of the subsurface with respect to its geotechnical and environmental engineering relevance. The area that shows engineering competence should be marked out by further confirming the depth of the competent formation and given the appropriate treatment for such purpose. The identified geological structures (faults and fractures) could be dedicated for groundwater development due to it hydrogeological significance.

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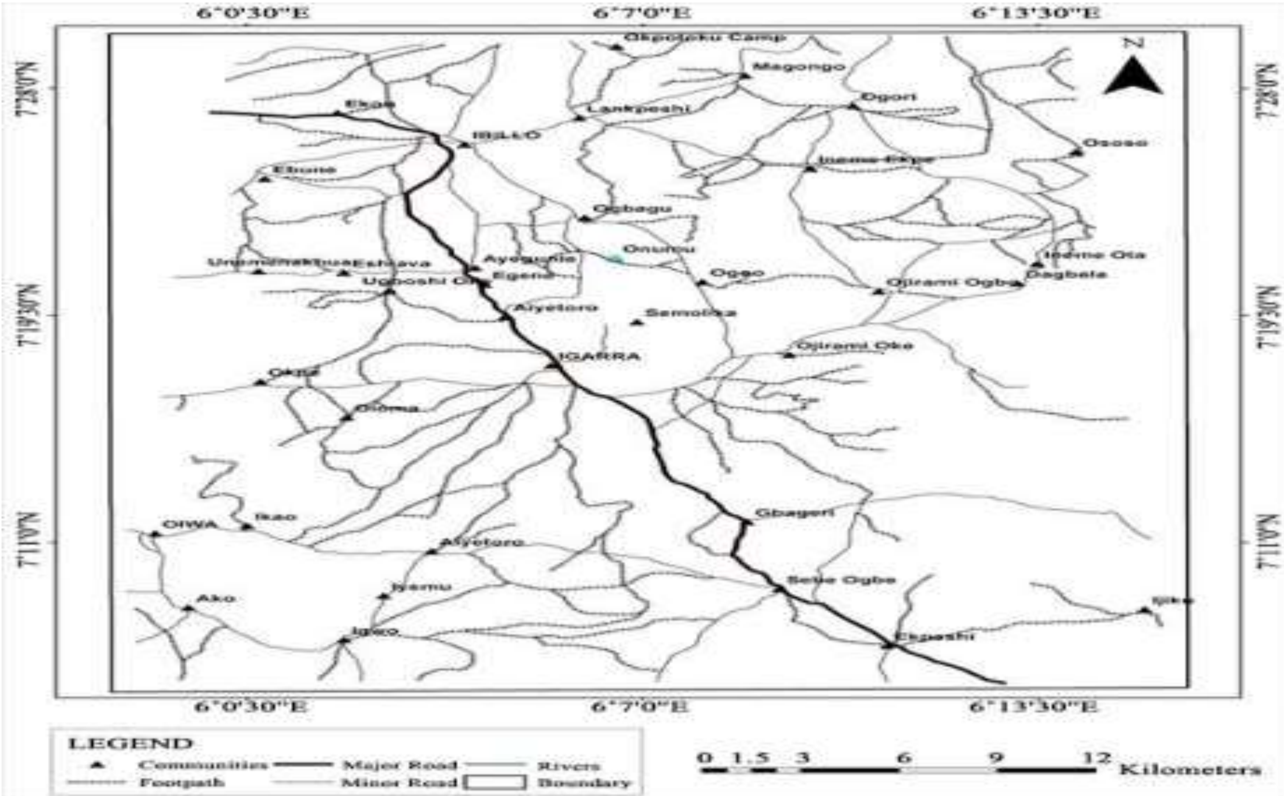

Figure 1: Accessibility Map of the study area (Mohammed et al., 2019)

