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Resistivity Survey at a Proposed Radioactive Waste Disposal Site

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ABSTRACT

Common field practice for electrical surveying relies on directly placing an electrical current into the ground (direct current electrical resistivity surveying) and measuring the response (the electrical potential drop) to that current over a set distance. Resistivity analysis was conducted at a site earmarked for a radioactive waste disposal facility known as the Borehole Disposal Concept (BDC) at the Ghana Atomic Energy Commission's site located at Kwabenya, in the Greater Accra Region of Ghana. Both resistivity profiling also known as electric trenching and vertical electrical sounding also known as electric drilling were employed in this study. The results from both techniques were processed and discussed. Medium to very low apparent resistivity were measured at certain stations/points on the survey lines which suggest the presence of geological structures/contacts such as faults and fractures at or around these stations. With the aid of the electrical sounding data the site was characterized as a four layer formation with the bedrock lying at depth of 17 m and beyond.

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1.0 Introduction

Resistivity is one of geophysics' widely used applications for studying near and subsurface of the earth and its components. Its application stretches from mineral exploration (gold, manganese, bauxite etc.) to environmental pollution (land fill delineation, site assessment etc.). It is a non-invasive method and simply involves taking measurements at or near the earth's surface that are influential by the internal distribution of physical properties [1, 2]. Other applications of the technique include:

- Depth-to-bedrock and bedrock location
- Foundation investigations (stability/competence of the subsurface)
- Dynamic moduli measurements
- Fault Location
- Stratigraphic mapping
- Gravel and aggregate mining

Most electrical techniques induce an electrical current in the ground by directly coupling with the ground [1, 2]. The resulting electrical potential is then used to measure the variation in ground conductivity, or its inverse, resistivity. Different materials, and the fluids within them, will show different abilities to conduct an electric current. In general, sequences with high clay content show higher conductivity as do saturated sequences and especially sequences where saline (or sometimes other contamination) fluids are present [3]. Since the resistivity of a soil or rock is generally controlled primarily by the pore water conditions, there are wide ranges in resistivity for any particular soil or rock type, and therefore resistivity values cannot be directly interpreted in terms of soil type or lithology.

In environmental pollution mitigation efforts, the method can be applied to determine the source of pollution the detection of the pollutant material in a geological matrix. Metallic objects of interest in a contaminated site assessment tend to have a very high conductivity contrast with their surroundings and therefore detectable by electrical and electromagnetic methods. Quantitative estimates of the metal contents are, however, not easily obtained. Nelson and Van Voorhis (1982) [7, 8] show the resistivities of a large number of sulfide-bearing rocks (from 0.5 to 15 weight percent) [2, 3].

Metals conduct electronically, however, in their absence in the earth formation, conductivity is related to the volume and conductivity of the water in earth materials [2, 6, 7]. The groundwater conducts through its ions, and its conductivity, therefore, depends strongly on the total dissolved solids. Within a porous, clay-free medium whose matrix is non-conducting, a relationship known as Archie's Law (Archie, 1942) [9-13] expressed in Eq. 1, is widely used and reasonably valid:

$$\frac{\sigma_w}{\sigma_f} = F = a\phi^{-m} \tag{1}$$

Where

σ_w = conductivity of water,

σ_f = conductivity of the formation as a whole,

a= empirical constant, typically 1 for unconsolidated sediments,

m= empirical constant, typically 2 for unconsolidated sediments,

ϕ = effective porosity, the fraction of interconnected pore space,

F = formation factor related the volume and tortuosity of the pore space.

Data from resistivity surveys are customarily presented and interpreted in the form of values of apparent resistivity, ρ_a [2, 14]. Apparent resistivity is the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential difference for a particular arrangement and spacing of electrodes [7, 8, 14]. Resistivity surveys are usually applied to satisfy the needs of two distinct geophysical interpretations [3]: (1) the variation of resistivity with depth, reflecting more or less horizontal stratification of earth materials; and (2)

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lateral variations in resistivity that may indicate soil lenses, isolated ore bodies, faults, or cavities [2]. In the first kind of problems, measurements of apparent resistivity are made at a single location or around a single center point with systematically varying electrode spacing. This procedure is also referred to as vertical electrical sounding (VES), or simply vertical profiling. Surveys of lateral variations may be made at spot or grid locations or along definite lines of traverse, a procedure sometimes called horizontal profiling [3].

