

Subsurface Structural Characterization of Filatan Area A, Zaria – Kano Road, using the 2D Electrical Resistivity Tomography

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Abstract

The method adopted for this paper was the 2D Electrical Resistivity Tomography (ERT), using the ABEM LUND Imaging System. A Wenner configuration WEN32SX was carried out to map the electrical properties as an aid to characterizing the subsurface conditions around Filatan area, Zaria aimed at determining the depth to the competent stratum in the subsurface and delineation of areas that are prone to subsidence or some form of instability, study the groundwater potential with a view of determining the depth to the bedrock and thickness of the overburden and probable depth of sewage system. Four profiles were occupied in the study area. For each profile, the layout geometry for the electrical imaging was such that two reels of cables were used with 5m intervals between the takeout electrodes. However, the two innermost electrodes adjoining the two reels of cables were connected together thus yielding a total of 41 electrodes and a spread length of 200m. The data obtained using ABEM Terrameter SAS 4000 were processed using RES2DIVN software. Based on the electrical images obtained in the study area, the following deductions were made. The depth to the fresh basement is generally well beyond 30.0m. The study reveals the presence of three to four distinct layers respectively; the topsoil, weathered basement/partly weathered basement and fresh basement with resistivity values ranging from 28 – 95 Ω m for topsoil, 95 – 276 Ω m for weathered basement, 97 – 815 Ω m for partly weathered basement and as high as 2435 Ω m for the bedrock (fresh basement). These layers constitute the overburden with a thickness of 29.3m revealed by the pseudosections. The topsoil composed of laterite and brownish sandy clay with an average thickness of 11.0m, which are indications of soil conditions requiring serious consideration in the design of massive engineering structures because of their low load-bearing capacity. The weathered basement underlies the topsoil with an

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average thickness of 18.3.0m and this is a good aquifer in the study area. The depth of sewage system in this area should not exceed 10m to avoid groundwater contamination since the entire area is shallow to the aquiferous zone.

Keywords: Electrical Resistivity Tomography (ERT), ABEM LUND Imaging System, Wenner configuration WEN32SX, delineation and Pseudosections.)

1 Introduction

Geophysical investigations of the earth involves the study of physical properties, of the ground, thereby providing vital information on subsurface material conditions for numerous practical applications by taking measurements at or near the earth's surface that are influenced by the internal distribution of physical properties. Consequently, analysis of these measurements can reveal how the physical properties of the earth's interior vary vertically and laterally and reflecting the subsurface geology. Alternatively, another method of investigating subsurface geology is of course by drilling and pitting which provide information only at discrete locations and are expensive. Many geophysical investigations are non-intrusive and non-invasive, thus avoiding the disruption caused by intrusive investigations such as drilling and pitting. The 2D Electrical Resistivity Tomography (ERT), using the ABEM LUND Imaging System was adopted for this work. A Wenner configuration WEN32SX was carried out to map the electrical properties as an aid to characterizing the ground conditions. Resistivity surveys measure variation in the electrical resistivity of the ground by applying small electric current across arrays of ground electrodes. Resistivity imaging is particularly useful in clayey ground where methods such as the ground penetrating radar GPR are less effective and helps define translational boundaries that are difficult to detect using other geophysical methods. One of the new developments in recent years is the use of 2D electrical imaging/tomography survey to map areas with moderately complex geology (Griffiths and Barker, 1993). Such surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. In this survey, the Wenner array with 5m interval between 41 electrodes was employed with each spread having a length of 200m aimed at determining the depth to the competent stratum in the subsurface and delineation of areas that are prone to subsidence or some form of instability, study the groundwater potential with a view of determining the depth to the bedrock and thickness of the overburden and probable depth of sewage system around Filatan area, Zaria-Kano road, Nigeria.

2 The Survey Area

Filatan area is situated within the North-Western Nigerian Basement Complex (figure 1). It lies between Latitudes $11^{\circ} 23' 50''$ N - $11^{\circ} 24' 01''$ N and Longitudes $7^{\circ} 39' 50''$ E - $7^{\circ} 45' 00''$ E. The site is situated along the Zaria-Kano expressway, at about 16 km northeast of Zaria. The topography is that of high plain (flat terrain) of Hausa land. The site is located within the tropical climatic belt with Sudan Savannah vegetation. The environment is Savannah type with distinct wet and dry season. The rainfall regime is simple but with slight variation which consists of wet season lasting from May to

September and characterized by heavy downpour at the start and end of the rainy season. The annual rainfall varies between 800 mm to 1090 mm while the mean annual temperature ranges between 24⁰C to 31⁰C reaching a maximum of about 36⁰C around April (Hore,1970; Adeleke and Goh Cheng Leong, 1978).

