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GEOTHERMAL DEVELOPMENT IN UGANDA: COUNTRY UPDATE

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ABSTRACT

Uganda currently hosts ~25 geothermal sites with an estimated 1500 MW of capacity. With a stark contrast between the geothermal resources in the two arms of the East African System, it has been imperative that favourable techniques be perfected for the integrated geological, geophysical, geochemical, and hydrological investigations of the major geothermal prospects in Uganda: Kibiro, Panyimur, Buranga, and Katwe. Recent studies indicate that a combination of these geological disciplines characterizes these systems as amagmatic, deep-circulation, and fault-controlled.

Two areas, Kibiro and Panyimur, have undergone temperature gradient hole drilling. Eight (8) temperature gradient wells have been drilled at Kibiro and Panyimur. The measured thermal gradient at Kibiro ranges between 85-138°C/km, above the global continental average thermal gradient of about 25-30°C/km. In addition, a concomitant occurrence of the hydrothermal resources and hydrocarbons was identified.

Temperature gradient measurement is yet to be done at Panyimur. However, the subsurface conceptual model has been tested by intercepting the fluid in PAN-7 at a temperature of 42.9°C at 300 m. The advantages, limitations, and challenges of temperature gradient hole drilling applications for geothermal exploration in Uganda are also discussed.

1. INTRODUCTION

1.1 Uganda's energy sector

Uganda's energy consumption and production trends are akin to other East African states. The prime energy source is fossil fuel, and the use of traditional biomass fuels is prevalent. Conventional biomass fuels account for 70 to 90% of total energy production, constituting the most considerable energy production class (Teklemariam, 2008). The high percentage of combustible waste and biomass usage has led to large areas of deforestation contributing to environmental degradation. For instance, the decline in forest cover between 1990 and 2005 in Uganda is attributed to increasing demand for land for agriculture and firewood to mainly support the country's growing population (NEMA, 2007; NPA, 2015).

Access to electricity in Uganda stands at 26.1% at the national level, 55% in urban areas and 10% in rural areas; 92% of the general population relies on biomass as a form of energy (MEMD, 2012; 2014). Uganda's energy mix is unsustainable! Uganda suffers from energy poverty, linked to an absence of reliable, affordable and environmentally friendly energy sources, with the ability to propel economic development. The principal modern source of energy in Uganda is vastly hydropower to which climate change is a severe threat. As history would have it, climatic change in the past has resulted in acute power shortage and hampered economic growth of the country, prompting the Government of Uganda to take strategic action to invest and develop the renewable forms of energy (Tumwesigye et al., 2011; NPA, 2015). Hence, the enactment of the Renewable Energy Policy of Uganda, a policy aimed at propelling the process of meeting the growing energy demand of the country while at the same time lessening the environmental impact associated with the prevalent use of biomass (MEMD, 2007).

Geothermal energy is earmarked as an alternative energy source in Uganda's renewable energy policy and national development plan, popularly known as "Vision 2040". It is envisioned that a 1500 MW contribution from geothermal, will be added to Uganda's energy mix by 2040; hence, significantly reducing the use of biomass along with the detrimental effects that have arisen from it.

1.2 Geothermal development in Uganda

The geothermal exploration timeline dates back to the 1950s when shallow wells were drilled in Buranga. This unsuccessful attempt was mainly attributable to difficultly in selecting favourable drilling sites, mainly tagged to the poor characterisation of geothermal fields (Hinz et al. 2018). This unsuccessful attempt to explore for geothermal resources in Uganda invited a decision to first clearly understand Uganda's geothermal systems, using a site-specific, multi-disciplinary approach with careful interpretation of each geoscience discipline to develop and refine the working conceptual models vital for successful geothermal development and eliminate guesswork.

A conceptual model approach is particularly effective when exploring geothermal prospects because it makes fuller use of more limited data and helps identify strategies to address the lack of information, as well as identify drilling targets.

Considering that the western arm is in the initial stages of rift evolution as opposed to the Eastern arm which is in mature stage, Uganda's geothermal systems have been classified as extensional deep circulation (non-magmatic) systems that are driven by deep circulation of meteoric waters corroborated by low helium signature and deep-reaching boundary faults. Conceptual models were developed to aid well targeting with rift border faults as principal exploration targets. Thermal gradient holes have been drilled prior to undertaking risky cost-intensive deep drilling.

