

## Geothermal Energy Exploration in Uganda, Country Update 2016

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### ABSTRACT

Exploration for geothermal energy in Uganda has been in progress since 1993. The studies by the Ministry responsible for Energy and Minerals have focused on four major geothermal areas namely Katwe, Buranga and Kibiro, and recently Panyimur. 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. The studies have used geological, geochemical, hydrological and geophysical methods with the aim of elucidating subsurface temperatures and the spatial extent of the geothermal systems, and in turn come up with a conceptual model that would be a basis for drilling exploration wells. The results indicate that the geothermal activity in the four areas appears to be a fault-controlled deep circulation systems rather than magmatically heated systems associated with volcanoes, which is consistent with the revised view of geothermal prospects in the Western Branch of the East African Rift System. Subsurface temperatures of approximately 140-200°C for Katwe, 120-150°C for Buranga, 150-250°C for Kibiro, and 110-140°C for Panyimur have been predicted by geothermometry and mixing models. In other areas, the current results suggest geothermal potentials with subsurface temperatures of 100-160°C. In all the areas, the temperatures are good for electricity generation and direct use in industry, agriculture and tourism.

Three areas namely Kibiro, Panyimur and Buranga have reached advanced stages of surface exploration, subsurface conceptual models have been developed and temperature gradient wells (TGW) sited at all the three prospects. Drilling of TGW is to start in January/February 2019 the results of which will be used to update the conceptual models that will be a basis for locating sites for deep exploration wells.

Other achievements of the Ministry include (i) Creation of a Geothermal Resources Department through restructuring in the Ministry of Energy and Mineral Development in 2014 to focus on exploration, promotion, licensing and management of geothermal resources; (ii) Formulation of a Geothermal Policy a draft of which is being finalized for presentation to Cabinet; (iii) capacity building that includes procurement of equipment and training of Ugandans; (iv) Sensitization of local governments and communities about the benefits of geothermal energy; (v) Preliminary geothermal environmental baseline studies at Kibiro and Panyimur geothermal prospects; and (vi) creation of a database to house all geoscience information and data related to the geothermal industry; and (vii) development of business and financial models to guide the explorers and developers on the most appropriate models to use in a specific prospect.

The challenges include inadequate policy, legal and regulatory frameworks to guide public interventions on a strategic basis; inability to attract significant financial support from International Development Partners; unskilled workforce capable of maintaining a sustainable geothermal

industry; low awareness amongst the public and limited community participation in geothermal exploration and development.

## 1. Introduction

### 1.1 The Geothermal Resources

Uganda geothermal resources are estimated at about 1,500 MW from 24 areas in the Ugandan Rift System (Uganda Vision 2040). Most of the geothermal areas of Uganda are all located in the Western Rift Valley that runs along the border of Uganda with the Democratic Republic of Congo, and is part of the Western Branch of the East African Rift System (Figure 1). The main geothermal areas are Katwe-Kikorongo (Katwe), Buranga, Kibiro and Panyimur located in Kasese, Bundibugyo, Hoima and Pakwach districts respectively. Other geothermal areas are located in the Southwest, North and Northeast Uganda. Geothermal resources exploration in Uganda is still at the pre-feasibility phase with two prospects Kibiro and Panyimur in advanced stages of surface exploration and will soon be subjected to the drilling of exploration wells and feasibility studies. The two are followed by Buranga and Katwe which are at detailed surface exploration study. Subsurface temperatures of approximately 150-250°C for Kibiro, 110-140 °C for Panyimur, 120-150°C for Buranga, 140-200°C for Katwe have been predicted by geothermometry and mixing models. The temperatures are suitable for electricity production, direct heat use in industry and agriculture, and spas and swimming pools in the tourism industry.

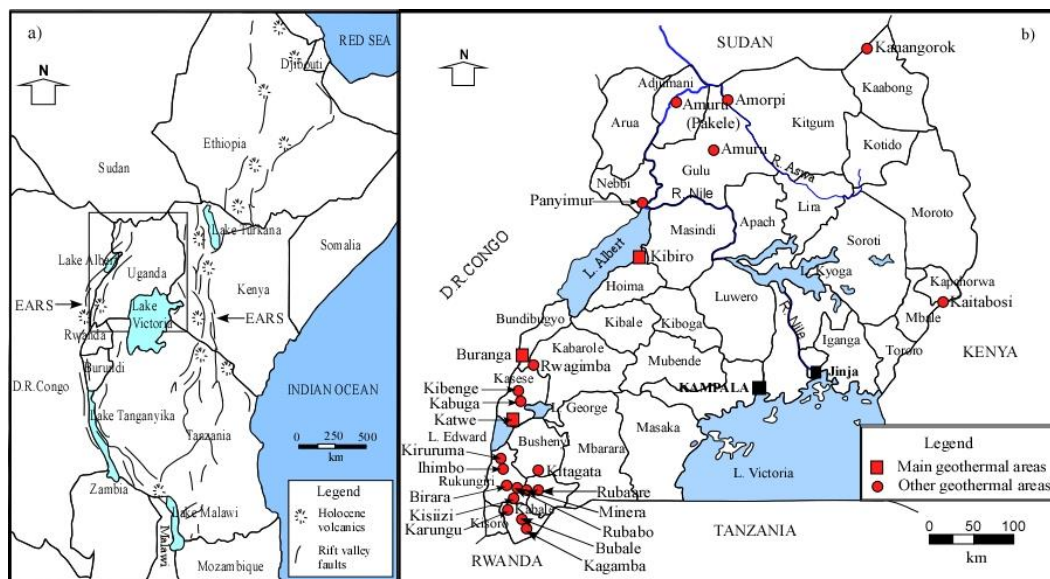


Figure 1: The geothermal areas of Uganda. *After Bahati et al. 2005.*

Reconnaissance investigations have also been done in the remaining the rest of the geothermal areas of Uganda. The results suggest reservoir temperatures in the range of 100 - 160°C also suitable for electricity production and direct uses.

Drilling of temperature gradient wells (TGW) is to start with Kibiro and Panyimur in January/February 2019 the results of which will be used to update the current conceptual models that will be a basis for exploration drilling.

### 1.2 The Energy Sector

Uganda has a potential for hydropower resources estimated in excess of 4,500 MW (Uganda Vision 2040) of which 2,000 MW is either installed or under construction suggesting that hydropower resources will soon be exhausted. Other alternatives being investigated are mainly renewable

sources that include geothermal, biomass, wind, peat, mini and small hydro, and solar energy. The discovery of oil in the Western Rift Valley in Uganda will also contribute to electricity generation. The country's *per capita* energy consumption of 150 Kwh is among the lowest in the world. The grid electricity access rate is very low: 22% for the whole country and about 10% for the rural areas. Electricity production is approximately 3,800 GWh per year with a demand for power growing by 10% per year.

### **1.3 Legal and Institutional Framework**

The Government established a Geothermal Resources Department through restructuring of the Ministry of Energy and Mineral Development in 2014. The Department has embarked on formulating a geothermal policy and legislation to promote exploration and development of the country's geothermal resources. The draft policy will soon be sent to cabinet for Government approval. The geothermal exploration is currently regulated by the Mining Act 2003, and geothermal development by the Electricity Act 1999. The current policy and legislation is inadequate and cannot promote geothermal exploration and development creating a risk profile for geothermal projects as they cannot be generalized with minerals and other energy resources. Government commitment to development and utilization of geothermal energy in Uganda is laid down in the Energy Policy 2002 and Renewable Energy Policy 2007. There is, therefore, a need for a specific policy and legislation for geothermal energy.

### **1.4 Current Status of Electricity Generation and Utilization**

Uganda presently has a total installed capacity of electricity production of 951 MW of which 692 MW is hydropower, the rest is from cogeneration in sugar industries and thermal power plants. The effective capacity therefore is estimated to be in excess of 724 MW. The demand for electricity is estimated at 620 MW. This demand is largely domestic consumption but government policy is to add value to the country's natural resources which calls for greater electricity generation. Government in the short-term is constructing two hydropower dams at Karuma (600 MW) and Isimba (183 MW) along the River Nile. The two dams are scheduled to come on line between 2018 and 2020 raising the installed capacity to over 2002 MW by 2020. In the long-term, government will develop Ayago (840 MW) and Oriang (392 MW) downstream Karuma on the River Nile.

## **2. Status of Geothermal development in Uganda**

The main geothermal areas are Katwe, Buranga, Kibiro and Panyimur. The four areas were chosen for study because of their impressive surface manifestations and tectonic features that indicate heat sources and high permeability. Reconnaissance investigations are also going on in the remaining geothermal areas across the country (Figure 1). The following is a summary of the current results of the study on the four areas.

### **2.1 Kibiro geothermal prospect**

The Kibiro geothermal prospect is located in Hioma district approximately 290 km from Kampala. The area can be accessed through a 250 km tarmac road from Kampala to Hoima and then 40 km murram road from Hoima to Kibiro.

