Proceedings, 6th African Rift Geothermal Conference
Addis Ababa, Ethiopia, 2nd – 4th November 2016

INTEGRATED GEOPHYSICAL MODEL FOR SUSWA GEOTHERMAL PROSPECT USING RESISTIVITY, SEISMICS AND GRAVITY SURVEY DATA IN KENYA

Raymond Mwakirani
Geothermal Development Company Ltd, P. O. Box 1770 Nakuru, 20100
rmwakirani@gdc.co.ke

ABSTRACT

Magnetotelluric (MT) method is prefered for sub-surface exploration of geothermal areas. The MT method is effective for delineating geothermal reservoirs that are characterized by high resistivity contrast between the reservoir and the overlaying cap rock (clay caps), The transient electromagnetics (TEM) was used to resolve the static shift problem in MT due to its good resolution near the surface. In this study, we investigate the geothermal potential over the Suswa geothermal prospect through correlation of electromagnetic, seismics and gravity survey results. The three data sets show quiet a good correlation and thus helps us confirm there exists a geothermal system at Suswa. A look at the resistivity maps reveal a low-resistivity anomaly at depth which is probably the deeper conductor acting as a heat source on the northern and the southern part of the prospect. This is confirmed by a high-density body seen on the gravity survey at similar locations of the prospect and also micro seismic events at depth reveal the same trend thus reducing ambiguities in the interpretation of either data set.

Keywords: Geothermal, Magnetotellurics, Transient Electromagnetic, Gravity, Seismics, Suswa, Kenya.

1. INTRODUCTION

The Suswa geothermal prospect is associated with a trachytic volcano located along the Kenyan rift valley (Figure 1). Geophysical surveys were undertaken in Suswa to give a structural image of the subsurface. The electrical resistivity method was used as its data are strongly affected by geothermal processes and may indicate the presence of a geothermal system. The magnetotelluric (MT) method is prefered for exploration of geothermal. The method is effective for delineating geothermal reservoirs, which are characterized by high-resistivity contrast between the reservoir and the cap rock (clay caps) that are located on top.

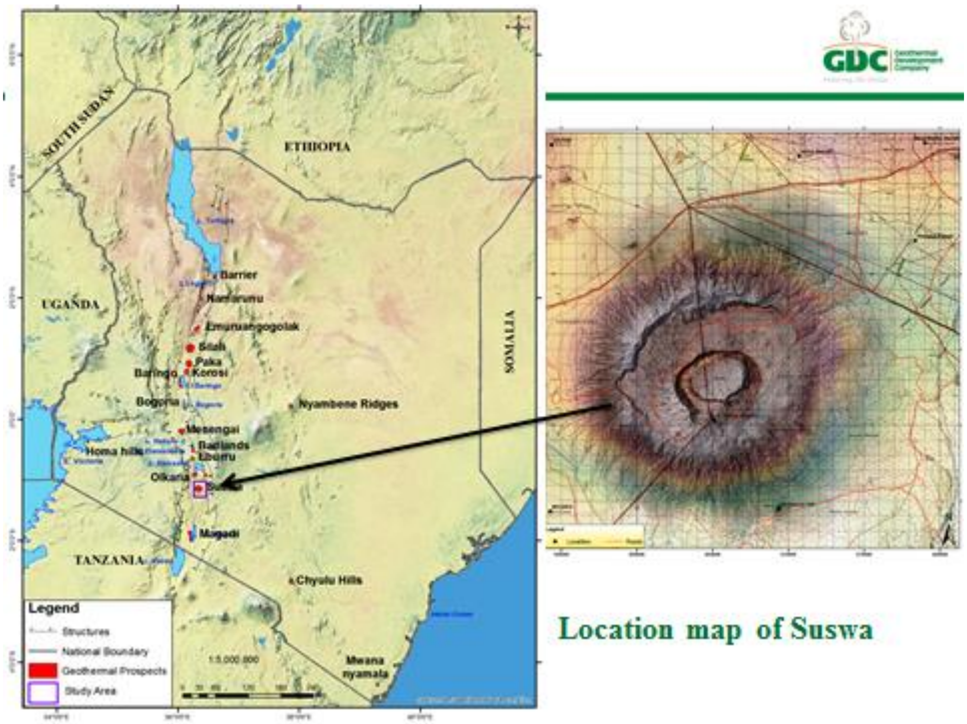

Figure 1: Location map of Suswa prospect in Kenyan rift valley.