From regional exploration studies in Uganda, four geothermal prospects have been prioritised for development. These are: Kibiro, Buranga, Katwe and Panyimur (Figure 1). The prospects of Kibiro and Panyimur have been subjected to exploratory drilling that is paving the way for a feasibility study. The rest of the 21 geothermal areas are at the preliminary or detailed studies stage.

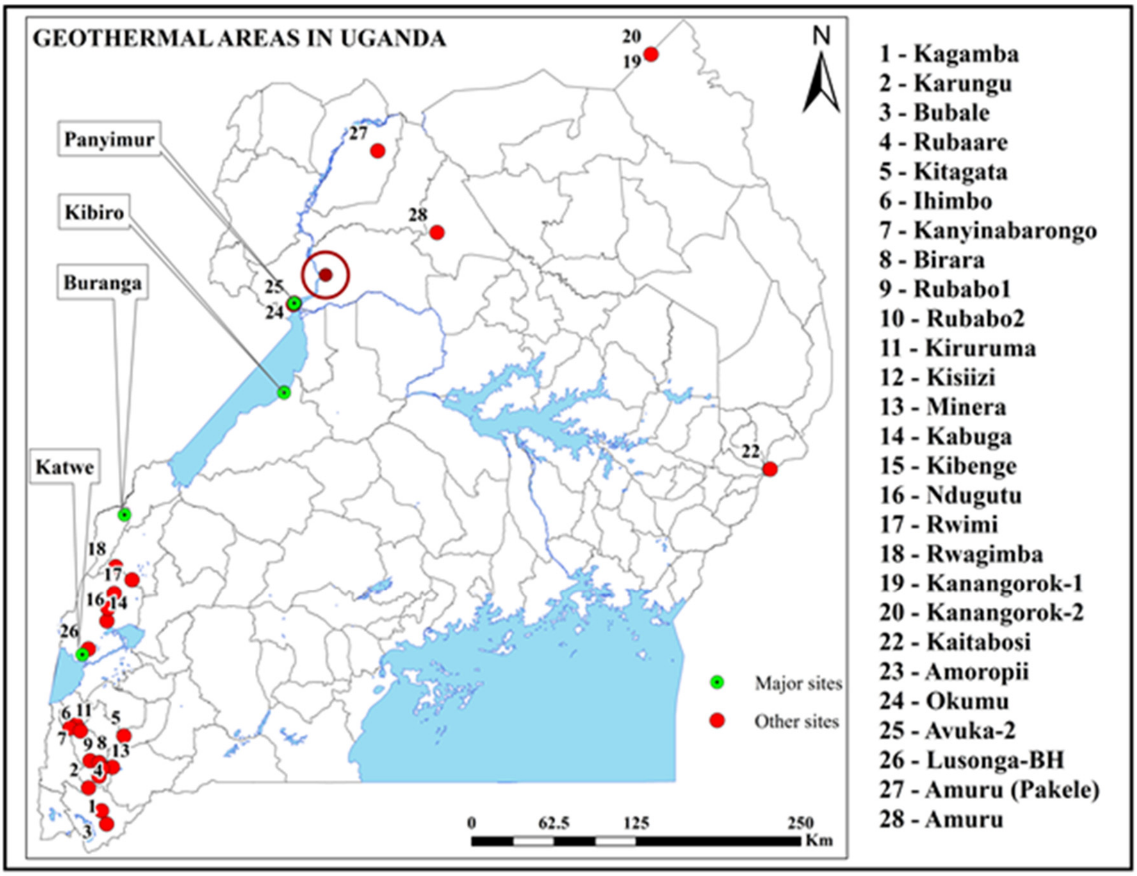

FIGURE 1: Geothermal Areas in Uganda adapted from (Bahati and Natukunda, 2008; Hinz et al., 2018)

2. REGIONAL GEOLOGY

Ugandan geothermal systems are hosted in the Albertine graben, the western branch of the East African Rift System (EARS). The Western Branch of the EARS spreads from Lake Albert in Uganda to the Urema Graben in Mozambique. The trend of the Western branch is less continuous than in the Eastern branch, with a number of apparent gaps, together with some clear offsets. It bears a lesser amount of active magmatism, hosting deep lakes with tons of sediments. The sparse volcanic activity coincides with accommodation zones (Ebinger, 1989). The locations of eruptive centers are found to be connected to faults and volcanic activity seems to originate 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). The layout of the Western branch is characteristically half grabens characterized by high angle normal rift fault.