In this study, a site earmarked for radioactive waste disposal facility was subjected to resistivity analysis. The principal aim is to appropriately characterize the site by identifying and mapping all fractured and fault zones which then will inform the suitability or otherwise of the site.

1.1 General Geology of the Site

The major geological formations in the area comprise of the Togo Series and the Dahomeyan System and it is characterized by various geological structures [4]. The Togo Series consists of phyllite, schist and quartzite. It occupies the north-western section of the Ghana Atomic Energy Commission (GAEC)-the current study location, up and over the highland areas. The Dahomeyan System, however, occupies the low-lying areas consisting mainly of schist, gneisses, and migmatites. The well-known and documented Eastern Boundary fault in Ghana is known to lie between the Togo Series and the Dahomeyan System whereas the Western Boundary fault follows the contact between the Birimian, the Voltaian and the Buem formations to the west of the Akuapim ranges of hills [4, 5]. Evidence of the uplift by thrust of the eastern block is shown by the fact that to the east of the Eastern Boundary fault, the land surface consists mainly of Dahomeyan rocks with few Togo Series whilst to the west, only a few outcrop of Dahomeyan rocks occur in the eastern flank of the Akuapim range. The micaceous quartzite which occurs only to the east of the Eastern Boundary fault is indicative of a higher grade metamorphic regime which suggests an up thrusting of the Eastern Boundary fault [4, 5].

2.0 Materials and Methodology

The study location is at the Ghana Atomic Energy Commission's site at Kwabenya; in the Ga East District of the Greater Accra region. The area lies at latitude 50 6'7"N and longitudes 00 21' W at elevation of 64 m. Kwabenya which used to be a rural settlement at the time of acquiring the Ghana Atomic Energy Commission's site has become part of urban Accra in the last two decades. Sizeable part of the site has also been encroached upon by private entities for both commercial and domestic facilities. The earmarked borehole disposal site is, however, under institutional/national security control. Figure 1 is the geological map Accra showing the study location and surrounding towns and features.

Approximately 200 m x 150 m land area was surveyed. The land was first cleared of its weeds and shrubs to allow easy movement and access to ground for measurements. Four survey lines, L1, L2, L3 and L4 at 20 m apart were drawn and pegged at 5 meters intervals for the electrical resistivity and sounding measurements. The first three lines (L1, L2 and L3) were 180 m each while L4 was only 90 m due to restriction by concrete structures in the way of L4.

Resistivity Profiling was first conducted followed by Electrical Sounding. By means of GPS device, both longitudinal and latitudinal coordinates of each surveyed point was taken on each surveyed line. Wenner electrode array in which all four electrodes have equal separation gaps was used in measuring the electrical profiling data whereas Schlumberger electrode configuration was used for the electrical sounding data. Profiling field data were measured using the ABEM SAS-4000 (Terrameter) resistivity equipment. As illustrated in Figure 2-3, four electrodes connected to electrical cables were planted into the ground; two inner electrodes labeled P1 and P2 (the potential electrodes) and two outer electrodes; C1 and C2 (the current electrodes). Current of 20 mA was introduced at C1 and C2 and the resistances measured.

