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Electromagnetic Characterization of the Fracture System
Within Older Granite of North Central Nigeria

Olatunji S.

Department of Physics
University of Ilorin, Ilorin, Nigeria.

Abstract

A VLF electromagnetic survey was carried out on the whole land area of Federal College of Education Zaria, seated on the older granite part of the basement complex of the north central Nigeria. VLF machine, model EM/6, was used to collect data along 8 VLF survey profiles at station spacing of 66 m across the strike of the geological formation. Fracture, sheared and faulted zones were reported all over the area, with the prominent ones concentrated at the north - western corner, which diminished progressively towards south-west direction of the site. The in-phase and quadrature component plots revealed conductivity high of +130% and +86% respectively around the north-west while the lowest conductivity occurred towards the eastern part of the campus. Consequently, north western side appears the most promising water-bearing zone.

Keywords: *VLF, Profile, In-phase, Quadrature, Fracture, Source-coil, Receiver-coil, Conductivity.*

Introduction

In carrying out any geophysical studies of a site consideration is usually given to a preferred method based on the nature and parameters of interest. Potential methods such as direct current (dc) resistivity and Very Low Frequencies (VLF) are very adequate, cheap and fast to investigate the nature of underlying earth materials in order to obtain parameters like aquifer depth and basement depth.

VLF is specifically good when to identify weathered basement and while studying the fracture systems in the subsurface rocks. This is so, in the words of Parasnis (1962), owing to the fact that VLF machine responds well to rock components at shallow depth which are good conductors of electricity. The field work could be done by a minimum number of field persons and few instruments are observed at a time. These make the method cheap, fast and most suitable for reconnaissance investigation that requires fewer details.

The outcome of this work would found its merits in the area of ground water location, plans of sewage system, clue to proper location of high rise building and so forth. The study site covered the whole landmass of the Federal College of Education, Zaria; bounded approximately by longitudes $7^{\circ} 43' 21''$ E and $7^{\circ} 43' 49''$ E and latitudes $11^{\circ} 05' 10''$ N and $11^{\circ} 05' 28''$ N within Zaria topographic map sheet 102 SW. The area is located on a plateau at a height 570 m above sea level with a tropical continental climate (Ologe, 1971). Harold (1970) further confirmed that the area falls within the semi-aride zone of Nigeria with 10.2 mm annual rainfall over a period of 40 years (Olufemi, 1985).

Corresponding author: E-mail: sam61ng@gmail.com

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Materials and Method

A total of 8 travel lines with eleven data points on each, were observed, making a total of 88 data points. Figure 1 shows the distribution of the VLF survey points in the study area: A grid size of 66 m was maintained in line with the recommendation of 50 x 50 ft along travel line perpendicular to the strike of the geological structure of interest and also perpendicular to the station used (Fraser 1969).

VLF machine model EM-6 was used to receive signals from a GAR European VLF, transmitting at frequency 16.0 Hz. The station coordinate is 01WW11-52N22. The signals were recorded at each of the VLF stations shown in figure 1. EM-6 VLF machine measures the in-phase and out-phase/quadrature components of the vertical magnetic field (H_s) as a percentage of the horizontal primary field (H_p) (that is, tilt/dip-angle and ellipticity). In-phase reading is taken from the mechanical inclinometer while quadrature reading is taken from a graduated dial located at the lower end of the VLF instrument.