In particular, the Albertine graben spreads in a NE-direction from the Rwenzori Mountains for approximately 200 km with a uniform width of 60 to 80 km with 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, 2014; Upcott et al., 1996). This, together with the escarpment heights suggest a maximum vertical throw of ~6700 m in the northwestern 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).

3. STATUS OF GEOTHERMAL EXPLORATION IN UGANDA

Unlike other energy sources for power generation such as solar and wind, geothermal energy is stored deep under the surface. Exploration activity and drilling are required to find and confirm the presence, magnitude and economic viability of the resource before the feasibility of the project can be assessed. This high upfront cost in the early stage of the project while the uncertainty is still very high makes investor reluctant to invest in the geothermal exploration activity. The main contributor to this high cost is the exploration drilling, which accounts for approximately 20-40% of the total project cost (FIGURE *1*) – a major deterrent to investment in geothermal exploration.

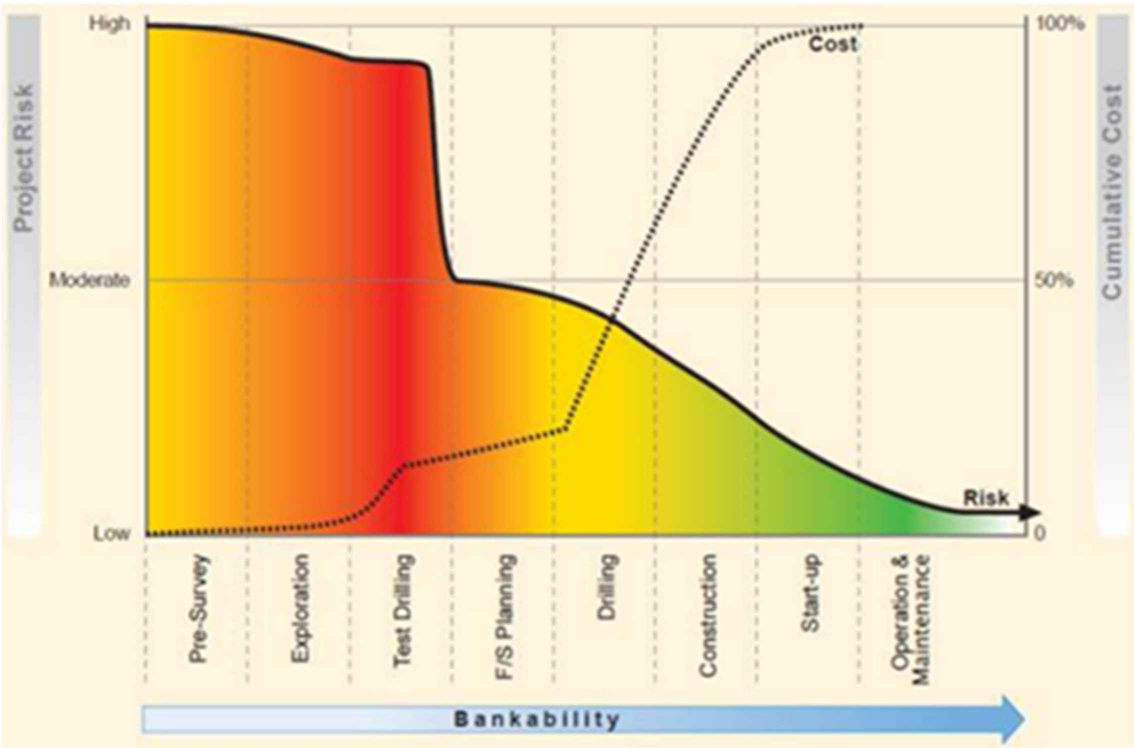

FIGURE 1: Bankability versus risk for a geothermal project. Note the strong drop in risk engendered by successful test drilling.

One alternative to reduce resource risk during exploration is to use a less expensive drilling method such as temperature gradient drilling instead of using standard or big hole drilling (Gul and Aslanoglu, 2018). For developing countries like Uganda where geothermal development is stifled by high upfront development costs, there is a need to minimize upfront costs and hence the overall cost of the project. According to Mackenzie et al. (2017), the use of temperature gradient wells for exploration reduces the early capital spend on geothermal projects. It in addition, improves the success-weighted net present value (NPV) of a project, particularly where there is a low probability of successfully finding a resource.

