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Geothermal Energy Exploration at Buranga Geothermal Prospect, Western Uganda

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ABSTRACT

Exploration for geothermal energy in Uganda has been in progress since 1993. The studies have focused on three major geothermal areas namely Buranga, Katwe and Kibiro. The three areas are in advanced stages of surface exploration and will soon be subjected to exploratory drilling that will pave the way for a feasibility study. The overall objective of the study is to develop geothermal energy to complement hydro and other sources of power to meet the energy demand of rural areas in sound environment. Recent studies in Buranga have used geological, geochemical, hydrological and geophysical methods to elucidate subsurface temperatures and the spatial extent of the geothermal system. The results indicate that the geothermal activity at Buranga is related to the volcanic and tectonic activities of the Rift Valley, which has a higher heat flow than the surrounding Precambrian crust. The geothermal surface manifestations include hot bubbling springs, water pools, gas vents, H2S gas, travertine tufas and geothermal grass. The main geological structure is the Bwamba escarpment that forms the western part of the Rwenzori horst mountain massif. This main rift fault is cut by numerous perpendicular and oblique striking faults which together with other faults/fractures contribute to the re-charge and up-flow permeability for the geothermal fluids at Buranga. Subsurface temperatures of 120 - 150˚C have been predicted by geothermometry. The results also indicate that hot springs show isotopic composition compatible with the local meteoric water line, confirming the meteoric origin of the water circulating in the geothermal system. Results from isotopes of hydrogen and oxygen (δDH2O, δ18OH2O) suggest that the recharge is from high ground in the Rwenzori Mountains. Sulphur isotopes (δ34SSO4) of hot water samples show magmatic contributions of sulphate, while strontium isotopes of water and rock samples (87/86SrH2O, 87/86SrRock) identify the rock type as granitic gneisses, suggesting that the major source of salinity is from water-rock interaction with a magmatic input. Micro-seismic surveys have located a subsurface anomaly within the vicinity of the thermal activity at Buranga, but is yet to be confirmed by additional geophysical surveys and drilling. Recently, TEM and MT surveys have been conducted at Buranga; the results indicate a low resistivity anomaly associated with the geothermal surface manifestations, the main rift escarpment and the faults associated to the main rift escarpment.

1. INTRODUCTION

Exploration for geothermal energy resources in Uganda has been in progress since 1950s. The studies have focused on surface exploration of three major geothermal areas: Buranga , Katwe-Kikorongo (Katwe) and Kibiro, all located in the Western Rift Valley in Uganda. The Western Rift Valley is a branch of the great East African Rift System (Figure 1).

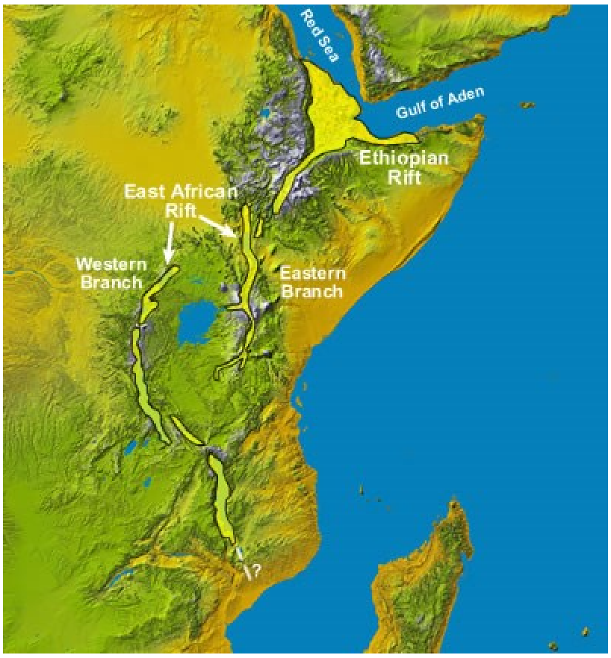

Figure1. The East African Rift System (Source: James Wood and Alex Guth; the base map is a Space Shuttle radar topography image by NASA).

The Albertine Rift forms the northern part of the western arm of the East Africa Rift. The East African Rift is an active continental rift zone that appears to be a developing divergent tectonic plate boundary in East Africa. The rift is a narrow zone in which the African Plate is in the process of splitting into two new tectonic plates, known as the Somali Plate and the Nubian (or African) Plate, all of which are sub-plates or protoplates (Wood and Guth, 2014)

A number of exploration methods have been used in the three areas which include geology, geochemistry, geophysics, and temperature gradient measurements. The current results indicate that the geothermal activity in the three areas is related to the volcanic and tectonic activities of the rift, which has a higher heat flow than the surrounding Precambrian crust. Subsurface temperatures of approximately 140-200˚C for Katwe, 200-220˚C for Kibiro and 120-150 ˚C for Buranga have been predicted by geothermometry. The temperatures are suitable for electricity production and direct use in industry and agriculture. This paper summarizes the status of the Buranga geothermal prospect. Buranga is one of the major geothermal prospects of Uganda (Figure 2b) with the most impressive geothermal surface manifestations.

