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GEOTHERMAL DEVELOPMENT IN UGANDA: COUNTRY UPDATE

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ABSTRACT

Access to clean, affordable and reliable energy sources to facilitate industrialization is one of the key challenges Uganda faces in attainment of upper middle-income status as stated in Uganda Vision 2040 and reaffirmed in the third National Development Plan (NDP III). As a strategic intervention, geothermal development is a priority as an alternative source of energy in the country's renewable energy policy and national development plan. Uganda's total installed capacity as at end of December 2020 was 1,268.9 MW of which 1,236.3 MW supplies the main grid, 13.9 MW is off the main grid and 18.7 MW is for own consumption which is mainly by the bagasse cogeneration plants. This is set to increase by 600 MW in 2022 after Karuma is fully commissioned.

Most of Uganda's geothermal prospects located in the western arm of the EARS are amagmatic, deep-circulation, fault-controlled systems. These unconventional geothermal systems in the western arm are set in various geological contexts (fractured basement, sedimentary basin) from a large range of heating sources such as upwelling asthenosphere and high radioactivity of the crust.

Integrated geological, geophysical, geochemical and hydrological investigations of the major prospects (Kibiro, Buranga, Katwe-Kikorongo and Panyimur) in Uganda have led to development of resource conceptual models as a basis for siting exploration wells. Subsurface temperatures of approximately 110-250°C predicted by geothermometry and mixing models are ideal for electricity generation and direct use in industry, agriculture and tourism. Eight (8) temperature gradient wells have been drilled in Kibiro and the measured thermal gradient ranges between 85-138°C/km, above the global continental average thermal gradient of about 25-30°C/km.

1. INTRODUCTION

Uganda like any other developing country has one of the lowest per capita electricity consumption rates. Generation capacity is dominated by hydropower, supported by other renewable energy sources including bagasse, and solar power plants. Similar to other Sub-Saharan African countries that predominantly rely on hydropower, erratic rainfall and droughts have previously affected electricity supply and led to frequent load shedding. The country is under pressure to find additional energy sources, as electricity demand is growing at an annual rate of 10-12%. It also intends to achieve a rural electrification rate of 22% by 2025 (NDP III).

Uganda is richly endowed with renewable energy resources for energy production and the provision of energy services. The total estimated potential is about 5,300 MW. These resources, however, remain largely unexploited, mainly due to the perceived technical and financial risks, together with high upfront cost of technologies. Hydro and biomass are considered to have the largest potential for electricity generation. But also solar power receives increasing attention by investors.

Moreover, located in the East African Rift Valley, Uganda has promising potential for the exploitation of geothermal energy. Uganda geothermal resources are estimated at about 1,500 MW (Uganda Vision 2040). The main geothermal areas are Katwe-Kikorongo (Katwe), Buranga, Kibiro and Panyimur located in Kasese, Bundibugyo, Hoima and Pakwach districts respectively (Figure 1). The Government of Uganda together with development partners have funded surface and sub-surface investigations of the geothermal prospects dating way back in 1954. This has led to detailed conceptual models of the major prospects and recent subsequent temperature gradient drilling in Kibiro.