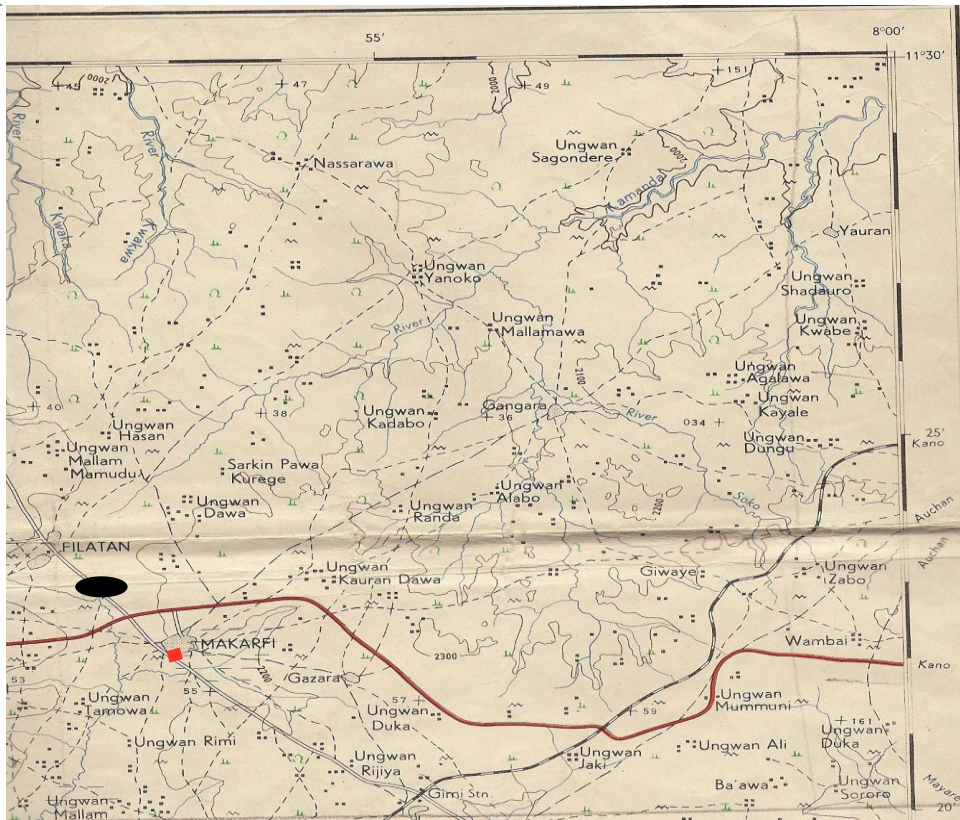
3 Geology of the Study Area

Nigeria lies in the Pan-African mobile belt which has been affected by Pan-African events through the ages of orogenic, epeirogenetic, tectonic and metamorphic cycles. The study area is part the Nigerian Basement Complex underlain by crystalline rocks, so the geology of the area is the same as that of the Nigerian Basement complex. The rocks of the Basement Complex occupy more than 50% of the total land surface of Nigeria, and accommodate the metasediments which are made up of gneisses. Exposures are scanty and highly weathered. The rock types are biotites, gneisses, granite gneisses and in parts with subordinate migmatites. The contact between the gneisses and metasediments are gradational (McCurry, 1970). Filatan area is underlain by basement rocks of Precambrian age. They are mainly granites, gneisses, and schists. Oyawoye (1964) showed that there is structural relationship between this Basement Complex and the rest of the West African basement. This is partly due to the fact that 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. Granitic intrusions form a suite of batholiths (the Zaria Batholiths), part of which outcrops as the Kufena Hill. The gneisses are found as small belts within the granite intrusions, and are also found east and west of the batholiths. The biotite gneiss extends westwards to form a gradational boundary with the schist belt. The gneiss continues eastwards to some extent and is occasionally broken up by the Older Granite (McCurry, 1970). The Older Granite intrusion is supposed to have been formed at the bottom of a fold mountain belt (Wright and McCurry, 1970).

