# In search of geothermal energy power potential in Tanzania: the role of geophysics

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## Abstract

A feasibility study was done to evaluate the Southwestern Tanzania geothermal prospects for their power potential. Vertical Electrical Sounding (VES), a geophysical survey method was deployed in this study. VES was done to study the vertical variations of electrical resistivity in the geothermal prospects and to locate the extent of the reservoir/ fracture zones or the outflow regime of the thermal waters.

The result showed that at Na John, River-muddy, Bwana Hutu, Mampulo, Mwakalinga and Kasumulo springs (VES 1, 2, 3, 4, 5 and 6 respectively), the apparent resistivities decreased with depth as one moves from the first top layer to the second. It was noted that in VES 3, 4 and 6, the second layers have low resistivity ranging from 3.3-5.0 Ωm. While in VES 5 the apparent resistivity decreased with depth in all three layers encountered. The layer thickness ranged from 0.9-1.2m in the top layers and from 0.9-33.0m in the second layers. VES 3, 4, 5, and 6 proved to be of hot thermal ground. The geothermal manifestation (hot springs) tended to be associated with regions of low resistivity.

The Mampulo, Mwakalinga and Kasumulo springs are found to be located at the foot of concealed thermal outflows, which are supposed to be emerging from beneath the Rungwe volcanics. At the Songwe prospect, contrary to the expected huge hydrogeothermal reservoir, which could account for the reported and observed huge deposit of travertine (>150 mill. $m^3$), only a low resistivity zone of maximum depth of less then 10 m was encountered. This can by no means account for the huge travertine deposit and the still on going deposition of calcium carbonate at a rate of 5 g/s. This suggests that the reservoir is further upstream.
*Keywords: VES, travertine, apparent resistivity, Songwe prospect.*

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## 1 Introduction

Geothermal energy is a natural calorific energy of the earth that partly originates from the decay of radioactive elements contained in the earth's mantle rocks. The other part, originate from the remnant heat of the hot magmatic rocks embedded in the crust. The hot springs, fumaroles and geysers, like volcanoes, are visible evidence of the existence of high temperature in the Earth's interior.

Geophysical electrical surveys have been used successfully in geothermal exploration (Hochstein [1]). They have been particularly important on mapping faults, fractures, low resistivity caused by thermal fluids and hydrothermal alterations that results from the interaction of the thermal fluid and the country rocks or reservoir rocks (Hochstein [1]). The success of any geophysical method in exploring a given geothermal system usually depends upon the contrast of a set of physical rock properties inside and outside of a geothermal system that give rise to certain geophysical anomalies. Geophysical anomalies are caused by hot geothermal fluids, which can be related to certain fluid parameters like, temperature, mineralization, gas content of fluid and fluid movement. Such anomalies can be categorised as shallow temperature anomalies, resistivity (fluid) anomalies, natural potential anomalies, less well-defined attenuation anomalies of seismic waves and (seismic) ground noise anomalies. It has been noted that these anomalies occur only over active geothermal system and are confined to the geothermal reservoir or lateral outflows from such a reservoir (Hochstein [1]).

SWECO-VIRKIR [2] in their preliminary study identified the geothermal resources potential of Tanzania, which unfortunately has few useful data for any of the thermal areas. Tanzania has an estimated geothermal energy potential of 650 MW (McNitt, [3]). Mbeya region was recommended for further investigation due to the reported high temperature (271$^{o}$C) of the predicted subsurface temperature of Rambo spring. The objective of this research is to determine hydrogeothermal power potential of some Hot Springs in South-western Tanzania.

## 2 Location and geology of the study area

Vertical electrical resistivity variation was studied, using Schlumberger symmetrical array, to locate the reservoir or the outflow regime of the thermal water in the Mbeya prospect (SWECO-VIRKIR [2]), which is located to the Southwest Tanzania. The prospect has three main areas of geothermal interest:

(1) Songwe valley area, which is located at Latitude 8$^{o}$ 50'-8$^{o}$ 56'S and Longitude 33$^{o}$ 10'E-33$^{o}$ 15'E (Fig. 1).
(2) The Mampulo/Kasumulo area, which is located at Latitude 9$^{o}$ 31'S-9$^{o}$ 54'S and Longitude 33$^{o}$ 44'E-33$^{o}$ 51'E (Fig. 2).
(3) The Rungwe-Kalambo area, which is located at Latitude 9$^{o}$ 22'S-9$^{o}$ 27'S and Longitude 33$^{o}$ 39'E-33$^{o}$ 59'E (Fig. 2).