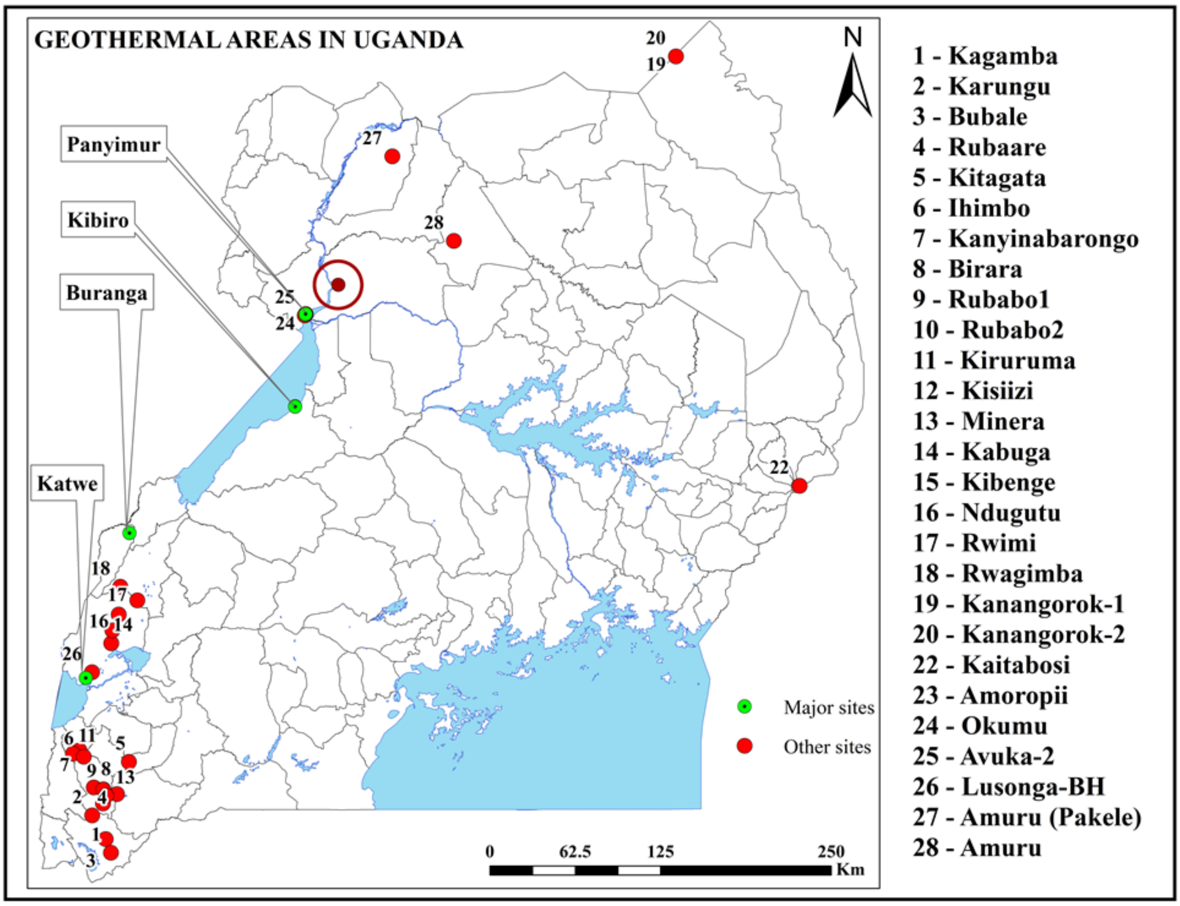

FIGURE 1: Geothermal areas of Uganda (Bahati and Natukunda, 2008)

2. POWER SECTOR SITUATION IN UGANDA

The aspiration of Agenda 2030 is to achieve universal access to electricity by 2030 (SDG 7), and this is in line with Uganda's Vision 2040 geared towards access to clean, affordable and reliable energy to facilitate industrialization, among others.

Uganda's total installed capacity as at end of December 2020 was 1,268.9 MW of which 1,236.3 MW supplies the main grid, 13.9 MW is off the main grid and 18.7 MW is for own consumption which is mainly by the bagasse cogeneration plants (Figure 2).

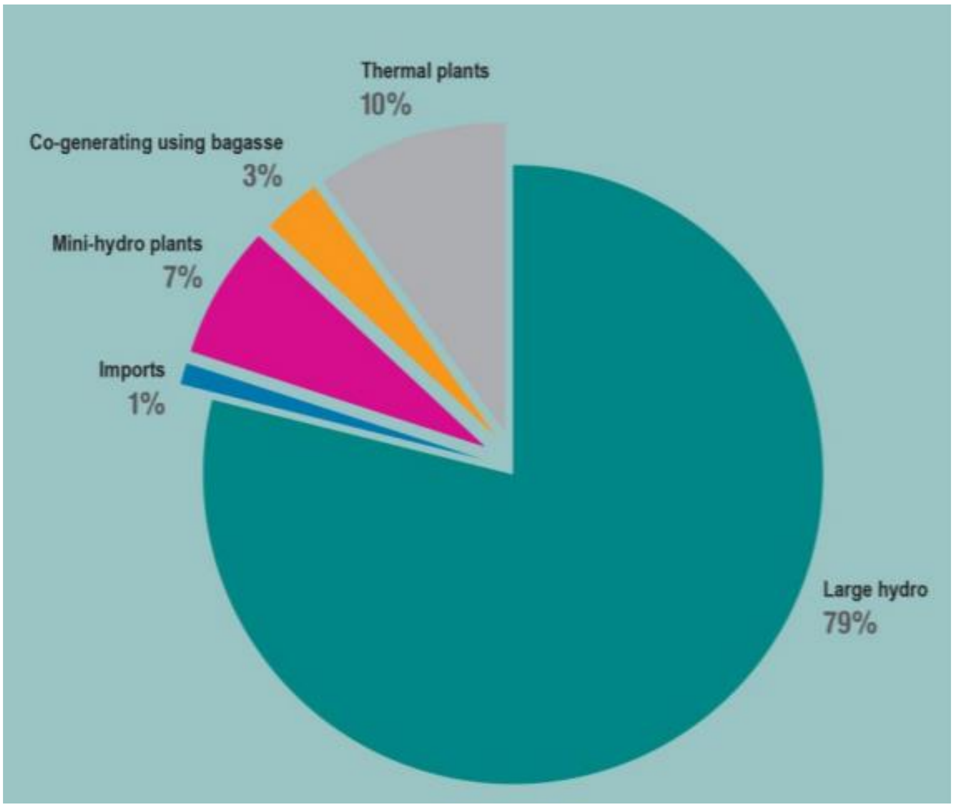

FIGURE 2: Electricity generation mix

This is set to increase by 600 MW in 2022 after Karuma is fully commissioned. Overall, 98% of the energy supply is from renewable energy sources including hydro, bagasse, and solar (large hydro 79%; small hydro 7%; other technologies combined 14%).

3. LEGAL AND INSTITUTIONAL FRAMEWORK

In order to fast track the development of geothermal energy, the Government of Uganda established a full-fledged Geothermal Resource Department (GRD) in 2014. GRD with technical assistance of the Climate Technology Centre and Network (CTCN) have been at the forefront in developing Uganda's geothermal legal and regulatory framework. The draft documents were submitted to Cabinet after stakeholder engagements and completion of a Regulatory Impact assessment. The Geothermal Policy together with other energy policies has been merged into the National Energy Policy being reviewed while the Geothermal Bill was incorporated in the Mining and Minerals Bill that is before Parliament.