4 Methodology

The electrical resistivity imaging is a survey technique recently developed for the investigation of areas of complex geology where the use of resistivity sounding and other techniques is unsuitable (Griffiths and Barker 1993). It involves measuring a series of constant separation traverses with the electrode spacing being increased with each successive traverse. Since increasing separation leads to greater depth penetration, the measured apparent resistivities may be used to construct a vertical contoured section displaying the variation of resistivity both laterally and vertically over the section. The major limitation of the resistivity sounding method is that it does not take into account horizontal changes in the subsurface resistivity. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes simultaneously in the vertical direction, as well as in the horizontal direction along the survey line. In many situations, particularly for surveys over elongated geological bodies, the imaging technique gives a clearer picture of the cross-section of the body than what the vertical electrical sounding (VES) would do. To obtain a good 2-D picture of the subsurface, the coverage of the measurements must be 2-D as well. As an example, figure 3 shows a

possible sequence of measurements for the wenner electrode array for a system with 20 electrodes. Here, measurement commences at one end of the line using electrodes 1, 2, 3 and 4. The spacing between adjacent electrodes is “a”. With wenner array, the first step is to make all the possible measurement with electrode spacing of “1a”. Electrode 1 is used as the first current electrode C₁, electrode 2 as the first potential electrode P₁, electrode 3 as the second potential electrode P₂ and electrode 4 as the second current electrode C₂. For the second measurement, electrodes 2, 3, 4 and 5 are used for C₁, P₁, P₂ and C₂ respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurements with “1a” spacing. The spacing is then doubled without moving on, the first active electrodes with “2a” electrode spacing being 1, 3, 5 and 7. For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing “2a”. The same process is repeated for measurements with “3a”, “4a”, “5a” and “6a” spacing. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made.



KEYS







	MAJOR ROADS		FOOT PATH
	STUDY AREA		RIVERS
	MINOR ROAD		SETTLEMENT

Figure 1: Location Map of the Study Area

This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke 1998, Loke, 1999). One technique used to extend horizontally the area covered by the survey, particularly for a system with a limited number of electrodes, is the roll-along method. After completing the sequence of measurements, the cable is moved past one end of the line by several unit electrode spacings. All the measurements which involve the electrodes on part of the cable which do not overlap the original end of the survey line are repeated.

The first stage in the production of an electrical image is the construction of a pseudosection by plotting each apparent resistivity on a vertical section at a point below the centre of the four measuring electrodes and at a depth that is equivalent to the median depth of investigation (Baker 1989, Edwards 1977) of the array employed. This depth is referred to as the pseudo – depth – section that qualitatively reflects the spatial variation of resistivity in cross-section (Fig 3).

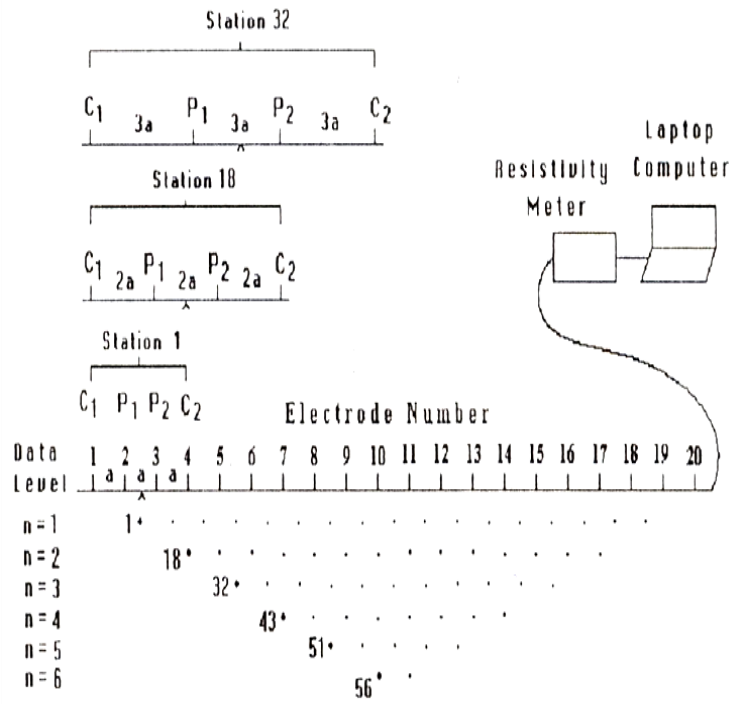


Figure 2: Principle for Building up a Pseudosection (ABEM Terrameter SAS4000/ SAS1000 manual 2006)