#### *(a) Geology*

Recent tectonic history at Kibiro shows that rifting originated in late Oligocene or Early Miocene (~23 Ma). The Second phase of rifting was during Pliocene (~2.6 to 5.3 Ma). The present-day Albertine Rift is presumed to have developed as a pull-apart in a sinisterly-trans-tensional environment that complicates interpretation due to different stress regimes. The Kibiro geothermal

prospect is divided into two entirely different geological environments by the escarpment, which cuts through the field from SW to NE (Figure 2). To the east of the escarpment, the geology is dominated by Precambrian crystalline basement, characterized by granites and granitic gneisses that are mylonitic in the fault controlled valleys while to the west lies an accumulation of thick sequences of Rift Valley arenaceous Kaiso and argillaceous Kisegi sediments of at least 5.5 km thickness.

Recent structural geology mapping shows that Kibiro is controlled by the Northern Toro Bunyoro (NTB) fault which shows that it takes multiple right and left steps across the geothermal area, forming a compound step-over region, 1.5 km-long and 150 m-wide (Figure 2). Each step is also associated with one or more fault intersections. This compound step-over contrasts the previous mapping which indicated that the NTB fault was a single linear feature extending through the Kibiro area (Alexander et al., 2016). Outside of this step-over area, the NTB fault is nearly as linear as depicted on previous maps. Fault surface measurements were obtained for both the upper splay of the NTB fault and the Kachuru fault (Figure 2). The upper splay of the NTB fault dips  $65^\circ$  NW and the Kachuru fault dips  $46^\circ$  to  $50^\circ$  NW. The  $65^\circ$  dip measurement of the upper splay of the NTB fault matches with the drill-hole data-derived dip estimate as reported in Alexander et al. (2016). The Waki B1 well, drilled near Butiaba, encountered basement at a depth of 1222 m. Based on the location of the well, the dip of the NTB Fault was estimated to be  $65^\circ$  NW. The Kachuru fault may sole into the footwall side of the NTB fault.

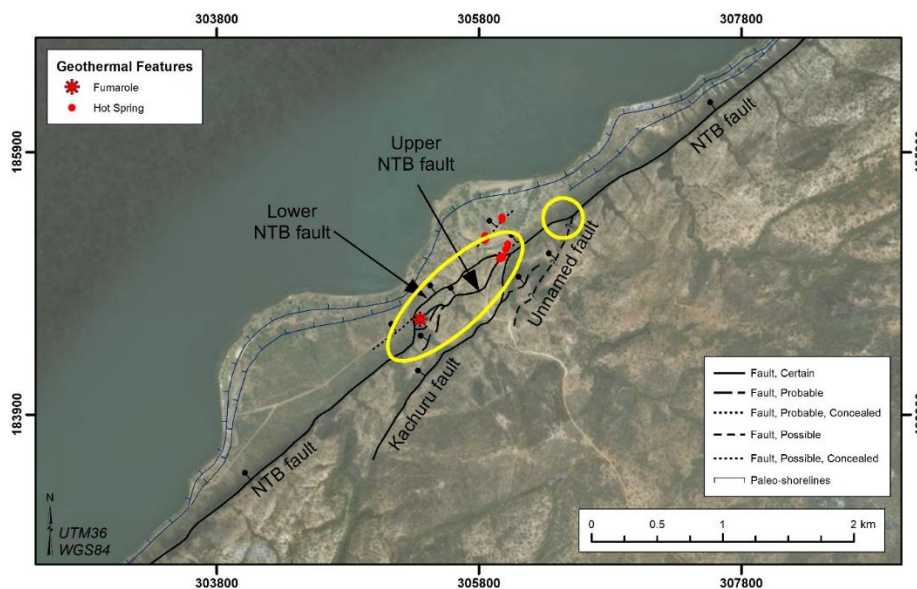


Figure 2. Structural map of the Kibiro geothermal prospect area based on the new mapping by EAGER and GRD in January 2018. Yellow ellipses correspond to step-overs at fault intersections along the NTB fault.

Surficial geothermal features include four (4) clusters of hot springs, inactive oil seeps, bedrock alteration, and a single weak fumarole (Figure 2). This weakly flowing  $45.4^\circ\text{C}$  fumarole was discovered by EAGER and GRD/MEMD in January of 2018 at the SW end of the step-over in a local area of intense argillic alteration of the bedrock with actively depositing fresh native sulphur and older bitumen. This weak fumarole extends the distance of surface thermal features about 750 m SW of the hot springs.

#### (b) Geochemistry

The geothermal surface manifestations in the Kibiro geothermal prospect are mainly concentrated at Kibiro along the Tooro-Bunyoro Fault at the contact of the Rift Valley sediments and the Escarpment. They comprise hot springs with a total flow rate of 16 l/s and the maximum surface

temperature is 86.4°C (Bahati, 2018). The thermal waters have H<sub>2</sub>S with limited evidence for carbonate precipitation, but white thread-like algae and in some places close to the stream the threads are coloured black with sulphides. The fluids are characterized by a neutral pH, and salinity of 4,000 - 5,000 mg/kg TDS. A subsurface temperature of 150 - 250°C is inferred by geothermometer and mixing models (Alexander et.al, 2016).

The  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  values of H<sub>2</sub>O for hot water samples of the Kibiro geothermal prospect have an oxygen isotope shift of ~1 ‰ units with respect to the Entebbe Meteoric Water Line (Entebbe MWL). This small oxygen isotope shift might be mainly due to the slow kinetics of the water-rock exchange of oxygen isotopes at low temperature. In addition, the hot springs have  $\delta^2\text{H}$  values lower than most sampled waters possibly due to higher recharge altitude represented by the Mukhihani-Waisembe Ridge approximately 20 km southeast of Kibiro. The tritium concentration of the Kibiro hot spring water is 1.25 TU which is similar to that of the groundwaters (0 - 3.5 TU), and indicates that the hot spring water has cold groundwater contribution. Hydrogen sulphide is typically generated through bacterial sulfate reduction coupled with oxidation of organic matter, which is abundant at Kibiro. It is therefore likely that the Kibiro geothermal end-member acquires sulfate through leaching of sulfate minerals present in lacustrine evaporite rocks. Then the dissolved sulfate is converted to sulfide through bacterial sulfate reduction coupled with oxidation of organic substances to carbonate species. Based on these considerations, dissolved sulfate is unlikely to be of magmatic origin as suggested in previous studies (Alexander et al., 2016).

### *(c) Geophysics*

Previous geophysical surveys carried out in 2005 used gravity, magnetics and TEM methods at Kibiro. The surveys were carried out in the crystalline environment to the east of the Tooro-Bunyoro fault and the sediments to the west on the shores of Lake Albert. Low resistivity anomalies were detected in the crystalline basement and in the sedimentary basin. Six thermal gradient wells were drilled up to 300 m in the low resistivity anomalous areas in the crystalline basement to test the presence of heat. The results indicated absence of a geothermal gradient (16°C/km) but slightly elevated towards the escarpment (31°C/km). This suggested that the anomalies in the crystalline basement are not caused by a geothermal activity. The elevated temperature gradient towards the escarpment suggested an influence from the hot springs at Kibiro through conductive heat transfer through the crystalline rocks.

Following lack of geothermal activity in the crystalline environment, follow-up and recent geophysical surveys were carried out in the sedimentary basin west of the escarpment at the Kibiro and Kachuru peninsulas on the shores of Lake Albert. The surveys also used MT/TEM resistivity method, marine reflection seismic surveys data on Lake Albert, airborne gravity surveys and regional aeromagnetic surveys in order to develop a conceptual model for Kibiro. The conceptual geophysical model based on MT geophysical method is presented in Figure 3.



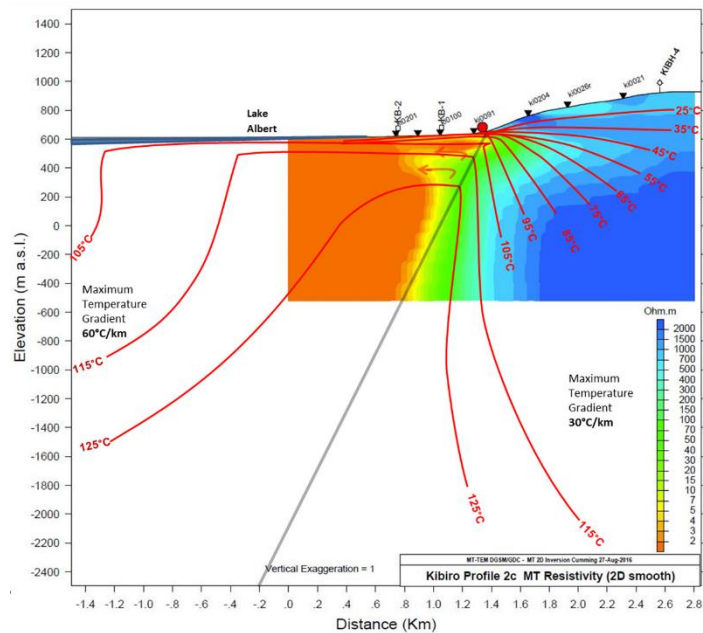


Figure 3: MT geophysical conceptual model for Kibiro with a 65° dipping fault. The purported reservoir is in green/yellow while red is the cap rock shielding the reservoir. The cross-section line is shown on Figure 5.