4. REGIONAL GEOLOGY

The western branch of the EARS where the majority of Uganda's prospects lie, extends more than 2000 km from Lake Albert in the north, to Lake Malawi to the south, and is considered an archetype of continental rifts with low-volcanicity and at an early stage of development (Ring, 2014). The sparse volcanic activity coincides with accommodation zones (Ebinger, 1989). The locations of eruptive centers are found to be related to faults and volcanic activity seems to begin during the initial stages of continental rift development. The rift system is composed of an arcuate series of elongate, deep sedimentary basins typically 80 to 100 km long and up to 6 –7 km deep (Morley, 1989). Normal fault characteristics vary along the length of the rift, including linear, arcuate or short en echelon fault traces arranged in different sectors of the rift, with the kinematics of single structures varying from pure dip slip to oblique slip (Ebinger, 1989).

The Albertine graben that is located in the western arm of the EARS is host of the major geothermal prospects. It extends in a NE-direction from the Rwenzori Mountains for about 200 km with a uniform width of 60 to 80 km and well-developed topographic escarpments defining the border faults. It is described as an asymmetrical full graben with well-developed border faults (Ebinger, 1989). The Albertine graben is filled with Miocene-Recent sedimentary rocks in the form of sandstones, shales and gravel derived from the Precambrian rocks. These sediments are thicker in the north-western part of the graben reaching ~5400 m compared to ~1250 m in the southeastern side of the graben (Ring, 2008; Upcott et al., 1996). This, together with the escarpment heights suggest a maximum vertical throw of ~6700 m in the north western border fault of the Albertine graben, and 1650 m in its southeastern border fault (Katumwehe et al., 2015).

The main rift bounding faults are exploration targets but fault intersections are main targets due to enhanced permeability. Faults have high permeability but fault intersections have increased permeability and fracture density (Kato, 2017).

5. STATUS OF GEOTHERMAL EXPLORATION IN UGANDA

The Government of Uganda outlined a systematic exploration and development strategy of the major geothermal prospects commencing 2011. This entailed establishment of the Geothermal Resource Department, human capital development, specialized equipment purchase and enactment of the legal and regulatory framework. The following section presents detailed descriptions, important results of the surface exploration studies, development strategies and current status of the major prospects;

5.1 Kibiro geothermal prospect

In collaboration with UNEP-ARGeo, GDC and GRD, a detailed geothermal resource assessment of the prospect comprising surface water analysis, MT/TEM, reflection seismic analysis among others was undertaken in 2015/2016. This culminated into development of a geothermal resource model that was a basis for the recent temperature gradient drilling program in 2020.

Geological structural mapping of Kibiro revealed that the prospect is controlled by the North Bunyoro Toro (NTB) fault with multiple 1.5 km and 150 m wide right and left steps across the area. This fault system was developed through Precambrian basement rocks mainly consisting of different granitoid rock units. Different high-grade banded metamorphic gneisses to granulitic gneisses with variable compositions (granite, tonalite-trondhjemite-granodiorite suite) are recognized in this area (Walter et al., 2016). The geochemistry analyses conducted in conjunction with the geologic structure, stratigraphy, and reflection seismic exploration conclude that the Kibiro hot springs are most likely associated with a 115-150°C fault-hosted upflow with no direct magmatic heating (Alexander et al., 2016).

The geophysical, geochemical and geological constrained model (Figures 3 and 4) revealed permeability to be structurally controlled by steeply dipping main rift bounding fault more so where it is intersected / interacted with cross-cutting faults. The highly permeable Bunyoro-Toro fault acts as a conduit that allows for deep circulation of meteoric waters into the thermal zone beneath the crust. Fault surface measurement indicate a 65° NW dip of the NTB while the oblique Kachuru fault dips 46° to 50° NW.

The government of Uganda committed funds to drill and log 8 temperature gradient holes (TGH) to a depth between 150-300 m at Kibiro geothermal prospect. The goal of the TGH drilling was to confirm the presence of hot (~ 150°C) geothermal resource at shallow depths, define the length of the North Toro Bunyoro (NTB) fault and update the conceptual model of the system. M/s Royal Techno Industries Limited was awarded the contract to drill the TGH and drilling commenced in February 2020 and was completed in March 2020.

