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GEO-ELECTRICAL PARAMETERIZATION OF IKOGOSI SPRING WATER

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ABSTRACT

This study examined the subsurface layers, structures and possible source of heat of Ikogosi warm spring employing Vertical electrical sounding technique and Spontaneous Potential (SP) measurement of the surface natural potentials resulting from electrochemical reactions in the subsurface. Vertical Electrical Soundings using Schlumberger array were carried out at three (3) locations along a profile parallel to the flow of the warm spring. Dipole-dipole configuration was also employed to obtain the pseudo section of the subsurface. Along the same profile, Self-potential measurements were taken at every 5m interval along the traverse. The VES survey revealed KH (67 % representation) and HK (33 %) curve types with four subsurface geoelectric sections (the topsoil, fresh Basement, fractured basement and the fresh basement). The 2-D model apparent resistivity structure however, revealed five geoelectric layers including open fractured zone, fractured zone, highly weathered zone, partly weathered zone and fresh basement. The fractured zone houses the groundwater accumulation which moves gradually to where the fracture is open at the surface. The SP revealed existence of deep fracture housing large volume of water as indicated by the + and – sigh of the SP potential (1197 volt that subsequently dropped to -1785volt) at the warm spring site. The anomaly also signifies abnormal heat been generated at the bottom of the fracture which may arise from geologic processes that took place within the earth crust. This research needs further work employing Geophysical Radiation Technique to really unravel the source of the heat responsible for Ikogosi warm spring.

KEYWORDS: *Natural Potentials, Schulumberger Array, Geo Electric Layers, Fracture, Hea*

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INTRODUCTION

Warm spring represents a natural spring with water temperature above human body temperature (normally about 37 °C (99 °F)) (Pentecost et al., 2003). There are occurrences of warm spring all over the world. China, Costa Rica, Iceland, Iran, Japan, New Zealand, Brazil, Peru, Taiwan, Turkey and the United States are well known for the occurrences of hot springs. Some of the hot springs in the world have their specific peculiarities. The Rio Hondo Hot Springs in northern Argentina; classified as one of the world's most electrolytic mineral waters have become among the most visited on earth (Welcome Argentina, 2009). Also, Chaudes-Aigues hot springs in Auvergne, France with temperatures ranging from 45 °C (113 °F) to more than 80 °C (176 °F) have served as sources of heat for the houses and for the church in the area since the 14th Century (Erfurt, 2011).

Occurrences of hot springs have been reported in many countries in Africa. Occurrences of hot springs have been reported in Egypt (Moses Springs and Pharaoh bath), South Africa (Aliwal North and Caledon Spa), Ethiopia (Dallol Hot Springs), Algeria (Hammam Essalihine and Guelma) and Morocco (Moulay Yacoub hot springs and Abayou) amongst others (Jones and Renault, 2003;. Simmons et al., 2006; Olivier et al., 2008).In Nigeria, many occurrences of hot springs have been reported in literature. Ikogosi Warm Springs and Wikki Warm Springs are the most popular (Oladipo et al., 2005; Talabi, 2013).

Ikogosi is a unique town in the south-western Nigeria because of the occurrence of a particular spring that has both warm and cold water flow side by side, being the only one of its kind discovered anywhere in the world. Ikogosi warm spring located in Ikogosi, Ekiti State, South-western Nigeria, is one of the warm water geothermal reservoirs in the world. The spring is classified as a warm spring because its temperature is not up to 50^{o}C to make it fall into the class of a hot spring. Oladipo et al. (2005) reported that the temperature of the Ikogosi warm spring is about 70^{o}C at the source and 37^{o}C at the confluence. Despite the special characteristics of some hot springs all over the world, Ikogosi warm spring stands out as the only spring where warm and cold waters flow parallel, and meet somewhere to form a confluence, with each maintaining its thermal quality. The warm spring has been a source of Tourist attraction in the area. The springs sprout out and flow with a constant temperature and volume up to 150 litres/seconds from morning till night, at all seasons, all-year round (Lateef et al., 2019).