2. LOCATION OF BURANGA GEOTHERMAL PROSPECT

The Buranga geothermal prospect is located in Bundibugyo and Ntoroko districts at the north-western base of the Rwenzori Mountains in the Western Rift Valley (Figure 2b). The two districts lie at the border with the Democratic Republic of Congo. While Bundibugyo district is predominantly an agricultural area, Ntoroko district is dominated by pastoralism. The two districts are also engaged in fishing on Lake Albert and River Semuliki.

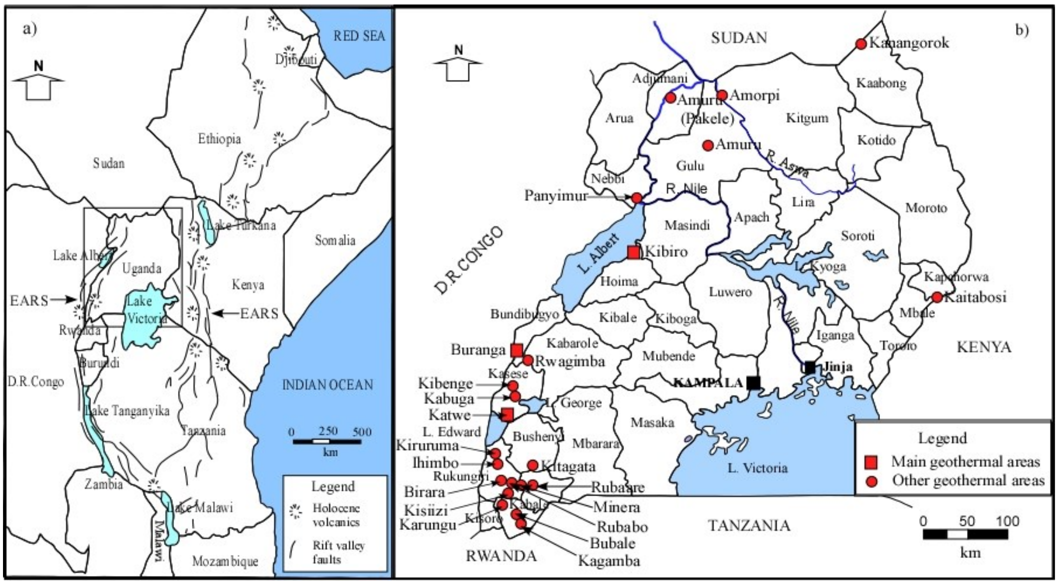

Figure 2: a) East African Rift System (EARS), b) Locations of the geothermal areas of Uganda; note the location of Buranga in western Uganda.

3. GEOLOGY

3.1 Regional Geology l

The geology of Uganda consists of an exposed pre-Cambrian basement dissected by the western branch of the East African Rift System in the western part of the country (Figures 1 and 2). The eastern branch, the Gregory Rift, passes through the central part of Kenya and Tanzania. The Western branch, (part of which in Uganda is referred to as the Albertine Rift), starts to the north along the Sudan border, and then curves to the west and then southwest along the border with the Democratic Republic of Congo, and south to Rwanda, Burundi and western Tanzania. Spreading began at least 15 million years ago in Miocene time. The western Rift is considered to be at an early stage in the development, and is younger (late Miocene-Recent) than the more mature eastern branch (Morley and Westcott, 1999). The Albertine rift is seismically active, characterized by deep-seated (15-30 Km) large earthquakes (Tugume, 2010?). The region of the Rift has a markedly higher heat flow than the surrounding Pre-Cambrian terrain. Two different en echelon strands are found in the Western Rift Valley, separated by the Rwenzori Mountains, which rise from a base of less than 1,000 m in the Rift to over 5,000 m elevation. Within the Rift Valley there are thick layers of late Tertiary and Quaternary sediments, fresh water and saline crater lakes, volcanic, and plutonic bodies have been identified beneath L. Albert and L. Edward (EDICON, 1984).

3.1 Geology of Buranga area

Buranga hot springs are located at the north-western foot of the Rwenzori massif near the base of Bwamba escarpment and localized by major Rift Valley faults (Figure 3). The hot springs emerge through sediments of Kaiso beds and peneplain gravels that consists of variable sands and gravels with irregularly distributed sub-angular boulders. The Kaiso sediments are underlain by fine to medium-grained, poorly consolidated sands and clays (some coated with calcareous material) and occasional tuffs.