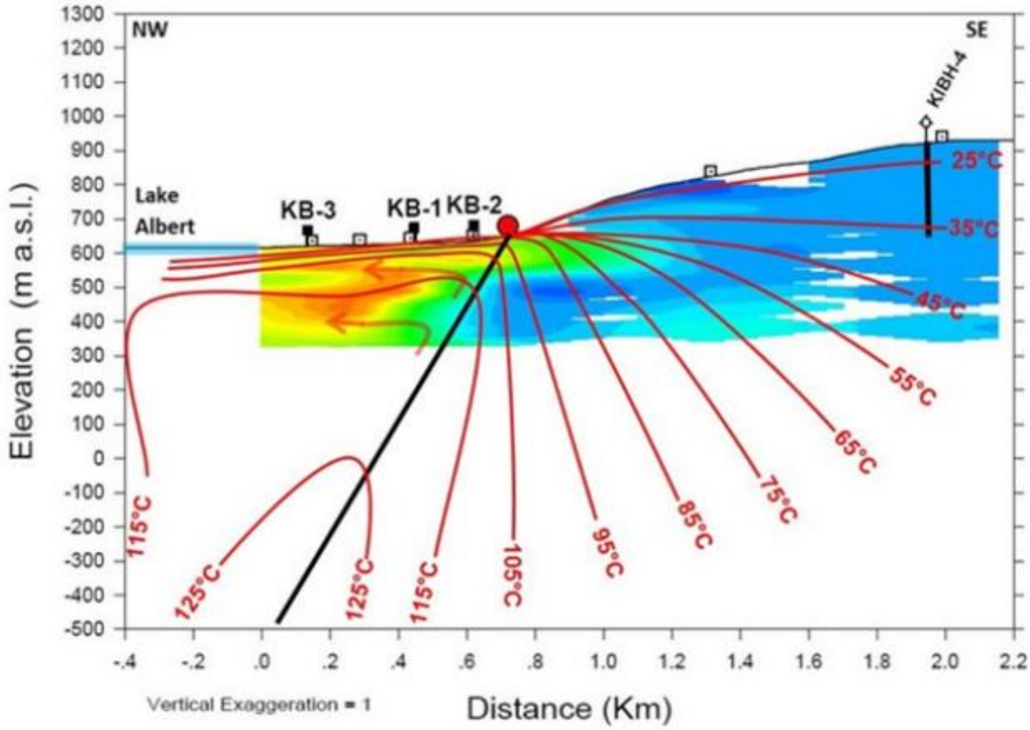

FIGURE 3: Kibiro conceptual model cross-section with isotherms illustrating the relationship of the proposed upflow along the NTB ault to the Mutabiga Hot Spring and the interpreted outflow

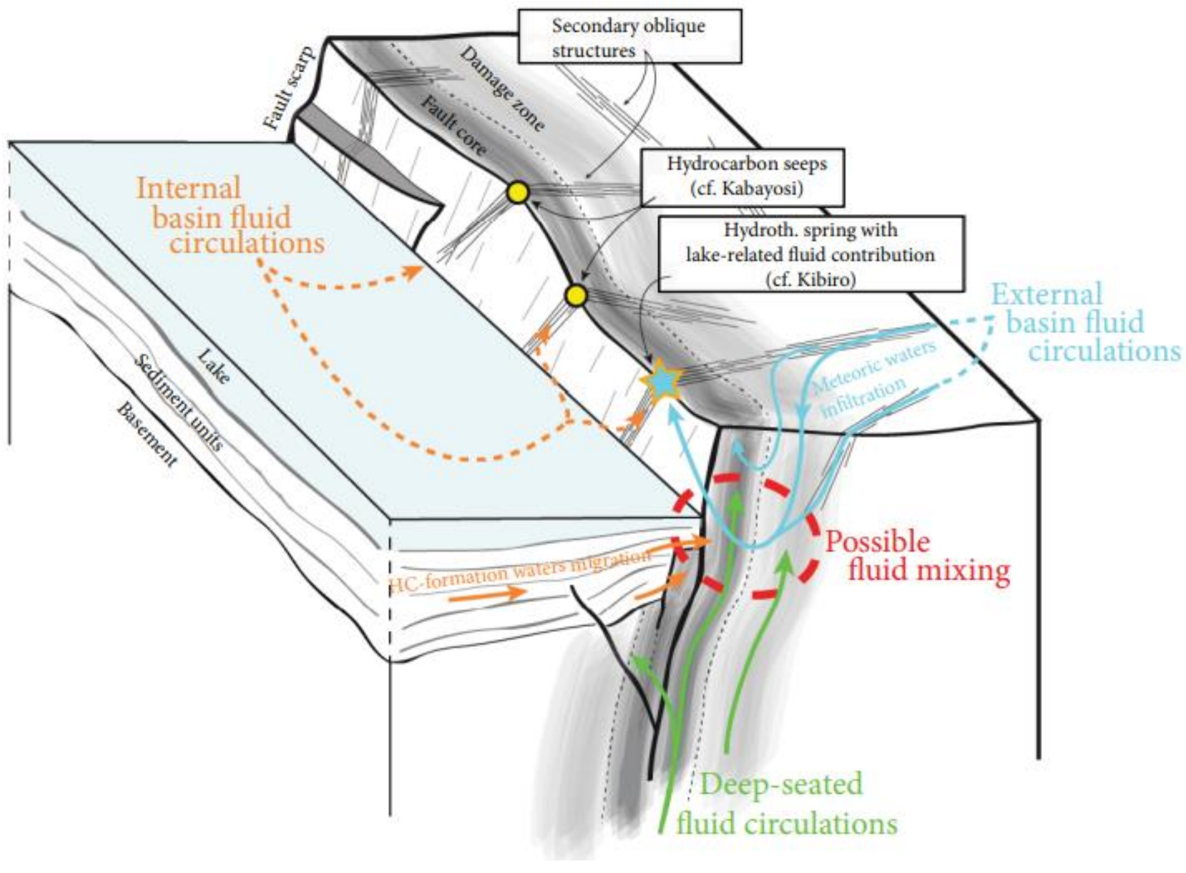

FIGURE 4: Schematic 3D block model of a rift-bounding fault system illustrating the three fluid inputs that flow and mix into the damage zone within Kibiro Prospect (Walter et al., 2019)