Hot springs are useful to humans for bathing, relaxation or medical therapy as is the case of Ikogosi warm spring with the mythical belief of its healing capability. Vaidya and Nakarmi (2020), in their research on “A qualitative study of patients’ Beliefs and Perception on Medicinal Properties of Natural Hot Spring Bath for Musculoskeletal problems revealed temporary relief of pain for those who took their hot bath in the Nepal springs. There is need for caution since some hot springs are hot enough that immersion can be harmful, leading to scorching and eventually death (U.S. National Park Service, 2021). Hot spring has a potential to be used as a heat source to generate electricity especially in a rural and isolated area. Hot springs can be converted into electricity by binary thermodynamic cycles such as Kalina cycle and ORC (Prabumukti and Purwanto, 2018). Additional uses include options for using hot springs thermal energy directly, rather than as a means of generating electrical power, include space heating, water heating (or pre-heating), greenhouses, and pools/hot tubs. Multiple factors must be taken into account when evaluating these opportunities for a specific location. From a geothermal resource perspective, the temperature of the water, its flow rate, and its chemistry are among the more critical focus areas..

Several research works exist in respect of formation of hot springs worldwide. Research of Gu et al. (2017), revealed that the Thermal and Mineral Springs in Arxan, North-eastern China was of meteoric origin as indicated by environmental isotopic analysis and that the springs rise from the deep basement faults with the estimated thermal reservoir temperature of 50.9 –68.8 °C. Research has it that much of the heat responsible for the hotness of the spring water is from the decay of natural radioactive elements. An estimated 45 to 90 percent of the heat escaping from the Earth originates from radioactive decay of elements mainly located in the mantle. (Turcotte and Schubert, 2002; Joe, 2006; Hamish, 2011). Furthermore, the major heat-producing isotopes in the Earth are potassium-40, uranium-238, uranium-235 and thorium-232 (Robert, 2003). In areas with no volcanic activity, this heat flows through the crust by a slow process of thermal conduction, but in volcanic areas, the heat is carried to the surface more rapidly by bodies of magma (Philpotts et al., 2009).

The resistivity of the geological formation depends mainly on its porosity, moisture content, quantity of water, salinity of water and electrical property of the rock itself governed by the preferred orientation of constituent minerals. Therefore, the measured resistivity will facilitate in the estimate of weathered zone thickness, extent of weathering, depth of the massive rock, quality of water and delineate the sheared and fractured zones, structures such as dykes, faults and lateral extent of aquifers. Resistivity which is the inverse of conductivity is dependent on temperature. Temperature is directly proportional to conductivity and inversely proportional to resistivity. Therefore, to identify the source of heat of the Ikogosi warm spring, which will have higher temperature than the surrounding temperature; areas of low resistivity will be of interest. This study intended using geophysical (VES and SP) methods to unravel the various subsurface geophysical signatures in the study area and subsequently deduce the source of heat responsible for Ikogosi warm spring.