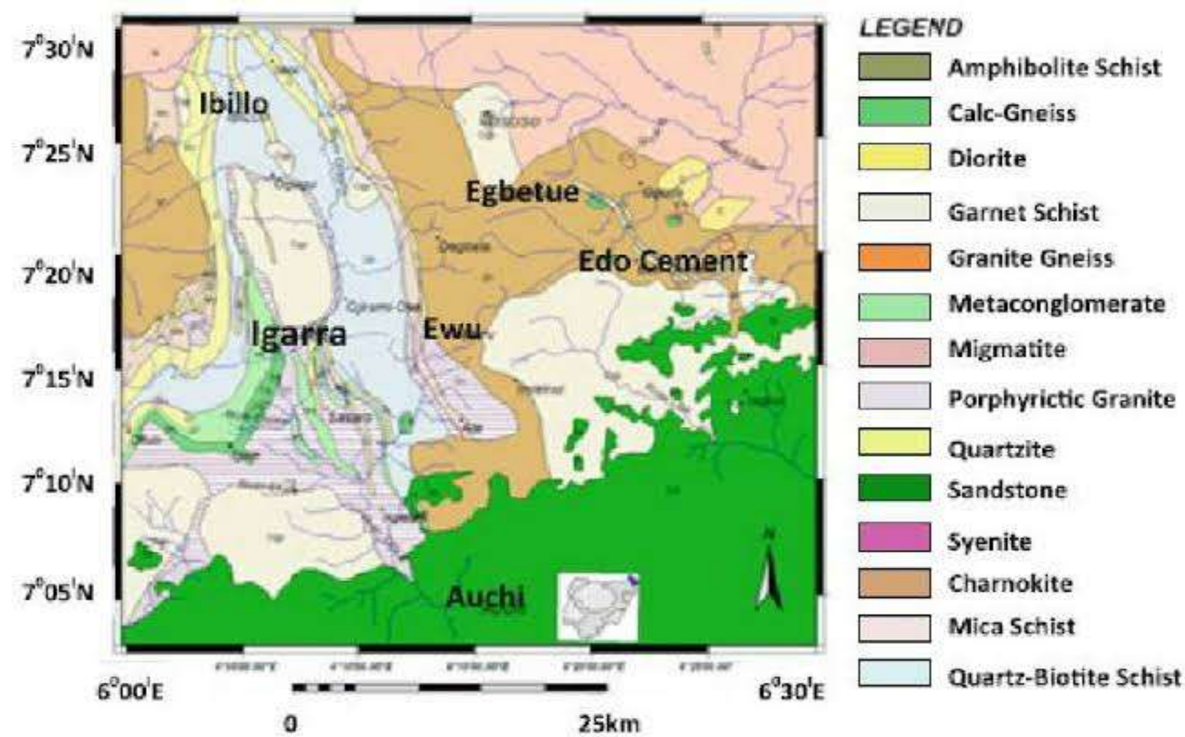

Figure 2: Geological Map of Igarra (Obiadi et al., 2015)