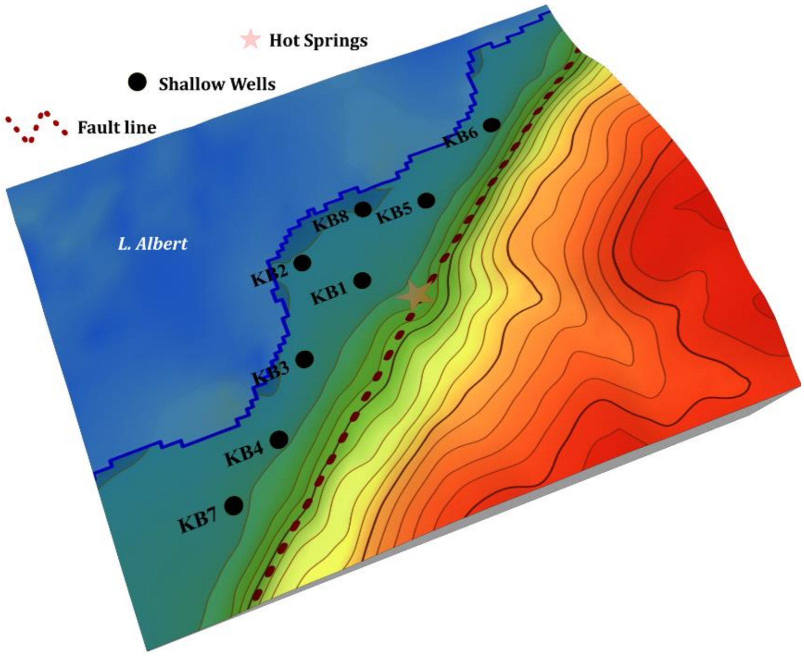

FIGURE 5: 3D image showing location of the TGHs with the Kibiro geothermal area

Eight shallow temperature gradient holes (KB1 to 8) were drilled in the vicinity of Kibiro (Figure 5). The wells targeted a shallow secondary reservoir (or a thermal outflow aquifer) probably present at depths <300 m below the Kibiro fan delta, from the lakeshore to the Kibiro hot springs, as consistently indicated by the TEM data (Figure 3).

The boreholes KB2, KB3, KB5, and KB8 were drilled to the planned total depth of about 300 m. Wells KB1, KB4, KB6 and KB7 did not achieve the desired depth majorly due to collapse of the well during the drilling operation that was attributed to the unconsolidated sand, gravel layers within the sedimentary basin. The wells were constructed with 6-inch diameter PVC casing for the upper unconsolidated sand, gravel layers and finally run a 2-inch iron and steel pipe with a cap on the bottom into the well.

Downhole temperatures have been logged after well completion and recovery using a U12 deep ocean temperature logger (Figure 6). However, wells KB2 and KB8 were inundated due to the rising water levels of Lake Albert and thus not accessible for logging. The maximum measured temperature was about 72.41°C measured at the bottom of well KB3. The measured thermal gradient was between 85-138°C/km (Table 1), above the global continental average thermal gradient of about 25-30°C/km. This showed that Kibiro geothermal prospect is a probable host of a medium enthalpy system and detailed resource assessment is still on-going.