LOCATION OF STUDY

This research work focused on the area covered by the Ikogosi warm spring in Ekiti state, South Western Nigeria. The study area lies between latitude 7°34' N and 7°35' N, longitude 4°58' E and 5°5' E (Figure 1.). The elevation of the area ranged from 473 – 549m above sea level. The study area is about 45km to Ado-Ekiti, the capital city of Ekiti State, Nigeria. The area is accessible by road networks from Efon Alaye, Ado-Ekiti, Ilawe-Ekiti and Igbara-Odo respectively. The study area can be accessed through bush paths on which tricycle and motorcycle can be used. The study area has rugged topography with undulating hills and valleys. The study area is in the tropics having rainy and dry seasons. The rainy season is as a result of the prevailing moisture laden winds emanating from the Atlantic Ocean while the dry season is from the North-East dry, hot and dusty winds from the Sahara desert. Ikogosi town is a rural area with population of 3,594 (National Population Commission, 2006). The primary occupations of people in the area are farming, fishing, crafting, among others (Opeyemi et al., 2019). Ikogosi Ekiti is home for the famous Ikogosi warm spring tourist centre, where cold and warm spring waters flow together, The Warm and Cold Springs are situated in a valley surrounded by hills which attract visitors to the tourist centre for leisure, vacation, conference and educational research (Opeyemi et al., 2019). The geology of the study area indicated quartzite, magmatite gneiss and psammites with the quartzite dominating most part of the area. Three varieties of quartzite are noticed including massive quartzite, fissile quartzite and mica schist quartzite. Most of the rock outcrops are high rising while few ones are low lying. The structural elements of the area include veins, veinlets, pegmatitic dyke, and joints. The hydrogeology of the area is controlled by the climate, topography that dictates the drainage system. The area is characterized by annual rainfall of 1500mm. It has high relative humidity of between 70 – 85 % with average annual temperature of 28°C (Talabi, 2013).

METHODOLOGY

The geophysical methods adopted in this study are the Vertical Electrical Resistivity Sounding (VES) and the Spontaneous Potential Method (SP). The VES is used to investigate the vertical variations of rock strata in a given location whereas the SP method is based on the surface measurement of natural potentials resulting from electrochemical reactions in the subsurface. The SP technique is based upon the measurement of naturally occurring electric potentials attributed to current sources in the subsurface. SP are measured with nonpolarizable electrodes in contact with the ground surface or inserted down in boreholes. Electrodes placed at the ground surface are connected via wire to a high impedance (>10 Ω-M) voltmeter and the electric potential is measured. Several mechanisms have been suggested to explain the SP anomalies; mineralization, electro kinetic, electrochemical, redox and thermoelectric potentials (Nyquist and Corry, 2002).

Prior to the survey, a site visit was conducted to decide the exact location and extent of the survey lines. A traverse line of 200m was selected which is located near the warm spring area and intercept outlet of the spring (Figure 2). The line is chosen basically near the occurrence of the warm spring because of certain factors such as the ease of access to the study area and the probability of occurrences of fractures at the selected lines. Self-potential measurement was carried out along the 200 m traverses. The Spontaneous potential data was collected at every 5m along the traverse. Data acquisition was done with fixed base configuration. Potential difference was measured between reference and moving electrode. A non-polarized electrode connected in a hole was used as the reference electrode (base). One electrode was moving with 5m spacing along the traverse which formed the line by using measuring tape. The location where the electrode was fixed when fixed-base configuration was chosen is the base station, to which all measurements are referred. The base station is chosen to lie outside any slope, be away from activity of humans and not be in an area of large negative potential or soil condition that dried up very fast. After the location of the base station was chosen the electrode was put into dug hole, and surrounded by mud made from soil that was taken out from that hole before. During the survey, the drift was observed as it increases usually over a period of time; therefore, the moving electrode require returning to the reference point measurement at the base station every 1-2 hours and when the last point on the profile was completed it must return again. It is important that the electrode at the base station must not be dried up, it should always be checked. The result from the survey was plotted graphically to reflect the SP along the profile.

Figure 2 shows as for the VES, four electrodes, two current and two potential electrodes were used for the survey employing Schulumberger array. The electrodes were hammered into the ground and electric current was transmitted through the cables to the current electrodes while the potential created on the surface by the circulation of this current into the ground was measured with other potential electrodes. This involves spacing of the four electrodes with two current electrodes widely spaced outside and two potential electrodes closely spaced within them along the survey profile. In this array potential electrodes MN are fixed while distance between the current electrodes A and B are increased five times after which the distance between the potential electrodes is moved. It is normally assuming that MN < AB/5. Increasing progressively the distance between the transmitting and the receiving electrodes permits an increase in the depth of investigations. Three (3) Vertical electrical soundings were carried occupied along the traverse. The traverse for the three VES points was parallel to the traverse of the SP. The VES points are positioned at 0m, 100m and 200m along the SP traverse. Sounding resistivity values were plotted against AB/2 or half the spread length on a bi-log paper and subjected to partial curve matching technique to obtain models for computer iteration to obtain the true resistivity and thickness of the layers. Computer iteration were carried out to reduce errors to a desired limit and to improve the goodness of fit of the curves.