Geophysical surveys confirmed the presence of these sediments down to a depth of 1,524 m. The boreholes drilled in 1950s showed that the Tertiary succession was terminated in the fault zone by a breccia cemented by calc-tuffs followed by mylonite (Harris et al., 1956). The clays are of various colours and the sands are fine-to medium-grained, varying in colour between white, brown, grey and green. The most common binding material is clay, although this may be patchily replaced by calcium carbonate, giving rise to calcareous sandstones and grits. Pebble beds are of rare occurrence and there are no fossils present apart from plant fragments. Close to the Buranga hot springs, a fault line (striking between 20° and 45° and dipping 60-65° westwards) is exposed (Johnson and McConnell, 1951). The mylonite rocks characterize the fault zone suggesting movement along a very old fracture zone of compression. Further north, the fault system displays both a change of direction and dip reduction. The topographic features indicate that step faulting is also present (Harris et al., 1956). Precambrian rocks of the main rift fault, which strikes N45^{o}E and dips N60-65^{o}E, underlie the sediments.

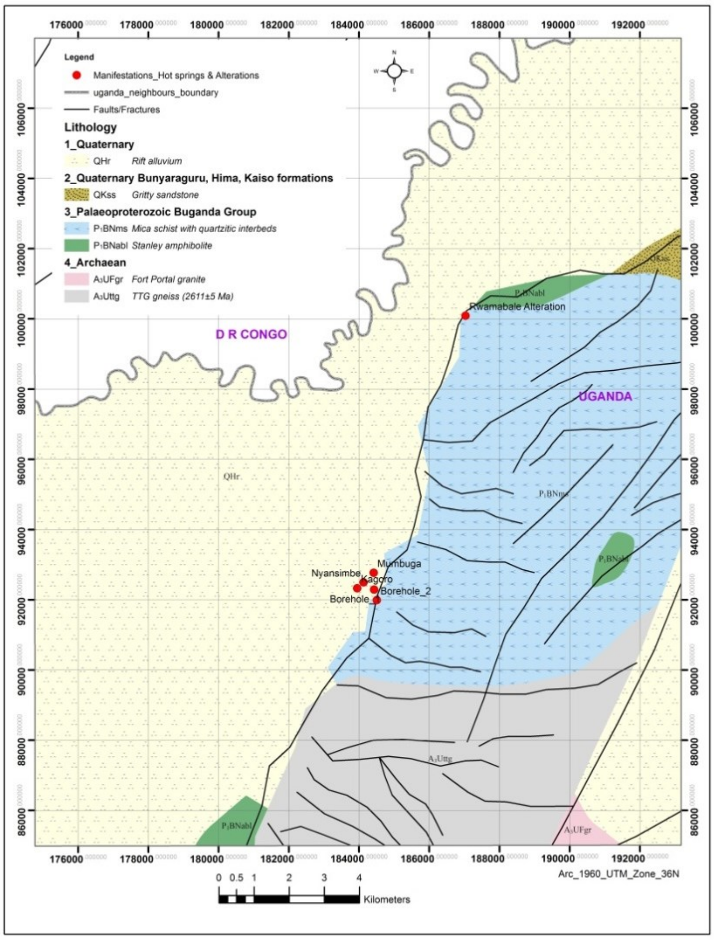

Figure 1: Geology of Buranga area.

The rocks around the northern half of Rwenzori massif in which Buranga is located consist mainly of migmitites, gneisses and amphibolites. There are four lithological units which fall in Archaean, Palaeoproterozoic Buganda Group and Quaternary ages. The Archaen is represented by the TTG gneiss in the south and Fortportal granite in the northeast. The Palaeoproterozoic Buganda Group is represented by the Stanley amphibolite and the mica schist rock that is intruded by quartzitic inter-beds (Figure 3).

The *TTG gneiss (2611±5 Ma) (A3Uttg)* consists of rocks with variable granitoid compositions namely, granites, granodiorites, and tonalites to trondhjemites (Westerhof et al., 2012). U-Pb age determinations of zircon cores (Laser-ICP-MS method) from the foothills gneisses of the Rwenzori Mountains yielded the following ages: 2584±18 Ma, 2637±16 Ma and 2611±14 Ma (Link *et al*. 2010). The *Stanley amphibolite (P1BNabl)* is hornblende-rich, garnet-bearing amphibolites in which medium-grained, foliated rocks have coarse amphibole segregations and epidote and quartz veins. The sequence begins with quartzites, which unconformably overlie Archaean gneisses. Quartzites show festoon cross-bedding and ripple marks. The upper unit is phyllitic schist with sedimentary structures. Tholeiitic Stanley metavolcanics occur as interlayers in these schists. They are characterised by pillow lava structures, which demonstrate a volcanic origin for these fine-grained amphibolites and tuffaceous volcanoclastics. The *Mica schist with quartzitic interbeds (P1BNms)* has a gneissose appearance and partly garnet-bearing. Pegmatitic dykes intrude these rocks in several places. Generally, the lithological units strike N10-30^{o}E and have complex joint systems. The hot springs seem to lie on a fracture/fault line striking N40^{o}E parallel to main rift fault (Gislason et. al., 1994).

3.2 Geology of Buranga area

Buranga has the most impressive surface geothermal manifestations with a wide areal coverage in the whole of the Western Branch of the East African Rift System. The geothermal manifestations are found at the foot of the escarpments in a swampy area enclosed by a dense rain forest. The geothermal surface manifestations are localised in three areas namely Mumbuga, Nyansimbe and Kagoro (Figure 3). At Mumbuga, the eruptive hot spring, bubbling hot springs, hot grounds, solfatara occur (Figure 4).