Harkin, [4] and Ebinger *et al* [5] has reported that moderate hydrothermal activity occurs over and adjacent to the Rungwe volcanic field that consists of

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mainly basaltic and trachytic rocks of Miocene to Quaternary age which infill the northern section of the Malawi Rift Valley. Mt.Kiejo, which is located north of the Mbaka fault, is an active volcano that erupted last time more than 200 yr ago. About 20 km to the north of Mt. Kiejo is the Rungwe volcano, which has no visible thermal activity is associated with the Rungwe volcano.

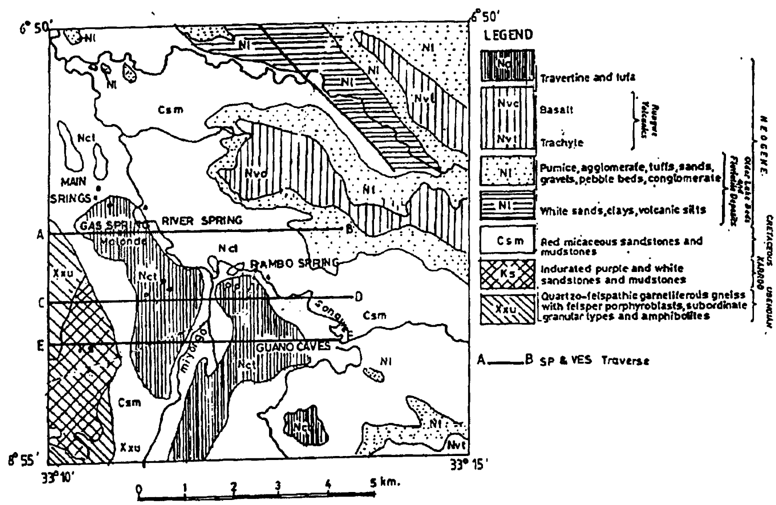


Figure 1: Geological map of Songwe valley area showing the location of the hotsprings (modified from Spurr [6] and Brown [7]).

The geology of some part of the study area that is shown in Fig. 1 was studied by various workers (Spurr [6]; Brown [7]; Morley *et al.* [8]; and Ebinger *et al.* [9]) who established that the surface geology consists of the following: the Rift related sedimentary basin believed to have been formed by the three rifting episodes namely the Permotriassic, the Cretaceous and the Cenozoic. On studying the evolution of the Rukwa basins, McConnell [10] and Cahen *et al.* [11] reported that the basins are faulted into the Ubendian Tectonic domain. They further stated that this tectonic domain, that forms the basement, is characterised by two facieses namely; high-grade metabasic and metasedimentary sequences with intensely mylonitized shear zones. The Songwe basin is filled with successions of sedimentary and volcanic rocks (Fig. 1). Brown [7] mapped the area during regional mapping programme. The hot springs referred in the text as geothermal manifestation discharge through vents in the Pleistocene travertine limestone draping over sandstone in the gorge above the Songwe River. Spurr [6] reported that the river flow is controlled by a major fault striking in a northwest-southeast direction to the north-west and an escarpment binding it to the south-east. Faulting has not been observed in the Karoo and Cretaceous rocks (Spurr [6]).