In such instances, temperature gradient wells play an important role in confirming the existence and the size of the resource (Kaspereit and Osborn, 2017). The EAGER 2017 preparation on Kibiro Temperature Gradient Hole (TGH) drilling programme further states that the method has proved most advantageous in areas where the geothermal system is confined to a fracture of local extent. In the Basin and Range geothermal systems, thought to be analogous to Uganda's geothermal systems, shallow temperature gradient hole drilling has long been known to be the most useful exploration tool in determining which geothermal prospects are worthy of additional exploration or deeper drilling. This section of the paper outlines how Uganda's geothermal industry approached exploration drilling, by deploying temperature gradient wells with the idea of minimizing early exploration drilling cost and determining the economic viability of geothermal fields Kibiro and Panyimur

3.1 Temperature gradient drilling for geothermal exploration in Kibiro geothermal prospect and Panyimur geothermal prospect

In 2020 through to 2022, the Geothermal Resources Department (GRD) of Uganda conducted temperature gradient hole drilling in the areas of Kibiro and Panyimur as a part of exploration activities. The temperature gradient option was chosen as the cost-effective means to confirm the presence of a hot (~115-150°C) geothermal resource at shallow depths, support the development of an improved conceptual model of the system and confirm the presence of a clay cap. If the existence of a suitable reservoir is indicated, GRD will then target 600 m deep small-diameter exploration wells to recover subsurface samples of the geothermal fluid.

3.1.1. Drilling result – Kibiro

GRD and others have conducted extensive exploration activities at Kibiro geothermal prospect, Uganda, through the drilling of 6 temperature gradient holes in 2006. The TGHs, which were drilled into old metamorphic basement rocks on the horst block to the east of the Western Rift valley, encountered low conductive crustal temperature gradients of about 16°-31°C/km. A team of UNEP consultants subsequently proposed that a fault-controlled geothermal system that could reach 150°C may occur within the Albert basin immediately west of the Toro Bunyoro fault. Based on a reinterpretation of the geophysical resistivity data and analogous "Basin and Range" geothermal systems in the US and Turkey, they proposed drilling additional shallow to intermediate depth TGHs into the basin sediments west of the graben-bounding fault based on the conceptual model (
FIGURE *2*).

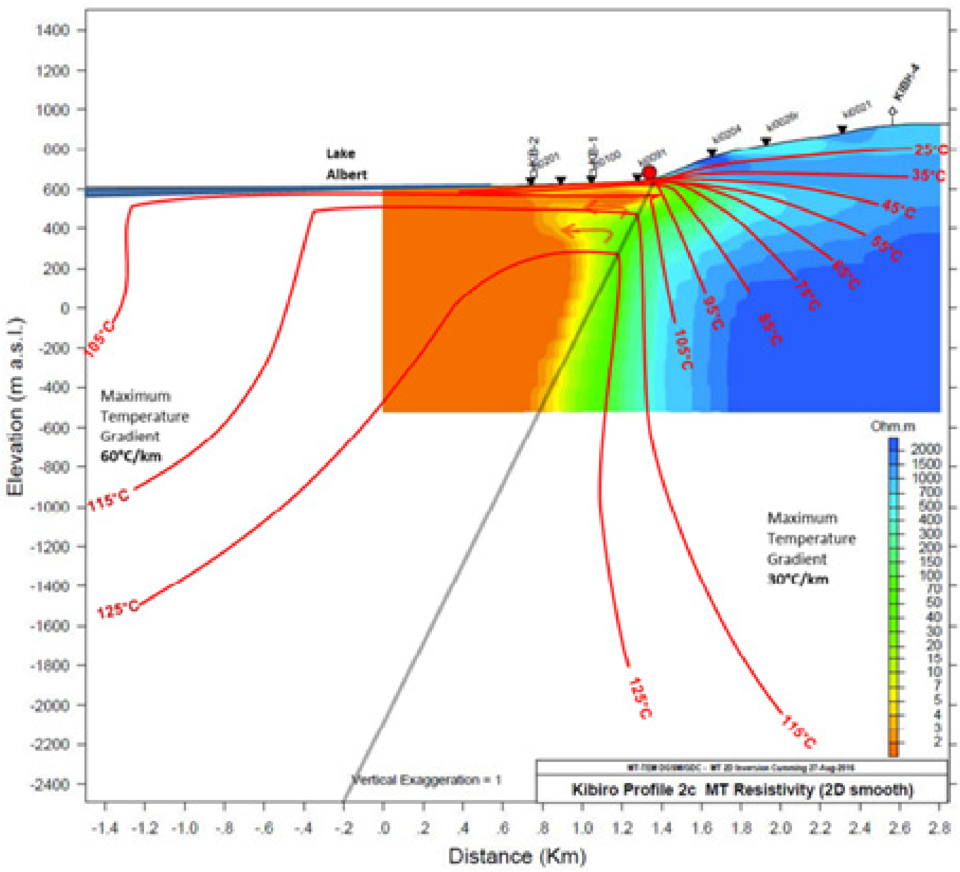

FIGURE 2: Updated conceptual model for Kibiro with a 65° dipping fault (Hinz et al., 2018)