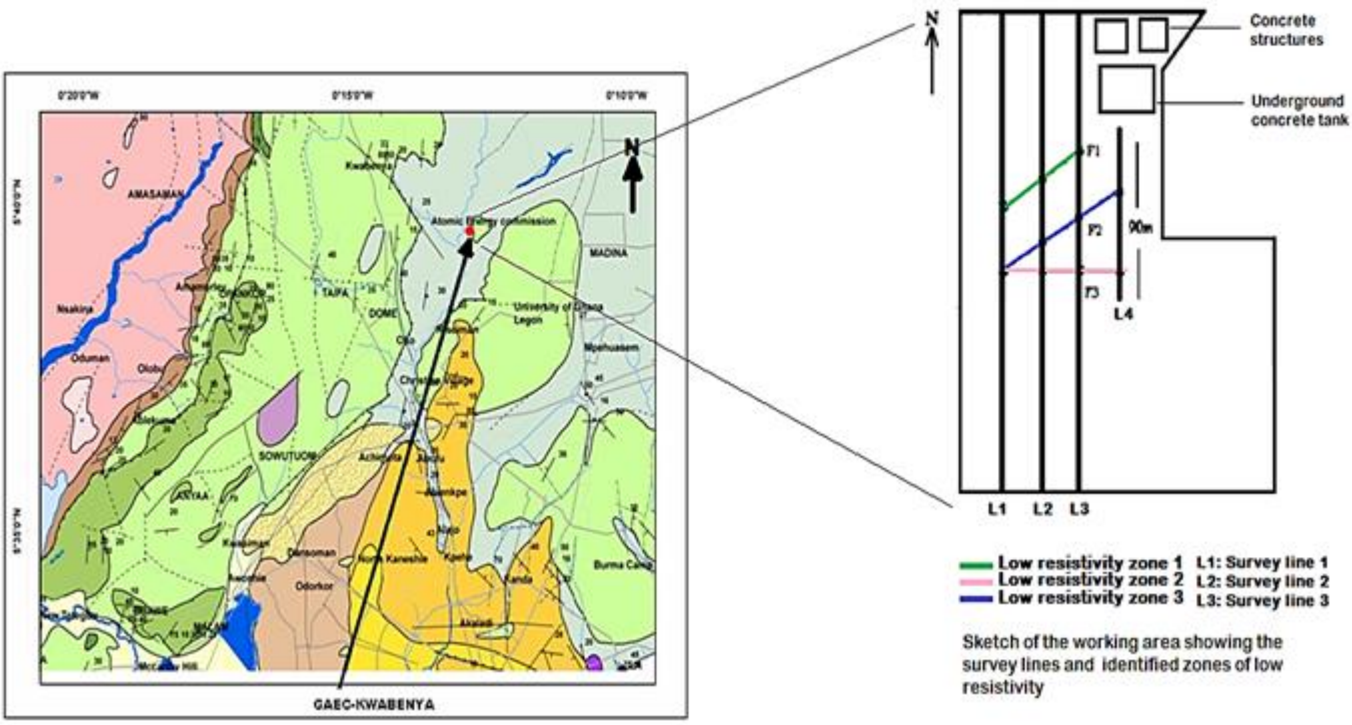


Figure 1. Geological map of Accra showing study location.

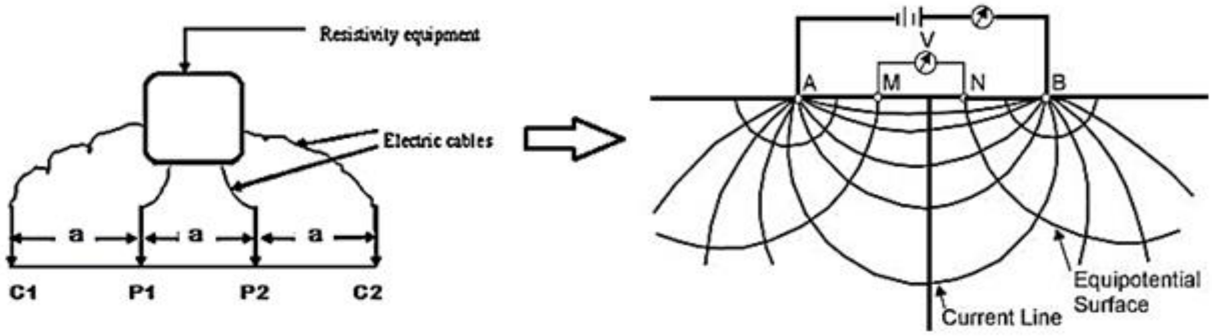


Figure 2. Potential and current electrode array; *a* is the separation (in meters) between the electrodes.