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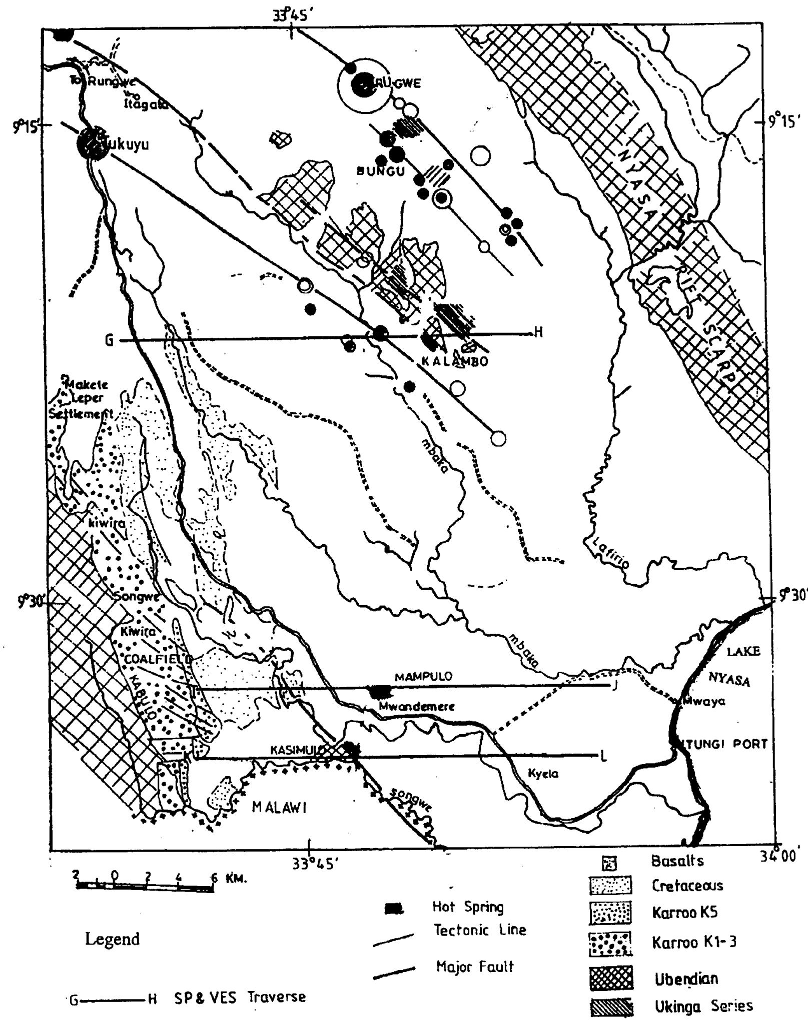


Figure 2: Geologial map of Tukuyu, Rungwe-Kalambo and Kyela, showing the location of the hotsprings (modified from Harkin [4]).

## 3 Material and methods

VES Soundings (Fig.3) were used to study the vertical variations of the electrical resistivity in the study area. Soundings with symmetrical Schlumberger array were used because they are less affected by near-surface disturbance than soundings made with other 4-point array (e.g. Werner or Dipole-dipole array). The apparent resistivity data was taken using a Sycal: JUNIOR-Ri Plus-R2/Elrec-T resistivity meter and ABEM Terrameter 3000C. The maximum

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distance for 'AB' (current electrodes) was 200 meters and 'MN' (potential electrodes) was 50 meters. The very poor terrain especially in the Songwe prospect limited this. The current was sent into the ground through A and B to form a closed circuit, while the potential difference V was measured between M and N electrodes, which were kept fixed. A and B electrodes were moved outwards symmetrically in steps to the maximum attained separation of 200m.

The VES lines were deployed along lines close to or across some hot springs as shown in Figs. 1 and 2. Traverse lines deployed at the Songwe prospect are as follows; AB (VES 1) at NaJohn hot spring, CD (VES 2) close to Songwe river above the boiling muddy springs, EF (VES 3) near Bwana Hutu springs in the thermal ground area (atm. T = 40°C, Fig.1). At the Mampulo prospect are GH (VES 4) and IJ (VES 5) at Mwakalinga hot springs and thermal grounds. At Kasumulu is LM (VES 6) at thermal ground area close to the Tanzania – Malawi border (Fig. 2).

At each measurement, the current electrodes (A, B) were moved outward from the centre of the traverse. The apparent resistivity was read directly from the resistivity meter but where ABEM Terrameter was used, the apparent resistivity was calculated using equation (1) in accordance with Parasnis [12].

$$\rho_a = \left[\frac{L^2 - l^2}{2l}\right]\left[\frac{\Delta V}{I}\right] \quad (1)$$

where $\rho_a$ is apparent resistivity (ohm-m), L is AB/2 (m), l is MN/2 (m) and ($\Delta V/I$) is the resistant (R) (ohms), (assuming symmetrical Schlumberger array).