At Nyansimbe, a large steaming water pool with several springs and travertine occur (Figure 5).

Figure 4: Erupting hot spring at Mumbuga area. Note the calcareous tufa cone building up from the spring waters.

Figure 5: Nyansimbe water pool with several hot springs and travertine around it.

At Kagoro, travertine cones, hot springs, sulphurous deposits occur. The three manifestation areas at Buranga are characterized by H_2S and geothermal grass that covers large swampy parts of manifestation areas. The surface temperature is close to 98˚C and the flow is approximately 10-15 litres/second, an indication of high permeability.

At Rwamabale which is located approximately 5 km northeast of Buranga hot springs, hydrothermally altered mylonitic rocks characterised are by iron oxide minerals, kaolinite and travertine in cracks and overlaid by bentonitic layers occur (Figure 6). The mylonites are strongly sheared and brecciated and their foliation fabric dips nearly vertical.

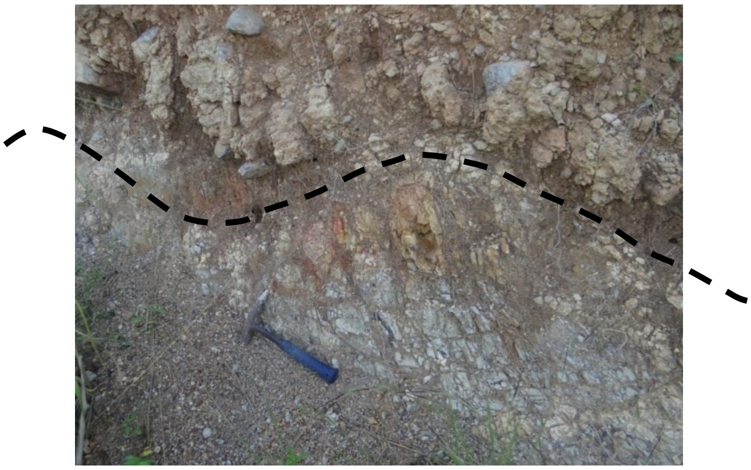

Figure 6: Hydrothermally altered mylonitic rocks (below dotted line) overlaid by bentonite (above dotted line) that cemented the cobbles and gravels. The travertine-deposits occur in cracks of the altered mylonites.

At Kibuku, located approximately 15 Km North-east of Buranga hot springs, gypsum that seems most likely to have been precipitated from the hydrothermal solutions occurs. The evidence of this is seen at the recent road cut where gypsum crystals are precipitated in the cracks that are vertical or nearly vertical or sometimes in the contact spaces between the sedimentary layers Figure 7). It is envisaged that the water and sulphur rich hydrothermal solutions got into contact with the calcium of the unconsolidated calcareous sediments and/or volcanic ash to provide favourable conditions to form gypsum. The occurrence of the bentonite clays indicated the existence of volcanic ash mixed with the sediments. The occasional occurrence of diatomite layers indicates the existence of silica-rich fluids that flourished the diatoms which eventually formed the diatomite. These silica-rich fluids most probably formed part of the ascending hydrothermal solutions.

Figure 5: Gypsum and bentonitic clay filling small cracks and inter-layer contact in sediments in another layer at Kibuku. Note the diatomised layer (white) with a bentonite layer in between.

3.3 Geochemistry .

The concentrations of Cl^-, SO_4^{2-} and HCO_3^- in Buranga geothermal waters are similar and therefore indicators have to be used with caution, and the high Cl relative to Li and B concentrations suggest relatively old hydrothermal a system (Giggenbach, 1991). The results of analysis of volatiles and physical parameters, and major constituents are presented in Tables 1 and 2 respectively.

Table 3: Results of analysis of volatiles and physical parameters. Concentrations in mg/kg.

Location	Sample no.	Temp. (°C)	pH	EC (µs/°C)	CO_2	H_2S	SiO_2	TDS
Mumbuga	BR-11-001	93.6	7.73	19550	2411	<0.05	76.0	14000
Nyansimbe-Pool	BR-11-002	85.8	7.81	21650	2878	<0.05	85.8	17050
Kagoro	BR-11-003	89.0	7.50	21600	2798	0.06	81.0	16400
Mungera Stream	BR-11-004	21.8	7.52	169.8	57	<0.05	36.9	74

The fluids are neutral with a pH of 7-8 and salinity of 14,000 – 17,000 mg/kg total dissolved solids. Plausible solute geothermometers tested for several hot springs and pools predict a subsurface temperature was 120 - 150°C for the Buranga prospect. The gas composition is dominated by CO_2 and has no H_2 which suggests that the subsurface temperature is less than 200°C (Ármannsson, 1994).

Table 4: Analytical results of major constituents. Concentration in mg/kg.