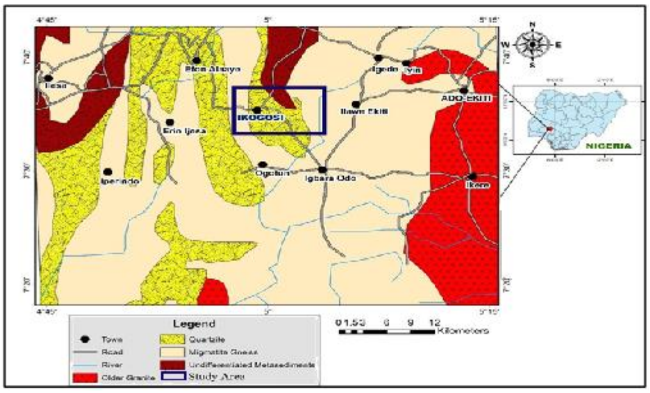


Figure 1: Location and Geology of the Study Area.

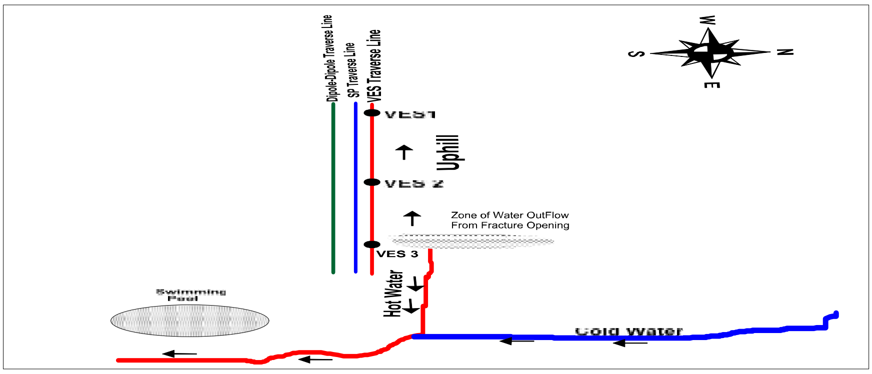


Figure 2: Sketch Diagram Indicating Profile Lines for Both VES and SP.

RESULTS AND DISCUSSIONS

Field Curves

The summary of the Vertical Electrical Sounding (VES) interpretation results are presented in Table 1. The observed depth sounding curves were classified into different curve types (KH and HK). Typical depth sounding curve obtained from the study area are presented in Figures 3(a-c). Four geoelectric layers along the single traverse of the warm spring were observed. The KH curve type dominates, constituting 67 % of the totals while the HK-type constitutes 33 %.