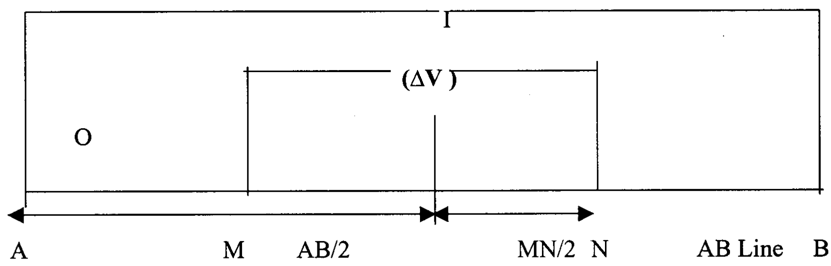


Figure 3: The Schlumberger array configuration.

Where delta V is potential difference between M and N, I is current flowing through AB; A and B, M and N are current and potential electrodes, respectively.

The interpretation of the data was done in the field for quick check of the quality of data on site and later on in the office by complete curve matching methods (E.A.E.G. [13]) to form a basis for modeling. Modeling was done using computer iterative techniques using VES software (SVES program). The data was plotted on a trace paper superimposed on a double logarithm graph (log-log graph of modulus 62.5). Any point, which plotted out of range, the measurements were repeated, and electrode connections checked. If all was well then the voltage was increased.

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The data was plotted on a trace paper superimposed on a double logarithm graph (log-log graph of modulus 62.5). The trace paper with data points was transferred to matching standard curve (E.A.E.G., [13]). The matching of the data point was done by trial and errors until a complete curve matching was attained, thus known as the complete curve matching. The marched curve was traced on the tracing paper to connect the data point and the curve index was written at the end point of the curve. Points for 1st ($h_1$) layer and the resistivities: $\rho_1$, $\rho_2$ and $\rho_3$ were marked on the trace paper. Then the trace paper with the curve was transferred to the double logarithm graph.

From the double logarithm graph the thickness of the 1st ($h_1$) layer was read and the thickness of the 2nd layer ($h_2$) was calculated ($h_2$ = $h_1$ multiplied by the respective curve index) in the probed point, respectively. Then $\rho_1$, $\rho_2$ and $\rho_3$, which are the resistivities of the three layers respectively, were also read from the same graph. This formed the initial model, required by the computer programs in order to complete the curve marching using interactive method (SVES Program).

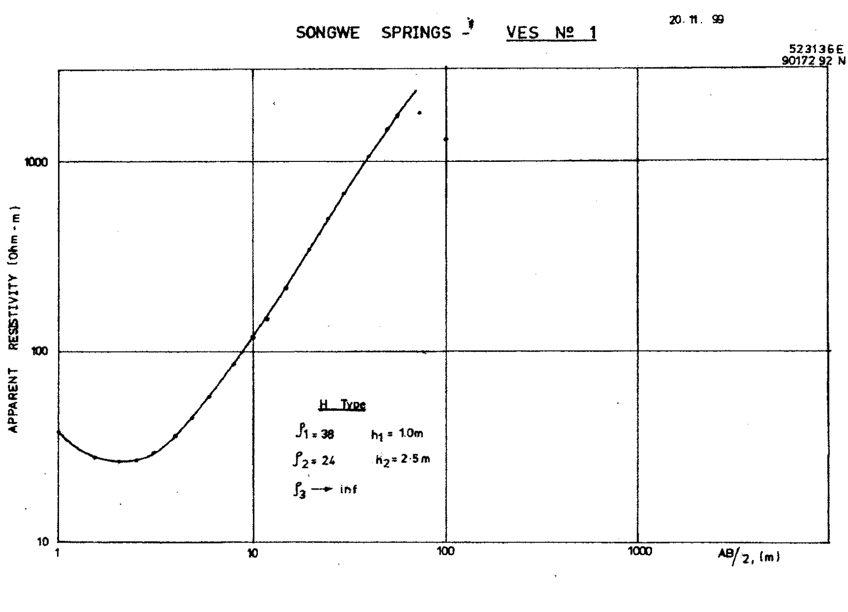


Figure 4: VES 1 across NaJohn hot spring.

## 4 Results and discussion

The results are as shown in Fig. 4-9 (VES Profiles.1-6). The interpretation is based on the assumption that the earth is composed of a finite number of horizontal layers. Each layer is electrically homogeneous as well as isotropic (Parasnis [12]).