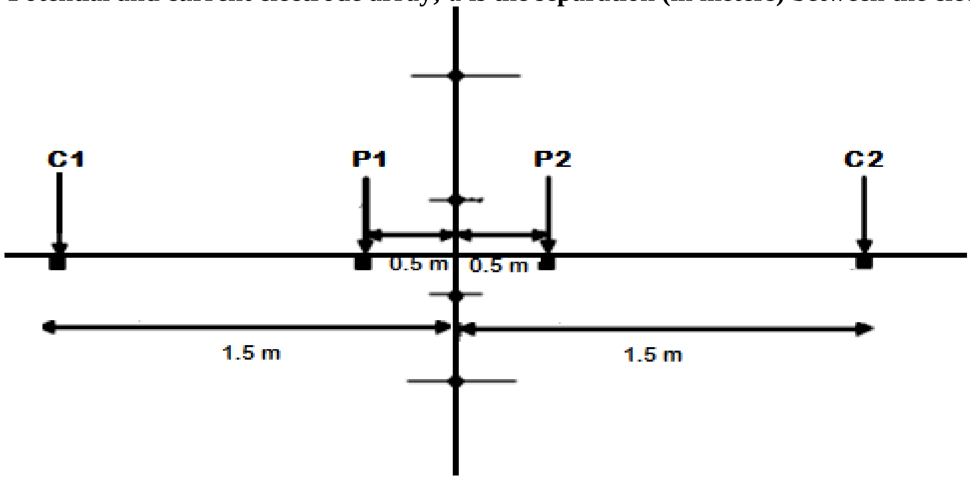


Figure 3. Resistivity sounding field array.

Experimentally, the current, I, flowing through a material of a constant cross section is directly proportional to the applied voltage, V (Ohm"s law) expressed in the following Equations, 2-12.

$$V \propto I \tag{2}$$

$$V = IR \tag{3}$$

Where R is a proportionality constant known as resistance.

For a given material, it is known that the resistance is proportional to its length, L and inversely proportional to the cross sectional area, A.

$$R = \rho \frac{L}{A} \tag{4}$$

Where ρ is called the resistivity of the material. Resistivity is therefore technically defined as the resistance of a cube with a side of unit length.

Given the distance between the electrodes,

$C_1P_1 = r_1$, $C_1P_2 = r_2$, $C_2P_1 = r_3$ and $C_2P_2 = r_4$

The potential due to C_1 and C_2 can therefore be expressed as:

$$C_1 = -\frac{\rho I}{2\pi r_1} \tag{5}$$

$$C_2 = \frac{\rho I}{2\pi r_2} \tag{6}$$

The potential at $P_1 = VP_1$ and at $P_2 = VP_2$ are deduced as:

$$VP_1 = \frac{\rho}{2\pi}\left[\frac{I_1}{r_1} - \frac{I_2}{r_2}\right] \tag{7}$$

$$VP_2 = \frac{\rho}{2\pi}\left[\frac{I_3}{r_3} - \frac{I_4}{r_4}\right] \tag{8}$$

Effective potential between the two potential electrodes, P_1 and P_2 is deduced as:

$$V = \frac{\rho}{2\pi}\left[\frac{I_1}{r_1} - \frac{I_2}{r_2} - \frac{I_3}{r_3} + \frac{I_4}{r_4}\right] \tag{9}$$

If C_1 and C_2 form a dipole system such as would be obtained by connecting C_1 and C_2 to the two terminals of a battery, then we can assume that all current entering the ground via C1 eventually leaves via C_2, and $I_1 = -I_2$, so that the effective potential difference between C_1 and C_2 (due to all four electrodes) is given by:

$$V = \frac{\rho I}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right] \tag{10}$$

The total resistivity due to all four electrodes is also deduced as:

$$\rho = \frac{2\pi V}{I}\left[\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)^{-1}\right] \tag{11}$$

$$\rho = 2\pi R\left[\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)^{-1}\right] \tag{12}$$

3.0 Results and Discussion

3.1 Electrical profiling

As indicated earlier, resistivity profiling was conducted on four lines and the results obtained for each line have been plotted and illustrated in this section. For each line, three electrode separation (5 m, 10 m and 20 m) were applied and apparent resistivity measured at various stations on the line. Observed apparent resistivity for Line 1 ranged between 50 and 250 ohm-m for the 5 m electrode separation; 10 and 170 ohm-m for the 10 m electrode separation and between 30 and 140 ohm-m for the 20 electrode separation.