Sample No.	Na	K	Ca	Mg	SO4	Cl	F	Fe	Al	B	Sr	Li	Br
BR-11-001	5160	190	2.56	2.27	3570	3490	27.2	0.05	0.014	4.2	2.46	1.3	16.4
BR-11-002	6300	234	2.04	1.98	4420	4240	31.5	0.01	0.017	4.8	2.15	1.54	20.4
BR-11-003	5950	219	2.69	2.19	4160	4030	30.8	0.02	0.019	4.7	2.54	1.47	19.6
BR-11-004	11.1	3.7	11.2	3.61	1.7	1.8	0.17	0.02	0.011	0	0.08	0.01	0

3.4 Isotope hydrology

The δD and $\delta^{18}O$ data all plot close to the line with equation $\delta D = 8*\delta^{18}O + 12.3$, the Local Meteoric Water Line (LMWL), obtained from rain water samples from Entebbe (GNIP, 1999). There are no signs of oxygen shift from this line so that reasonable permeability is inferred as is expected from the physical characteristics of the geothermal system. The isotope composition of the geothermal water is depleted in both δD and $\delta^{18}O$ compared to the local cold ground- and river waters suggesting that the geothermal water is from high ground in the Rwenzori Mountains (Figure 6). A subsurface temperature of 200°C is predicted by isotopic geothermometers. There is no tritium in the thermal water from Buranga which implies that it is not a mixture of hot water and cold groundwater. The strontium ratios in rocks indicate that the geothermal water, most likely, interacts with granitic gneisses. The source of sulphate is minerals or rock (terrestrial evaporates) with a possible magmatic contribution (Bahati et. al., 2005). Studies by the Federal Institute for Geosciences and Natural Resources (BGR) of Germany and the Government of Uganda using helium isotopic ratio ($^3He/^4He$) in gaseous discharges from hot springs also suggest a magmatic source of solutes for Buranga (BGR-MEMD, 2007).

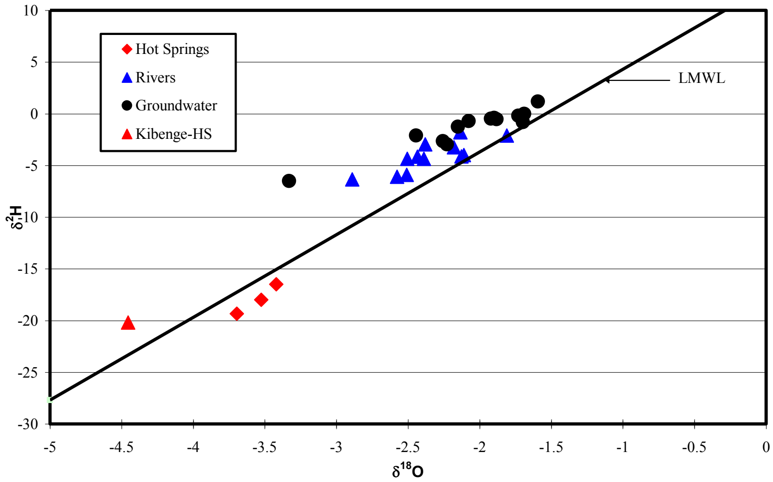

Figure 6: Buranga. Stable isotopic composition of hot and cold water samples.

3.5 Micro seismic surveys

BGR-MEMD (2007) carried out micro-seismic surveys at Buranga and surroundings. The distribution of earthquakes recorded within the year 2007 is presented in Figure 8. The concentration of earthquakes around Buranga hot springs suggests an area of weakness around the hot springs. This may be interpreted as an out flow zone and not an up flow zone for Buranga. The up flow zone is likely to be located away from the thermal area where there is low concentration of earthquakes.

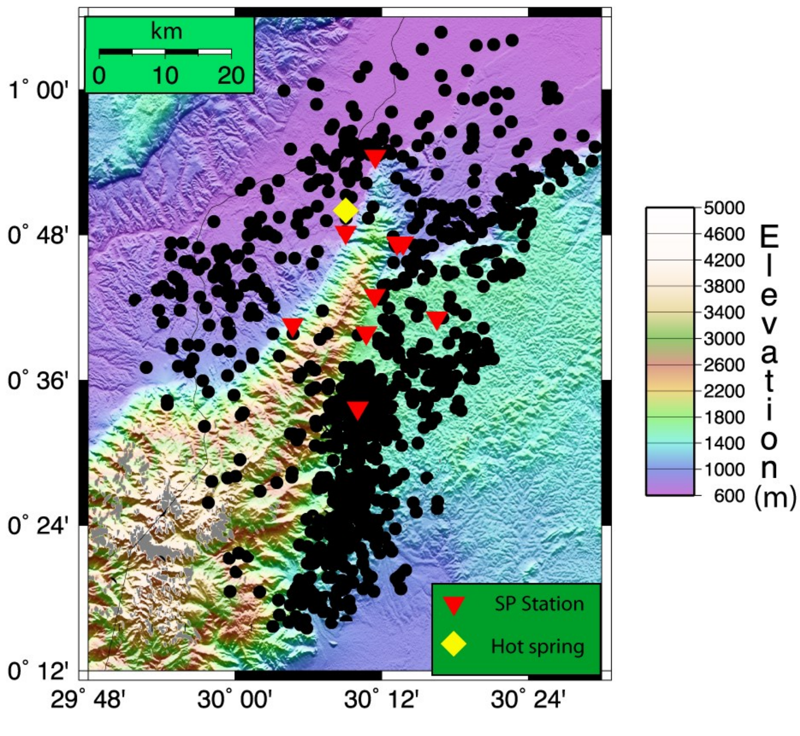

Figure 7: Distribution of earthquakes in Buranga and surroundings (sources: BGR-MEMD, 2007).