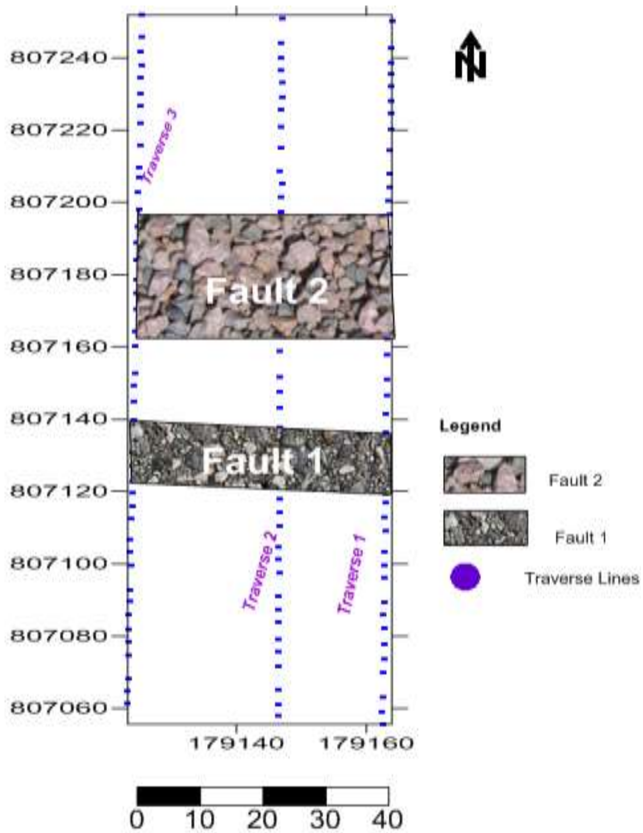

Figure 3: Data acquisition Map of the study area

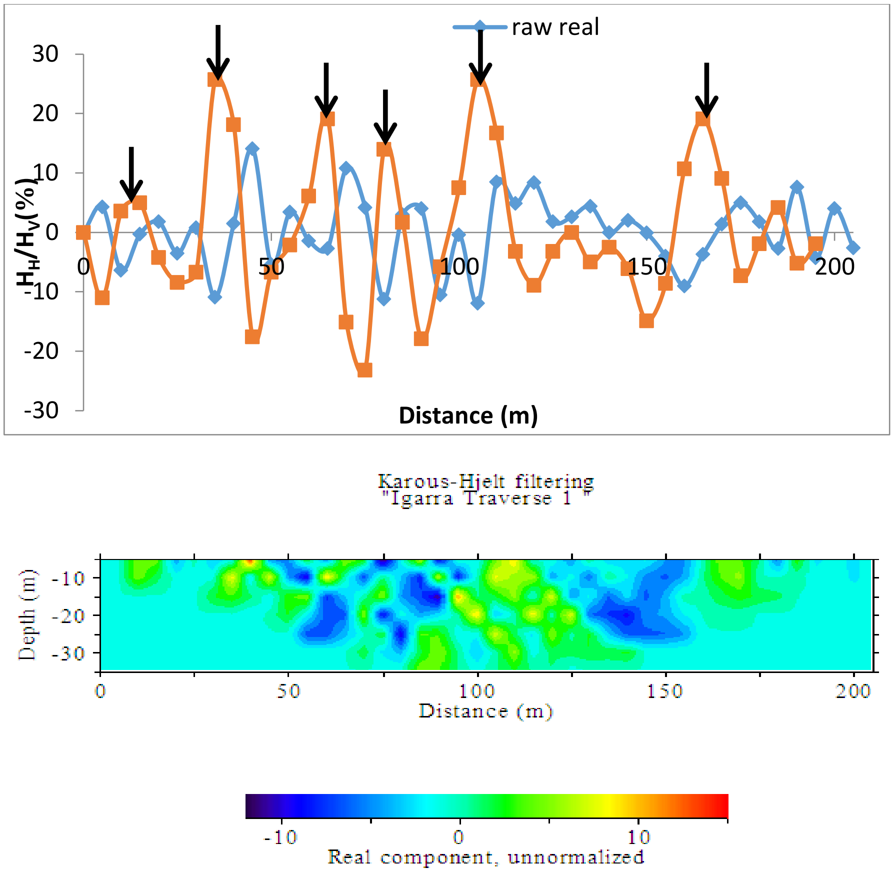

Figure 4a: (VLF) profile and pseudo-section for Traverse 1

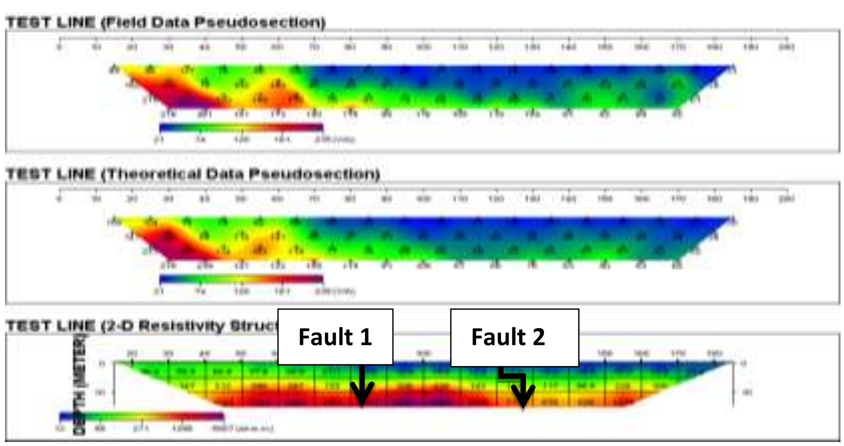