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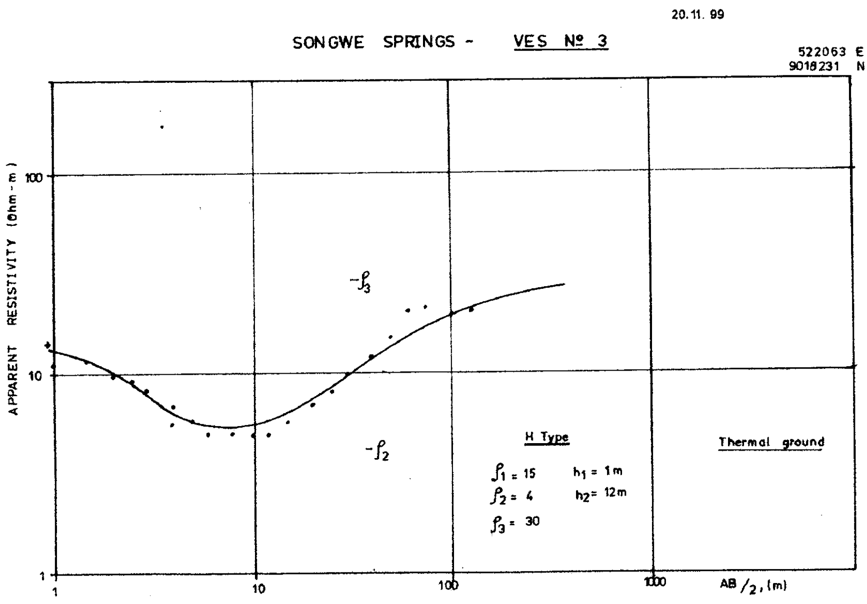


Figure 5: VES 3 at Bwana Hutu.

### 4.1 The Songwe prospect

Part of the Songwe prosect proved to be difficult to make accurate (AB/2 = 200 m long) VES due to topography especially at NaJohn hot spring and the fracture controlled hot spring above the boiling springs. The travertine has developed sort of cliff like structure draping over sandstone on the wall of the gorge and the hot springs are coming out through travertine and precipitated calcium carbonate vents or fractures. Also at the riverbank a cluster of hotsprings are emptying their water into the Songwe River. Three VES were deployed at the Songwe prospect. VES 1 and 2 at the sidewall of the gorge on the draping travertine and VES 3 at low topography area close to and opposite the river bank as shown in Fig. 1.

(1) VES No. 1 is an H type curve. Its apparent resistivity varying with depth from high in the first layer to low in the second layer and increased to infinity at the third layer ($\rho_1 > \rho_2 < \rho_3$); where the resistivity of the top layer is 38.0 Ω-m with a thickness of 10.0 ($h_1$), that of the second layer is 24.0 Ω-m with a thickness of 2.5 m ($h_2$) and increased to infinity in the third layer.

(2) VES No. 2 is an A type curve with apparent resistivity increased with depth ($\rho_1 > \rho_2 > \rho_3$); where the resistivity of the top layer is 14.0 Ω-m with a thickness of 0.9 m ($h_1$), that of the second layer is 28.0Ω-m with same thickness as layer one ($h_2$) and 36.0 Ω-m for layer 3 (Table 1).

(3) VES No. 3 is an H type curve with apparent resistivity varying with depth from high to low and then high ($\rho_1 > \rho_2 < \rho_3$ ). The resistivity of the top layer is 15.0 Ω-m with thickness of 1.0 m ($h_1$), that of the second layer is 4.0 Ω-m

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with a thickness of 12.0 m ($h_2$) and 36.0 Ω-m of the third layer. It is a hot thermal ground area (Fig. 5).

Table 1: Summary of results.

| Prospect | Location of hot spring | VES No. | Type | Top layer | | Intermediate layer | | | Bottom layer |
|---|---|---|---|---|---|---|---|---|---|
| | | | | ρ (Ω-m) | h (m) | ρ (Ω-m) | h (m) | ρ (Ω-m) | h (m) |
| Songwe | NaJohn hot springs | 1 | H | 38 | 10.0 | 24 | 2.5 | infinity | infinity |
| | Ilatire hot spring | 2 | A | 14 | 0.9 | 28 | 0.9 | 36 | infinity |
| | Bwana Hutu hot springs | 3 | H | 15 | 1.0 | 4 | 12 | 36 | infinity |
| Mampulo/ Kasumulu | Mampulo | 4 | H | 5 | 1.1 | 3.3 | 33 | 8 | infinity |
| | Mwakalinga | 5 | Q | 17.5 | 1.2 | 11.5 | 7.2 | 5.8 | infinity |
| | Kasumulu | 6 | H | 11 | 1.1 | 5 | 2.2 | 21 | infinity |

## 4.2 Mampul/Kasumulu

At Mampulo prospect, two VES were deployed. The area is of very low terrain except for two little hills, Mampulo and Mwakalinga, one on the eastern part of Mampulo and the other one separating Mampulo from Mwakalinga. VES 4 and 5 were made at Mampulo itself and Mwakalinga in Mwampulo.