5 Results and Discussion

The raw field data were processed using RES2DINV (Loke and Barker, 1996, Loke, 1999). This is a computer program that automatically determines a two-dimensional (2-D) resistivity model for the subsurface for the data obtained from electrical survey. It is a Window based program. This method is based on the following equation:

$$(\mathbf{J}^T \mathbf{J} + u \mathbf{F}) \mathbf{d} = \mathbf{J}^T \mathbf{g}$$

$$\text{Where } \mathbf{F} = \mathbf{f}_x \mathbf{f}_x^T + \mathbf{f}_z \mathbf{f}_z^T$$

\mathbf{f}_x = horizontal flatness filter

\mathbf{f}_z = vertical flatness filter

\mathbf{J} = matrix of partial derivatives

u = damping factor

\mathbf{d} = model perturbation factor

\mathbf{g} = discrepancy vector

The results obtained shows measured apparent resistivity pseudosection, the calculated apparent resistivity pseudosection and the inverse model resistivity section of four profiles, but with colour infill instead of line contours. These data have been inverted to produce the image of Figs.3-6. The electrical image revealed three to four layers, ranging from top soil which is reddish brown laterite to fresh basement. The surface material in the entire area is intercalation of sandy soil lateritic clay with resistivity values ranging from about 28Ωm - 95Ωm and thick of about 7m – 18m. The weathered basement is highly fractured with resistivity values as low as 95Ωm and as high as 276Ωm of the materials underlying the clay which is second distinct layer in the model, the third layer is the partly weathered portion with resistivity value ranging from 471Ωm - 815Ωm. The materials extend to about 29.3m below the surface, towards the end of the profile striking the fourth layer with resistivity value as high 2435 Ωm which is probably the crystalline rock (fresh basement). The low resistivity values of the layers is a clear evidence that they are saturated with water, since the resistivity of rock decreases as the percent water saturation increases.

Profile 1

The electrical image revealed four layers, ranging from topsoil to fresh basement (Fig. 3). The surface material (topsoil) is intercalation of sandy soil lateritic clay with resistivity values ranging from about 28Ωm - 88Ωm and thickness of about 15m. The materials extend to the weathered surface at about 20m with resistivity values ranging from 154Ωm - 273 Ωm. The weathered basement is highly fractured. Groundwater localization within the Basement Complex occurs either in the weathered mantle or in the fracturing, fissuring and jointing systems of the bedrock (Jones, 1985).The low resistivity values of the layers is a clear evidence that they are saturated with water, since the resistivity of rock decreases as the percent water saturation increases. A fractured zone was picked between spacings 100 and 115m, with resistivity values ranging from 471Ωm - 815Ωm considered to be partly weathered zone. This layer extends to the fresh basement with resistivity value as high as 1461Ωm. One factor that could contribute to structural defect of building is the seasonal variation in the saturation of clay which causes ground movement and is caused by clay swells and shrinkages which are occasioned by alternate wet and dry seasons. Since the thickness of the topsoil with low load bearing strength is about 15m along this profile, this area forms a good site for the erection of small civil engineering structures.

