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Geophysical assessment and characterization of a nuclear waste disposal site

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ABSTRACT

A site earmarked for radioactive waste disposal facility was subjected to geophysical assessment and characterization. The principal aim was to ascertain the 'competence' or otherwise of the site and to determine whether or not the geological setting is stable enough to contain the waste. The investigation employed two geophysical techniques; electrical resistivity and seismic refraction surveys. The resistivity profiling survey have shown some zones of low resistivities at specific stations on all four survey lines which implies discontinuities in the rock formation suggesting the presence of geological contact. The seismic surveys have also revealed weak zones at same and close to the stations of the resistivity surveys. These weak zones suspected to be as a result of faults or fractures have been mapped. With the aid of the resistivity sounding data and that of the seismic refraction, the site was thus characterized as a four layer formation with geological contacts at certain points.

Introduction

Disposal of radioactive waste in a geological repository has been accepted by the International Atomic Energy Agency (IAEA) as safe method for permanent disposal of radioactive sources. This method implies disposal of radioactive waste/sources in a facility located underground at a suitable depth and in a stable geological formation.

The disposal option uses the multiple concepts based on a system of several passive barriers which consist of the conditioned and packaged waste, repository lining, back-filling and other engineered barriers within an excavated repository. The aim is to isolate the waste from the biosphere and substantially reduce the likelihood of inadvertent human intrusion into the waste and also contain the waste until most of the radioactivity has decayed.

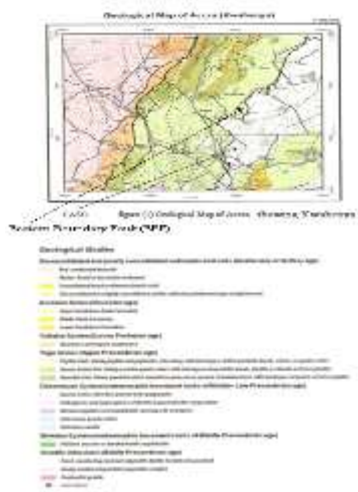
In this study, a proposed site for a radioactive waste disposal facility located at the Ghana Atomic Energy Commission's site at Kwabenya was assessed and characterized by geophysical techniques. Geophysical techniques involve the application of the principles of physics to the study of the earth. This includes taking measurements at or near the earth's surface that are influential by the internal distribution of physical properties [1]. Site characterization is the integrated process of data collection, interpretation, and modelling needed to determine the suitability of a site for a repository and to evaluate the long term performance of the repository at the site [2].

Electrical Resistivity and Vertical Electrical Sounding were employed in this study. These techniques have varying application which include; depth-to-bedrock and bedrock location, foundation investigations (determination of stability/competence of the subsurface), dynamic moduli measurements, fault location, stratigraphical mapping etc. [1].

The techniques can also be employed to solve specific environmental problems. Although the range of environmental problems is very broad; typically, they involve the need to determine the location and nature of fixed or mobile environmental hazards. Fixed hazards include buried waste containers and discarded objects. Spilled contaminants or fluids leaking from tanks or barrels constitute mobile hazards. In the case of mobile hazards knowledge of the geological and hydrological conditions that effect the transport of contaminants is often required.

Description of study area

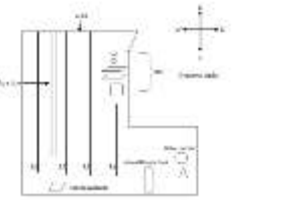
The area under investigation is located at the Ghana Atomic Energy Commission's site at Kwabenya; in the Ga East District of the Greater Accra region. The area lies within latitudes $5^0 6'7''$N to 5^0 $6'9''$N and longitudes 0^0 21' W to 0^0 26' W at elevation of 64 m.



Site Plan

Tele:

E-mail addresses: dawuud2000@yahoo.ca



Geology of Site and Surrounding Areas

The major geological formations in the area comprise of the Togo series and the Dahomeyan system. The Togo consists of phyllite, schist and quartzite. The Dahomeyan system comprises schist, gneisses, and migmatites. The Togo occupies the north-western section of GAEC and occupies the highland areas whereas the Dahomeyan outcrop in the low-lying areas [5].

Tectonics and Structures

As stated earlier, the investigated site falls under the Togo Series and the Dahomeyan system and it is characterized by various geological structures as shown in the geological map of the area in figure 2 [5].