Drilling in Kibiro started on the 8th of February 2020. Eight holes were drilled in the following order: KB-7, KB-6, KB-5, KB-1, KB-2, KB-8, KB-3 and KB-4 (Figure 4) to a depth between 150-300 m. The operations took a total of 53 days meaning each well was drilled in an average of 6.6 days. Longer than the estimated 3.3 days originally planned. The boreholes KB-2, KB-3, KB-5, and KB-8 were drilled to the planned total depth of approximately 300 m. Wells KB-1, KB-4, KB-6, and KB-7 did not attain the desired depth primarily due to collapse of the well during the drilling operation that was attributed to the unconsolidated sand, gravel layers within the sedimentary basin (Kahwa, 2021).

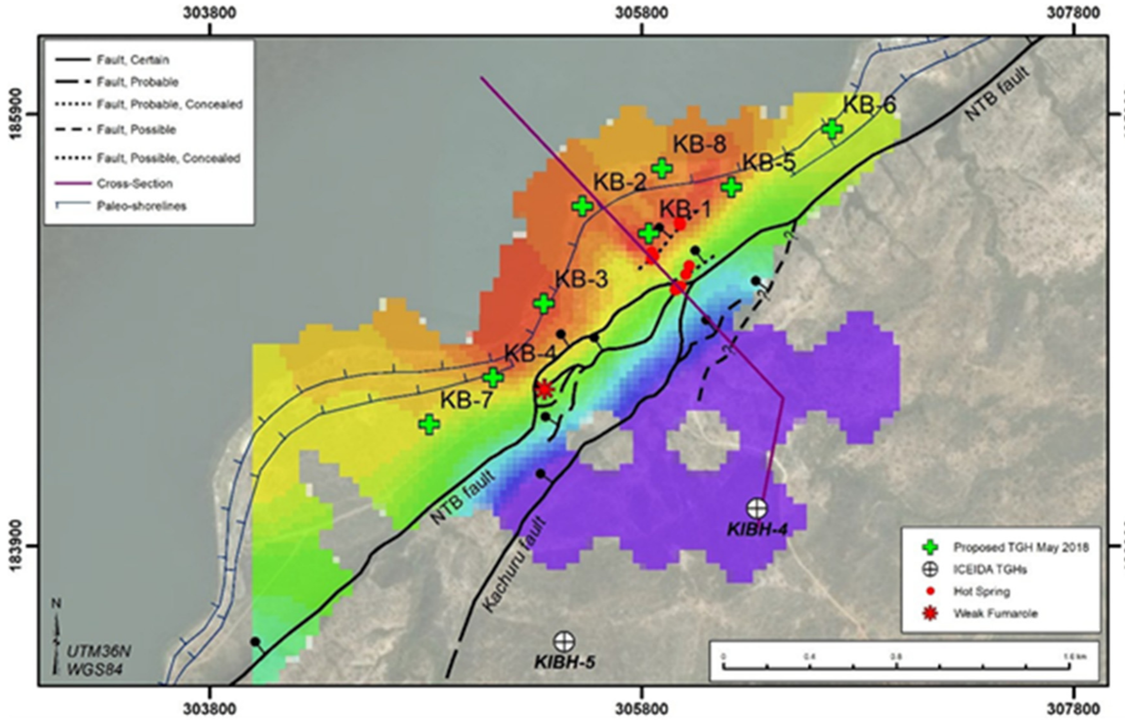

FIGURE 4: TGH targets for Kibiro

In addition, oil sand and oil traces were encountered for KB-7 and KB-4 (Figure 5), indicating a concomitant occurrence of hydrothermal resources and hydrocarbons. A gaseous blowout was also experienced at KB-7 and KB-4 with the gas highly suspected to be methane. The Kibiro gases have the highest concentrations of methane, ethane, and propane of all the gases from the East African Rift Systems reported by Darling (1998), confirming their affinity with oil field gases.