The geophysical model suggests that a shallow aquifer may underlie a clay zone over much of the Kibiro peninsula. Its thickness is not well constrained due to limitations caused by the Lake Albert. The upflow options could also still feed productive outflow into basin-fill sediments as suggested in the UNEP studies. Given the higher confidence in the step-over along the NTB fault providing the conduit for deep circulation, the updated conceptual model is constructed to >2000 m a.s.l. to illustrate the control that convection along this structure has on the isotherms.

(d) *Conceptual model based on micro-seismic*

Based on the results of all disciplines, a conceptual model has been developed to explain the flow of the geothermal fluids in the subsurface at Kibiro (Figure 4). In Model this model, the 240°C reservoir hosting the geothermal liquid is assumed to be situated below the lacustrine sediments at depths of 2.0 to 2.3 km on the southeastern side of Lake Albert, close to Kibiro. A temperature of 150°C is attained through mixing between the uprising geothermal liquid and the descending cold brackish water establishing a secondary reservoir. Conductive cooling occurs afterwards during the final upflow of the mixed water to the surface.

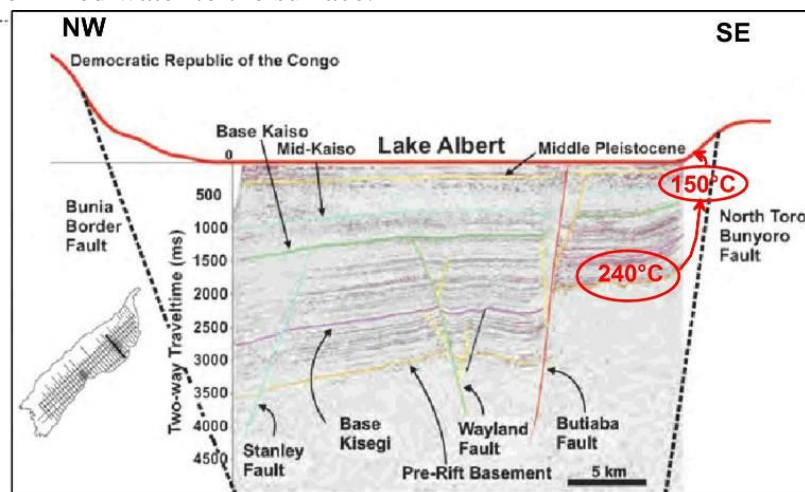


Figure 4: Seismic cross-section (Karp et al., 2012) on which the possible geothermal reservoir and paths of the geothermal liquids are indicated.

(e) *Temperature Gradient Wells (TGW) locations*

Based on the new structural mapping and updates to the conceptual modelling, TGW targets have been expanded to cover a slightly greater strike length of the NTB fault (Figure 5). The eight (8) proposed TGW now straddle the full width of the step-over and low resistivity anomaly.

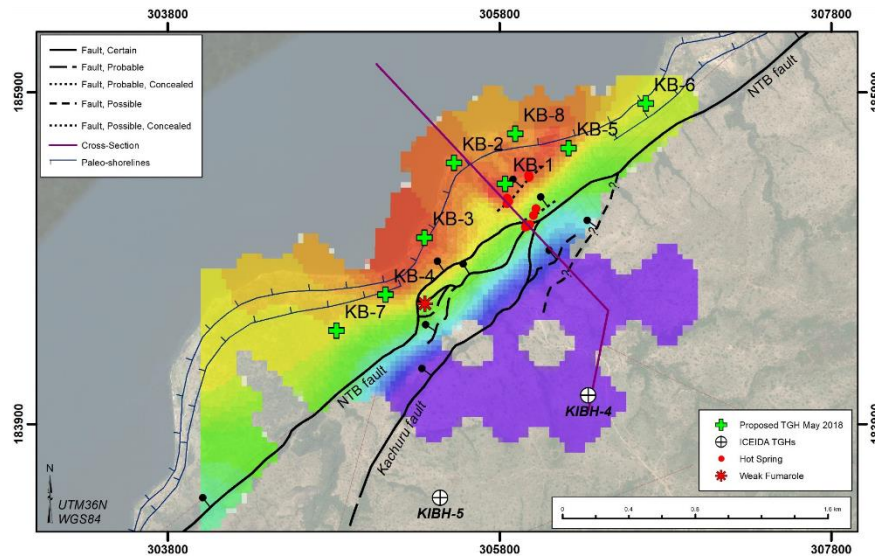


Figure 5: Kibiro. Location of the eight TGW targets.

(f) *Recommendation*

A two stage approach is recommended as follows: (i) Drill shallow temperature gradient wells to explore the possibility that a shallow aquifer exists, as hinted by the resistivity (MT/TEM) data at about 150 to 300 m depth; (ii) If the well shows more definitive indications of being over 230°C, then consider options to target the deeper system, possibly by directional drilling offshore; and if the temperatures are closer to 140 to 150 °C, then design a low temperature exploration plan for the discovered resource.

## 2.2 Panyimur Geothermal Prospect

(a) *Geology*

The Panyimur geothermal prospect is located in Pakwach District, West Nile Region. The Panyimur geothermal area appears to be a fault-controlled system that is associated with a 1.5 to 2 km-wide step-over linking two NNE-striking faults. The local and regional geomechanical data indicate that these NNE-striking faults are nearly pure dip-slip, making this setting a step-over between pure normal faults in contrast to a pull-apart between oblique- or strike-slip faults. Normal fault step-overs are the most common structural setting for geothermal systems in the Basin and Range regions (Faulds and Hinz, 2015), which are similar to Panyimur.

The area is dominated by two major NNE-striking faults with normal, down-to-east displacement, and are known as the Upper Fault and the Lower Fault (Figure 6). The Upper Fault offsets only Precambrian metamorphic rocks with a 75 to 95 m scarp, whereas the Lower Fault, located from 600 to 2000 m to the southeast of the Upper Fault, offsets the Precambrian by perhaps 1500 m, however its scarp is smaller at 40-70 m high, due to infill by sediments. There is also a secondary set of minor NE- to ENE-striking, north and south dipping faults with dextral-normal or sinistral-normal sense of displacement. The two major NNE-striking bounding faults are locally linked

through a left fault step, 1-2 km southwest of Panyimur hot springs. The major NNE-striking faults also make left steps on the scale of 100 m to 600 m, with some local right step on the scale of 100 m to 200 m.

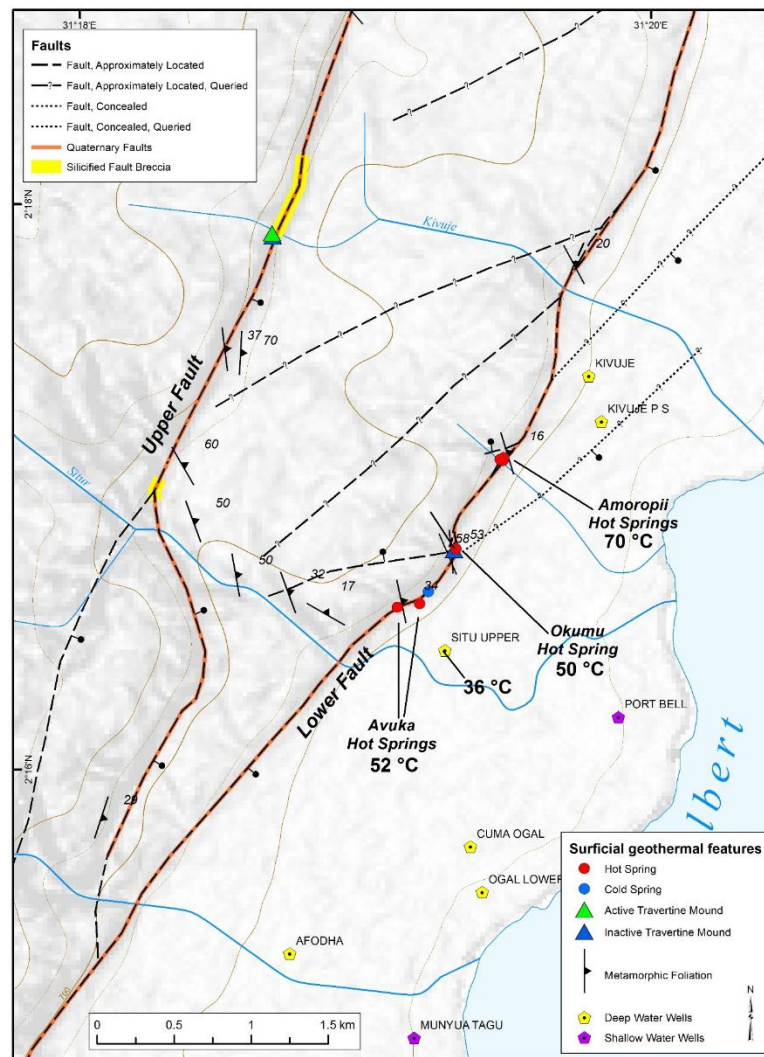


Figure 6: Structural geology map of the Panyimur geothermal prospect with active and inactive surficial geothermal features.