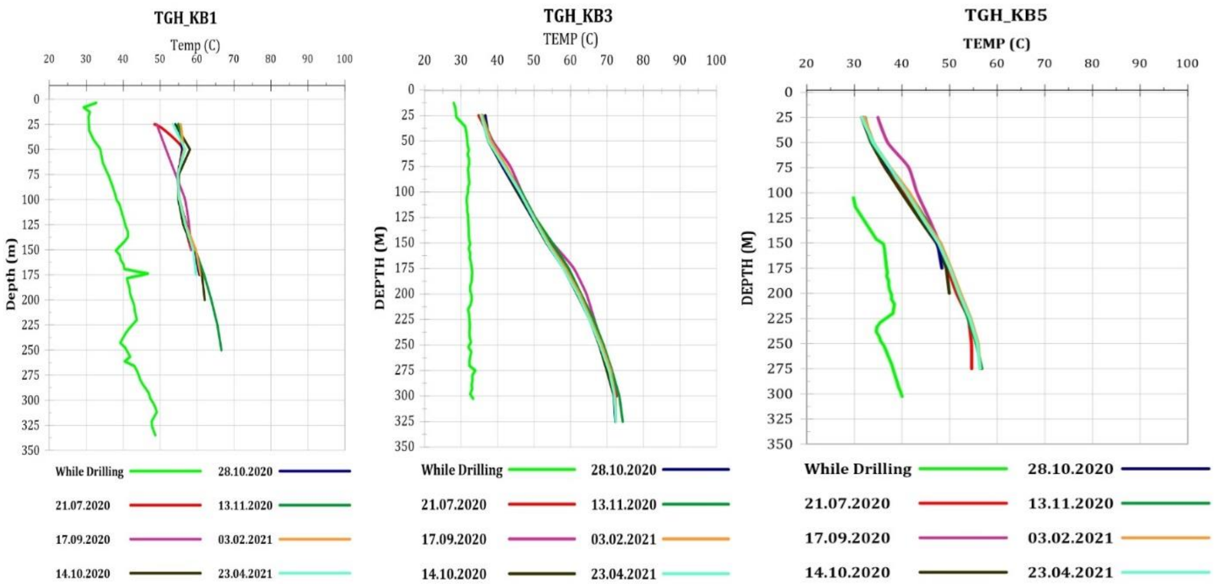

FIGURE 6: Depth vs temperature logs for representative TGHs

TABLE 1: Kibiro TGH locations, drilled depth and temperature gradient values

Label	Depth (m)	WGS84 Zone 36N		Temp. gradient (°C/km)
		Easting	Northing	
KBH1	150	305764	185279	85
KBH2	300	305521	185476	-
KBH3	325	305360	185004	138
KBH4	50	305114	184680	-
KBH5	275	306216	185563	108
KBH6	150	306686	185831	83
KBH7	100	304819	184462	69.5
KBH8	300	305905	185640	-

5.2 Panyimur geothermal prospect

The government of Uganda with technical support of the East African Geothermal Facility (EAGER) has recently conducted detailed surface geoscientific investigations at Panyimur. These investigations included geophysical MT/TEM, geological structural mapping, soil gas survey and thereafter geothermal resource model development (EAGER, 2017).

The geology of Panyimur is predominantly Precambrian metamorphic crystalline basement and Cenozoic basin-fill deposits. The Precambrian basement is dominated by flaggy gneiss with some banded paragneiss, felsic paragneiss, and mafic amphibolite (EAGER, 2017; Westerhof et al., 2014).

Two major NNE striking faults have been recognised to control the geothermal system. The upper fault that dips 60° to 65° ESE with 75 to 90 m scarp; only offsets Precambrian metamorphic rocks while the lower fault dipping 43° to 50° has a smaller scarp of 40-70 m due to infill by sediments (EAGER, 2017; Hinz et al., 2018).

Interpretation of existing geochemical data by Ármannsson et al. (2008) revealed Amoropii spring to originate from a 100-120°C thermal aquifer without groundwater dilution; Okumu springs are partially diluted while Avuka springs are majorly meteoric water. K-Mg, chalcedony/quartz and quartz geothermometers suggest an aquifer temperature in the range of 100-120°C. However, based on sulphur and oxygen isotope equilibria, re-equilibration in a shallow 100-120°C aquifer derived from a deeper upflow that might be as hot as 150°C is inferred (EAGER, 2017).

Two resource conceptual models were developed by integrating the structural geology, geochemical and MT data; the median resource conceptual model reveals upflow in a fault zone associated with the lower fault and modest outflow in the shallow sediments at < 85°C and > 75°C outflow at the hot spring temperature in a > 5 ohm-m layer, poorly consolidated sand/gravel below a < 5 ohm-m clay cap. An upflow greater than 125°C is confined to the fault zone deeper than 1500 m. The optimistic resource model shown in Figure 7 assumes a deep 150°C upflow along fracture permeability associated with the Lower Fault and outflows at 115-125°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. Based on the two conceptual models, fifteen (15) temperature gradient wells were proposed and are expected to be drilled in 2022.