FIGURE 3: Oil patches in circulation ponds in KB-7 and KB-4 and oil sand sample between 70 and 80 m in KB-4

The wells were constructed with 6-inch diameter PVC casing for the upper unconsolidated sand and gravel layers, and finally a 2-inch iron and steel pipe with a cap on the bottom was run into the well. Down hole temperatures have been logged after well completion and recovery using a U12 deep ocean temperature logger. However, wells KB-2 and KB-8 were flooded due to the increased water levels of Lake Albert and thus not accessible for logging. The average temperature gradient (TG) along the possible outflow zone close to the hot springs is 70 to 100°C/km and the TG close to the fumarole, probably the up flow zone, is estimated at 140°C/Km and above. This shows that Kibiro geothermal prospect is a possible host of a medium enthalpy system and a detailed resource assessment is still underway with the aim of updating the subsurface conceptual model.

3.1.2 Drilling result – Panyimur

Two resource conceptual models (Figures 6 and 7) were developed for Panyimur geothermal prospect. The median resource conceptual model depicting up flow 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 up flow greater than 125°C is confined to the fault zone deeper than 1500 m (Kahwa 2021; Hinz et al., 2018). The optimistic resource model shown in Figure 7 assumes a deep 150°C up flow 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.

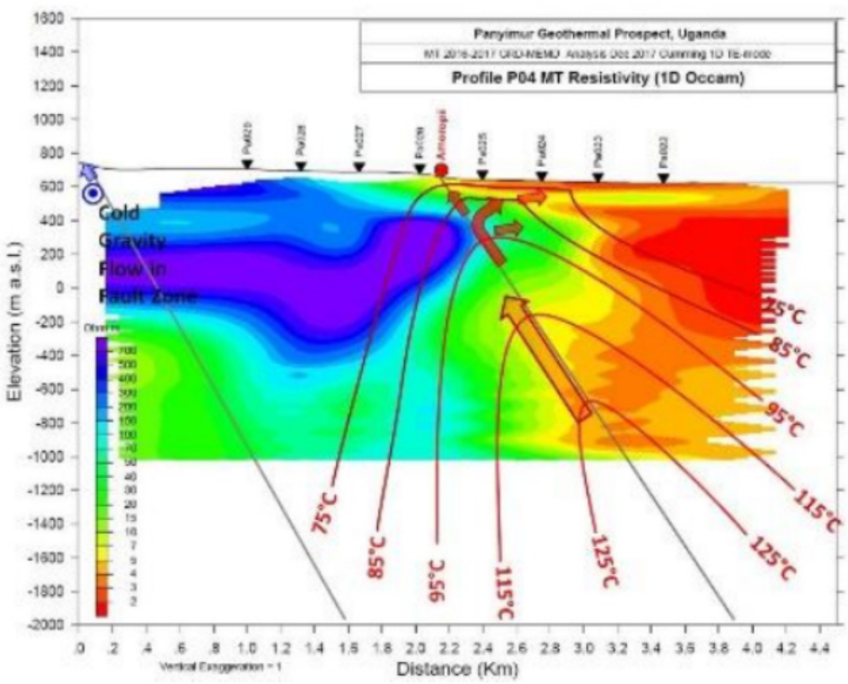

FIGURE 6: Panyimur median case resource conceptual model through Amoropii hot spring

Based on the two conceptual models (Hinz et al., 2018), 8 TGHs out of 15 TGHs were drilled in 2022. The eight holes were drilled in the following order: PAN-7, PAN-5, PAN-3, PAN-13, PAN-2, PAN-12, PAN-11 and PAN-06 (Figure 8). All wells were drilled to the planned total depth of approximately 300 m. The operations took a total of 31 days meaning the average drilling time was 3.9 days per well. The TG holes were supposed to be drilled in three (3) days. A fluid in PAN-7 at a temperature of 42.9°C was intercepted (FIGURE).