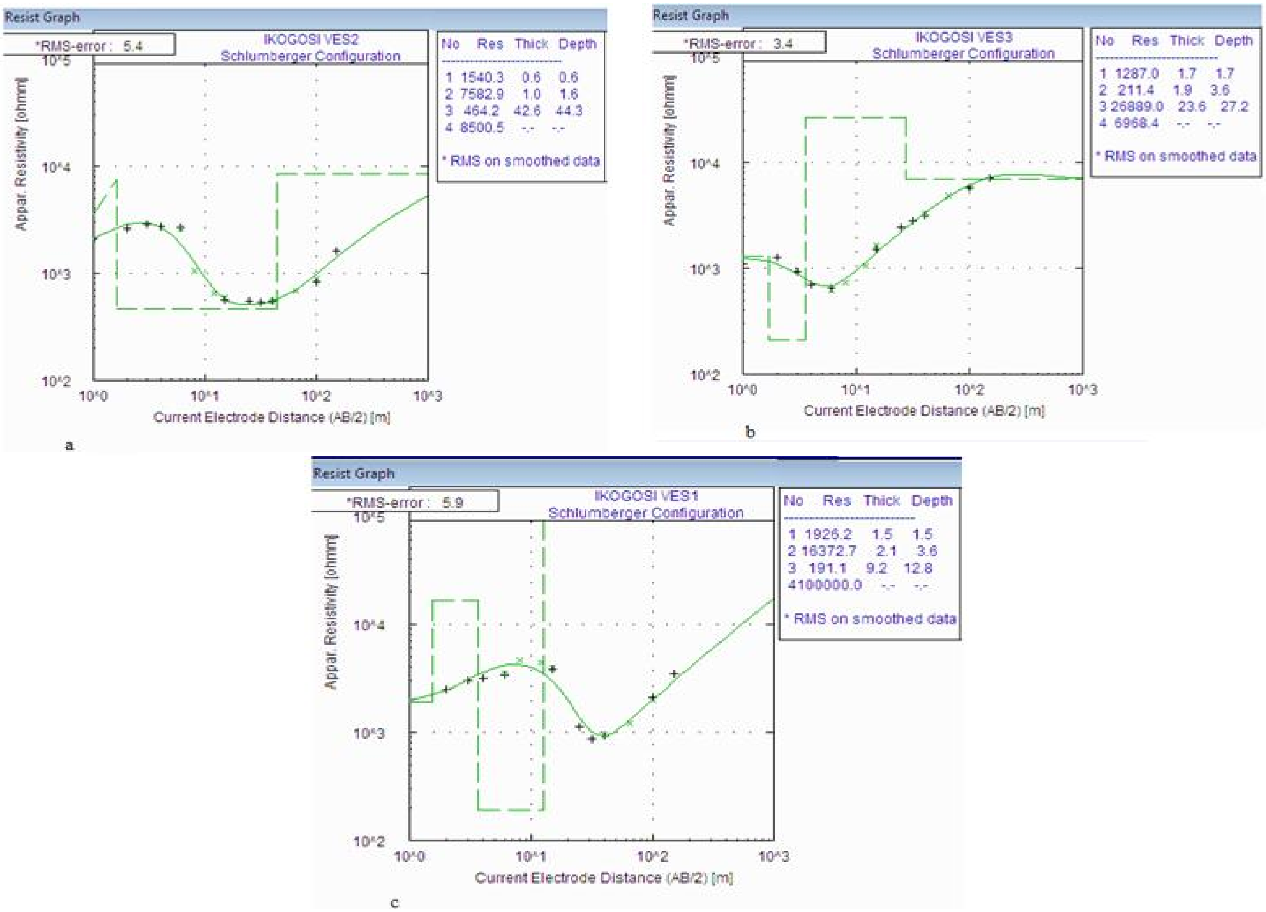
Geoelectric-Sections

The geo-electric sections generated across the study area are shown Figure 4. Four subsurface geoelectric sections were delineated. These are the topsoil, fresh Basement, fractured basement and the fresh basement. The topsoil resistivity values range from 1289 – 1926 Ω-m and thickness values ranges from 0.6-1.7 m (Table 1). The topsoil is made up of loamy to sandy-loamy soil; the sands were originated from weathered quartzite formation of the study area. The second layer is the fresh basement with resistivity values that range from 7583-16363Ω-m and thickness ranging from 1.0 – 2.1 m. The second layer is characterized with quartzite rock (Figure 4).

The Third layer is the fractured basement with resistivity values range from 191 – 464 Ω-m and thickness value varying from 9.2 – 46.2 m. The fractured basement is made up of partly weathered/ fractured basement. The last layer is the fresh basement. The resistivity values range from 8501 – 100000 Ω-m. The fractured basement constitutes the aquifer units in the study area (Figure 4).