The Eastern Boundary fault (EBF) is between the Togo Series and the Dahomeyan system whereas the Western Boundary fault follows the contact between the Birimian, the Voltaian and the Buem formation to the west of the Akuapim ranges of hills [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 rocks while to the west, only a few outcrop of Dahomeyan rocks occur in the eastern flank of the Akuapim range [6].

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 upthrusting of the Eastern Boundary fault [6].

Materials and Methodology

Two surface geophysical techniques; resistivity and seismic refraction were employed in this study. With respect to resistivity, both vertical electrical sounding (VES) and resistivity profiling were conducted using; Wenner electrode array for the profiling and Schlumberger array for the sounding.

Resistivity Profiling Data Measurement

The profiling field data were measured with the ABEM SAS-4000 (Terrameter) resistivity equipment. Four electrodes connected to electrical cables were planted into the ground. The two inner electrodes labelled p_1 and p_2 are the potential electrodes and the two outer electrodes; c_1 and c_2 are the current electrodes, figure below. Current (20 mA) was introduced at c_1 and c_2 and the resistances measured.

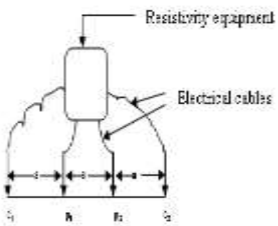


Figure (3) Wenner array resistivity profiling set-up

Resistivity Sounding Data Measurement

Resistivity sounding also referred to as vertical electrical sounding has its importance stated by text books of geophysics as, to recognize the variation of electrical resistivities with depth and to correlate the variations with geological information to explain subsurface structures and components. Vertical electrical soundings were conducted at the 90 m station on both L2 and L3. The potential electrodes were kept at a fixed position whilst the current electrodes were moved symmetrically with respect to the mid-point of the symmetrical array.

This is shown schematically in figure below. The Schlumberger electrode configuration was used.

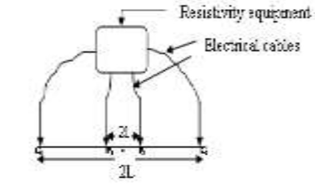


Figure 4 Resistivity Sounding Set-Up

Seismic Refraction Data Measurement

Seismic data collection, analysis and processing were done in collaboration with the Ghana Geological Survey Department. Seismic refraction field data (compressional and shear velocities) were measured on lines L2 and L3 with the SmartSeis Exploration Seismograph, ES 3000 manufactured by Geometrics Inc. The SIPIK programme developed by RIMROCK Geophysics of U.S.A. was used to pick the arrival times.

Figure (5): SmartSeis Exploration Seismograph

Results and Discussion

The results of resistivity profiling, resistivity sounding and seismic refraction are graphically represented and discussed. Each profiling line with the exception of line 4 has three graphical representations of data arising from the three different electrode separations. The first three lines; L1, L2 and L3 have three sets of data, those of the 5 m electrode separation, 10 m electrode separation and 20 m electrode separation. The fourth line; L4 , however has two sets of data comprising of 5 m electrode separation and 10 m electrode separation.

Graphs of Resistivity Profiling

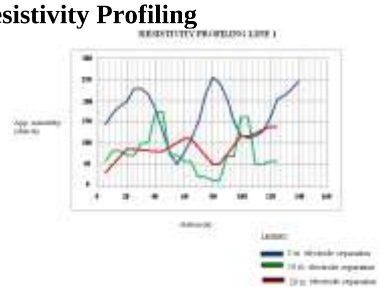


Figure (6) composite graph for line 1

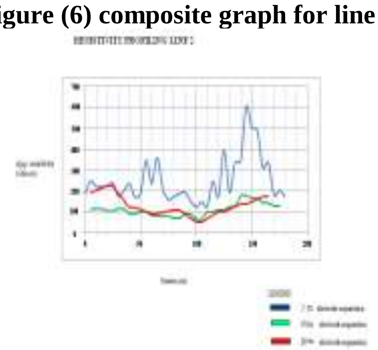


Figure (7): Composite graph for line 2

Figure (8) composite graph for line 3

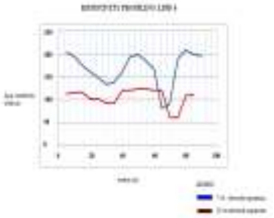


Figure (9) composite graph for line 4

Inference from the composite graph:

The composite graphs show the variation or relationship among the three electrode separation curves on each survey line.

Resistivity profiling line 1 (figure 6) shows low resistivity zones at stations 58 meters, 82 meters and 110 meters for the 5, 10 and 20 meters electrode separation curves respectively.