Figure 4b: Dipole-dipole pseudo section for Traverse 1

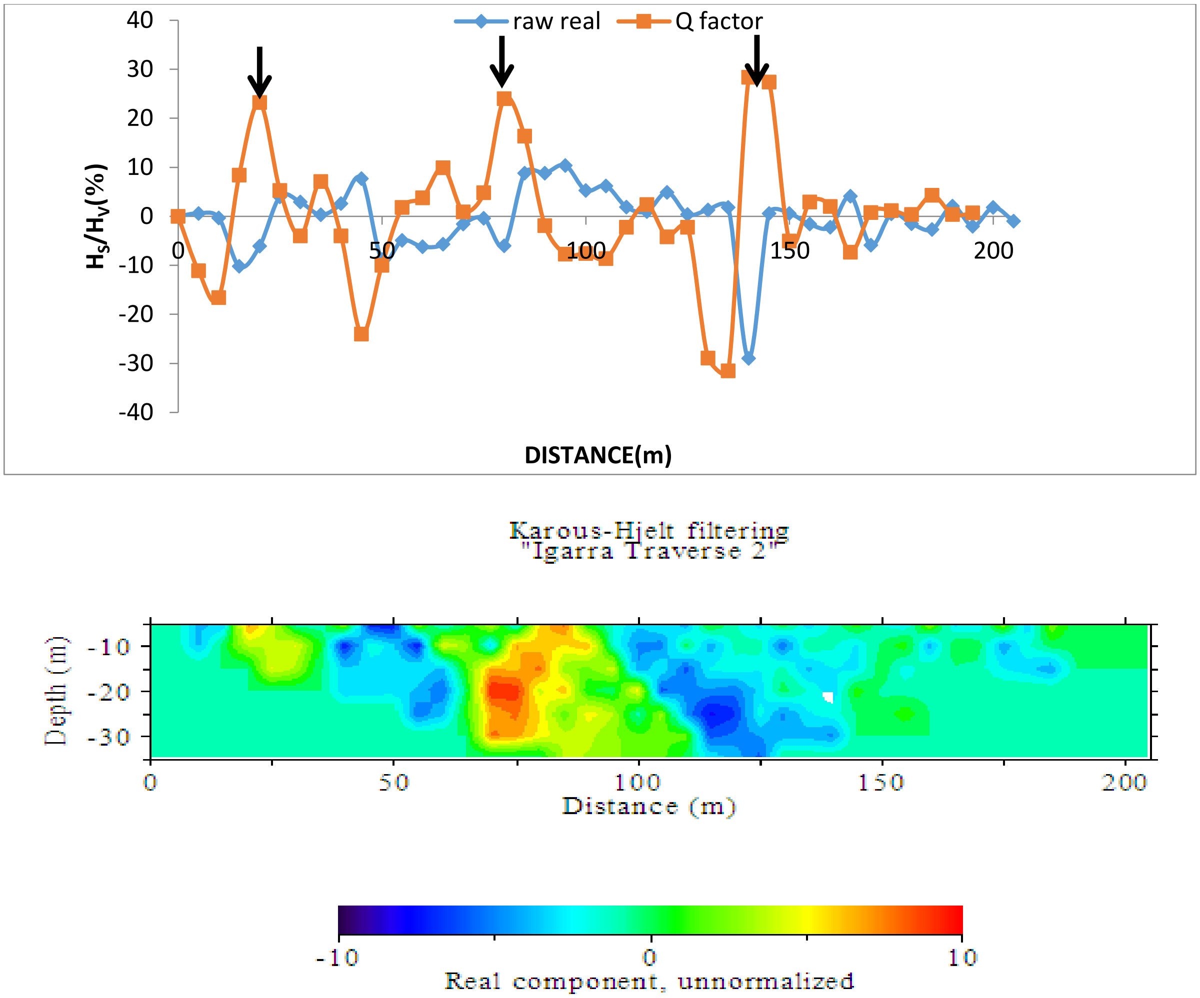

Figure 5a: (VLF) Profile and pseudo section for Traverse 2

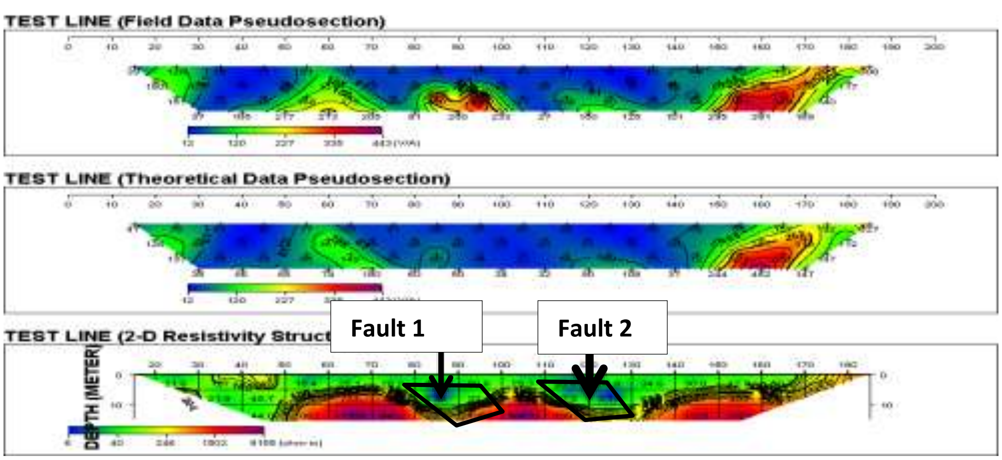