The transient electromagnetics (TEM) was used to resolve the static shift problem in MT due to its good resolution near the surface. The hypothesis used is that an increased fluid content due to fracturing, and the development of more conductive alteration clay minerals can give rise to an electrical resistivity contrast which with reliable mapping can increase chances of discovering geothermal resources and defining the extent of geothermal reservoirs. This is done through imaging the controlling structures of geothermal systems, and in locating and characterizing permeable fracture zones. Apparent resistivity data from MT and TEM surveys were analysed to understand the resistivity structure within the prospect. Gravity surveys carried out by Geotermica Italiana (1989) suggest that a positive anomaly related to shallow bodies made of dense lava flows and negative anomalies are related to deeper sources. Gravity data is consistent with volcanological and geophysical evidence suggesting that the area of late quaternary caldera volcanoes are thermally privileged sites (Cantini, 1990). A high-density body seen on the gravity survey at similar locations of the prospect and also micro seismic events at depth reveal the same trend. Seismic surveys were carried out in Suswa by Simiyu, et al, 1997 and show the distribution of events located within the Suswa prospect that are more concentrated at the North eastern and southern edge of the inner caldera. The seismic activity depth plot shows that the area to the south-west is thermally privileged as the seismic cloud density decreases with depth.

2. MAGNETOTELLURICS (MT) AND TRANSIENT ELECTROMAGNETICS (TEM)

Magnetotelluric uses natural electromagnetic waves induced by magnetosphere or ionosphere currents. The signals are used to image the resistivity structure of the earth, Vozoff, 1991; Jiracek et al, (1995). Since the source is far away from the earth's surface, MT waves can be treated as planar, Zhdanov and Keller, (1998). The MT wave is comprised of electric and magnetic fields which are recorded orthogonally using two electric and three magnetic channels.

In the TEM method, an electrical current is induced in the ground and the magnetic field created is measured at the surface, from which the resistivity of the subsurface rocks is determined. The current in the ground is generated by a time-varying magnetic field. Yet, unlike MT-soundings, the magnetic field is not the randomly varying natural field, but a field of controlled magnitude generated by a source loop. A loop of wire is placed on the ground and a constant magnetic field of known strength is built up by transmitting a constant current into the loop. The current is then abruptly turned off. The decaying magnetic field induces electrical current in the ground. The current distribution in the ground induces a secondary magnetic field decaying with time. The decay rate of the secondary magnetic field is monitored by measuring the voltage induced in a receiver coil (or a small loop) at the centre of the transmitter loop.

