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Geothermal Training Programme



GEOHERMAL EXPLORATION IN UGANDA

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ABSTRACT

A secure and sustainable energy mix is a key challenge facing the Government of Uganda (GoU) as the entire world responds to the issues of climate change, energy security, energy independence and economic competitiveness. Based on current projection, energy demand could double or even triple in the next twenty years. GoU faces the need to increase its power generating capacity to meet the increasing energy demand. As a strategic intervention, GoU decided to grow its energy sources including renewable generation to mitigate the increasing energy demand. Among the renewables, is geothermal resources distributed in several districts all over Uganda. Once developed, geothermal energy has a potential to provide large scale, base load power 24 hours a day, 365 days a year.

Geothermal exploration timeline in Uganda has stretched too far dating way back in 1950's when shallow wells were drilled in Buranga. Numerous donor-supported projects have been undertaken to support geothermal exploration in Uganda. These have included UNDP, ICIEDA, BGR, IAEA, BGR, JICA, WB, AfDB and UNEP-ARGeo. The situation warranted breakthrough techniques and technology to fast track geothermal development in Uganda. Experience has shown that successful geothermal development is related to four main elements: Policy, institution, information and finance. GoU initiated a four-pronged strategic intervention and established a Geothermal Resources Department (GRD) with a budget and logistics. GoU is in final stages of putting in place a geothermal energy policy and regulation. Since Financial Year 2011/12, GoU has committed funds to undertake government-led exploration in four high priority areas. Preliminary geothermal conceptual models have been developed for four areas and surveys have commenced in another site (Ihimbo). There are key accomplishments and impacts. A geothermal workforce is in place but with capability gaps. There is need to reinforce the skills mix by recruiting engineers, managers and technicians to compliment the mostly geo-scientists workforce.

It is now recognized that Western arm of EARS is quite different structurally and tectonically from the Eastern arm. The western arm is in initial stages of rift evolution as opposed to Eastern arm which is in mature stage. Uganda's geothermal systems are extensional deep circulation (non-magmatic) systems that are driven by deep circulation of meteoric waters. This is attested by low helium signatures and deep reaching boundary faults. Rift border faults are principal exploration targets

more so where they are fault interaction due to increased permeability and high fracture density. Exploration workflow applied include a combined soil gas and gas flux measurements, shallow temperature probe, micro-seismic survey, detailed mapping, structural analysis, MT/TDEM survey, reflective seismic data from oil and gas companies. LiDAR data will be acquired to provide high resolution images to map subtle fault systems in the basin. Integrated conceptual models will be developed to aid well targeting. Thermal Gradient Holes are recommended prior to committing risky and cost intensive deep full diameter exploration.

1. INTRODUCTION

A secure and sustainable energy mix is one of the key challenges facing Government of Uganda (GoU) as the entire world responds to the challenges of climate change, energy security, energy independence and economic competitiveness. Based on current projection, energy demand could double or even triple in the next twenty years. GoU faces the need to increase its power generating capacity to meet the increasing energy demand. As a strategic intervention, GoU decided to grow its energy sources including renewable generation to mitigate the increasing energy demand. Among the renewables, is geothermal energy distributed in several districts all over Uganda. Once developed, geothermal has a potential to provide large scale, base load power 24 hours a day, 365 days a year.

Experience dictates that successful geothermal energy development is tied on four main elements; policy, finance, information and institutions. GoU embarked on a four-pronged intervention to its geothermal development strategy. Geothermal investigation surveys timeline in Uganda has stretched too far dating back in 1954 when 4 shallow holes were drilled in Buranga. The situation invited breakthrough techniques and technology to fast track geothermal development. Several projects were implemented but with no key accomplishments.

Since Financial Year 2011/2012, GoU committed funds towards the development of geothermal resources. Government-led exploration in Kibiro, Panyimur, Katwe and Buranga has advanced to pre-production drilling investigations. Preliminary geothermal conceptual models have been developed for these sites presumed to be fault hosted extensional geothermal systems (non-magmatic). Models will be refined and constrained with new data which will lead to more informed sound decisions regarding proceeding with deep exploration drilling, while also identifying drilling sites that are more favorable. Outlined below is a current status of geothermal exploration in Uganda.