Table 1: Summary of Interpreted VES Curves

VES	Resistivity (Ωm)	Thickness(m)	Depth	Curve type	No of Layers	Remark
1	1926	1.5	1.5	KH	4	Topsoil
	16373	2.1	3.6			Fresh Basement
	191	9.2	12.8			Fractured Basement
	100000	-	-			Fresh Basement
2	1540	0.6	0.6	KH	4	Topsoil
	7583	1.0	1.6			Fresh Basement
	464	42.6	44.3			Fractured Basement
	8501	-	-			Fresh Basement
3	1287	1.7	1.7	HK	4	Partly weathered Basement
	211	1.9	3.6			Fractured Basement
	26899	23.6	27.2			Fresh Basement
	6968	-	-			Fractured Basement



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No    Res   Thick  Depth
---------------------------
 1  1540.3   0.6    0.6
 2  7582.9   1.0    1.6
 3   464.2  42.6   44.3
 4  8500.5   -.-    -.-

* RMS on smoothed data
```

```
No    Res   Thick  Depth
---------------------------
 1  1287.0   1.7    1.7
 2   211.4   1.9    3.6
 3 26889.0  23.6   27.2
 4  6968.4   -.-    -.-

* RMS on smoothed data
```

```
No    Res   Thick  Depth
---------------------------
 1  1926.2   1.5    1.5
 2 16372.7   2.1    3.6
 3   191.1   9.2   12.8
 4100000.0   -.-    -.-