4. GEOPHYSICAL INVESTIGATIONS

The two techniques used were Transient Electro-magnetics (TEM) and Magneto-tellurics (MT). The TEM survey was aimed at mapping shallow structures and for static shift correction on the MT soundings made on the same site, and the MT survey was used to map deeper resistivity structures of the area. During the surveys, 27 pairs of MT and TEM soundings were made in the Buranga prospect covering part of the licensed area (Figure 8).

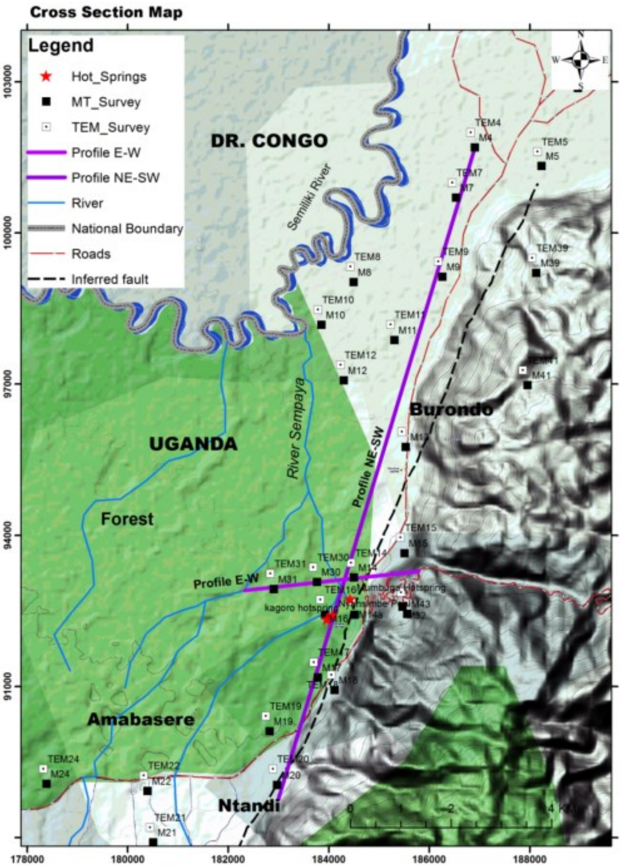

Figure 8: Location of the survey point for MT and TEM soundings.

4.3 Results

The MT resistivity cross-section that cuts across cuts across profile 1 in the NE – SW direction is presented in Figure 9.

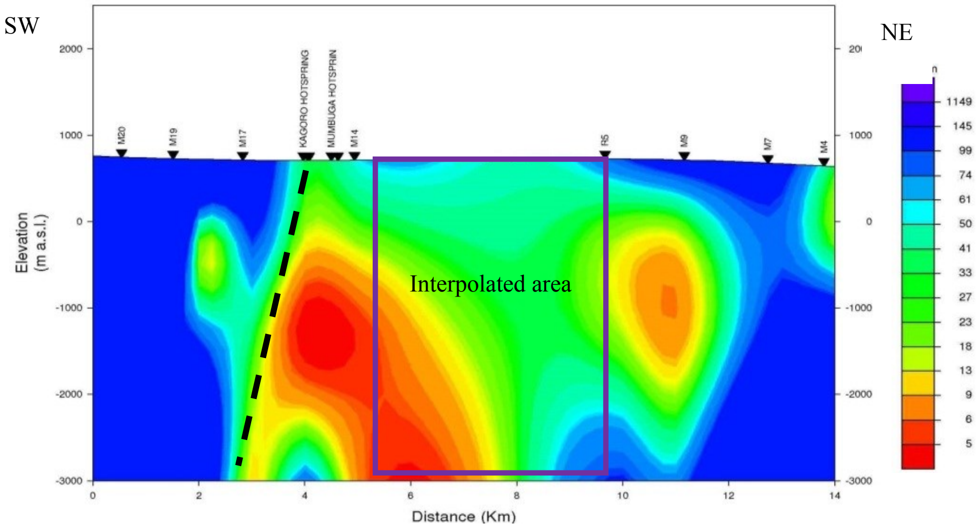

Figure 9: MT Resistivity cross-section for Profile 1 down to -3000 m a.s.l., dotted line implies a fault/fracture.