Zones of low resistivity can be mapped on resistivity profiling line 2 (figure 7) at stations 40 meters, 60 meters and 100 meters for all three electrode separation curves. There is lateral overlap of the three curves of resistivity profiling line 3 (figure 8).

Low resistivity zones can be mapped laterally at some stations, particularly at 20-50 meters and 80 -100 meters.
Profiling line 4 (figure 9) which comprise of only two curves i.e. 5 meters and 10 meters electrode separation curves. Low resistivity zones of these two curves occurred at station 30 meters and at 65 -75 meters. These weak zones have been mapped in figure 14.

Electrical Sounding Data Interpretation

Two electrical sounding surveys were conducted on lines L2 and L3 on which the profiling survey had relatively many weak zones.

The raw data (field data) of the vertical electrical sounding were processed and analyzed using the ipi2-win software. The data were thus modelled in accordance to the geology of the site. The site according to the electrical sounding data is a four layer formations.

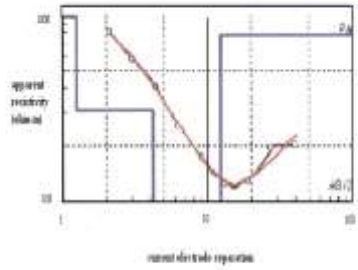
The first two layers which make-up the 'overburden' have resistivities of 1041 ohm-meter and 618 ohm-meter with thicknesses of 0.39 meters and 1.58 meters respectively. These layers comprise of loose sand and gravel to a depth of 2.0 meters.

The layer underlying the topsoil has relatively low resistivity which can be attributed to relatively high porosity, salinity or 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, has a thickness of 17 meters and resistivity of 72 ohm-meter. 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 also likely to be present. Borehole logging had confirmed water-bearing fractures at this depth [24.5].

The third layer is underlain by the bedrock whose resistivity was measured as 891 and 980 ohm-meters on L2 and L3 respectively

Graph of electrical sounding on line 2

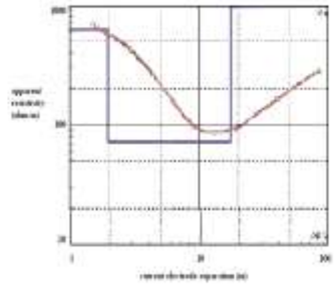


Error = 4.25%

N	ρ	h	d
1	1088	1.16	1.16
2	379	2.27	3.43
3	82.7	8.33	11.8
4	891		

N = layer, ρ = resistivity, h = thickness of layer d = depth
Figure (10) VES graph-line 2

Graph of electrical sounding on line 3



Error = 2.62%

N	ρ	h	d
1	1041	0.39	0.39
2	618	1.58	2.0
3	72.6	15.0	17.0
4	980		

N = layer, ρ = resistivity, h = thickness of layer d = depth
Figure (11) VES graph-line 3

Seismic Refraction Graph & Site Models

Line 2 was covered by only one spread. The weathered layer recorded compressional and shear velocities of 2176 m/s and 1256 m/s, the topsoil recorded 479 m/s and 277 m/s respectively.

Line 3 was covered by two spreads. Along spread 1, the topsoil, the weathered layer and the bedrock recorded compressional and shear velocities of 375 m/s and 221 m/s, 2124 m/s and 1180 m/s, 3918 m/s and 2262 m/s respectively. The weathered layer and the bedrock were located at varied depths of 0.9-2.2 meters and 3.9-12.7 meters respectively. Between depths of 0.9 meters and 1.6 meters is the weathered bedrock which has formed part of the overburden.

Spread 2 recorded compressional and shear velocities for the three layers as 637 m/s and 368 m/s, 927 m/s and 535 m/s, 4844 m/s and 2797 m/s. The weathered zone and bedrock were located respectively at varied depths of 0.8-7.3 meters and 5.8-13.9 meters.

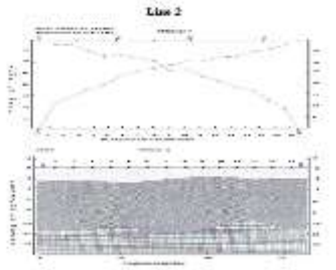


Figure (12) Seismic Refraction Graph and Model for line 2

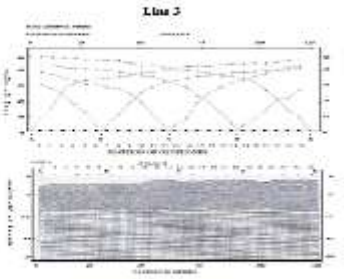


Figure (13) Seismic Refraction Graphs and Models for line 3.