* RMS on smoothed data
```

Figure 3: (a, b and c). Geo-Electric Curves from the Study Area.

D Apparent Resistivity Structure

Figure 5 presents the 2-D model apparent resistivity structure along Traverse 1. The section delineated five geoelectric layers which are; open fractured zone, fractured zone, highly weathered zone, partly weathered zone and fresh basement. They are the zones characterized with low resistivity values of bluish and greenish colour bands; medium resistivity values of yellowish bands and high resistivity values of purple colour bands respectively. The open fracture is observed between distances 180 – 200 m to a depth of about 5 m. The fractured zone is observed between distances 100-200 m within a depth of 5 – 25 m while the fresh basement zones are within distances 40-90 m and135- 180 m to a total depth of over 25 m. The fractured zone houses the groundwater accumulation which moves gradually through to where the fracture is open at the surface. The undulating topography actually aggravates the hydrostatic pressure which resulted into generating the free flow of the warm spring out where the fracture is open at the surface.

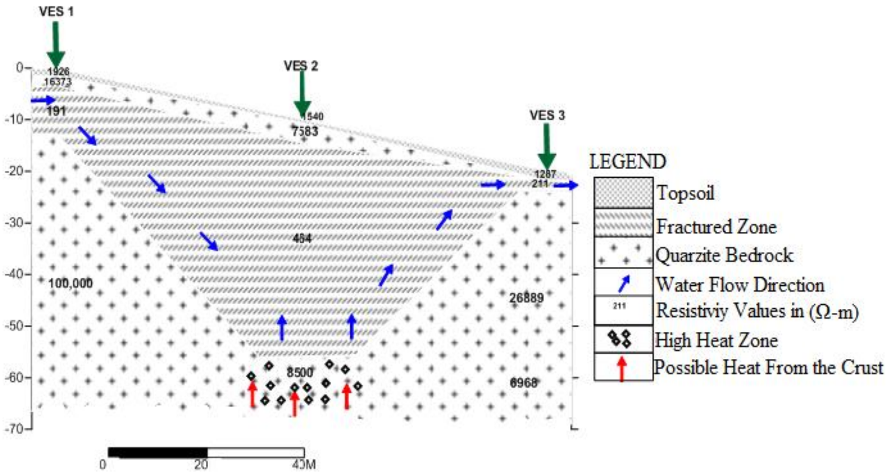

Figure 4: Geo-Electric Section across the Study Area.

Spontaneous Potential

SP Profile was conducted using the gradient array technique with interstation distance of 5m within the study area. The environment generally has high natural potential ranging from -126 to 448 volts (Figure 6). This can also contribute to the hydrothermal effect within the geologic formation that characterizes the study area. Within distances 85 to 110 m, an anomaly was observed with value as high as 1197 volt which dropped to -1785volt which signalled existence of deep fracture that houses large volume of water. The anomaly also signifies abnormal heat being generated at the bottom of the fracture which may arise from geologic processes that took place within the earth crust.

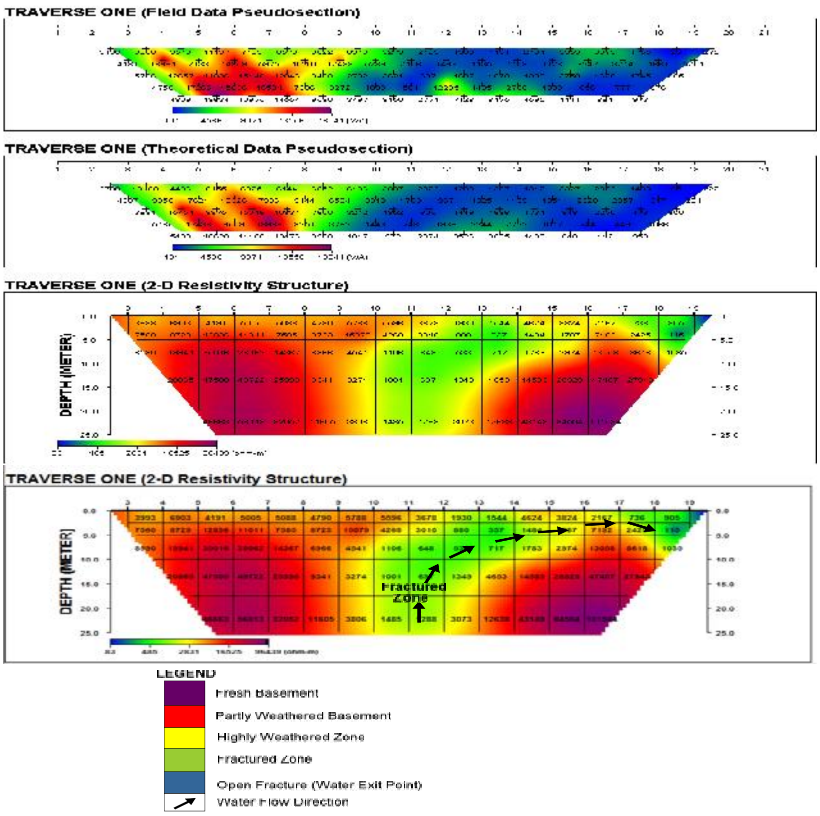

Figure 5:-D Model Apparent Resistivity Structure along Traverse 1.

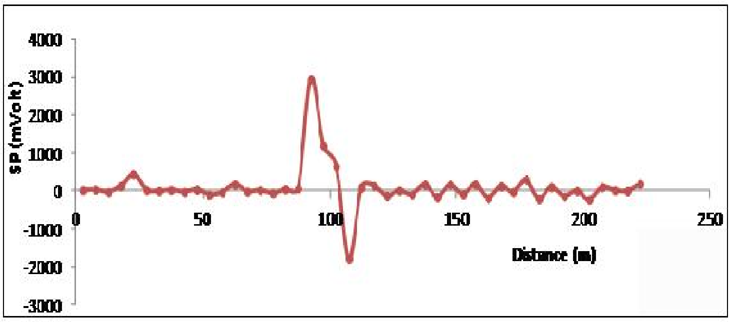