Figure 9 shows that there is a clear resistivity contrast delineated on the SW side of MT profile 1 from shallow to deep depths which suggests the existence of a fracture that separates the Rwenzori massif and the lowland area. The fracture could be channelling heated fluids from a possible intrusion slightly to the south of hot springs at depth to the surface where they are manifested as hot springs and pools. Beneath the hot springs area, the highly conductive body extends deeper to the SW part of the profile. The NE side of the MT profile 1 shows a resistive body at shallow depth and a conductor below that is not clearly resolved probably due to large spacing between the soundings.

The results of the survey are also presented as Iso-depth resistivity maps showing resistivity distribution at different elevations with respect to sea level. The resistivity at 500 m.a.s.l is presented in Figure 10.

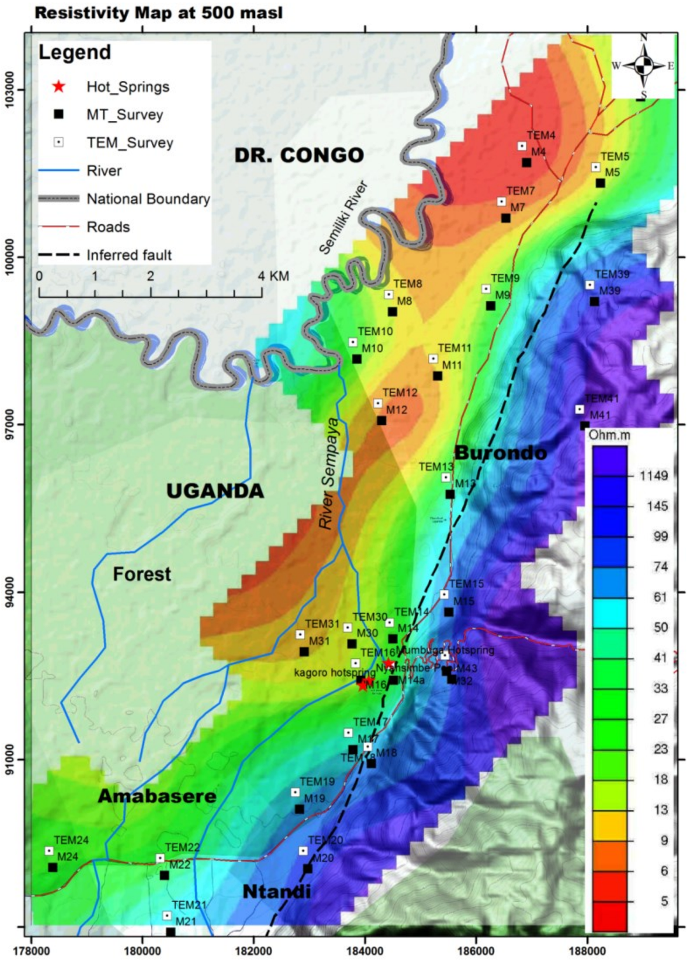

Figure 10: Resistivity map at 500 a.b.s.l.

Figure 10 shows two distinct low resistivity areas aligned to each other in a near parallel direction. The highly conductive layer is interpreted to be saline fluids contained in the sediments and gravels with poorly consolidated sands and clays (Kaiso beds) that cover the low land area at this depth. The high conductivity could also be influenced by a low saline water table below the swampy plains. A contact zone between the resistive Rwenzori massif rocks and the conductive low land area is clearly delineated.

Similarly, the resistivity at 3000 m.b.s.l is presented in Figure 11 below.

Figure 11 shows that the resistivity towards the NE side increases leaving a low resistivity anomaly concentrated on the central portion near the location of the hot springs. This low resistivity anomaly is the probable thermal conductor that heats the fluids feeding the hot springs. The figure also shows other emerging low resistivity areas to the extreme SW and NE.

5. CONCLUSIONS

Impressive geothermal surface manifestations occur at Buranga. Subsurface temperatures of 120-150°C are inferred by geothermometry for Buranga. These temperatures, if confirmed, are good for electricity production and for direct use in industry and agriculture. Isotope hydrology results indicate the source of the geothermal fluids at Buranga to be from high ground in the Rwenzori Mountains; subsurface temperatures of 200°C have been predicted; source of heat is magmatic and reservoir rock types are granitic gneisses. The faulted and fractured basement of the Rwenzoris provides adequate permeability necessary for recharge and thermal fluids at Buranga.

Recent TEM and MT geophysical surveys at Buranga geothermal prospect have located resistivity anomalous areas up to 3000 m.b.s.l with a major anomaly close to the hot springs.

