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VERY LOW FREQUENCY ELECTROMAGNETIC SURVEY FOR SUBSURFACE CHARACTERIZATION WITHIN PART OF PHASE II, AHMADU BELLO UNIVERSITY, ZARIA, KADUNA STATE

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ABSTRACT

Lately, there has been an increase in the rate of structural failure in Nigeria and many parts of the world due to many reasons among which is subsurface inadequacy. This has led to loss of lives, properties, a lot of casualties and has become a critical problem that requires proper attention. Very low frequency (VLF) electromagnetic method was used for subsurface characterization within part of phase II, Ahmadu Bello University, Zaria, Kaduna State. VLF data were collected along fourteen (14) profiles covering an area of 84000m^2 and measurements were made at 10m interval along each profile with profile length of 300m. The VLF data were collected using Terra-Plus VLF instrument and interpreted using KHFFILT software. The interpretation of VLF data using the Hjelt-Karous filter resulted in current density sections. The representative current density plots show the conductivity distribution of the subsurface. The current density variation was assumed to indicate the presence of fractures at the 14 stations of which profiles 7, 10 and 12 are not well fractured. The fractures identified are mostly oriented in the N-S direction of the study area.

Keywords: Very Low Frequency, Terra-Plus VLF, Fracture zone, Current density

INTRODUCTION

Structural failures are often associated with poor quality building materials, age of buildings and foundation problem. In recent times, Ahmadu Bello University, Zaria – phase II has been undergoing some form of development with structures being erected and so the assessment of subsurface geology with respect to the durability of the buildings is important.

Foundations are affected not only by design errors but also by foundation inadequacies such as sitting them on incompetent earth layers (weak zones). When the foundation of a building is erected on less competent layers, it poses serious threat to the building and can also lead to its collapse (Adelusi *et al.*, 2013).

The mapping of fracture zone which is a break in crystalline basement rock due to tectonic forces or intrusion of magmatic bodies is important for civil engineering and hydrogeology (George *et al*. 2013). Areas that are extensively fractured are considered as weak zones but on the other hand are considered suitable for groundwater development (Alagbe *et al*. 2013).

George *et al*. (2013), carried out VLF-EM method for fracture zone detection in parts of Oban Massif, Southeastern Nigeria. A total of twelve (12) profiles were covered during VLF data collection with 5m sample interval along each profile with spread length of between 120 and 650m. The results of the study showed the presence of fracture zones and that are prominently oriented in the NE-SW and NW-SE direction. The results also showed that most of the fracture zones were located at a depth range of 0 to 60m within the subsurface.

In 2014, Adagunodo *et.al*. used VLF-EM profiling to investigate the cause(s) of road failure along Takie-Ikoyi road, Ogbomoso, Southwestern Nigeria which occurred in barely two (2) years of construction. VLF-EM data was taken at 10m interstation spacing on 2 traverses along the road where each traverse covers a total length of 300m. The VLF-EM raw real data was converted to the pseudosection using the KHfilter software which allows for the determination of the length of fractures and depth to top and bottom of fractures and attitude of the conductive body.

This research is therefore aimed at characterizing the subsurface structures in order to determine the competence of underlying rocks which will serve as valuable information for civil engineers for the construction of buildings within the study area.

Location and Geology of the Study Area

The study area occupies a portion of the Kubanni River Basin and lies between longitudes 7º35′40″- 7º38′50″E and latitudes 11º05′50″ - 11º10′25″N on the North-Western part of the basin (Fig 1). The Kubanni River Basin is underlain by rocks of the Precambrian age. Outcrops of the biotitic gneiss are common in the area, especially along the stream channel where they occur as deeply weathered rocks (Wright, 1970). The biotitic gneiss complex consists of medium to coarse grain and moderate to weekly foliated rocks which constitute about 30-40% of the basement complex exposed in the basin (Wright and McCurry, 1970).

Oyawoye (1964), explains that there is a structural relationship between the basement Complex and the rest of the West African basement. This is partly because the whole region was involved in a single set of orogenic episode, the Pan African orogeny, which left an imprint of structural similarity upon the rock units. The gneisses are found as small belts within the granite intrusions, and are also found east and west of the batholiths (McCurry, 1970). The biotite gneiss extends westwards to form a gradational boundary with the schist belt and eastward where they are occasionally broken up by the older Granite. (Wright and McCurry, 1970).