The surface manifestations are hot springs distributed in three clusters along a 1.25 km-long segment of the Lower Fault (Figure 6). The three hot spring clusters from north to south are namely Amoropii, Okumu and Avuka. The Amoropii hot springs emanate in the active stream bed and in a swampy area with the highest temperature of 70°C while Okumu was measured at 50.1°C and Avuka at 52°C. However there are more springs within an area of heavily vegetated swampy ground that were inaccessible for measurement in 2017. A village water well with a hand pump located about 400m SE of the hot springs produces 36°C fluids.

Inactive travertine spring mounds are associated with both the Upper and Lower Faults (Figure 6). Active travertine mounds are only building along the Upper Fault. Fault breccia is locally cemented with amorphous silica and quartz druse along the Upper Fault, adjacent to Kivuje stream (Figure 6). No active silica deposition was observed across this geothermal area.



*(b) Geochemistry*

The geothermal fluids are slightly above neutral with a pH of 7-9 and low salinity of 300 – 900 mg/kg total dissolved solids. Presence of hydrogen sulphide in Amoropii (12.0 ppm), Okumu (10.7 ppm) and Avuka (6.1 ppm) hot spring waters and almost all the ground waters sampled is very rare and needs further investigations (Armannsson et. al., 2007). Although there is no evidence for volcanism in the area, the origin of H<sub>2</sub>S in the geothermal and groundwaters could be explained like at Kibiro. The sulphate concentration in the end member is very low, probably due to the occurrence of bacterial sulphate reduction sustained by concurrent oxidation of organic substances to carbonate species and hydrogen sulphide (Alexander et.al., 2016). The subsurface temperature, predicted by geothermometry, is in the range of 110 – 140°C suitable for use in electricity production and direct use in industry and agriculture (Ármannsson et al. 2007).

*(c) Geophysics*

Previous geophysical studies carried out in 2015 at Panyimur used gravity and magnetics methods which clearly delineated the major NE-SW trending fault but did not delineate the perpendicular NW-SE faults that cross cut the major NE-SW fault. Recent geophysical investigations used MT/TEM geophysical methods are presented (Figure 7).

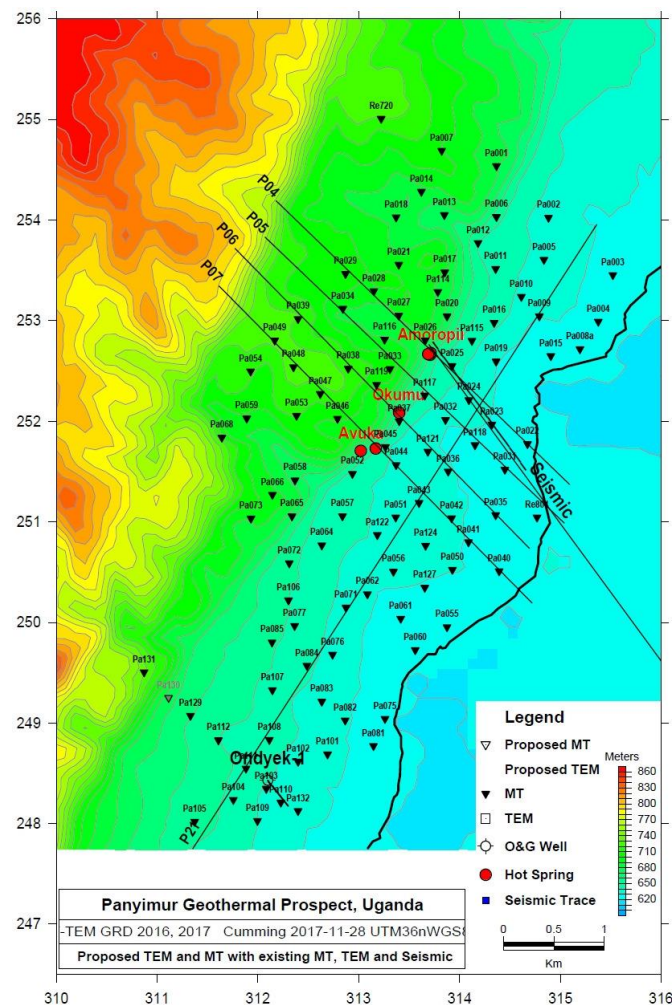


Figure 7: Topographic map of the Panyimur area showing MT/TEM stations and profiles and location of the reflection seismic section used to develop a conceptual model for the system.

Figure 7 shows the locations of the 78 MT stations acquired in 2016 and 26 in-fill stations in 2017. TEM data were acquired at 45 of the MT sites from the 2016 survey and 38 TEM stations

were reliable enough to correct MT static shift. The GRD used its Phoenix V8 TEM system, which does not provide useful data over resistive rocks like the Precambrian gneiss and so TEM data were acquired only at MT stations over the sediments.

*(d) Proposed Conceptual Model at Panyimur*

The conceptual model proposed for Panyimur based on MT results include: 1) downflow and upflow in fault/fracture hosted permeability within the damage zone and fault splays directly associated with the Lower fault; 2) scenario 1 with 125°C extending to shallower depths where geothermometers re-equilibrate in a shallow outflow aquifer, implying a larger volume system; and 3) either scenarios 1 or 2 coupled to up-dip outflow in a sand or gravel formation toward the River Nile/Lake Albert (Figure 8 and 9).

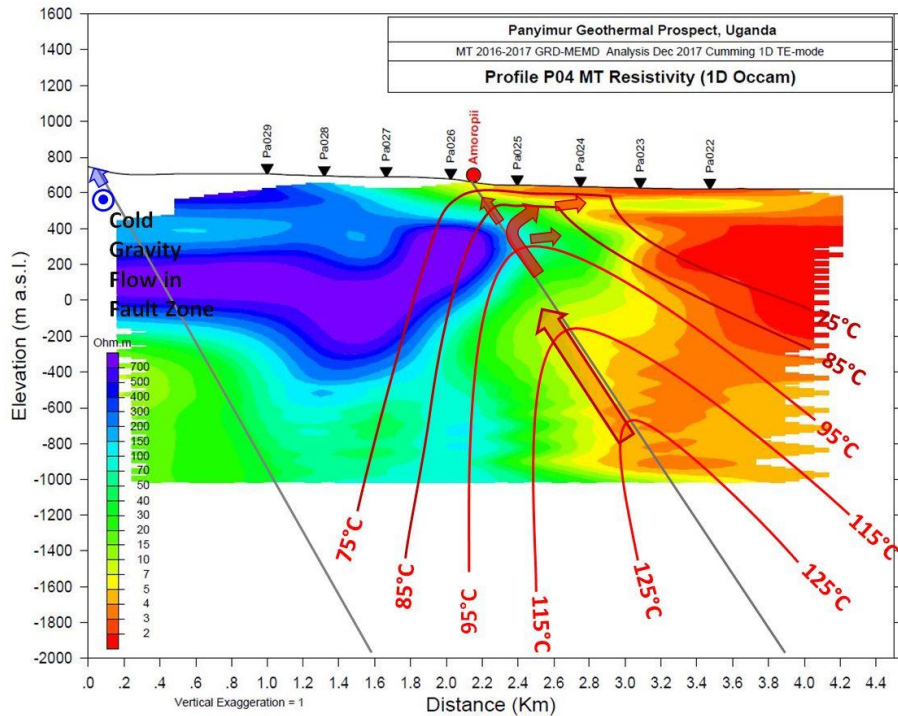


Figure 8: Panyimur. Conceptual model along Profile P04 through Amoropii.

Figure 8 shows a resource model for Panyimur based on geophysics illustrated with isotherms along a Profile through the highest temperature hot spring, Amoropii. The isotherm pattern assumes that a deep 150°C upflow ascends through fracture permeability associated with the Lower Fault and outflows at 115 to 125°C in a sand/gravel aquifer at about 300 m depth, and also indirectly outflows at 75°C into a shallower and thinner sand-gravel aquifer at about 70 m depth (red arrows). The geothermometry re-equilibrates in the outflow aquifers to be consistent with the chemistry of the hot springs.