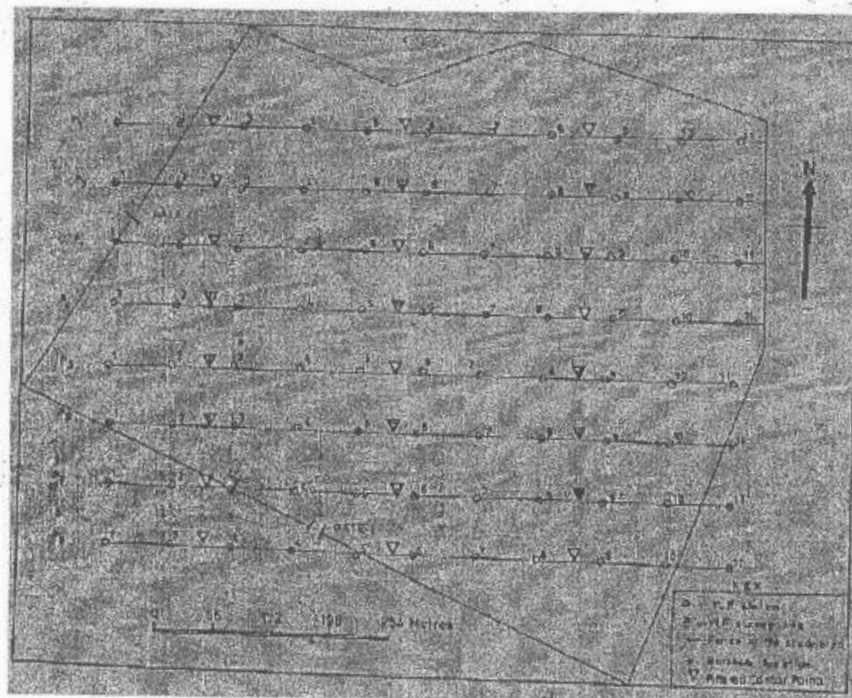


Figure 1: VLF and Filtered Sample

Theory

EM method involves the propagation of time-varying low frequency electromagnetic field in and over the earth from a transmitter. An induced signal from the buried conductive geologic features is received by the VLF machine (Olatunji, 2005) via the resonance principle. Thus, the method could respond well to geological minerals and archaeological artifacts as it responds well to good electrical Conductors at shallow depths.

The VLF machine measures the resultant waves in two folds: that which is in phase with the primary field whose amplitude is referred to as in-phase or "real" component of the resultant field; and second component which is usually 90° displaced and hence considered as been out of phase with the primary. So its amplitude is called 'out-phase', 'Imaginary' or 'quadrature' component of the resultant.

In simple form, inductive coupling is considered within three arbitral coils- transmitter as coil 1, subsurface conductive body as coil 2 and receiver (that is, VLF machine) as coil 3 (Figure 2) The inductive coupling between coil 1 and 2 is responsible for the 90° phase lag of secondary field; and additional phase lag of θ depends on the conductivity property of the coils2 (Figure 3).

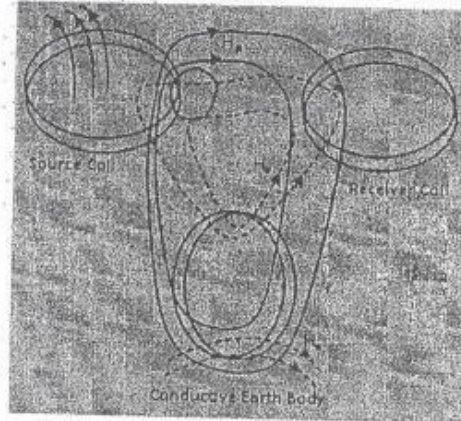


Figure 2: Transformer Analogy of the Induction System

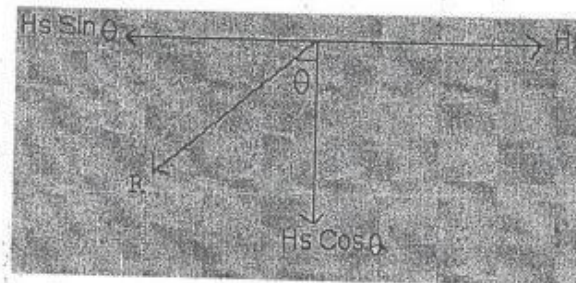


Figure 3: Vector Diagram of the Resultant EM Fields

$Hs \sin \theta$ is 180° out of phase with the primary fields and thus it is 'in-phase' component of the resultant waves. $Hs \cos \theta$ is 90° out of phase with the primary fields and it is the quadrature component. Fraser (1969) maintained that the closer θ is to 90° the more conductive is the subsurface rock encountered.