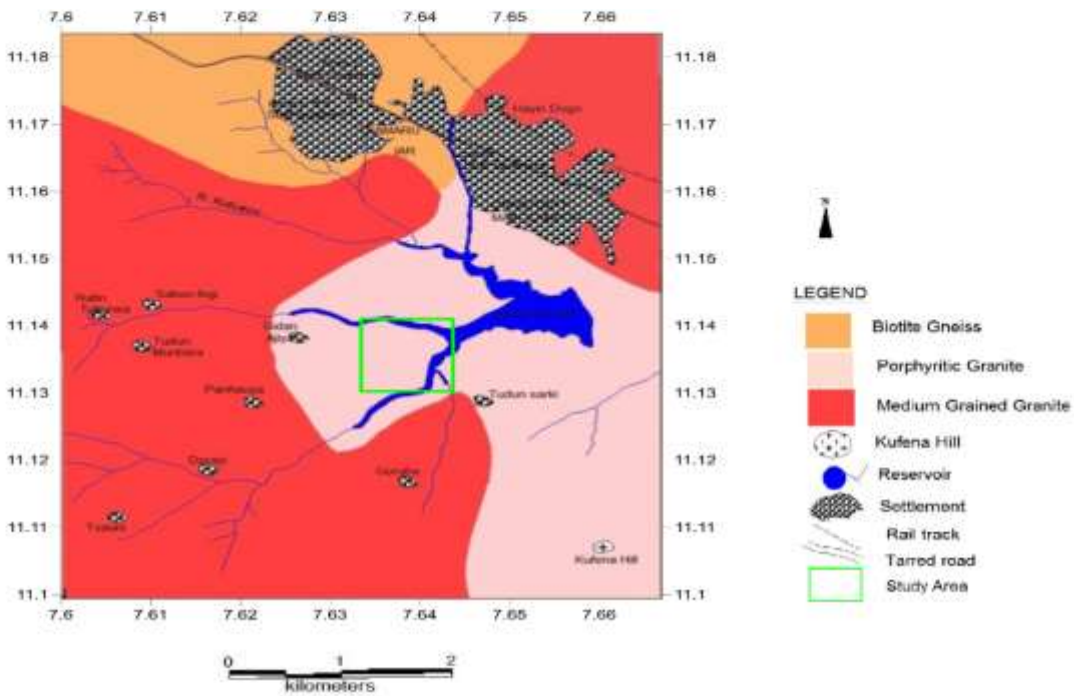

Fig. 1: Geologic map of the Study Area (modified after Garba *et al*., 2014)

Very Low Frequency (VLF) Electromagnetic Method

VLF is a non-invasive electromagnetic method that uses very low frequency (VLF) radio waves ranging from 15–30 kHz to locate water-bearing fractures and other conductivity contrasts in the subsurface that may be indicative of mineralization, contaminant plumes, and gross variations in lithology.

When a conductor (like a fracture zone) is crossed by the electromagnetic field, an induced current (Eddy current) flows through it and produces a secondary magnetic field *(Hs)* out-of-phase with the primary magnetic field oriented in any direction (McNeill and Labson 1991). However, in the absence of subsurface electric conductors the transmitted signal is horizontal and linearly polarized. Interference between the primary magnetic field and secondary magnetic field generates a magnetic field which is resultant polarization ellipse. The components measured in the VLF method are tilt angle α and ellipticity ε.

Qualitative interpretation of VLF method data can be performed with Fraser filter and Karous–Hjelt filter (linear filter). Data used in the process of filter is the tilt angle (%). Fraser filter is a low-pass function for estimating the average of tilt angle measurements produced by a subsurface conductor. In Fraser filter, large amplitudes can be estimated as signatures from conductive zones (Sundararajan *et al.*, 2006; Monteiro-Santos *et al*., 2006). The filter divides tilt angle data with 90° to transform zero-crossing into peaks and reduces noise, such as topographic effect. In a linear sequence of tilt angle measurements M_1, M_2, M_3, ..., M_n, the Fraser filter $f2,3$ is expressed as:

$$f2,3 = (M3 + M4) - (M1 + M2) \qquad (1)$$

$f_{2,3}$ is filter Fraser value that plotted midway between M_2 and M_3 tilt angle data.