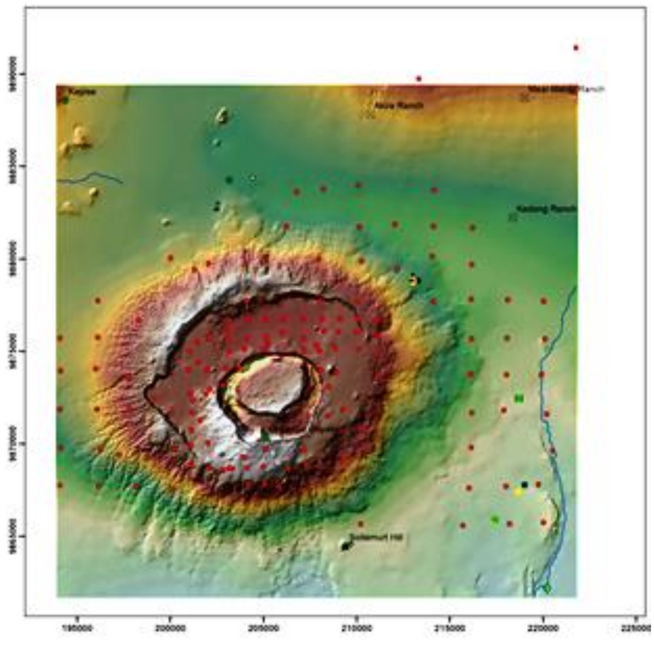

Figure 2: Location of MT soundings in red

2.1 TEM and MT joint inversion

The joint 1-D inversion of TEM and MT sounding data was designed to solve the static shift problem in MT data in the volcanic environment of the Suswa prospect. In joint 1-D inversion of TEM and MT data, one more parameter is inverted for, in addition to the layered model resistivity and thickness parameters, namely a static shift multiplier by which the apparent resistivity has to be divided so that both the TEM and MT data can be fitted with the same model (Figure 3). The program can do both standard layered inversion (inverting resistivity values and layered thicknesses) and Occam inversion with exponentially increasing layer thicknesses with depth. A joint 1-D Occam inversion was performed for the rotationally invariant determinant apparent resistivity and phase of the Suswa MT soundings and the associated TEM soundings as seen in Figure 4.

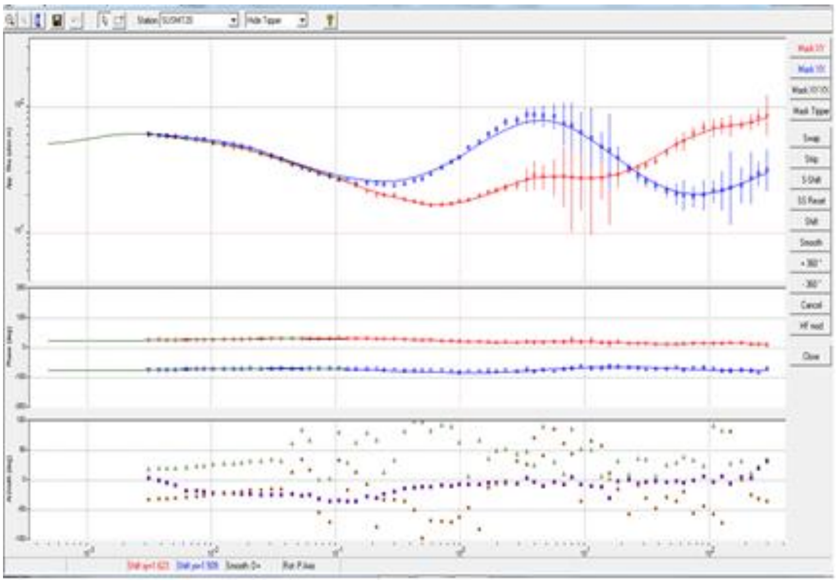

Figure 3: Joint 1-D inversion of TEM and MT soundings.