On each of the survey line, very low resistivity also known as dip were observed at various stations on the lines. Line 1 with electrode separation of 5 m for instance, recorded its lowest resistivity of 50 ohm-m at station 56 m while 10 and 20 m electrode separations recorded their lowest resistivity of 8 ohm-m and 30 ohm-m, respectively at 80 m and 5 m.

Apparent resistivity on Line 2 ranged between 110 ohm-m and 600 ohm-m for 5 m electrode separation; 70 and 180 ohm-m for 10 m electrode separation and 60 and 220 ohm-m for 20 m electrode separation. It is interesting to note that, all three electrode separations recorded their lowest resistivity at the same station at 108 m-making their dips overlap at this station. All three electrode separations recorded relatively low resistivity on Line 2 at stations 20–50 m and 80–100 m.

On profiling Line 3, the three electrode separations recorded their lowest dips at 120 m, 135 m and 170 m stations of the line, respectively. The 5 m electrode separation recorded 90 ohm-m and 302 ohm-m as it lowest and highest apparent resistivity; 50 ohm-m and 130 0hm-m for the 10 m electrode separation and 98 ohm-m and 154 ohm-m for the 20 m electrode separation. Line 4 had only 2 electrode separation, 5 m and 10 m. this is because survey Line 4 was shorter due to the presence of concrete structures along it way. Both 5 m and 10 m electrode separation recorded two major dips each at 30 m and 62 m stations for the 5 m electrode separation and at 30 m and 68 m stations for the 10 m electrode separation. The lowest recorded apparent resistivity for 5m electrode separation was 80 ohm-m at the 62 m station and its highest apparent resistivity of 208 ohm-m was recorded at the 80 m station. For the 10 m electrode separation, the lowest apparent resistivity of 64 ohm-m was recorded at station 68 m while the highest apparent resistivity of 120 ohm-m was recorded at the 60 m station.

Zones of low resistivity suggest high porosity or different rock types of different electrical properties occurring within the same formation. It also suggests the occurrence of geological contacts which could be a fault or fracture. It was observed in general; in all four plots that, the 5 m electrode separation profiling gave a much detail subsurface information than both the 10 and 20 m separations. This is explained by the fact that, geological contacts (faults and fractures) could be very small in size (length and breadth) and therefore could easily be missed if the electrode separations are wider. Figure 4-7 are an illustrations of the resistivity profile for Line 1, Line 2, Line 3 and Line 4.

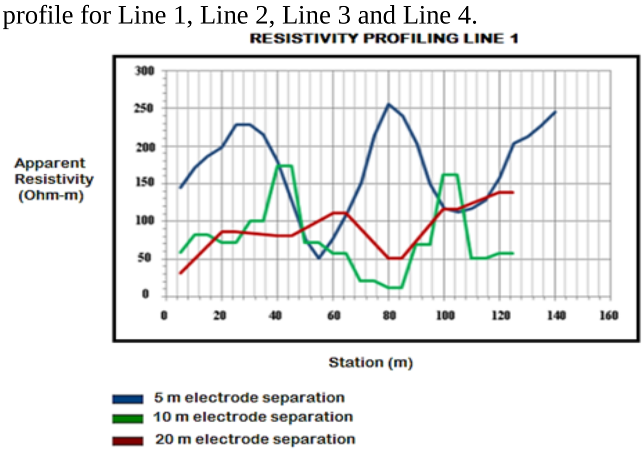


Figure 4. Resistivity profiling Line 1 showing the dips and the highest observed apparent resistivity.