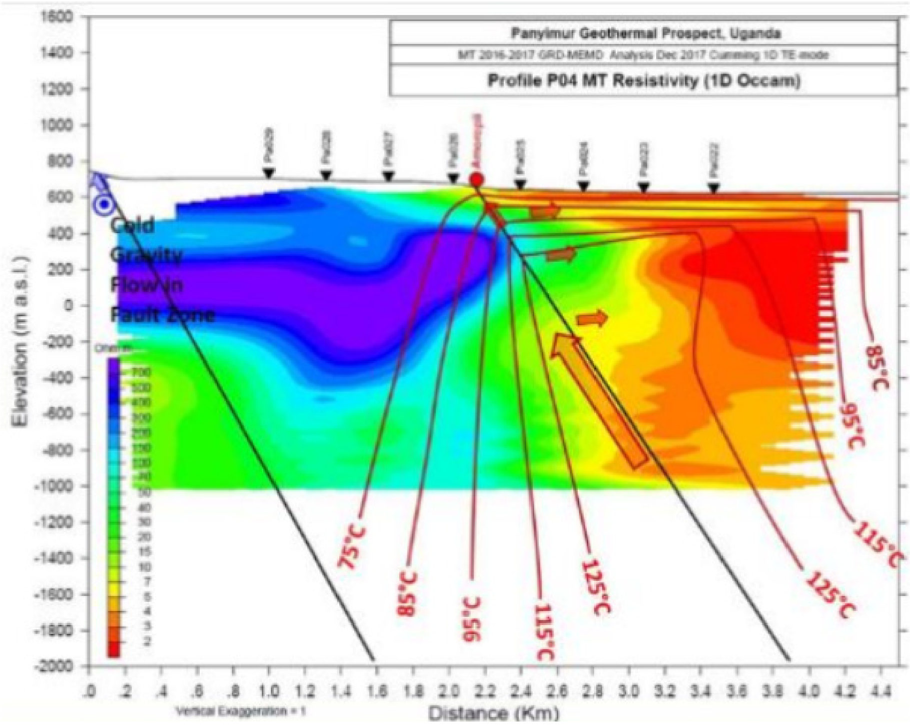

FIGURE 4: Panyimur optimistic case resource conceptual model

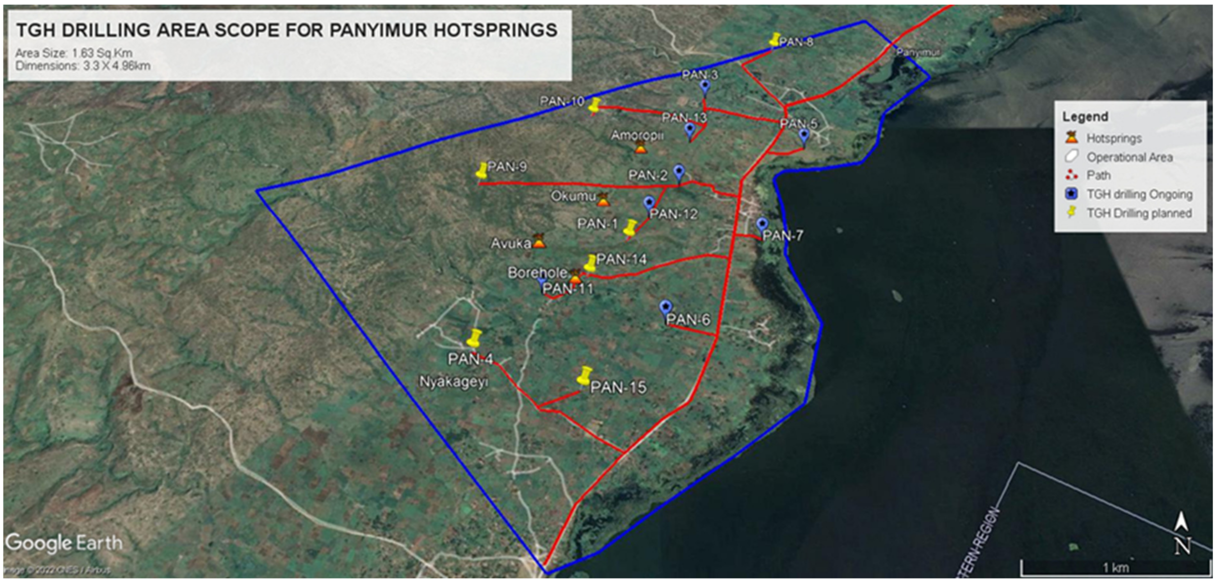

Figure 8: TGH targets for Panyimur

The fluid intercepted at PAN-7 is suspected to be either modest outflow in the shallow sediments at < 85°C and > 75°C or indirect outflows at 75°C into a shallower and thinner sand-gravel aquifer as suggested by the conceptual models. Results indicate the conceptual model proposed at Panyimur is probably valid and indicative of geothermal heat at shallow depth. TG measurement is yet to be done after acquiring a new thermometer. These results are to be used to locate 4 TGHs to reduce the target area.