Karous-Hjelt filter is used to determine the value of the current density equivalent. Resistive zones are interpreted as areas with lower values of current density and vice versa (Benson *et al*., 1997 in Monteiro Santos F A *et al.*, 2006). Karous-Hjelt filter uses linear filter theory to solve the integral equation in the current distribution. The linear equation obtains current density values for various depths along the line from vertical magnetic field of each measured point. The position of current density can be used to interpret the width and dip of anomaly at certain depths.

The formula used is:

$$\frac{\Delta z}{2\pi}\left(\frac{I}{A}\right)\frac{\Delta x}{2} = -\,0.102\,H_{-3} + 0.059\,H_{-2} - 0.561\,H_{-1} + 0.561\,H_1 - 0.059\,H_2 + 0.102\,H_3 \qquad (2)$$

where Δz is the depth (m), (I/A) is the current density (A/m^2), Δx is the distance between data points (m). The H_2 through H_3 values are the normalized vertical magnetic field anomalies at each set of six points. The location of the calculated current density is assumed at the geometrical center of the six data points (Sundararajan *et al.* 2007).

Data Acquisition

The survey was carried out using the Terra-Plus VLF equipment, a hand-held Global Positioning System (GPS), pegs, hammers and a measuring tape. An area of $84000m^2$ was covered and VLF data were collected along fourteen (14) VLF-EM profiles (Fig 2). The readings were taken at station interval of 10m along each profile in the N-S direction with profile length of 300m. In the course of this survey, areas that contain cultural features that may mask anomalies associated with the intended target strike were avoided. Also, the direction of the transmitting stations was almost perpendicular to the traverse before readings were taken.

Fig. 2: Google Earth Image of Study Area with profile layouts

RESULTS AND DISCUSSION

The VLF data were interpreted using the KHFFILT software. The filtering procedures were based on Fraser (1969) and Karous and Hjelt (1983) methods. Fraser filter turned the crossing points into peak signals that enhance the conductive structures and Karous and Hjelt (1983) filtering was used to obtain current density pseudo-sections (mA/cm^2). The results show both positive Fraser and Karous-Hjelt anomalies and negative Fraser and Karous-Hjelt anomalies along the traverses and is indicative of the possible fracture zones along each transverse. For each profile, a plot of the Fraser filtered data and the Karous-Hjelt plots are shown (Fig 3-Fig 14).

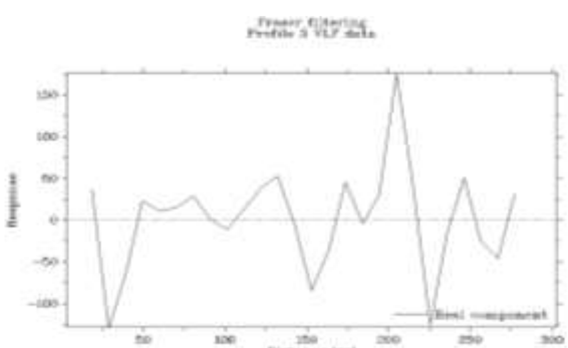

Fig. 3: A plot of filtered in-phase data against distance for profile 3

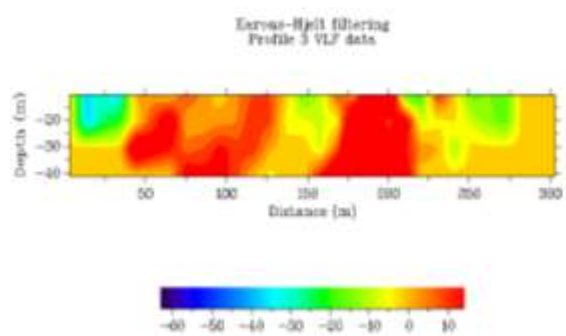

Fig. **4**: Current density cross section plot of in-phase data against distance for profile 3. The scale of values represents the current density, positive values represent conductive zones.