Numerical filtering technique aimed at eliminating erroneous interpretation of VLF data caused by large geological noise component generated from the transmitted frequency. This filtering method improves the resolution of anomalies which will ease their recognition. The filter $F_{2,3}$ for instance, is given by $F_{2,3} = (M_3 + M_4) - (M_1 + M_2)$ (Fraser, 1969), where M_1, M_2, M_3 and M_4 are four consecutive data points on the base map with $F_{2,3}$ fixed midway between M_2 and M_3 . This is done for M_4, M_5, M_6 and M_7 to get $F_{5,6}$ midway between M_5 and M_6 , similar filters were obtained for all other data points on all the travel lines (Figure 1). The filtered values are tabulated with their appropriate co-ordinates

and then contoured. However, all negative F values were ignored during contouring; according to Fraser, they are only caused by dip angle flanks and can distort the expected picture.

Results and Discussions

The 'cross-over' points (i.e. point of intersection) of in-phase and quadrature plots) along a profile sometimes indicate fracture or shear zones (Fraser, 1969). It is sometimes associated with vertical contacts between intrusive materials and the 'country' rocks (Telford, Gelfart and Sheriff, 2004). The positive quadrature values imply possibly faults zones (Anneke, 1988). The negative ones are likely due to earth surface targets/conductors and are usually confusing during interpretation (Fraser, 1969). Thus, surface conductors are separated from the subsurface ones by separating the negative quadrature signals from the positive values. The inphase and quadrature versus distance along various profiles are shown in figures 4 through 11. Figure 4 through 11 relate inphase & quadrature variations along all the profiles.

Figure 4 shows that the secondary in-phase field generated by the subsurface rocks along profile P1 ranges from -52 to +80% while the quadrature components range is -6% to +76%. The cross-over points which indicate shear zones exist at distance 130, 540 and 640 m from the starting point. The positive quadrature values which indicate fault zones exist between 80 and 680 m along the profile. This suggests that the underlying basement between 130 and 640m along P1 is most likely fractured to some extent. The degree of conductivity, expressed by the positive in-phase response, exists from 110 m to 190 m and from 480 m to 670 m.

Inphase responses vary between -90% and +86%, while quadrature responses are between -36% and +86% (Figure 5). The shear zone is located between 90 and 280 m along P2 where the 'cross-over' occurred. The positive quadrature values exist from 160 to 680 m; hence, there is the location of fractured or shear zones. The positive in-phase responses are between 100 to 280 m and 350 to 460 m along P2. This marks the degree of conductivity of the areas mentioned.

Inphase and quadrature vary from -90% to +130% and from -125% to +30% on profile P3 (Figure 6). The 'cross-over' that marks fractures exist at 340, 420 and 490 m along P3. A mild fault zone appeared from 403 m to 660 m at positive quadrature. The positive in-phase and hence the conductive zones lie between 0 to 50, 70 to 310 and 420 to 510 m on the profile.

Figure 7 shows in-phase and quadrature ranges of -130% to +130% and -45% to +20%; 'Cross-over' at 220, 460 and 570 m along P4 indicate fractures while positive quadrature is minima here, implying less or no faulting.

Profile P5 (Figure 8) shows in-phase and quadrature ranges of -140% to +44% and -32% to +16% with 'cross-over' point at 70, 160, 370 and 500 m along P5, indicating fracture locations. However, a low positive quadrature response suggests mild faulting or shear. The conductive areas along the profile are at 0 to 30 m, 100 to 360 m and 400 to 490 m.

-130 to +115% and -20 to +140% are the in-phase and quadrature response ranges along P6, (Figure 9) 'cross-over' equally exists at 160, 270, 440 and 560m, implying series of fracture along P6. Positive in-phase, depicting high conductivity, showed from 150 to 290 m, and 430 to 580 m.

Figure 10 further shows in-phase and quadrature ranges of -74 to 14% and -24 to +32%, 'cross-over' occurred at 70, 340, and 410 m. Positive quadrature exists from 0 to 380m while positive in-phase starts from 410 m and extends to the end of the profile P7. This equally confirmed the occurrence of fracture, shear and fault on this profile.

Figure 11, finally shows the in-phase and quadrature response range of -50% to +33% and -16% to 29% with 'cross-overs' at 0, 200 and 520 m, meaning the occurrence of fracture as well. The positive quadrature covers from the origin to 520 m along the profile, indicating a large scale faulting. From 0 to 220 m and 530 m to the end of the profile marks positive in-phase, this means a widely conductive region in the study area.