Observation

At stations 25 meters and 65 meters along line 2 - spread 1; some geological anomalies had been observed along the curves with shotpoints at either end of the spread. This effect is clearly seen at geophone 5 and 12 of line 2 - model 1 (figure 41).

Geological anomalies are attributed to discontinuities in the rock formation which implies occurrence of a geological contact. This suggests that along line 2 there are at least two geological contacts occurring at stations 25 meters and 65 meters.

Along line 3, geological anomalies were recorded by the seismic refraction survey at stations 25 meters, 50 meters and 100 meters at geophone 5, 9 and 20. The resistivity profiling, however, recorded its anomalies at stations 20 meters, 50 meters and 100 meters along the same line. This confirms at least three geological anomalies along this line.

Mapped Weak Zones

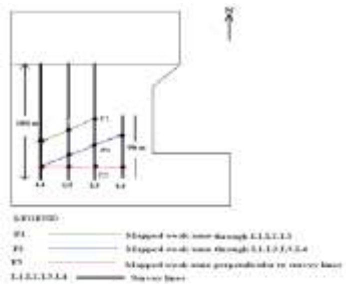


Figure (14): A sketch of the investigated area

Conclusion

Surface geophysical methods namely resistivity and seismic refraction were conducted to test the competence as well as to identify and map out weak zones of the site under investigation.

The results of the resistivity profiling showed zones of low resistivity at stations 50 metres on Line 1 and at station 100 metres and 110 metres on Line 2. Line 3 recorded low resistivities at stations 90 metres and 100 metres. The lowest resistivity was recorded on Line 4 at station 65 metres. Resistivity sounding was conducted for purposes of correlating electrical variation with geological information and to aid in characterizing the site. Vertical electrical sounding (VES) was conducted on line 2 and line 3.

Resistivity sounding data obtained from this investigation was processed using “ipi2win” software. The site was thus characterised as a four-layer formation with the bedrock at a depth greater than 17 metres from the surface. The first two layers which make up the overburden recorded high resistivities. The seismic refraction survey revealed geological anomalies which are attributed to discontinuities in the rock formation. These discontinuities are suspected to be faults or fractures.

Both resistivity and seismic refraction survey revealed same or similar geological anomalies indicating zones of low resistivity or weak zones. These are suspected to be as a result of fractures or fault. Resistivity profiling and seismic refraction surveys have confirmed at least two weak zones on lines L2 and L3. These are mapped (fig. 13) laterally as F1 and F2. F3 is a mapped weak zone solely due to low resistivities.

The seismic refraction survey recorded geological anomalies at station 25 meters and 65 meters along line 2. Resistivity profiling survey, however, recorded these anomalies at station 30 meters, 50 meters and 65 meters on the same line. Along line 3, geological anomalies were recorded by the seismic refraction survey at stations 25 meters, 50 meters, 80 meters and 100 meters. The resistivity profiling, however, recorded its anomalies at stations 20 meters, 50 meters, 60 meters and 100 meters along the same line. As stated in the aim and objectives of this project, the site under investigation was duly subjected to a geophysical assessment. The two techniques employed have both confirmed some weak zones in the area. High resistivity (fracture-free) areas have also been identified as suitable points to drill boreholes radioactive waste disposal. Thus the findings of this project will inform the decision of locating a suitable site to construct the borehole disposal facility in order to ensure safety and security and to prevent radionuclide migration into groundwater and hence prevent exposure to the general public.With the aid of the resistivity sounding and the seismic refraction survey, the site was characterized as a four layer formation with the bedrock at a varying depth of 12-17 meters from the surface.

Recommendations

To ensure safety and security, radioactive waste management system must comprise both administrative and operational activities in the following order: handling, pre-treatment, treatment, conditioning, storage and eventual disposal.

Borehole disposal facility for radioactive waste must be constructed at high resistivity zones and must be away from the weak zone areas. It must be constructed with high standard physical barriers that will prevent or delay migration of any radioactive material or radiation.

Any activity with the potential of disturbing the geological setting should be barred in the surroundings of a geological disposal facility.

It is recommended that a conventional hydrogeological method be conducted to determine the flow direction of the area. Knowledge of the flow direction will aid in determining the flow rate and hence the extent at which the radionuclide will travel from one point to another should there be a leakage.

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