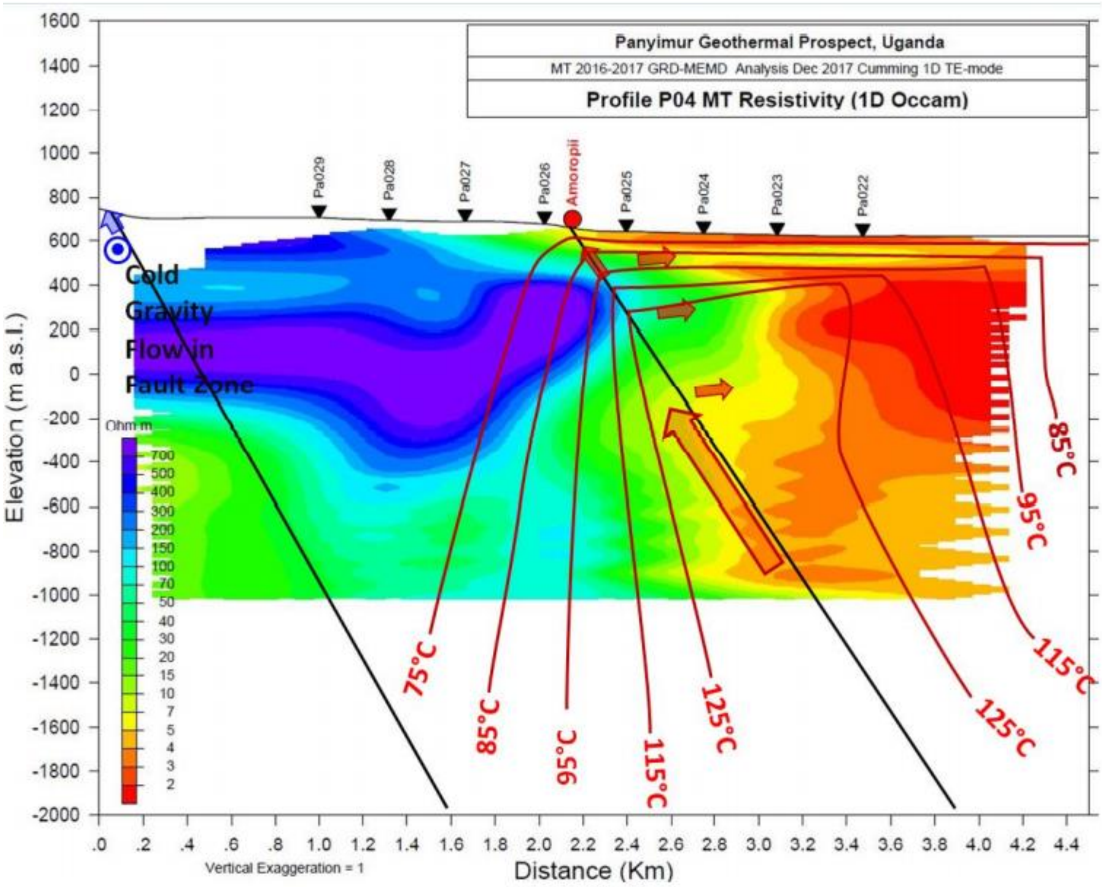

FIGURE 7: Optimistic conceptual model through Amoropii hot spring (EAGER, 2017)

5.3 Buranga geothermal prospect

Buranga geothermal area is within the Albertine Rift in the Semliki National Park at the north-western/western end of the Rwenzori Mountains. The prospect is currently concessioned to a private developer, M/s Gids Consult Ltd. However, the Government of Uganda continues to undertake exploration investigations in collaboration with the licensee.

Geologically, the area is dominated by two dominant units, Precambrian metamorphic basement, and late Cenozoic basin-fill. Geothermal manifestations include hot springs (37 springs with flow rates of 10-30 l/s and temperatures up to 98.4°C.), fumarolic activity and travertine deposits. Tectonically, the Buranga geothermal area sits adjacent to a 0.5 km wide, left step along the range-front. Additionally, a NE-striking, northwest-dipping fault intersects the range-front fault directly north of the hot springs area.

Based on the prospect conceptual models developed by EAGER together with Gids Ltd and GRD, the upflow at Buranga is probably along multiple fault segments within the step-over (Figure 8). As such, upflow could favour one or more faults, including the primary range-front fault, the outer concealed NE-striking fault, intervening concealed faults, or any combination of these structures (EAGER, 2017). Subsequently, fifteen (15) temperature gradient wells were sited (3 high priority) and upon drilling, their results shall improve the conceptual model in addition to targeting deeper slim holes or full-sized wells as appropriate based on these updated models and risk assessments.

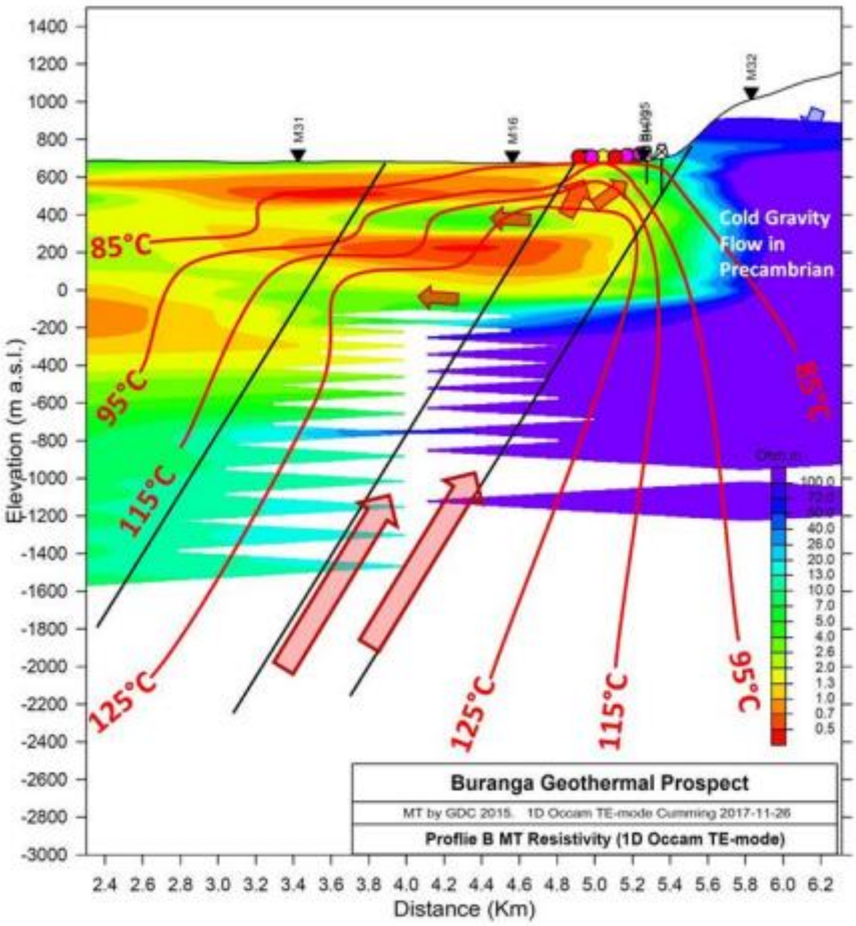

FIGURE 8: MT geophysical conceptual model of Buranga (EAGER, 2018)

5.4 Katwe geothermal prospect

Katwe geothermal prospect is located in southwest Uganda and has had a number of surface exploration expeditions and TGH drilling program funded by the government of Uganda together with ICEIDA, IAEA, UNDP and BGR. The prospect lies along the southern part of the NNE-striking, east-dipping Nyamwamba fault system that bounds the southeast flank of the Rwenzori horst block and the west side of the Lake George basin. Katwe prospect is dominated by explosion craters, ejected pyroclastics, tuffs with abundant granite and gneissic rocks from the basement. The geothermal manifestations cover a 0.2 km^2 area and are situated within the 30 km long by 10 km wide Katwe-Kikorongo volcanic field that straddles the Nyamwamba fault zone.