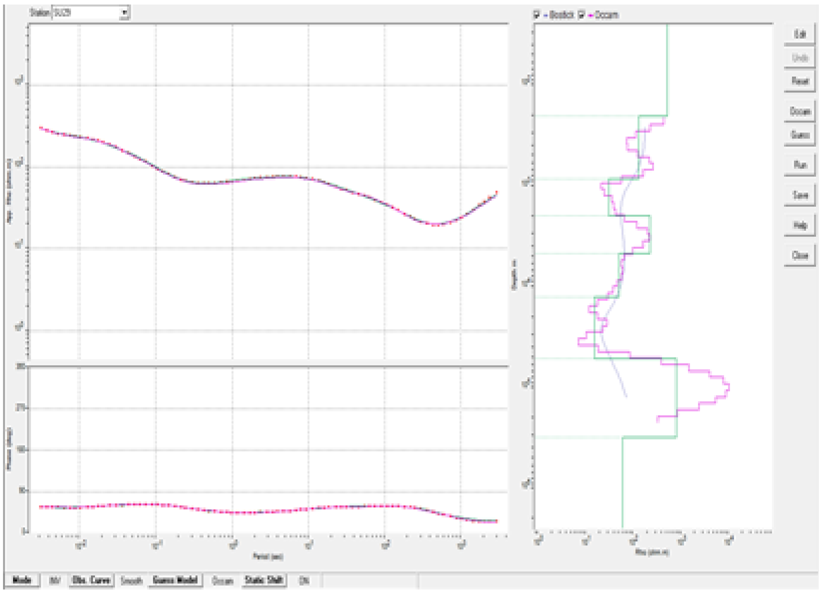

Figure 4: Shows the results of the 1-D resistivity inversion model.

3. MICRO-SEISMICS SURVEY

Seismic surveys carried out in Suswa by Simiyu, et al, 1997 and figure 10 show the distribution of events located within the Suswa prospect that are more concentrated at the northern and southern edge of the outer and inner caldera. The seismic activity shows that the area to the south-west is thermally privileged as the seismic events are dense. This zone of shallow events represents an area overlying the heat source for the geothermal system. Magnitude evaluation show that duration magnitudes >2.0 are only recorded outside the caldera. Depth and magnitude variation might reflect the intensity of the heat flux received from the deep heat sources. These results are consistent with gravity and resistivity data that show the volcano has a positive anomaly trending ENE similar to the shallow seismic events trend.

4. GRAVITY SURVEY

Gravity method assists in mapping gravity contrasts in the subsurface and helps in structural analysis, as well as identifying dense bodies that can be associated with magmatic bodies, which is of importance in geothermal exploration. Gravity surveys done by Geotermica Italiana (1989) suggest that a positive anomaly related to shallow bodies made of dense lava flows and negative anomalies are related to deeper sources. See the gravity survey network in figure 5.

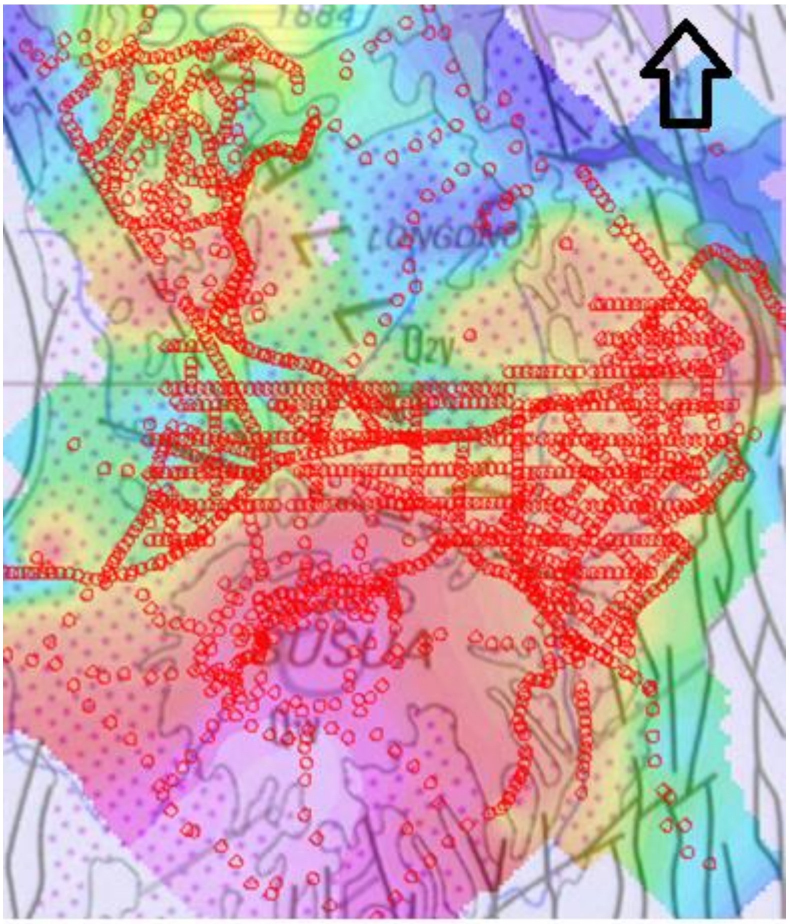

Figure 5: Red circles shows locations of the gravity survey network overlying the Suswa geological map