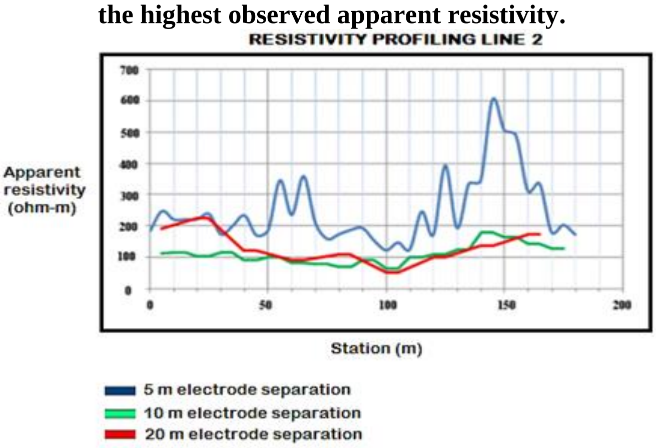


Figure 5. Resistivity profiling Line 2 showing the dips and the highest observed apparent resistivity.

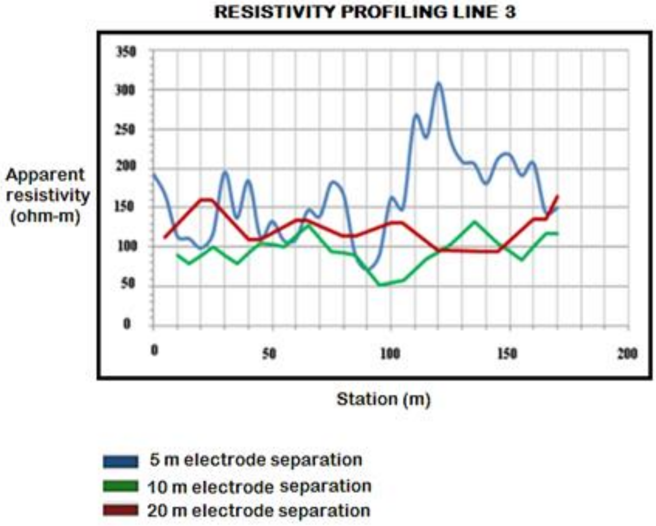


Figure 6. Resistivity profiling Line 3 showing the dips and the highest observed apparent resistivity.

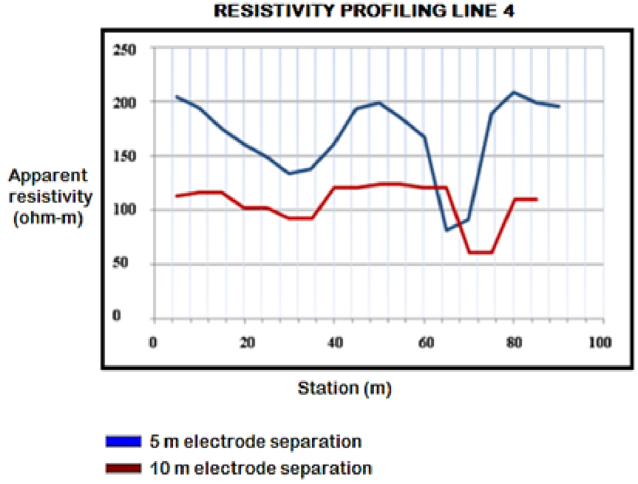
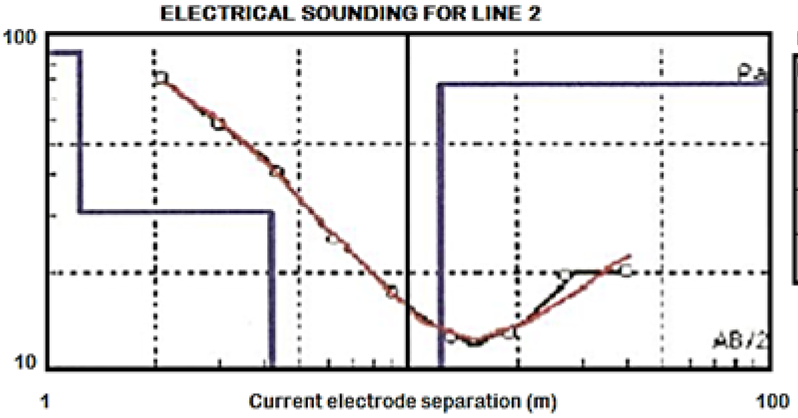


Figure 7. Resistivity profiling Line 4 showing the dips and the highest observed apparent resistivity.