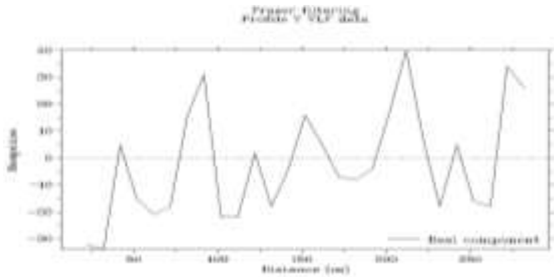

Fig. **5**: A plot of filtered in-phase data against distance for profile 7

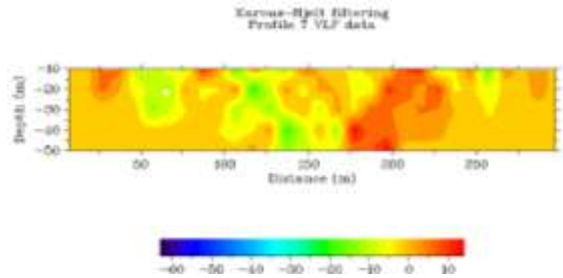

Fig. **6**: Current density cross section plot of in-phase data against distance for profile 7. The scale of values represents the current density, positive values represent conductive zones.

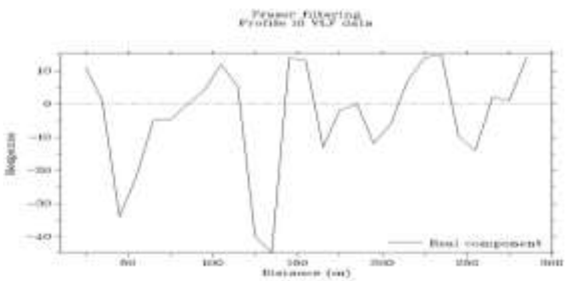

Fig. **7**: A plot of filtered in-phase data against distance for profile 10

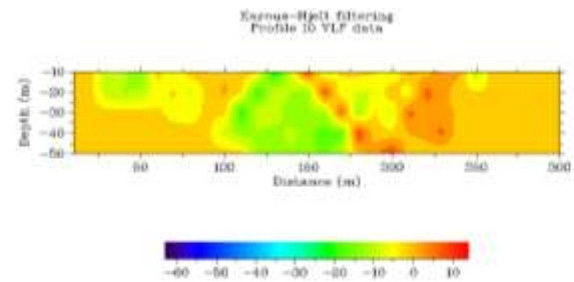

Fig. **8**: Current density cross section plot of in-phase data against distance for profile 10. The scale of values represents the current density, positive values represent conductive zones.

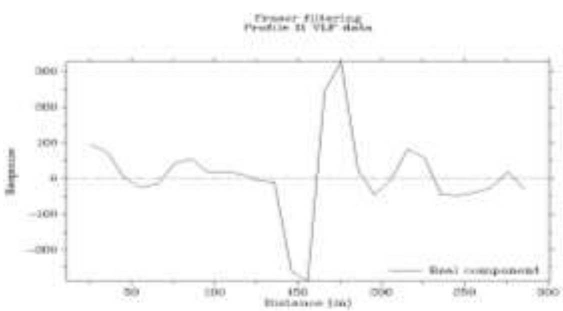

Fig. **9**: A plot of filtered in-phase data against distance for profile 11

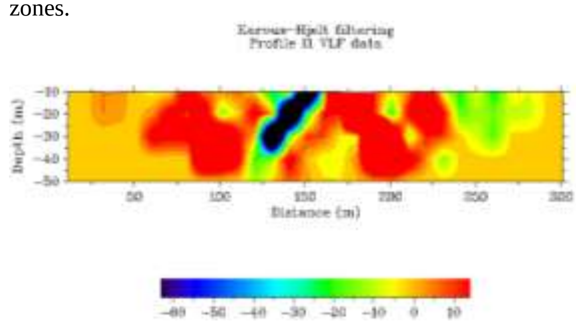

Fig. **10**: Current density cross section plot of in-phase data against distance for profile 11. The scale of values represents the current density, positive values represent conductive zones.