5. RESULTS

Various MT cross sections (Figure 6 and 7) taken on the northern and southern part of the prospect show a typical resistivity structure of a high-temperature geothermal system. Both are characterised by a shallow layer of high resistivity near the surface due to unaltered formations, overlying a low-resistivity anomaly due to hydrothermal alteration, followed by a fairly high-resistivity associated with the reservoir level due to hydrous minerals found at that level, this is underlain by a low-resistivity anomaly associated with the possible heat source controlling the Suswa system. Figure 8 shows the different cross sections projected in a 3-D view which gives a good picture of the resistivity structure in the prospect. Figure 9 shows a resistivity map taken at 6000 mbsl and the structural orientation correlates quiet well with the seismic event location and bouguer anomaly map (Figure 10 and Figure 11). Gravity high (Red) where we have the low resistivity anomalies (Red) in the southern part of the resistivity map and dense seismic events reveal a magmatic body below the prospect and which is the heat source for the geothermal system.

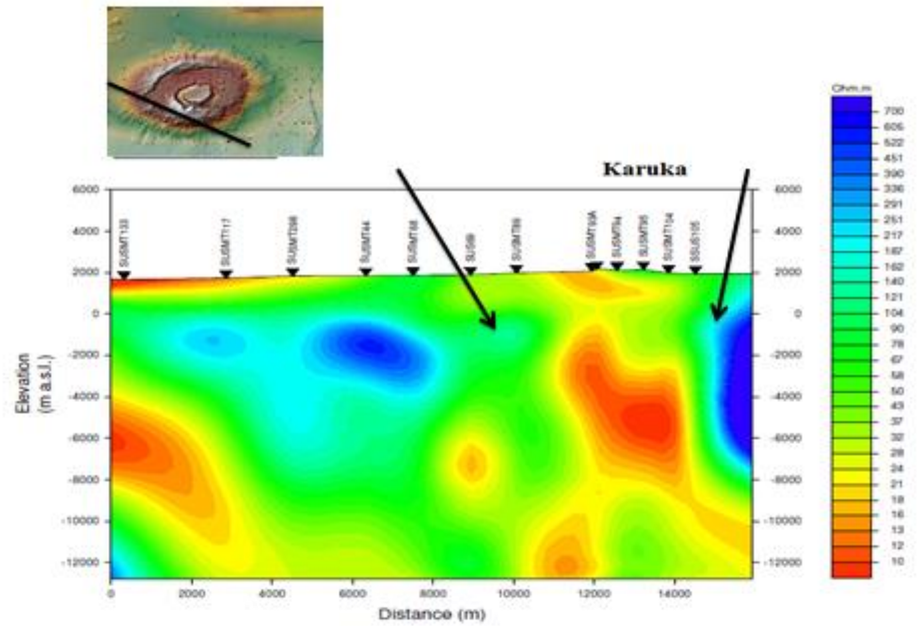