(1) VES No. 4 is an H type with apparent resistivity varying with depth from high to low and then high ($\rho_1 > \rho_2 < \rho_3$). The resistivity of the top layer is 5.0 Ω-m with a thickness of 1.1.m ($h_1$), that of the second layer is 3.3 Ω-m with the thickness of 33.0 m ($h_2$) and 8.0 Ω-m of the third layer. It is a hot thermal ground area.

(2) VES No. 5 is a Q type curve with apparent resistivity varying with depth from high to low ($\rho_1 > \rho_2 > \rho_3$ ). The resistivity of the top layer is 17.5 Ω-m with the thickness of 1.2 m ($h_1$), that of the second layer is 11.5 Ω-m with a thickness of 7.2 m ($h_2$) and 5.8 Ω-m of the third layer. It is a hot thermal ground area.

(3) VES No. 6 was deployed at Kasumulu where the terrain is of low relief as compared to that of Songwe prospect. VES No. 6 is an H type curve (Fig. 8). Its resistivity varying with depth from high to low and then high ($\rho_1 > \rho_2 < \rho_3$); where the resistivity of the top layer is 11.0 Ω-m with a thickness of 1.1 m ($h_1$), that of the second layer is 5.0 Ω-m with a thickness of 2.2 m ($h_2$) and 21.0 Ω-m of the third layer.

The difference between the values in VES 1 and 2 as compared to those in VES 3, 4, 5, and 6 may be due to topographical effect. However, since errors due to noise usually result in higher, rather than lower apparent resistivity values, the

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lowest values here are taken to be the most likely reliable. This is supposed to be true because the study area is far away from any human activities. Thus representative values of 3.0 - 6.0 m are taken to be indicative of the hot thermal ground/ weathered formations of the study area. Hot thermal grounds exist over some parts of the Songwe, Bwana Hutu area and all over Mapulo/Kasumulu prospects.

In VES 1,2,3,4 and 6 the apparent resistivities decreased with depth as one moves from the first top layer to the second. It was noted that the second layers of VES 3, 4 and 6, have low resistivity ranging from 3.3 – 5.0 m. while in VES 5 the apparent resistivity decreased with depth in all three layers encountered. The layer thickness of the top layer ranged from 0.9 – 1.2 m and from 0.9 – 33.0 m in the second layer. VES 3,4,5, and 6 proved to be of hot thermal. The geothermal manifestation tends to be associated with regions of low resistivity. Low values of resistivities implies that:

(a) The phenomena is reflecting the geothermal reservoir itself, which contains hot water with a lot of dissolved minerals in it or

(b) Hydrothermal altered zone that is formed partly over the geothermal reservoir by the movement of fluids from the deep to the shallower parts near the surface and partly by concealed outflows along the flowing regime.

The low resistivity encountered in this study indicated the presence of hot thermal grounds at VES 3, 4, 5 and 6.