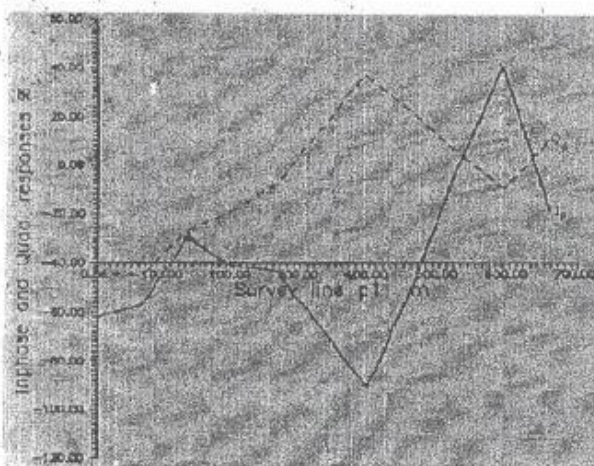


Figure 4: I_p & Q_d /Distance (Profile 1)

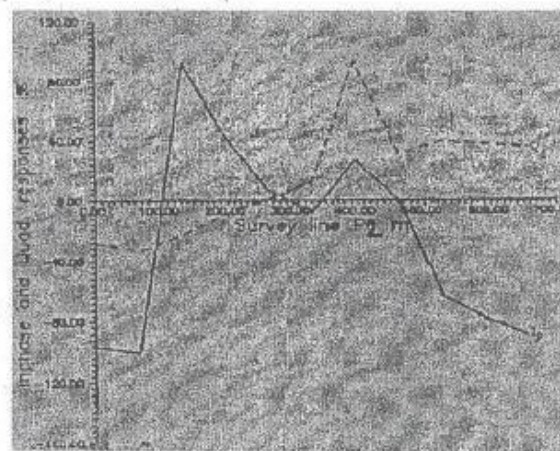


Figure 5: I_p & Q_d /Distance (Profile 2)

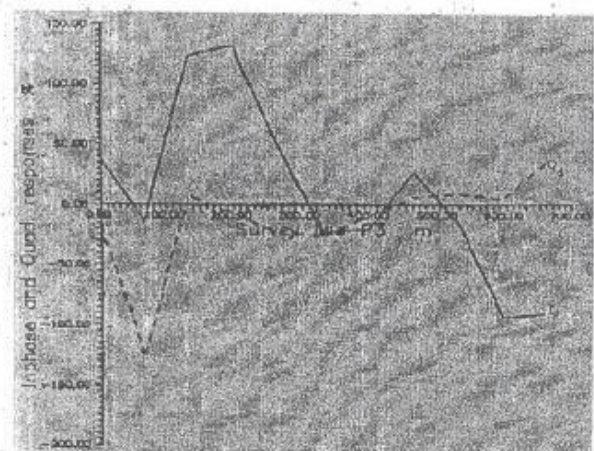


Figure 6: I_p & Q_d /Distance (Profile 3)

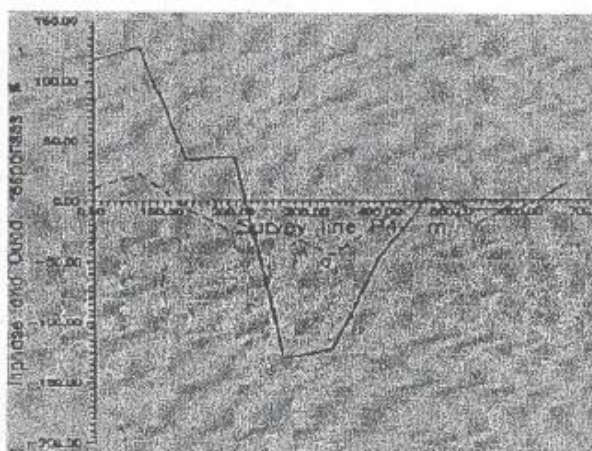


Figure 7: I_p & Q_d /Distance (Profile 4)