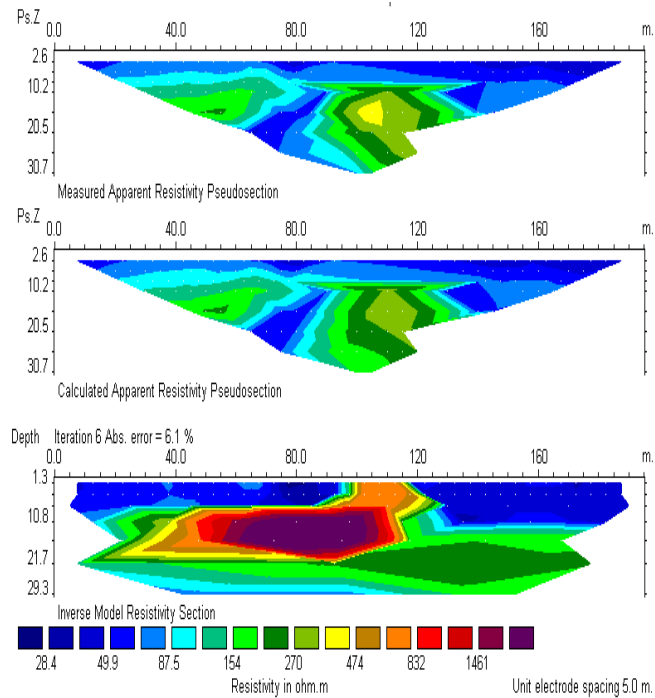


Figure 3: Electrical image along profile 1, (a) is observed data plotted as a coloured pseudosection; Ps.Z = pseudo-depth, (b) is the pseudosection computed from the model and (c) is the image or model showing true depth and true formation resistivity.

Profile 2

Four layers were revealed along this profile (figure 4). The top layer is composed of consolidated laterite, sand, silt and clay with resistivity ranging from $32\Omega\text{m}$ - $95\Omega\text{m}$. The weathered bedrock clearly shows on the image immediately underneath the topsoil with a resistivity range of about $95\Omega\text{m}$ - $276\Omega\text{m}$ with thickness of about 19m. It is made up of gravel sand and other weathered rock materials. The partly weathered rocks have resistivity values ranging from $476\Omega\text{m}$ - $805\Omega\text{m}$ and thickness of about 10m extending to the fresh basement. Between 105m – 125m spacing marks fractures with resistivity value as low $32\Omega\text{m}$ and high as $94\Omega\text{m}$ is observed rising to the surface. This is probably groundwater trapped in the aquifer streaming to the surface. This position would be the best location to site a borehole. Patches of high resistivity material are observed between 65.0m – 80.0m, 90.0m – 95.0m, 135.0m – 140.0m and at 160.0m and 198.5m marks with resistivity greater than $1376\Omega\text{m}$ and is probably a hard crystalline rock or possibly corestones or unweathered bedrock at depth less than 10.8m with appreciable thicknesses of weathered and partly weathered basement which will serve as pillar supports to buildings, suggesting this profile suitable for siting medium to high civil engineering structures.

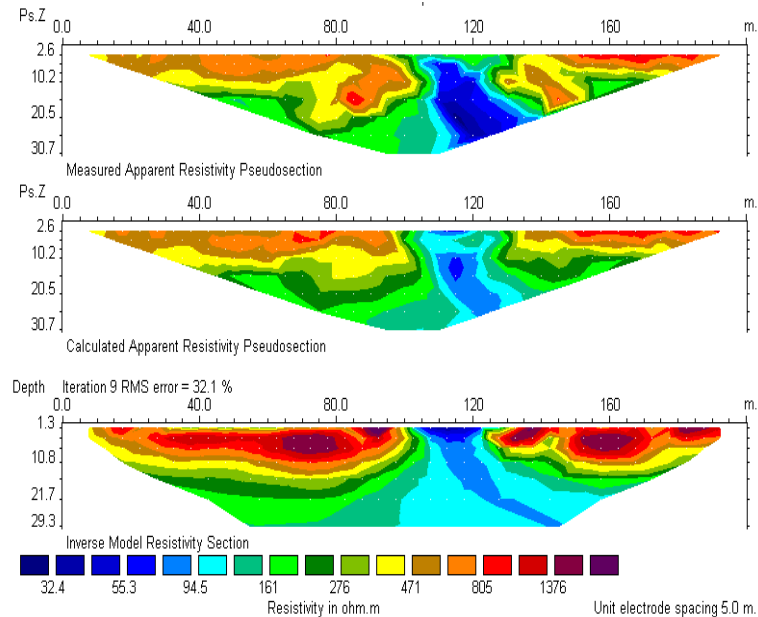


Fig. 4: Electrical image along profile 3, (a) is observed data plotted as a coloured pseudosection; Ps.Z = pseudo-depth, (b) is the pseudosection computed from the model and (c) is the image or model showing true depth and true formation resistivity

Profile 3

The electrical image along this profile shows three to four layers (Fig.5). The surface is rigid with resistivity values ranging from $158\Omega\text{m}$ to $815\Omega\text{m}$ with the thickness of about 18m suggesting this to be weathered to partly weathered bedrock. Underlying these layers is highly fractured bedrock probably gravel sand with resistivity value ranging from $52\Omega\text{m}$