2. UGANDA'S GEOTHERMAL POTENTIAL

Geothermal resources with a moderate to high sub-surface temperatures can be found at several locations in Uganda (Figure 1). This is the result of the presence of deep reaching tectonically active fault zones in extensional terrains. Uganda is endowed with geothermal resources due to its geographic location in the western arm (Figure 1) of the East Africa Rift System (EARS). Western rift valley is a zone which experienced crustal extension and thinning of the crust which caused the mantle to become elevated. This elevated mantle results in a higher geothermal gradient within the crust. Meteoric water circulates through deep fault zones or permeable formations in the crust and becomes heated. This type of geothermal systems are called extensional domain type.

In an Extensional Domain Geothermal Play (CV3), like those occurring in Uganda, the mantle is elevated due to crustal extension and thinning. The elevated mantle provides the principal source of heat for geothermal systems associated with this Play Type. The resulting high thermal gradients facilitate the heating of meteoric water circulating through deep faults or permeable formations. During rifting, faults are formed and these are usually high angle rift faults. The faults normally extend to considerable depth forming deep geothermal resources. Permeability is usually restricted to fault zones

bounding the rift (Glassley, 2010). Most of Uganda geothermal systems are deep-circulation system and typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. Fluid movement is by fault zones that bounds the rift valley.

3. GEOTHERMAL ENERGY IN UGANDA'S ENERGY MIX

To date, geothermal energy has not played any role in Uganda energy mix. It remains largely undeveloped with enormous potential. In the current climate change and energy security environment, it is an interesting power generation source. The geothermal sector in Uganda shows great promise as a near zero-emission base-load supplier of renewable energy. However, the industry is still relatively young, and much learning is yet to be achieved.

In addition to providing energy source, geothermal energy can contribute to Government's commitments to renewable energy and climate change, and energy security requirements. The resource is not intermittent like other renewable energy sources, and therefore does not require large amounts of offsetting excess capacity.

Economic activity and standards of living more generally are underpinned by access to reliable, competitively priced energy. The role played by energy sector is of importance to the society and economy. Securing energy is top priority for Uganda's energy policy.

4. EARLY STUDIES

Geothermal studies by Department of Geological Survey and Mines (DGSM) dates way back in 1950's when shallow wells were drilled in Buranga area (McConnell and Brown, 1954). In early 1970s, preliminary studies were initiated by DGSM. Subsequent projects conducted are briefly summarized below.

Geothermal Energy Exploration Programme, phase 1 (1993-1994): This was the first detailed exploration programme carried out on the three highly ranked prospects. The project was funded by the GoU, United Nations Development Programme (UNDP), Organization of Petroleum Exporting Countries (OPEC), and Government of Iceland. It was implemented by DGSM and executed by Department of Development Support and Management Services of United Nations (UNDDSMS). Work included geological, geochemical and isotopic surveys, in Kibiro, Katwe-Kikorongo and Buranga (Gíslason et al., 1994). The results justified further exploration efforts.

Isotope Hydrology for Exploring Geothermal Resources, phase 1 (1999-2003): This was funded by IAEA together with Ministry of Energy and Mineral Development (MEMD) with the aim of up-grading and refining the exploration models of Kibiro, Buranga and Katwe-Kikrongo prospects, using isotopes. This was a data gap closure and follow up of the UNDP-ICEIDA project of 1992-1994.



FIGURE 1: Map showing distribution of geothermal sites in Uganda

Katwe-Kikorongo preliminary exploration (2003): African Development Bank (ADB) funded geothermal investigation surveys in Katwe-Kikorongo in 2003, under the “Uganda Alternative Energy Resource Assessment and Utilization Study (UAERAUS). This was to upgrade the exploration model of Katwe-Kikorongo to pre-feasibility status.

Kibiro prospect investigations (2004): This exploration project was implemented by ICEIDA experts and GoU counter parts with the aim of refining the pre-drilling assessment initiated by MEMD. Activities included geophysical studies (Resistivity, gravity and magnetic survey) and geological mapping.

GEO THERM Project: Germany Federal Institute for Geosciences and Natural Resources (BGR) together with MEMD conducted preliminary surveys in Buranga beginning 2003. This was under the GEO THERM programme, which promoted the utilization of geothermal energy in developing countries. Exploration workflow included surface water sampling and analysis, isotopic studies, geophysical surveys (Gravity, TEM, and Schulmberger sounding). Micro-earthquake survey was conducted around Buranga to map seismically active structures (Ochmann et al., 2007). Results indicated active Rwenzori bounding faults presumed to control geothermal fluids flow. A magma body was inferred under Rwenzori Mountain. The $3\text{He}/4\text{He}$ ratios of geothermal fluids were measured to determine if a deep mantle signature was present. These elevated $3\text{He}/4\text{He}$ ratios were believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs.