Figure 6: Spontaneous Potential Graph.

SP 2-D Inverted Potential Structure

Dipole-dipole array was also adopted to produce a potential pseudo-section which further revealed that the environment was characterized with very high natural potential within distances 0 – 95 m and 118 to 200 m to a depth beyond 25 m of probe as signified with reddish to pinkish coloration (Figure 7). Also, the abnormal low values that revealed the fractured zone can be observed within distance 95 - 118 m.

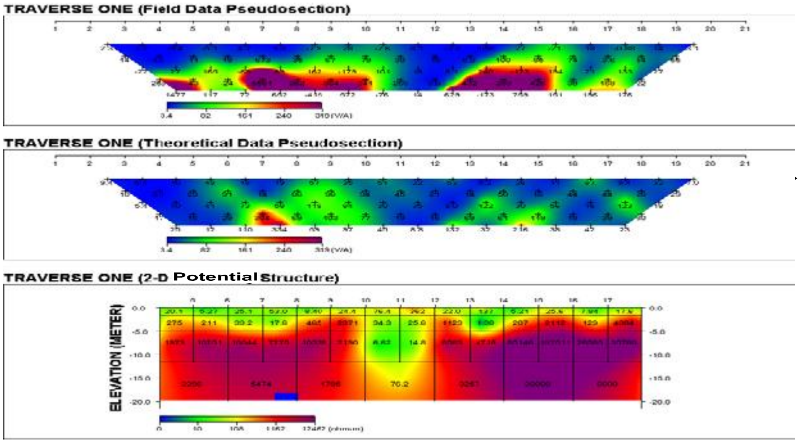

Figure 7: Potential Pseudo-Section from Dipole-Dipole Array.

CORRELATION OF RESULTS

The two electrical methods (VES and SP) applied to this study using different configurations lead to the derivation of SP graph, 2-D pseudo-sections and the geo-electric section. The results show the existence of fracture within distances 100 and 120 (Figure 8).

Also, the study reveals that water flow from the east to the western part along the established traverse. We can also deduce from the 2-D Electrical resistivity and geo-electric section that the thickness of fracture that produces the water in the quartzite rock of the warm-spring is about 43 m.

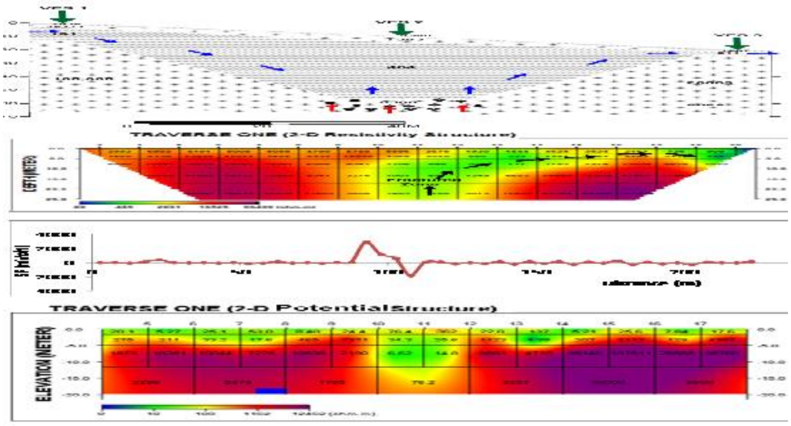

Figure 8: Correlation of Results.

CONCLUSIONS

The VES revealed that the study area is highly fractured and that the fractures serve as conduits to convey the warm spring to the surface. The SP reveal existence of deep fracture housing large volume of water as indicated by the + and – sigh of the SP potential (1197 volt that subsequently dropped to -1785volt) at the warm spring site. The anomaly also signifies abnormal heat been generated at the bottom of the fracture which may arise from geologic processes that take place within the earth crust. This research needs further work employing Geophysical Radiation Technique to really unravel the source of the heat responsible for Ikogosi warm spring.

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CONFLICT OF INTEREST

There is no conflict of interest with regards to this manuscript.

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