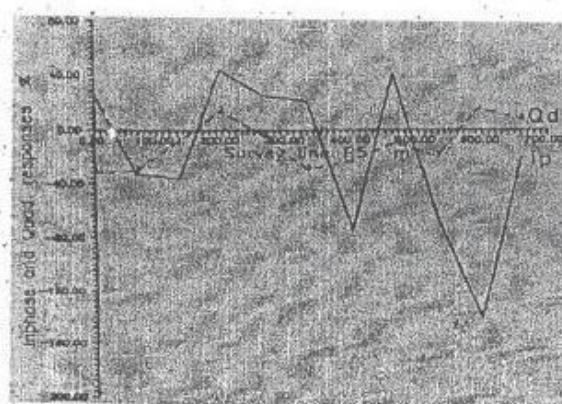


Figure 8: I_p & Q_d /Distance (Profile 5)

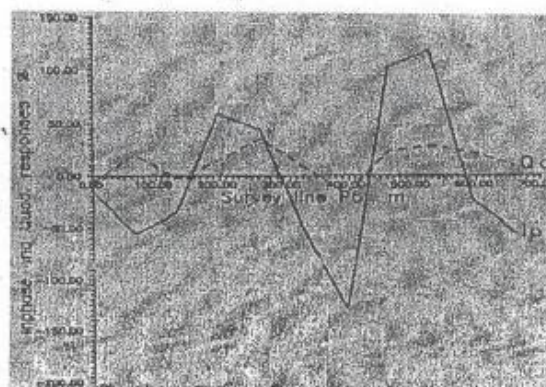
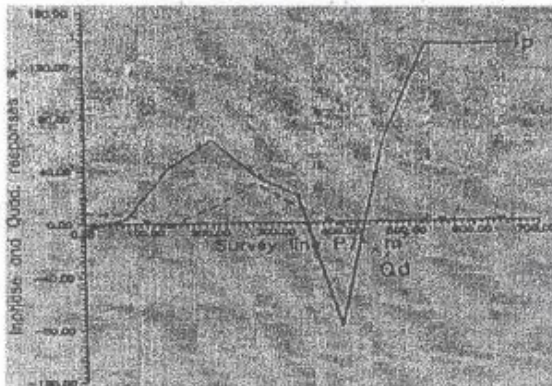
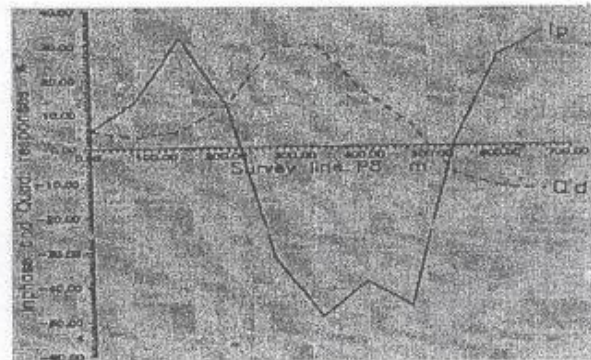


Figure 9: I_p & Q_d /Distance (Profile 6)

Figure 10: I_p & Q_d /Distance (Profile 7)Figure 11: I_p & Q_d /Distance (Profile 8)

Filtered positive values of inphase responses were contoured to reveal clearly areas of high or low conductivities as obtained along the profiles in figures 4 through 11. The zero crossings are transformed into peaks. This aids clearer identification of subsurface zones with greater underground water potentials. The process also helps to delineate surface conductors from the subsurface causative geologic bodies. Figure 12 shows a tendency to form closures of high positive inphase values towards western part of the study area with greater concentrations around north-western corner of the area. This extends toward south-east. This is an indication of high subsurface conductivity. The only existing borehole in this study area is located few meters away from the west towards the central part in the area, which used to fail during dry season. This confirms wrong location of the borehole. Further, a hand-dug Well located closer westward than the borehole and not as deep as the borehole used to be resourceful round the year, in line with the outcome here. This suggested that the thickest part of the aquifer in the area could be in the western part of the study area; however, the thickness reduces toward east.

A closure of a very low positive inphase value is formed around the eastern part of the area (Figure.12). This implies low conductivity. This could explain why a hand-dug Well located near the east within this area has not been resourceful at all.