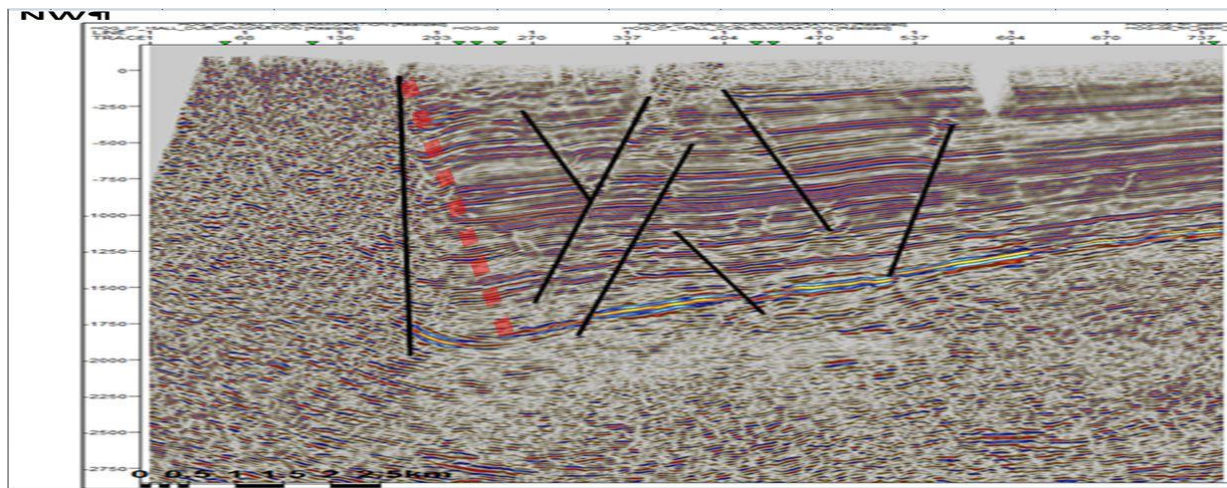


Figure 9: A reflection seismic section that meets the Lower Fault (red) near the Panyimur hot springs.

Figure 9 shows a red dashed line with a dip of 40 to 60° which is consistent with measured dips at the surface and in the MT profiles. Most importantly, the seismic reflection data at Panyimur indicated that formations truncated against the Precambrian at the Lower Fault dipped up to the east, implying that any thermal upflow in the fault zone that was diverted into a sandstone or gravel formation would outflow gently up-dip eastward beneath the lake. Therefore, a shallow formation-hosted outflow is feasible that may represent a relatively shallow target for TGW and production wells. Because the sands/gravels appear to dip upward beneath a clay cap toward lake, the lake would hide any evidence of outflow leakage.

*(e) Temperature Gradient Wells (TGW) locations*

The locations of the proposed temperature gradient wells (TGWs) are presented in Figure 10. The procedure is to permit a total of fifteen (15) TGW. Drill the first three (3) high priority TGWs (red circles) first to about 300 m east of the Lower Fault, in a line parallel to the fault, outboard of Amoropii hot springs. Then drill the remaining 5 according to first results in offset pattern as necessary to define the geothermal target. Upon completion of the TGW, the conceptual model(s) and resource assessment would be updated to support targeting deeper slim holes or full-sized wells as appropriate based on these updated models and risk assessments.



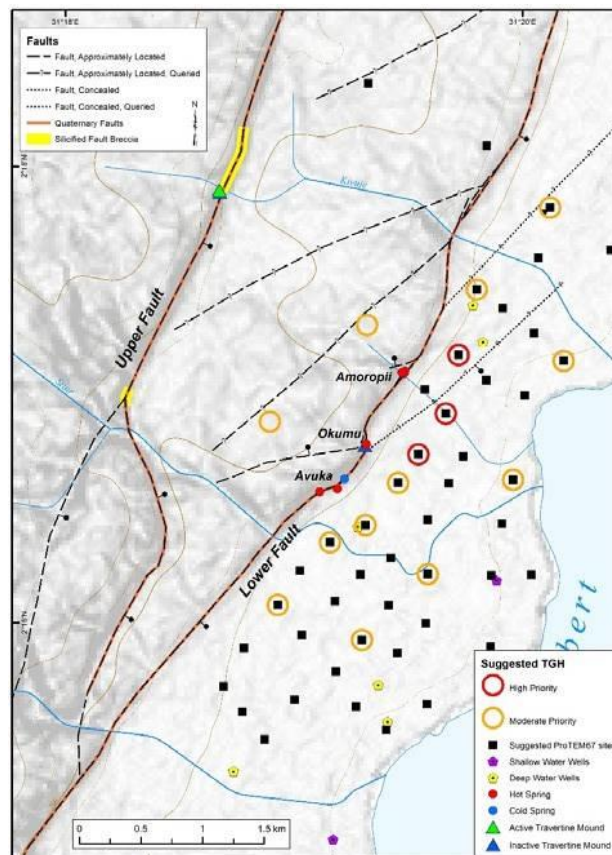


Figure 10: Panyimur. Proposed location of TGWs.

(f) *Recommendations for Panyimur*

Targeting a deep geothermal reservoir is not recommended at this time. The following are the recommendations:

- Drill 5 to 8 TGW to a depth of 200-300m to discover a geothermal reservoir.
- Acquire TEM data using GRD's recently repaired Protem67 system at up to 80 proposed locations and interpret the shallow hydrology based on it.
- Complete an integrated reflection seismic and MT cross section through the Amoropii hot springs.
- Update the conceptual models.
- Slim hole or full-size hole drilling.

### 2.3 Buranga geothermal prospect

The Buranga geothermal prospect is located at the foot of the Rwenzori massif near the base of the Bwamba escarpment in Semuliki National Park in Bundibugyo District. Buranga is localized by the major Rift Valley faults (Figure 11). The survey area is rugged and steep to the east on the edge of Rwenzori escarpment while to the west is located in thick tropical rain forest. To the north of the hot springs the forest diminishes into swampy grass land with meandering Semliki River that marks the Border of Uganda with the Democratic Republic of Congo (DRC). The Government of Uganda carried out geothermal exploration at Buranga from 1993 to 2010 before the area was licensed to the private sector. Since 2010, geothermal surveys have been carried out by the licensee, Gids Consult Ltd, with support from the Geothermal Resources Department (GRD).



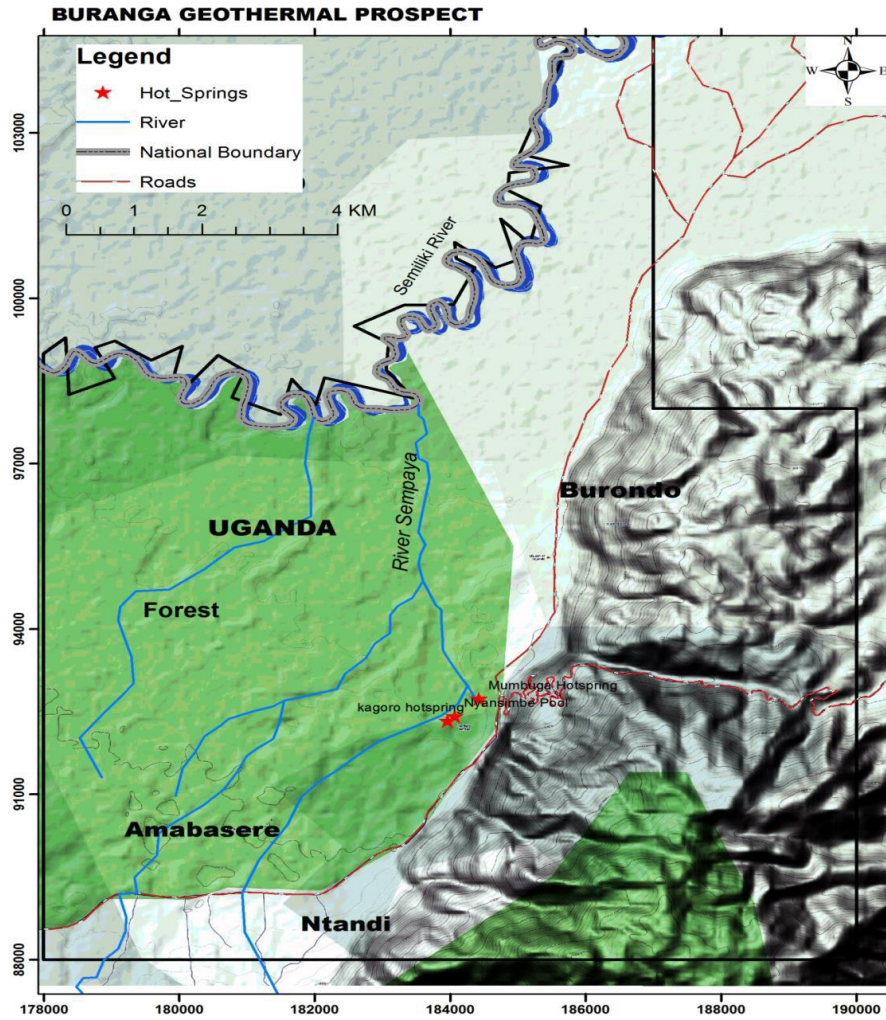


Figure 11: Buranga geothermal prospect.