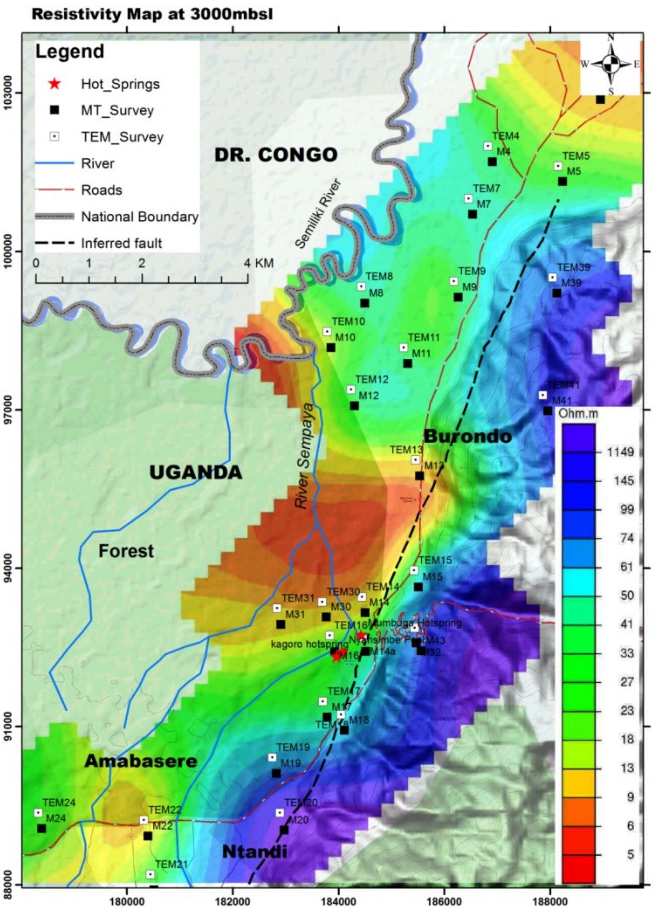

Figure 11: Resistivity map at 3000 m b.s.l.

6. RECOMMENDATIONS

The authors recommend:

- Detailed TEM/MT surveys, gravity together with micro-seismic and refraction seismic methods to delineate the boundaries of the geothermal reservoir, probe in the deeper layers of the crust and delineate the heat source are recommended.

- Additional structural geological mapping to delineate buried faults that could be conduits for the geothermal water and groundwater;

- Geochemical/hydrological surveys to delineate the chemistry of thermal fluids and groundwater, and trace the flow of groundwater.

- Updating of the geothermal models and location of drill sites; and collecting baseline data for sociological and environmental impact assessment.

- Drilling exploration wells in the delineated geothermal anomalies

REFERENCES

Ármannsson, H., 1994. Geochemical Studies on three geothermal areas in West and Southwest, Uganda. *Final Report*. Geothermal Exploration UGA/92/003, UNDESD, GSMD, Uganda, 85pp.

Bahati, G., Z. Pang, H. Armannsson, E.M. Isabirye, V. Kato, 2005. Hydrology and reservoir characteristics of three geothermal systems in Western Uganda, *Geothermics,* 34, p.568-591.

BGR-MEMD, 2007. Detailed surface analysis of the Buranga geothermal prospect, West-Uganda. *Final terminal report*, 168 pp.

EDICON, 1984: Aeromagnetic interpretation of Lake Albert/Edward portion of the Western Rift Valley. *Unpubl. report*, EDICON inc., Denver Colorado, sept. 1984.

GIDS, 2013. Reconnaissance Geothermal Investigations of Exploration Area (EL) 275 and its surroundings. GIDS Consult Ltd., Progress Report 1, 2013.

Gislason, G., G. Ngobi, E.M. Isabirye, and S. Tumwebaze, 1994. An Inventory of three Geothermal Areas on West and Southwest Uganda. Prepared by the *United Nations for a Project of the UNDP*.

GNIP, 1999: Data from the Global Network for Isotopes in Precipitation (GNIP) since 1960. Site Entebbe (Airport), Uganda; latitude 0º,05',0" N and Longitude 32º,45',0" E.

Harris, N., J.W. Pallister and J.M. Brown, 1956: Oil in Uganda. *Memoir No. IX*, Geological Survey of Uganda, 33 p.

James Wood and Alex Guth. East Africa's Great Rift Valley: A Complex Rift System. Michigan Technological University., http://geology.com/articles/east-africa-rift.shtml *(Tuesday 28 May 2014).*

McNitt. J.R., 1982. The geothermal potential of East Africa. In *Proceedings* of the Regional Seminar on Geothermal Energy in Eastern and Southern Africa, Nairobi, Kenya. P. 3 - 8.

Morley, C. K., D. K. Ngenoh, and J. K. Ego, 1999a: Introduction to the East African Rift System, *in* C. K. Morley ed., Geoscience of Rift Systems – Evolution of East Africa: AAPG Studies in Geology No. 44, p. 1 – 18

PEPD, 2008. Petroleum Potential of the Albertine Graben, Uganda, November Brochure, 2008. Petroleum Exploration and Production Department, Entebbe, Uganda.

Tugume, 2010. The Depth Distribution of seismicity at the northern Rwenzori Mountains: Implications for heat flow in the Western rift, Uganda

Wayland, E.J., 1935. *Notes* on thermal and mineral springs in Uganda. UGSM Bull. 2, p. 44-5.