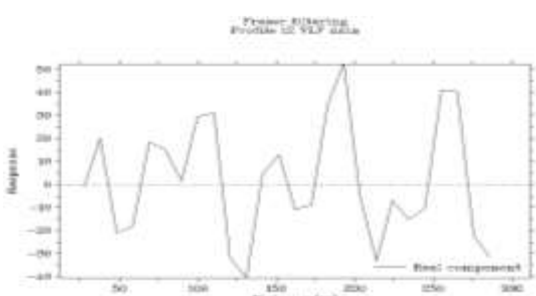

Fig**. 11**: A plot of filtered in-phase data against distance for profile 12

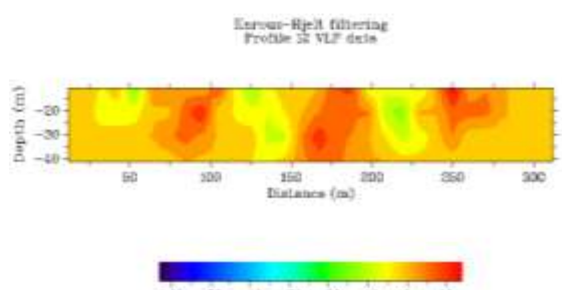

Fig. 12: Current density cross section plot of in-phase data against distance for profile 12. The scale of values represents the current density, positive values represent conductive zones.

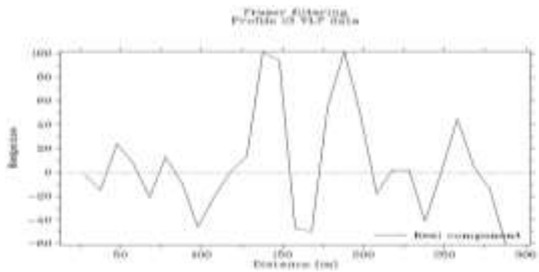

Fig. 13: A plot of filtered in-phase data against distance for profile 13

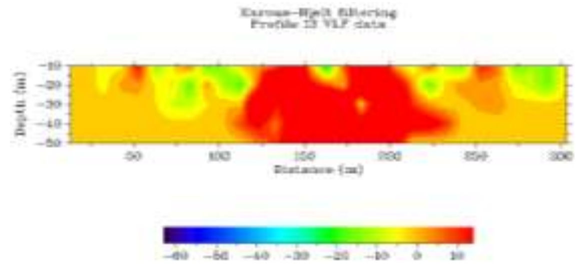

Fig 14: Current density cross section plot of in-phase data against distance for profile 13. The scale of values represents the current density, positive values represent conductive zones.

The filtered data plot of profile 3 shows a prominent positive response at a distance of 150-220m (Fig 3). The probable fracture zone is at a depth of 0-40 m and is oriented in the N-S direction (Fig 4). Other possible fracture zones are observed at distance 50-75 m and 100-150 m at a depth of 20-35 m and 0-40 m respectively (see Fig 4).

Along profile 7, Five (5) not well-fractured but positive responses were identified on the Fraser filter plot (Fig 5 and 6) at distance 25-40 m, 75-100 m, 140-170 m, 200-225 m and 260-300 m. They are positioned at depths 0-20 m, 0-15 m, 0-30 m, 0-50 m and 0-25 m respectively (Fig 6).

Two (2) conductive zones with positive responses were spotted along profile 10 (Fig 7). One is located at a distance of 140-160 m, at a depth of 0-50 m and is oriented in the NE-SW direction while the other is at a distance of 210-240 m, at a depth of 0-45 m and is oriented in the N-S direction (Fig 8).

Along profile 11, four (4) conductive zones can be identified with positive responses on the Fraser filter plot (Fig 9). The pronounced fractures are at distance 75-125 m, 160-180 m and 200-300 m all at depth of 0-50 m while the not well fractured zone is at a distance of 0-50 m and at a depth of 0-25 m (Fig 10).

Three (3) conductive zones with positive Fraser filter responses can be spotted along profile 12 (see Fig 11). The probable fractures are at distance 60-110 m, 175-200 m and 240-275 m. They are all at the depth of 0-40 m and are oriented in the N-S direction (Fig 12).

Along profile 13, four (4) conductive zones with positive responses on the Fraser filter plot can be observed (Fig 13). Two (2) are identified as well fractured and interconnected. They are at a distance of 125-150 m and 175-200 m, both at a depth of 0-50 m and are oriented in the N-S direction. The other two (2) are not well fractured and are distance 30-60 m and 250-275 m at depths 0-20 m and 0-35 m respectively (Fig 14).

CONCLUSION

Very low frequency (VLF) method is one of the geophysical methods that are rapid, cost effective and have proven to be effective for subsurface characterization. It was used to locate fractures that may pose danger to the structures being erected, determining their depths, lateral extent and orientation. A probable fractured basement was observed at the 14 stations of which profiles 7, 10 and 12 are not well fractured. The fractures identified are mostly oriented in the N-S direction of the study area.

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