*(a) Geology*

Buranga hot springs emerge through sediments of Kaiso beds and peneplain gravels which consists of variable sands and gravels with irregularly distributed boulders containing sub-angular fragments. The Kaiso sediments are underlain by fine to medium-grained, poorly consolidated sands and clays; some coated with calcareous material. The structural geology of the area is characterized by the Range-front fault making a number of 250m to 1km right and left steps (Figure 12). Measurements on exposed fault surfaces in Precambrian rock east of the hot springs range 50-60° and, average 55° to NW (Hinz et al., 2017). Additional observations indicate that the NE-striking, down-to-NW normal faults intersect the range-front fault. Large landslide deposit along range-front NE of Buranga hot springs has locally concealed range-front fault traces. The main geology of Rwenzori massif which forms the Eastern escarpment of the Rift, the Bwamba fault, is metamorphic composed mainly of migmatites, amphibolites and gneisses.

This type of fault pattern is typical of other normal fault step-overs and normal fault intersections along major range-front faults in the Basin and Range region in the U.S.A (e.g., Steptoe Valley, Nevada). As with other step-overs, upflow could favour one or more of the primary faults, including the primary range-front fault, the outer concealed NE-striking fault, intervening concealed faults, or any combination of these structures.

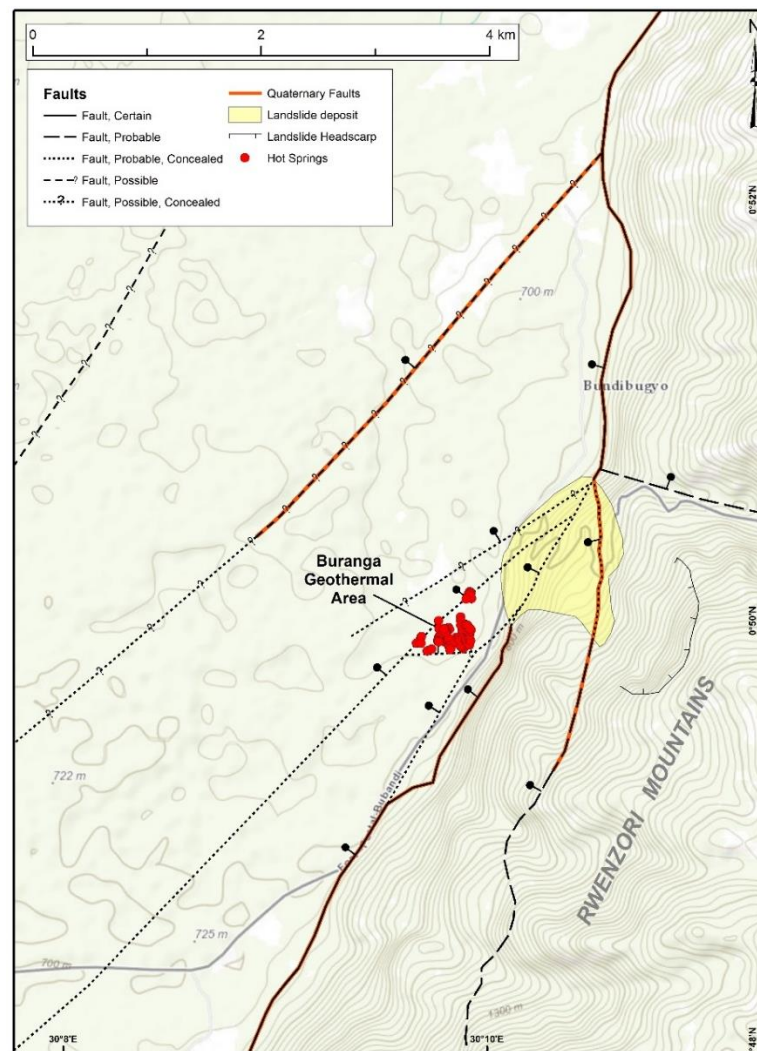


Figure 12: Buranga. Structural geology map. Yellow is the landslide deposit that has concealed range-front fault traces.

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. They include hot springs that are close to boiling and calcareous tufas. The highest surface temperature is close to  $98.7^{\circ}\text{C}$  and the flow is approximately 28 litres/second, an indication of high permeability (Bahati, 2018).

#### (b) Geochemistry

The fluids are neutral with a pH of 7-8 and salinity of 14,000 – 17,000 mg/kg TDS. In the earlier study by Ármannsson (1994) a good agreement was obtained for all plausible solute geothermometers tested for several hot springs and pools at Buranga and it was concluded that the subsurface temperature was  $120 - 150^{\circ}\text{C}$ . This temperature is in agreement with the results of gas analysis which show absence of hydrogen, suggesting that the subsurface temperature is less than  $200^{\circ}\text{C}$ .

Isotopes hydrology suggests that the geothermal water is from high ground in the Rwenzori Mountains. There is no tritium in the thermal water from Buranga which implies that it is not mixed with cold groundwater. The source of sulphate is minerals or rock (terrestrial evaporates) from the surrounding sedimentary formation that is rich in gypsum (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 ( $^3\text{He}/^4\text{He}$ ) in gaseous discharges from hot springs suggest a magmatic source of solutes for Buranga (BGR-MEMD, 2007).

*(c) Geophysical surveys*

Aeromagnetic survey acquired in 1980s by the Department of Geological Survey and Mines in Uganda revealed two distinct areas of high and low magnetization (Edicon, 1984). The low magnetic susceptibility was interpreted as the probable areas of geothermal interest due to reduced magnetization as a result of thermal activities. A joint seismic study by BGR (German Geological Survey) and DGSM was carried out in 2007. The inversion tomography of the huge seismic data set indicated low P-wave velocity anomalies in the subsurface located south of the hot springs at 10 km depth. The reduced velocity anomalies were interpreted as high temperature anomalies inferred to be hot actively degassing magmatic intrusions which could be the heat source for the hot springs (BGR-MEMD, 2007).

Recent geophysical surveys used the MT method which probes deeper into the subsurface up to 15 km while the TEM method is used to collect the Telluric shift in the MT data. The current data was collected between 2014 and 2017. A total of 108 MT and 94 TEM soundings have been conducted at Buranga. The sedimentary basin at Buranga is highly conductive due to the clay type minerals which are consolidated in the sediments.

*(d) Conceptual model for Buranga*

In a manner analogous to the prolific 129°C Don Campbell development in Nevada, a prolific shallow sedimentary outflow aquifer might be a viable target that would be lower cost to explore and drill than a deeper fault-hosted system (Hinz., personal communication). The conceptual models proposed for Buranga include: 1) downflow from the highland to the east and upflow in fault/fracture hosted permeability within the damage zone and fault splays directly associated with the hot springs fault trace; 2) downflow within the basin and upflow within the damage zone and fault splays directly associated with the hot springs Fault trace; 3) either scenarios 1 or 2 coupled to updip outflow in a sand or gravel formation westward toward the basin, and 4) 1 or 2 and maybe 3 coupled with a very shallow outflow from the hot spring fault to the basin margin to the east (Figure 13).

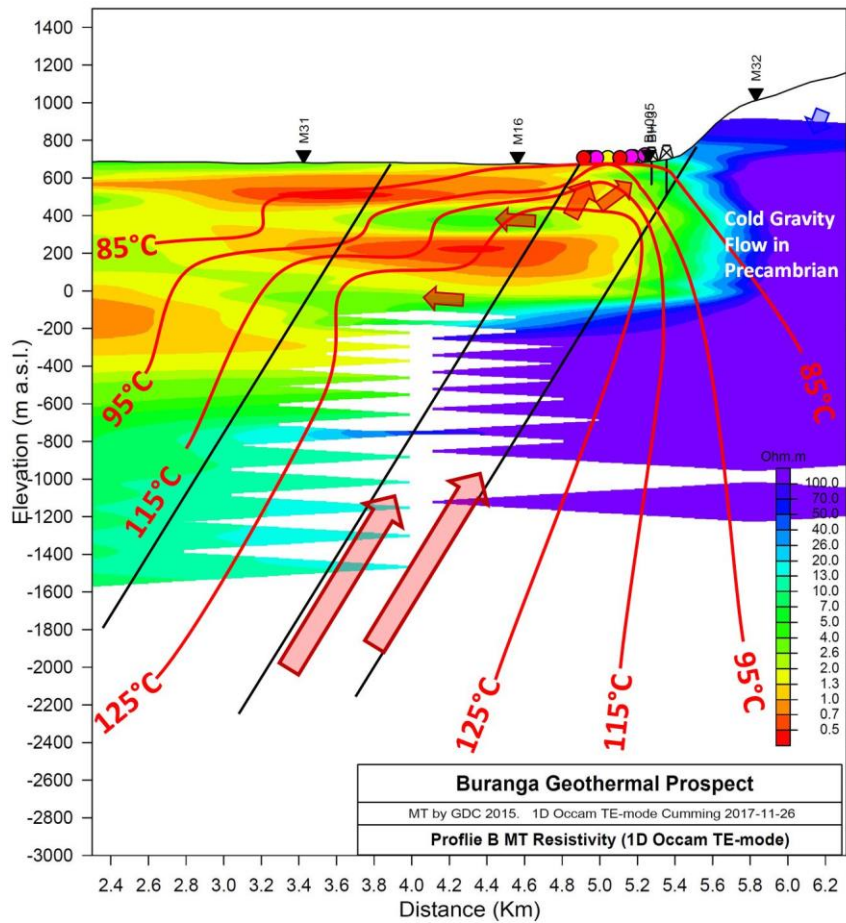


Figure 13: Buranga. MT geophysical conceptual model.