Regional earthquake activity of 15 to 30 km deep, implies that the magmatic activity is too deep to create a magmatically heated >230°C geothermal field (EAGER, 2018). The hot spring geochemistry is strongly influenced by the presence of evaporites in the sediments, likely accounting for the unreliable cation geothermometers, but the silica content is consistent with a 110-126°C source aquifer.

The EAGER-DGSM structural geology field work in 2018 delineated fault intersections at the Kitagata Crater and step-overs extending over 7 km to the southwest along the strike of the Nyamwamba fault system (Figure 9). A more detailed local review of a large-scale TEM survey conducted over the entire Katwe area was consistent with the low temperature found by the ICEIDA TGH and permissive of an upflow near the west margin of the Kitagata Crater or southwest of the crater.

6. CONCLUSIONS

Most geothermal prospects in Uganda are fault-bounded systems related to high crustal heat flow and thus such major rift-bounding fault systems represent a composite hydrogeological system in which significant economic amounts of fluids preferentially converge and show surface manifestations locally at structural intersections.

Preliminary temperature gradient results from the recent Kibiro drilling program indicate an anomalous area as earlier predicted by surface investigations. This is a favorable target for deep exploration drilling to further confirm the resource.

The associated high exploration risk has hindered private sector participation. However, the Government of Uganda is committed to investing in the exploration and feasibility phases so as to attract the anticipated private sector involvement. Drilling of eight (8) temperature gradient wells in Panyimur prospect is planned for early 2022.

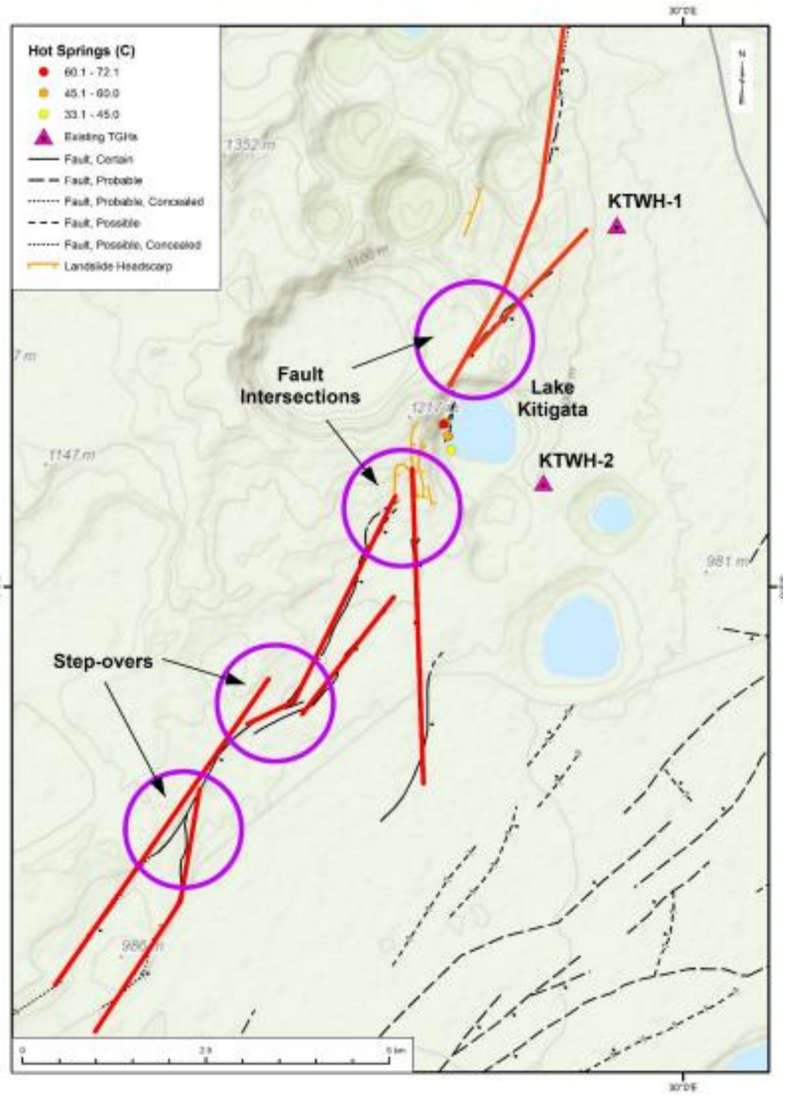

FIGURE 9: Katwe structural target areas along the Nyamwamba fault zone in the Lake Kitagata area (EAGER – GRD 2018)

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