FIGURE 9: TGH drilling at Panyimur intercepting of fluid of at a temperature in PAN-7

3.2 Lessons learnt

Temperature gradient holes offer an advantage of not only providing temperature and hydrologic data but also of providing the first subsurface look at the actual formations involved in capping and hosting the geothermal system in a cost-effective manner. This is shown by the temperatures recorded during drilling at Kibiro and Panyimur being indicative of geothermal heat at shallow depths.

Differences in planned drilling time and actual drilling time: The average drilling time at Panyimur was 3.9 days per well compared to Kibiro geothermal prospect with an average drilling time of 6.6 days per well. Much of the time lost during the drilling operations was due to land compensation and community-related issues. Although the issues were not serious during the drilling period it is important that caution be taken in future drilling operations.

Inadequate water supply: There were several occurrences when the water on the pond was depleted and the drilling stopped. It could only be continued after the water was replenished by the tank truck. This discontinuity of the water supply was critical, not only in terms of schedule but in terms of well control to prevent steam kick/blowout.

Drilling program that is not designed for the local geological conditions: Kibiro peninsula has had minimal drilling for geothermal, petroleum, or even for domestic water supply. There was no history of what to expect in the subsurface. This posed a challenge to the drilling contractor and the supervisory team that didn't account for hydrocarbon influence in the area. Hence the unfortunate incidents of oil spills and gas blowouts could have been avoided if the subsurface conditions were known.

4. GEOTHERMAL LEGAL AND REGULATORY FRAMEWORK

The legal and regulatory environment is among the crucial facilitating factors for sustainable geothermal development and utilization. Geothermal bears unique characteristics which distinguish it from other renewable energy sources. These include among others, resource identification and ownership, accessibilities, investment risks as well as resources uncertainty which require sufficiently accurate resource assessment and evaluations to reduce risks and uncertainties. In the area of financing, geothermal stands out for its inability to access global markets as a commodity (as e.g. oil, minerals and gases) which are liberally and transparently priced (Shakiru Idrissa Kajugus). In stark comparison, geothermal can largely be utilized and sold into the energy market with localized specific regulations and price. These unique features require creation of suitable legal and regulatory environment for sustainable development of geothermal resources within its locality of occurrence. The Government of Uganda evaluated alternative options for geothermal regulatory environment in Uganda and found that integrating geothermal with other existing laws addresses the challenges pertaining to definition of geothermal, and licensing for geothermal development and utilization. Therefore, geothermal in Uganda is currently regulated under a hybrid model.

The energy generation aspects earlier addressed in a draft Geothermal Policy and Legislation produced with support from CTCN 2016 are incorporated into the National Energy Policy under review and the aspects of electricity generation regulated by the Electricity Act 2022. Geothermal direct use and mineral extraction are regulated by the Mining and Minerals Act 2022 (assented to October 13, 2022) through a licence for extraction of geothermal for direct uses. Under the section of geothermal in the Mining and Minerals Act of 2022, emphasis is heavily put on the regulation and sustainable development of geothermal resources to ensure the exploration and utilisation of geothermal resources for direct use. The highlighting of direct use brings forth a more aligned geothermal development policy for the country. The policy direction clearly stipulates a need for balance between power production and direct use applications that can potentially contribute to the socio-economic development of the country.

4. CONCLUSIONS

Preliminary temperature gradient results from the recent Kibiro drilling program indicate an anomalous area as earlier predicted by surface investigations. This is a favourable target for deep exploration drilling to further confirm the resource. Oil sand and oil traces are encountered. Enormous possible methane gas blow outs point to concomitant occurrence of the hydrothermal resources and hydrocarbons.

At Panyimur, the subsurface conceptual model has been tested by intercepting the fluid in PAN-7 at a temperature of 42.9°C, an indication that the conceptual model proposed at Panyimur is probably valid and indicative of geothermal heat at shallow depths. The results from TGH drilling in Panyimur are to be used to locate 4 TGHs to reduce the target area. Results from TGH drilling in Panyimur and Kibiro will improve planning for the next stage of deeper holes, significantly resulting into cost reductions.

Geothermal in Uganda is currently regulated under a hybrid model. The energy generation aspects fall under the National Energy Policy, which is under review, and the aspects of electricity generation are regulated by the Electricity Act 2022. Geothermal direct use and mineral extraction are regulated by the Mining and Minerals Act 2022.

The most important factor in cost effective drilling is local experience with all aspects of the program including permitting, community relations, equipment and materials availability, having a drilling program that is designed for the local geologic conditions with the right amount of safety consideration.

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