Figure 6: Resistivity cross section along NW-SE direction

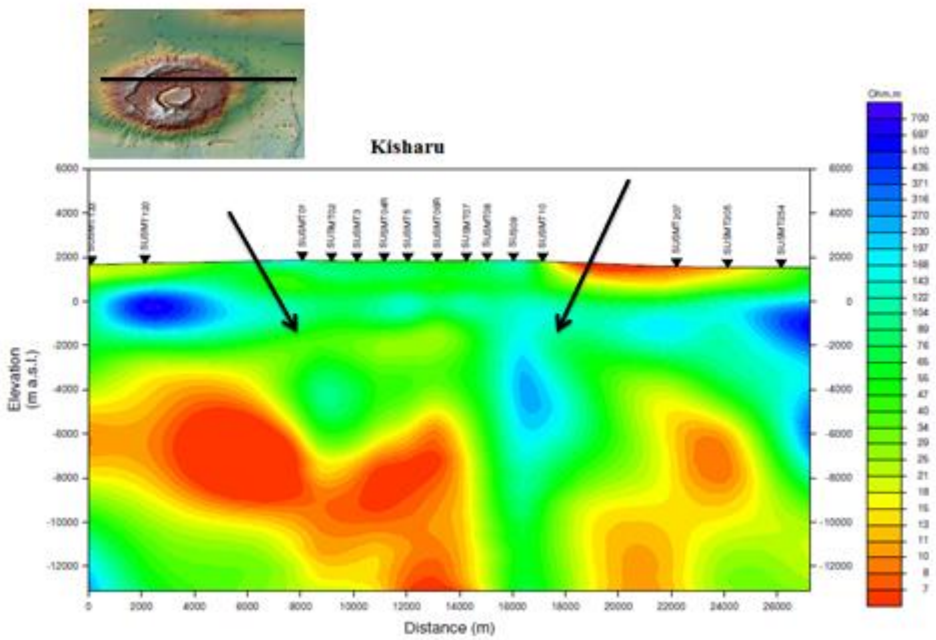

Figure 7: Resistivity cross section along W-E direction

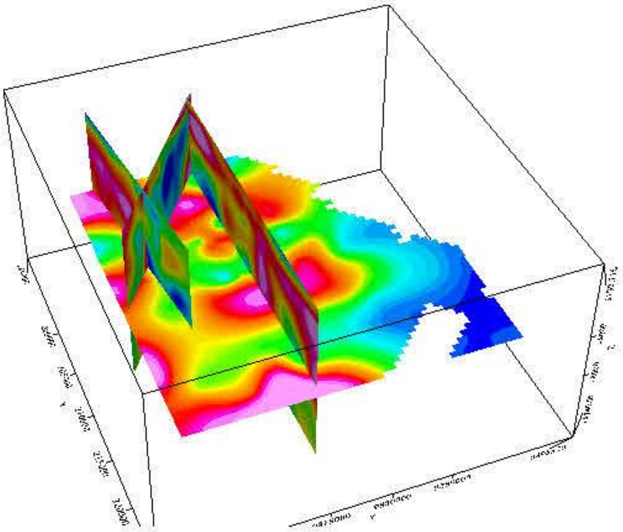

Figure 8: 3-D visualization of resistivity cross sections

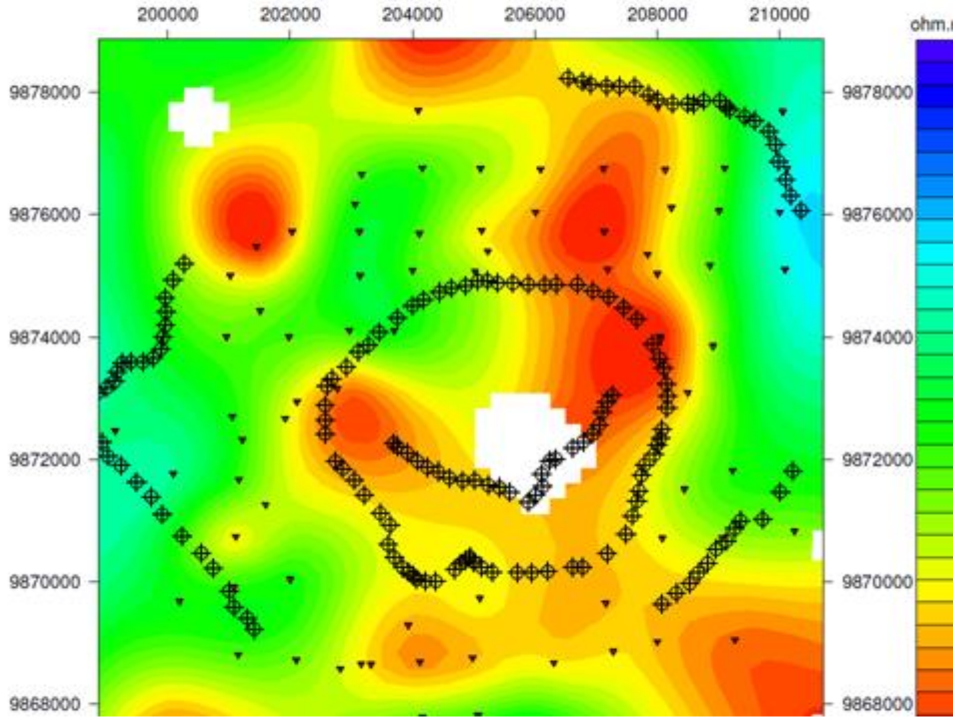

Figure 9: Resistivity map at 6000 mbsl (Red is low resistivity, yellow moderate and green fairly high, pale blue is high).

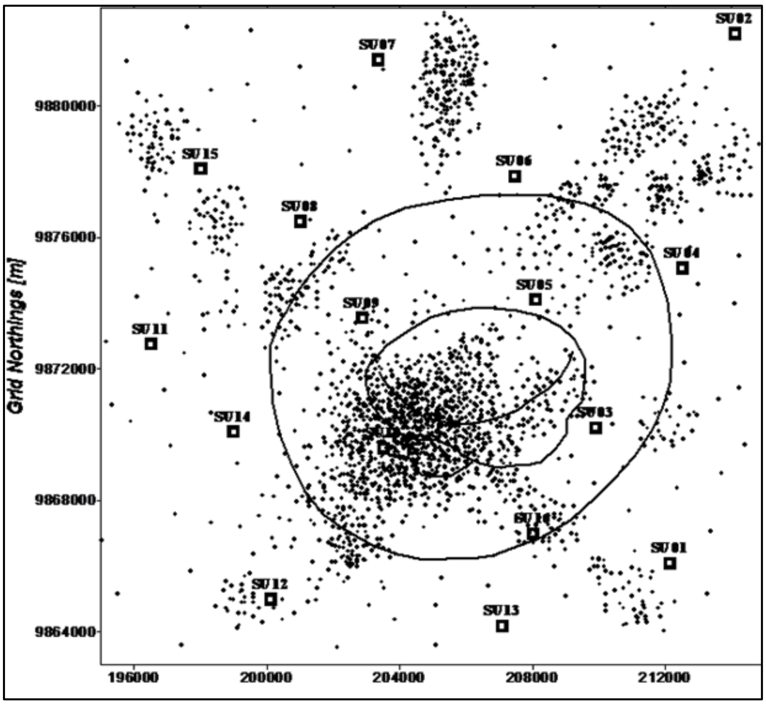

Figure 10: Map of Suswa showing event locations, inner and outer caldera and recording stations (after Simiyu 1997).