Figure 5b: Dipole-dipole pseudo section for Traverse 2

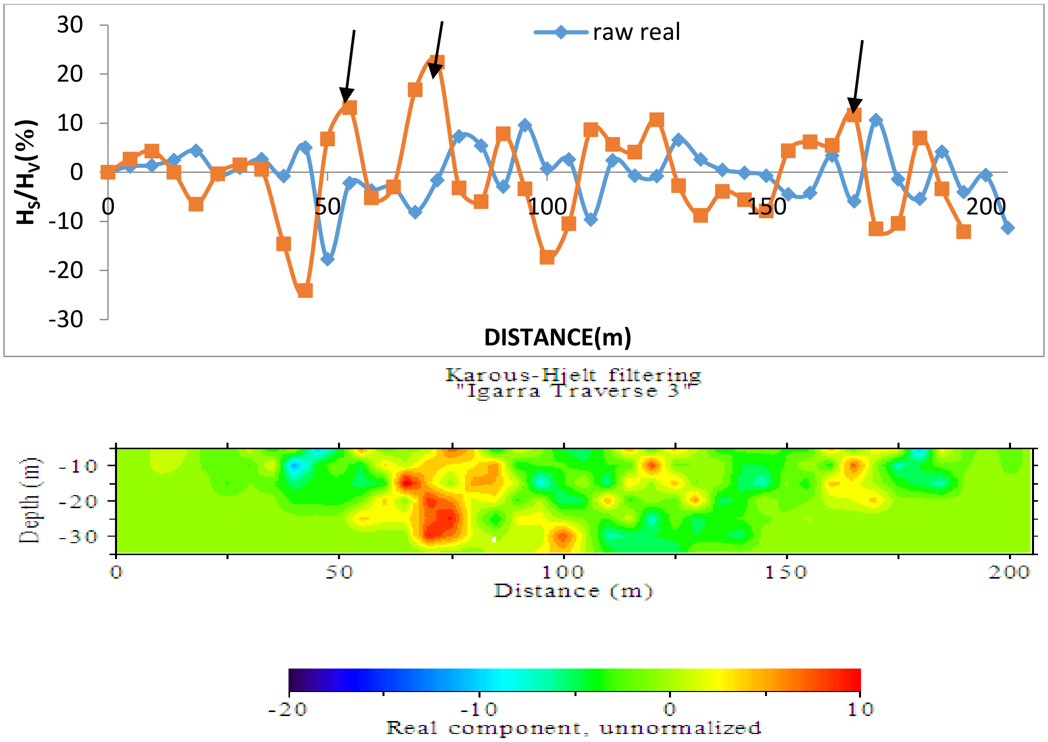

Figure 6a: (VLF) Profile and pseudo section for Traverse 3

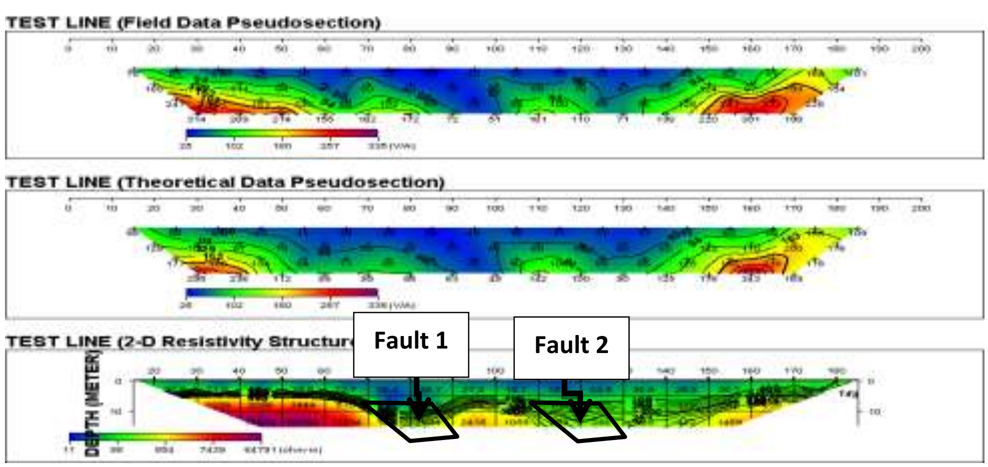

Figure 6b: Dipole-dipole pseudo section for Traverse 3