- $92\Omega\text{m}$ around the depth of about 18.0m to about 29.3m. This is an indication that this point is an aquiferous zone, a potential position for siting borehole. This layer cut across the whole profile. The weathered and partly weathered basement with resistivity values ranging from $273\Omega\text{m}$ – $471\Omega\text{m}$ and $471\Omega\text{m}$ and $815\Omega\text{m}$ nearly exposed to the surface is a good platform for massive structures because of their high load bearing capacity with appreciable thickness of about 12m but due to the weak base which could fail because of its low load bearing capacity, suggests a medium scale civil engineering structures along the profile while putting the layer with low resistivity value into a serious check.

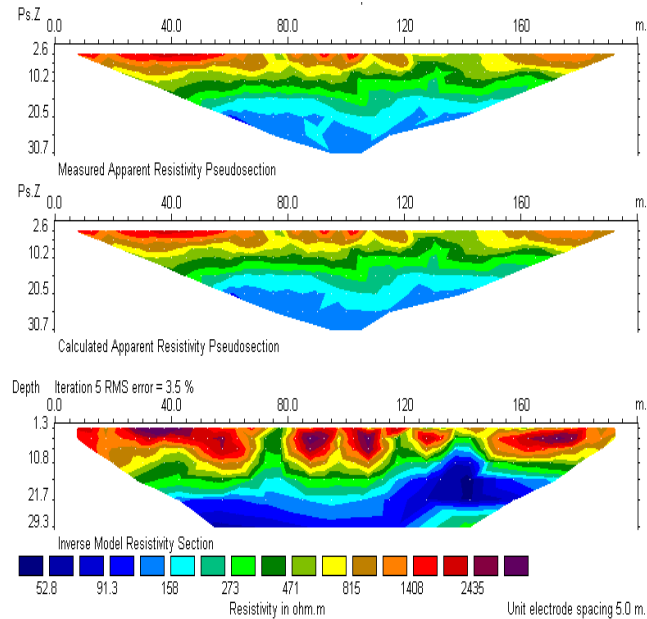


Fig.5:Electrical image along profile 2, (a) is observed data plotted as a coloured pseudosection; Ps.Z = pseudo-depth, (b) is the pseudosection computed from the model and (c) is the image or model showing true depth and true formation resistivity.

Profile 4

A careful look at the electrical image of this profile shows intercalation of sandy and lateritic clay as the top soils with the thickness of about 10m and resistivity values ranging from 40Ωm to about to 65Ωm (Fig.6). Underlying these layers is the weathered basement from the depth of about 12.0m with resistivity values ranging from about 81Ωm to 105Ωm, extending to the partly fractured layer with resistivity value ranging from 132Ωm to values >213Ωm with thickness of about 18m. The low value of the resistivity is a clear indication that the basement is highly fractured. This profile cannot support massive structures but viable for groundwater exploration.

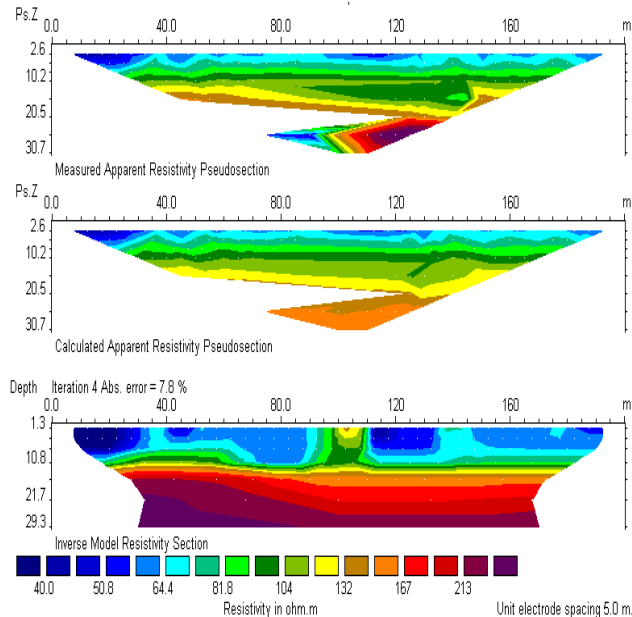


Fig.6:Electrical image along profile 4, (a) is observed data plotted as a coloured pseudosection; Ps.Z = pseudo-depth, (b) is the pseudosection computed from the model and(c) is the image or model showing true depth and true formation resistivity.