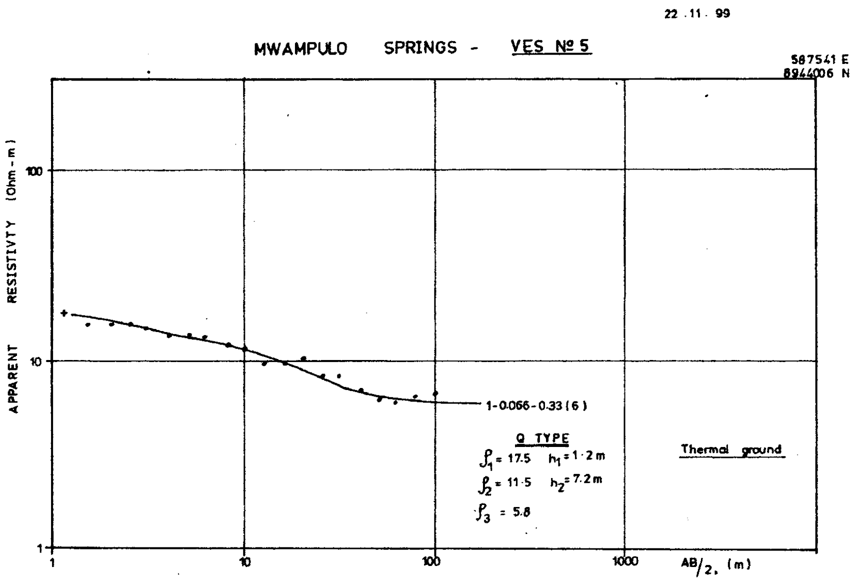


Figure 6: VES 5 at Mwakalinga hot springs.

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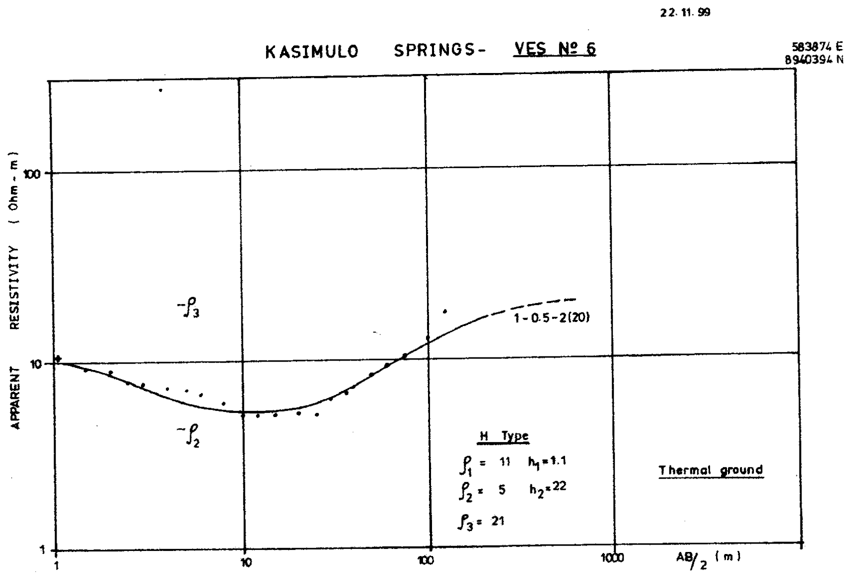


Figure 7: VES 6 at Kasumulu hot spring.

From the big volume of travertine deposited at Songwe prospect, one would have expected a big reservoir to account for such deposition but the maximum thickness of the second layer with the lowest apparent resistivity of 4.0 ohm-m was just 12.0m. This implies that the geothermal manifestation at Songwe prospect is just an outflow regime of far away big reservoir (s) that can replenish such volume and continuing rate of depositing travertine (estimated to be 5g/s).

The big area of hot thermal ground at Mampulo had previously been thought to be the top of the reservoir. However, from the VES Sounding, the results indicate that the source is far away from the prospect. It seems that Mampulo/Kasumulu prospect are outflow areas (faults, fractures or underground channels) from some hot upflow sources located somewhere else. Kilambo prospect, which is not discussed in this paper, is about 15 km SSE of Kiejo volcano and close to a NW trending major fault zone (Mbaka fault) (Fig. 2).

## 5 Conclusion

From the field observation and the VES survey results it can be concluded that the low shallow resistivity values are associated with geothermal activities. It has been shown that the geothermal manifestations in the case study area identify the outflow regime. It seems that this outflow originates from a high temperature reservoir, probably some tens of kilometres upstream from the spring areas. From the location of the different prospects in relation to the volcanic mountains, it can be concluded that the Mampulo/Kasumulo prospects hot springs originate

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from the Rungwe volcanic and flow through confined aquifers or concealed faults and fractures to the place where geothermal manifestation are observed. Those of Songwe are thought to originate from Panda Hill, which is a carbonatite intrusion.

The field results presented in this paper indicate that shallow low resistivity anomalies are associated with geothermal activity. This suggests that there is some active flow of geothermal fluids creating rock alterations like clays, which are electrically conductive. Therefore, further work is being done in areas that showed low resistivities anomalies to identify the upflows and the outflows. This will help in locating faults, thermal water channels or the reservoir itself, as it is not yet known. It still remains a challenge to locate the reservoir upstream by geophysical methods.

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