3.2 Electrical sounding

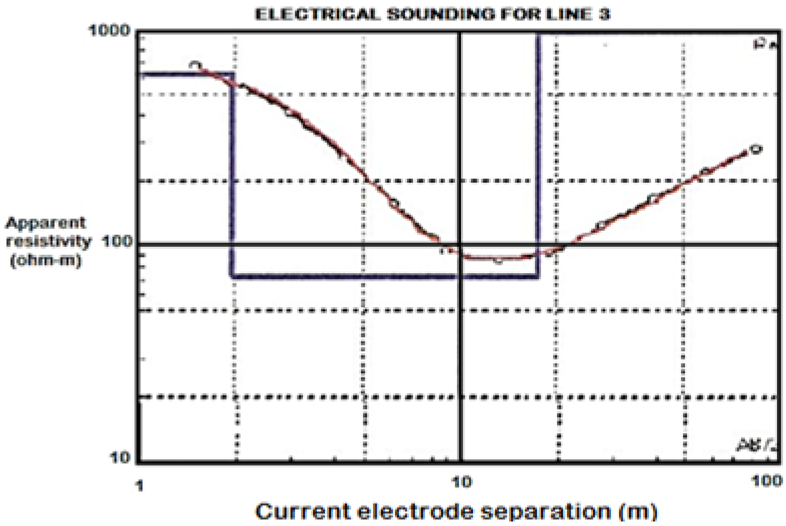
Like electrical resistivity, vertical electrical sounding (VES) was conducted for purposes of correlating electrical variation with geological information and to aid in characterizing the site. VES was conducted along Line 2 and Line 3 in perpendicular direction to those of the electrical resistivity surveys. VES field data were processed using ipi2-win software obtained free online. The data were thus modeled in accordance to the geology of the site. Based on the electrical sounding data the site was identified as a four layer formation. The first two layers which make-up the ‘overburden’ recorded a resistivity of 1041 ohm-m and 618 ohm-m with layer thicknesses of 0.39 m and 1.58 m, respectively. The ‘overburden’ comprises loose sand and gravel to a depth of 2.0 m. The layer underlying the ‘overburden’ a relatively low resistivity attributable to high porosity, salinity and other conductive materials present in this layer making current flow to concentrate in this layer. The third layer is located at a depth of 15 meters from the surface with thickness of 17 m and resistivity of 72 ohm-m. The fall in resistivity at such a thick layer suggests it is the weathered part of the bedrock or a high porosity stratum. A geological contact is highly suspected to be present within this stratum. Underlying the third layer is the bedrock whose resistivity was measured as 891 and 980 ohm-meters on Line 2 and Line 3, respectively. Figures 8-9 are illustrations of the processed VES data for the survey lines L2 and L3. VES graph for L2 was lost during the data processing.



Error = 4.25%

Layer	Resistivity (ohm-m)	Layer thickness (m)	Layer depth (m)
1	1088	1.16	1.16
2	379	2.27	3.43
3	82.7	8.33	11.8
4	891		

Figure 8. VES Graph for Line 2.



Error = 2.62%

Layer	Resistivity (ohm-m)	Layer thickness (m)	Layer depth (m)
1	1041	0.39	0.39
2	618	1.58	2.0
3	72.6	15.0	17.0
4	980		

Figure 9. VES Graph for Line 3.

3.0 Conclusions

Electrical resistivity and vertical electrical sounding were conducted at a site earmarked for a radioactive waste disposal facility known as the Borehole Disposal Concept at the Ghana Atomic Energy Commission's site in Kwabenya, Accra. Results from both techniques revealed low resistivity at some stations on the four survey lines. The Lowest dips (resistivity) were recorded at 80 m on Line 1 and 108 m on Line 2. Line 3 recorded its lowest resistivity at station 98 m while Line 4 recorded its at 64 m. With the aid of the electrical sounding data the site was characterized as a four-layer formation with the bedrock extending from of 17 m from the surface.

Acknowledgement

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