6 Conclusion

A total number of four profiles were taken along the surface of the ground and electrical imaging was carried out along the lines. Electrical images provide a more detailed view of subsurface structure that cannot be obtained using other geophysical techniques and may therefore lead to a better understanding of the fracturing system. The inversion results of profile one reveals four distinct layers ranging from lateritic clay to fresh basement. The low resistivity value of the layers is an indication that the materials are saturated with water and erecting a massive structure along this profile is not advisable as a result of the thickness of the topsoil (clayey nature) of about 15m but rather accommodate structures of low load bearing capacity. The electrical image also reveals that the basement is fractured. The electrical image of profile two shows intercalation of lateritic clay and sandy clay as near-surface material with resistivity values ranging from $32\Omega\text{m}$ - $95\Omega\text{m}$ with relatively thick weathered basement with resistivity values as high as $805\Omega\text{m}$ and fresh basement as high as $1376\Omega\text{m}$ which could serve as pillar support to giant structures, suggesting this profile best suitable for massive civil engineering structures. The resistivity inversion results for profile three also reveals that the near – surface material is not uniform. It shows that the weathered basement and partly weathered basement are nearly exposed with high load bearing capacity but with a weak base of low resistivity values ranging from $52\Omega\text{m}$ - $158\Omega\text{m}$, suggesting serious check and pilling to avoid building failure. The resistivity inversion result of profile four also indicates that the near – surface is not uniform. The weathered and partly weathered basement is severely fractured as revealed by the low resistivity ranging from $81\Omega\text{m}$ - $132\Omega\text{m}$, which is an

indication of highly saturated zone (aquiferous zone) for siting borehole. Since the entire area is shallow to the saturated or aquiferous zone, the depth of sewage system should not exceed 10m and should be sited far away from the borehole site to avoid groundwater contamination because of the fractures picked or noticed at the subsurface in almost the entire study area.

References

- [1] ABEM Instrument AB, Terrameter SAS4000/SAS1000 LUND Imaging System, Instruction Manual. 2006.
- [2] Barker, R. D. (1989). Depth of investigation of a generalized collinear 4-Electrode array. *Geophysics*, 54, 1031 – 1037.
- [3] Dahlin, T. and Loke, M. H. (1998). Resolution of 2D Wenner Resistivity Imaging as assessed by numerical modelling, *Journal of Applied Geophysics*, 38, 237-249.
- [4] Edwards, L.S. (1977). A modified Pseudosection for Resistivity and Induced Polarization. *Geophysics*, 42, 1020 – 1036.
- [5] Griffiths, D. H. and Barker, R. D. (1993). Two-dimensional resistivity imaging and modeling in areas of complex geology. *Journal of Applied Geophysics*, Vol. 29, Pp 211-226.
- [6] Goh, C.L., and Adeleke, B.O., (1978). Certificate Physical and Human Geography' Oxford University Press, Ibadan, pp78-150.
- [7] Hore, P.N (1970). Weather and Climate of Zaria and its Region .(Ed.) By M.J. Mortimore, Department of Geography, Occasional Paper No4. A.B.U. Zaria. pp. 41-54
- [8] Jones, M.J.(1985). The weathered zones aquifers of Basement Complex Area of African, *Quarterly Journal of Engineering Geology*, London Vol.18, pp35-45.
- [9] Loke, M. H. and Barker R. D. (1996). Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. *Geophysical Prospecting*, 44, 131 – 152.
- [10] Loke, M.H.(1999). Electrical imaging for environmental and Engineering studies, A practical guide, 2-D survey geophysical prospecting pp44.
- [11] McCurry, P. (1970). The geology of Degree Sheet 21, Zaria. Unpublished M.Sc. Thesis, Thesis, Department of Geography, Ahmadu Bello University, Zaria.
- [12] Oyawoye, M. O. (1964). Geology of the Nigerian Basement Complex, *Journal of Nigeria Mining*, Geological and Metallurgical Society, Vol. 8, pp. 87-102.
- [13] Wright, J. B. and McCurry, P. (1970). The geology of Nigeria Sheet 102 SW, Zaria and its regions. Edited by M. J. Mortimore. Department of Geography, Occasional paper, No. 4, Ahmadu Bello University, Zaria.