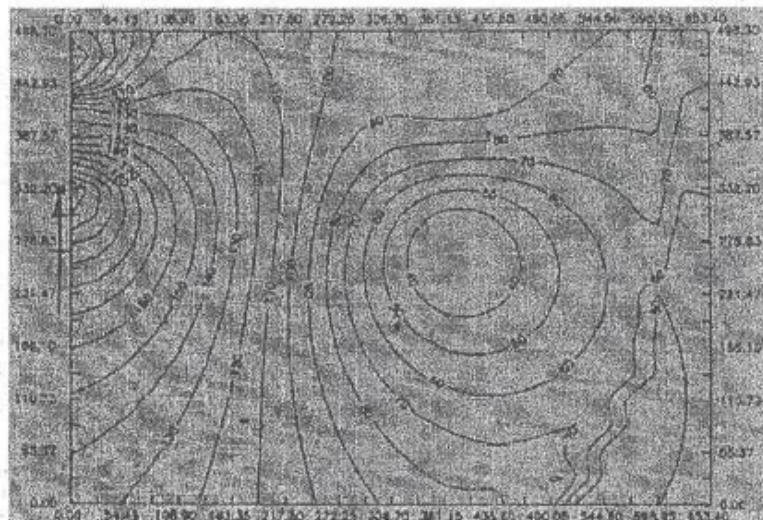


Figure 12: Conductivity Anomaly Map (Cot. Interval: 10%)

A surface reflection of the subsurface topography as detected by the filtered positive VLF responses is shown in figure 13. The figure is a replica of the feature in figure 12 at a glance. It can be seen that there exist a progressive decrease in the conductivity of the subsurface conductors from west to the east over the survey area depicted by deep to shallow surface expressions. That is, western part showing trough implies highest conductivity is best for underground water exploration while the crest nature implies diminutive conductivity is underlain by hard insulating rocks. In the same vein, figure 13 equally suggested that the thickest aquifer in the area could be in the western part of the study area; however, the thickness reduces toward east.

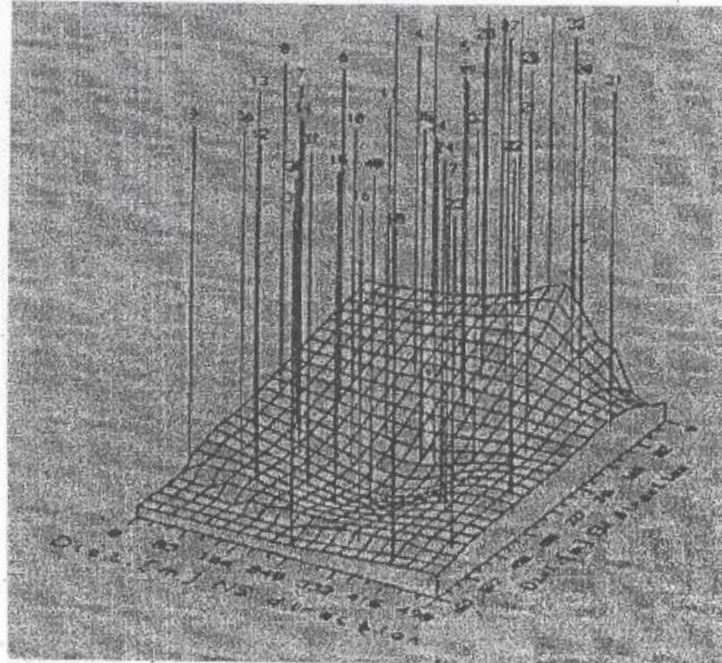


Figure 13: 3D Filtered Inphase Responses

Conclusion

This study confirmed the presence of fractures, shears and faults all over the study area. The occurrence is most pronounced westward of the study site as shown in figures 4c and d. The results further suggested that the basement structure is partly erosional and partly basement depression caused by block faulting. This agrees with findings by Shemang (1990) who reported the existence of buried structures such as faults and fractures around west to south-western part of Kubanni basin. In the same vein the finding is in line with Hassan, Ajayi and Ojo (1988) who reported that the deep seated structure in the western part of Kubanni basin is either a basement subsidence due to faulting or an erosional surface.

The North western part of the study site has a highly conductive region coincides with a widely fractured and faulted part as shown in figure 10 and 11. This gives a favorable condition for underground water exploitation. This is an additional derivable merit of this work.

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