Figure 13 illustrates a variation on the model along a profile through the hot springs that includes an optimistic wide upflow that carries 125°C to <500 m depth. Although omitted from this figure, a 150°C contour is implied by the model. A low resistivity layer close to the surface could represent a clay cap (cap rock) made by highly conductive clay minerals and beneath would lie a geothermal reservoir which is expected to be highly resistive. The above model looks ambiguous because only a few soundings were done in the area and therefore a need to collect more data at a close spacing.

*(e) Temperature Gradient Wells (TGWs) locations*

The locations of the proposed temperature gradient wells (TGW) are presented in Figure 14. Although significant data gaps remain including MT-TEM, structure and access data, recommend 8 TGW based on available data. The procedure is to permit a total of fifteen (15) TGW. Select and drill the first three (3) high priority TGW first, based on the results of the additional MT-TEM and access data. Then drill the remaining 5 according to first results in offset pattern as necessary to define the geothermal target. Upon completion of the TGW, the conceptual model(s) and resource assessment would be updated to support targeting deeper slim holes or full-sized wells as appropriate based on these updated models and risk assessments.



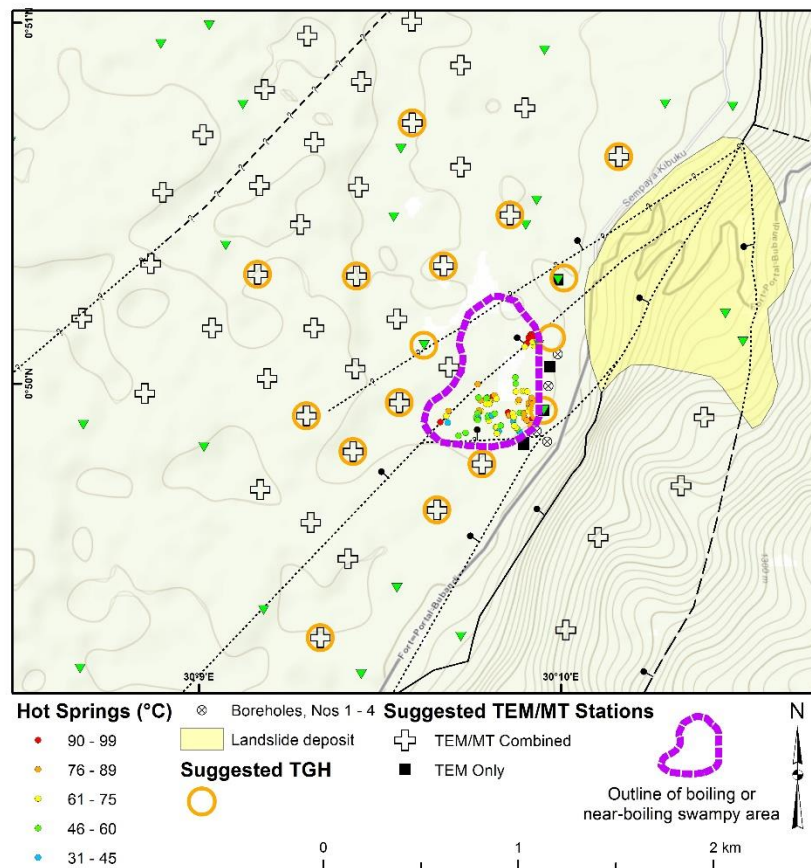


Figure 14: Buranga. Proposed location of TGWs.

(f) *Recommendations*

The following are the recommendations for Buranga:

- MT/TEM data (~30 MT stations and ~40 Protem67 TEM stations) to improve understanding of the shallow sedimentary sand-gravel aquifers and clay-rich aquicludes.
- Soil temperature and gas surveys to delineate the faults that control the flow of geothermal fluids.
- Drilling of five to eight (5 to 8) TGW based on available data. Because of the likely deep origin of the geothermal system and the ambiguity in the interpretation of a shallow sediment-hosted resource, TGWs are recommended as a follow-up to a geophysical survey that is more focused on the hot spring area.
- Update the conceptual model(s) and resource assessment to aid targeting deeper slim holes or full-sized wells.

However, of paramount concern to a development at Buranga is the management of access and impacts in a manner consistent with safety and environmental issues in the national park that covers the most prospective area.

## 2.4 Katwe geothermal prospect

The Katwe geothermal prospect is located in Kasese district, southwest Uganda. The prospect stretches from Lake Katwe to Lake Kikorongo and occupies an area of approximately 150 km<sup>2</sup>.

*(a) Geology*

The geology of the Katwe prospect is dominated by explosion craters, ejected pyroclastics, tuffs with abundant granite and gneissic rocks from the basement (Figure 15). The volcanic rocks, mainly composed of pyroclastics and ultramafic xenoliths, are deposited on the extensive Pleistocene lacustrine and fluvial Kaiso beds and in some places directly on Precambrian rocks. Minor occurrences of lava are found in the Lake Kitagata and Kyemengo craters. The age of the volcanic activity had been estimated as Pleistocene to Holocene (Musisi, 1991). The lava flows, craters and extinct hydrothermal deposits give an indication of a heat source for the geothermal activity. Outside the crater area, the geology is characterized by surficial deposits to the east and the west, and to the north lie the Rwenzori Mountains whose geology is dominated by gneisses, granites, granulites, amphibolites, schists and in some places quartzites.

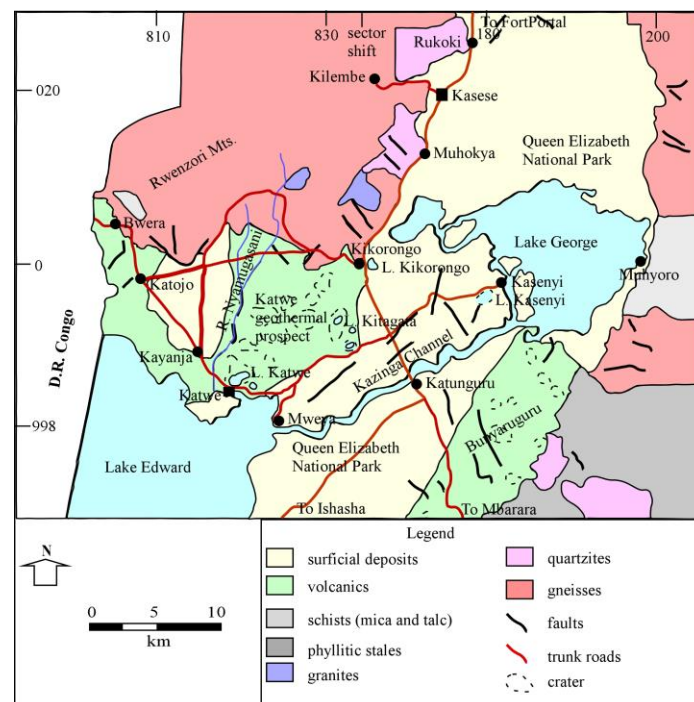


Figure 15: Geology of Katwe-Kikorongo volcanic field and surroundings.

Recent structural geological mapping was carried out in January 2018 (Hinz et al., 2018). The mapping concentrated in an area between Lake Kitagata and Lake Katwe. The two craters are the only ones with hot and warm springs. The warm water in Lake Katwe has a temperature of 32°C while highest temperature in the Kitagata craters is 70°C. Three hot springs were mapped along the western shores of Lake Kitagata and one was observed flowing up into the lake about 20m offshore. Measured temperatures of the onshore springs range from 39.4 to 72.1°C (Figure 16) while the temperature of the offshore hot spring was previously measured at 70°C (Gislason et al., 1994). In addition to the warm springs, numerous cold springs emerge from the perimeter of the entire lake about 2-3 meters above the lake level, which probably corresponds to the water table elevation as it is intersected by this crater. The hot springs at Lake Kitagata are located along the main strand of the Nyamwamba fault system, which is likely to host a deep circulation upflow.