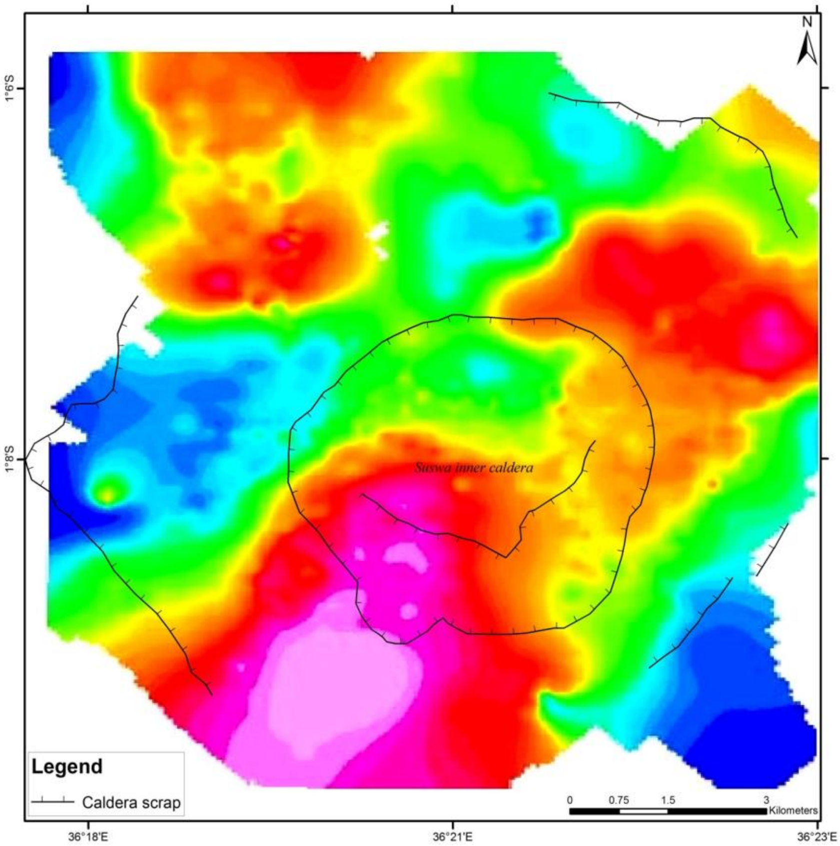

Figure 11: Suswa Bouguer anomaly map (Red is gravity high, green moderate and blue low)

6. CONCLUSIONS

The geophysical surveys completed at the Suswa geothermal prospect show that:-

1. Resistivity, seismics and gravity results are in good correlation on the final interpretation of the data sets.
2. Correlating the data sets helps reduce ambiguity on either data set, which is useful in making final interpretations, in other words, it increases confidence when it comes to decision making.
3. Therefore its good to use joint geophysical imaging techniques for a reliable interpretation then correlate with the surface geology too.

REFERENCES

Árnason, K., 2008. The magneto-telluric static shift problem. ÍSOR – Iceland GeoSurvey, Reykjavík, report, ISOR-08088, 17 pp.

Cantini, P., 1990. Gravity study of the structure of Suswa volcano and basement in the Kenya rift. *Geothermics*, Vol. 19, No. 4, pp. 367-384, 1990.

Christensen, A., Auken, E., and Sørensen, K., 2006. The transient electromagnetic method. *Groundwater Geophysics, 71*, 179-225.

Jiracek, G.R., Haak, V., and Olse, K.H., 1995. Practical Magnetotellurics in a continental rift environment, in Continental rifts: Evolution, Structure and Tectonics, edited by K.H. Olsen, elsevire, New York, 103-129.

Geotermica Italiana, 1989. Supplement of surface investigations within the calderas of Longonot and Suswa Volcanoes. Unpublished Report to the UNDP. Vol. 1.

Hersir, G.P., and Björnsson, A., 1991. Geophysical exploration for geothermal resources. Principles and applications. UNU-GTP, Iceland, report 15, 94 pp.

Simiyu, S.M., Keller, R.G., 1997 . *Seismic and gravity inter-pretation of the shallow crustal structure in the Southern Kenya Rift Valley.*, Geophys J. Int

Sternberg, B.K., Washburne, J.C., and Pellerin, L., 1988. Correction for the static shift in magnetotellurics using transient electromagnetic soundings. *Geophysics, 53,* 1459-1468.

Vozoff, K., 1991. The Magnetotelluric Method, in Electromagnetic method in applied geophysics, 2B, edited by M.N. Nabighian, *soc Explor. Geophys,* Tulsa Okla, 641-711.

Zhdanov, M.S., and Keller, G.V., 1998. The Geoelectrical Method in Geophysical Exploration, *Elsevier Amsterdam*, pp.873