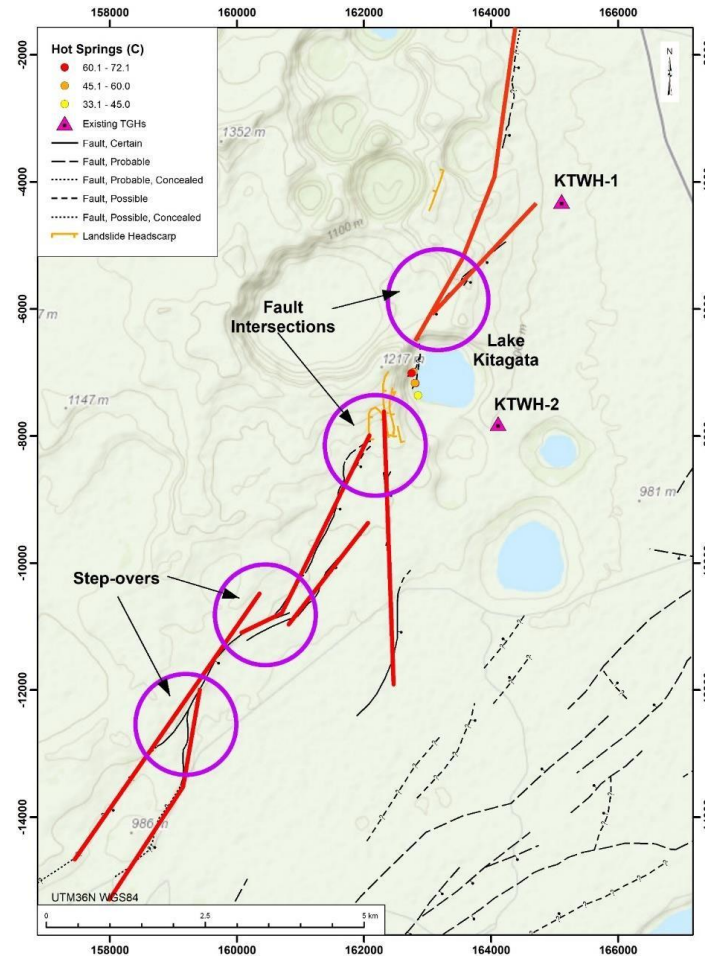


Figure 16: Structural target areas along the Nyamwamba fault zone in the Lake Kitagata area. Red lines highlight key fault segments and purple circles highlight the structural target areas.

There are multiple fault intersections and step-overs along the Nyamwamba fault zone near Lake Kitagata (Figure 16), and it is possible that one or more of these structures could provide focused circulation along the fault zone. The nearest TGH (KTWH-2), which is 1.5 km southeast of the hot springs, showed a straight-line conductive temperature gradient typical of “continental background” regions worldwide. This would suggest that an ascending plume of geothermal water is locally restricted to a single structure or fault intersection proximal to the hot springs (Figure 16). However, given the degree of cover by young tuffs, it is also probable that additional structural architecture of the Nyamwamba fault zone is obscured by both Quaternary deposits and vegetation.

#### (b) Geochemistry

The geothermal fluids are characterized by high carbonate and sulphate, and salinity of 19,000 - 28,000 mg/kg total dissolved solids. High carbonate and sulphate in the geothermal water tend to invalidate solute geothermometer results at Katwe. Subsurface temperatures are estimated at 140-200°C using plausible solute geothermometers (Armannsson, 1994). The results from stable isotopes suggest that the Katwe geothermal system is most likely recharged from high ground in the Rwenzori Mountains. The tritium concentration in the thermal waters from the Katwe area is minimal suggesting that the hot spring water is not mixed with cold groundwater. The isotopic composition of sulphur ( $\delta^{34}\text{S}$ ), and oxygen ( $\delta^{18}\text{O}$ ) in sulphate suggest a magmatic and hydrothermal source for the geothermal water. Strontium isotopes in water and rock ( $^{87/86}\text{Sr}_{\text{H}_2\text{O}}$ ,  $^{87/86}\text{Sr}_{\text{Rock}}$ ) indicate an interaction between the rocks sampled and the geothermal fluids. The rocks interacting with the fluids, i.e the reservoir rock types, in Katwe are basalt. The major source of salinity is rock dissolution, but some magmatic input is suggested (Bahati, et. al., 2005).

*(c) Geophysics*

Geophysical surveys; Transient Electromagnetics (TEM) and Gravity were conducted in the Katwe geothermal prospect (Figure 17). The high resistivity anomaly coincides with trace of the Rwenzori Mountains while the low resistivity anomalous areas are located east of the Rwenzori Mountains and controlled by the NNE-SSW Nyamwamba fault passing through Lake Kitagata and Lake Kikorongo area (Figure 17).

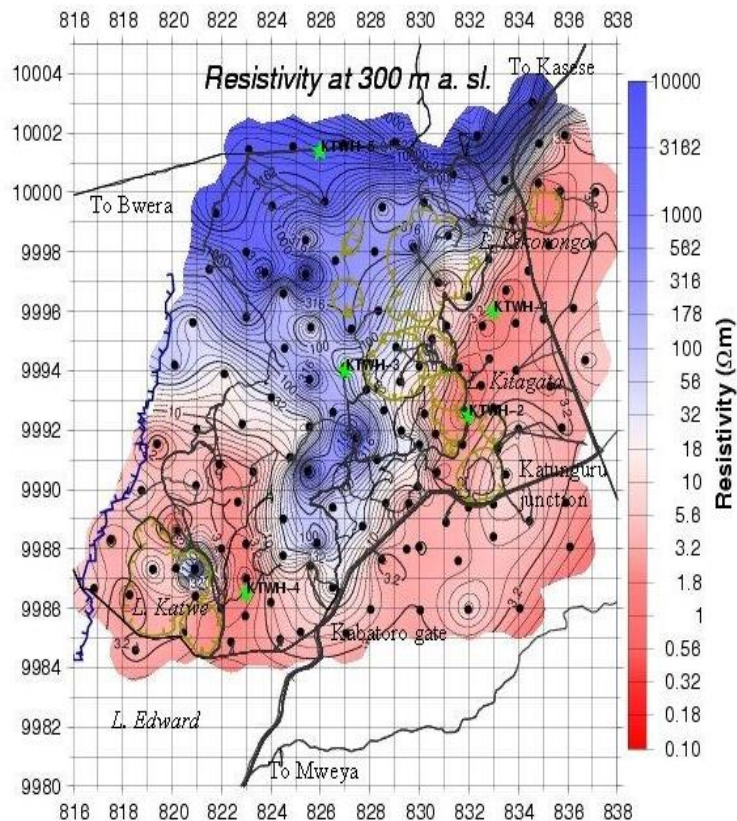


Figure 17: Katwe. Resistivity at 300 m a.s.l.

*(d) Recommendations for Katwe prospect*

The following are the recommendations for the Katwe geothermal prospect:

- Carry out additional geochemical sampling and analysis of gas samples for CO<sub>2</sub>, H<sub>2</sub>S, NH<sub>3</sub>, N<sub>2</sub>, O<sub>2</sub>, He, Ar, CH<sub>4</sub>, H<sub>2</sub>, and CO; together with He isotopes and C isotopes of CO<sub>2</sub> and CH<sub>4</sub>.
- Carry out soil temperature and gas surveys to delineate structural faults.
- Carry out MT and additional TEM surveys to delineate possible reservoirs.
- Develop an integrated geothermal resource conceptual model for the prospect to assist locating temperature gradient wells (TGW).

### 3. Investment opportunities

Out of the 24 geothermal areas of Uganda, only three are licensed to the private sector. The remaining areas are still in the hands of the Government which is carrying out surface exploration to prepare them for feasibility studies and later private sector investment.

The key strategies for fostering investment include: (i) Implementing through public private partnerships (PPP), innovative financing mechanisms, including targeted subsidies to stimulate the market penetration of renewable energy technologies; (ii) Introduction of specific regimes that favor



renewable energy, these include preferential tax treatment, tax exemption and accelerated depreciation; (iii) Implementation of innovative risk mitigation mechanisms and credit enhancement instruments, to provide comfort to project lenders.

#### **4. Challenges**

The challenges facing geothermal energy development in Uganda include: Inadequate policy, legal and regulatory frameworks to guide public interventions on a strategic basis; inability to attract significant financial support from International Development Partners; lack of a skilled workforce capable of maintaining a sustainable geothermal industry that adds value to the national economy; and low awareness amongst the public and limited community participation in geothermal exploration and development.

#### **5. Conclusions**

Subsurface temperatures of 150-250°C, 110-140°C, 120-150°C, and 140-200°C are inferred by geothermometry for Kibiro, Panyimur, Buranga, and Katwe-Kikorongo respectively. These temperatures, if confirmed, are good for electricity production and for direct use in industry and agriculture.

In other areas, the current results suggest geothermal potentials with subsurface temperatures of 100-160°C also good for electricity production and direct heat for use in industry and agriculture.

Kibiro, Panyimur and Buranga have reached advanced stages of surface exploration. Subsurface conceptual models have been developed to guide the location of sites for exploration drilling. While Katwe-Kikorongo still lags behind at intermediate stage of surface exploration.

A new method of Temperature Gradient Wells (TGW) had been introduced as part of surface exploration in fault-controlled geothermal systems that characterize the Western Branch of the East African Rift System. The MEMD is planning to use this method at Kibiro, Panyimur and Buranga in the FY 2017/18 and 2018/19.

Private sector participation is a challenge due to high upfront costs and high geological risk in the upstream stages of geothermal exploration. Therefore, Government should take up the exploration and contain the geological risk up to the feasibility study when the areas will attract private sector interest.

#### **6. Acknowledgement**

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