ICEIDA-World Bank Power IV program: ICEIDA together with MEMD undertook studies in Kibiro and Katwe-Kikorongo. Project activities included drilling shallow Thermal Gradient Holes (TGH). TGH results were not encouraging. Under this project a national wide preliminary resource assessment was carried out to down-select prospective areas for future advanced studies.

UGA/8/005 – Isotope Hydrology for Exploration Geothermal Resources, phase 2: IAEA funded project “UGA/8/005 - Isotope Hydrology for Exploration Geothermal Resources- phase 2” was undertaken. This was a data gap closure intended to refine exploration models for Kibiro, Buranga and Katwe-Kikorongo prospects using isotopes.

Introducing Isotope Hydrology for exploration and management of geothermal resources, RAF/8/047: This project was funded by IAEA together with GoU to improve the exploration models of the geothermal systems in Uganda.

JICA-2014: Following the situation analysis, JICA and MEMD undertook a joint venture technical study of Uganda’s geothermal resources. The preliminary survey was implemented by West Japan Engineering Consultants Inc. and Mitsubishi Materials Techno Corporation. 17 geothermal sites were sampled for geochemical surveys. These included Kagamba, Karungu, Bubaale, Kiruruma, Ihimbo, Kanyinabalongo, Rubaare, Kitagata, Minera, Rubabo, Kizizi, Biarara, Rwimi, Kibenge, Muhokya, Rwagimba and Bugoye-Ndugutu. On ground verification of interpreted satellite data was undertaken as well as preliminary geological mapping. Satellite images used included LANDSAT/ETM+ and SRTM/DEM, ASTER, and ASTER/GDEM. The main objective of this study was to down select prospective sites for possible further technical assistance from JICA.

UNEP-ARGeo Study-2016: UNEP-ARGeo under its programme, technical assistance for surface studies, funded pre-feasibility study of Kibiro prospect. Exploration efforts were complimented by GRD and GDC of Kenya. Preliminary conceptual models of Kibiro were developed for this fault hosted extension (non-magmatic) system. UNEP Donated micro-seismic equipment which were installed around Kibiro to delineate active faults presumed to control geothermal activity.

5. CURRENT STUDIES

5.1 Uganda geothermal energy resources development project (1199)

GoU has invested public funds in geothermal energy project over the last five years. This exploration project started in FY 2011/12 and is ending in December 2016. This Government-led exploration was aiming at developing exploration models of four geothermal prospects (Panyimur, Buranga, Kibiro and Katwe-Kikorongo) and locate test drilling sites. Exploration models of Kibiro and Panyimur have been developed. Data gap closure is going in Buranga and preparation for pre-drilling data acquisition at Katwe is in advanced stages. GoU has worked in collaboration with UNEP-ARGeo, Geothermal Development Company (GDC) of Kenya and EAGER.

5.2 Regional geology

Without a good understanding of the geology of a prospect area, exploration is merely guesswork. Approximately 100-km-long normal fault systems with 1- to 6-km throws bound the deeper side of asymmetric basins (border-fault segments), and the sense of basinal asymmetry commonly alternates along the length of the rift valley. The broad flanks of the Western rift have been uplifted 1-4 km above the surrounding topography of the East African Plateau, and metamorphic basement lies below sea level beneath many basins.

Lithologically, it has tertiary-quaternary sediments in the graben and Precambrian basement metamorphic rocks at the escarpment. The Western rift is seismically active both from felt and instrumental information. Frequent occurrences of earthquakes were reported at Kibiro by early explorers. Krenkel reported that the Western rift is the most seismically active zone in Africa with a frequency of more than 100 felt earthquake per year on average. This seismicity attest to seismically active basin bounding faults. The available geophysical and geological data in the Albertine Graben indicate that rifting was initiated from the western side during mid Miocene about 17 ma (Abeinomuigisa, 2010). Main bounding fault permeability increases during and after an earthquake as evidenced in flow rate of geothermal fluids.

The Western Rift System hosting most of Uganda's geothermal prospects is at different stage of rift evolution (initial to intermediate stage) compared to the Eastern Arm of the EARS. According to Corti (2009), in the initial rifting phases, widespread magmatism may encompass the rift, with volcanic activity localized along major boundary faults, transfer zones and limited portions of the rift shoulders (off-axis volcanism). Major bounding Cenozoic normal faults are key players during early stages of rifting. Western rift is between boundary faults stages 1 to intermediate stage of evolution where by incipient internal faults begin to develop. The rift evolution is indicative of a progressive transition from fault-dominated rift morphology in the early stages of extension (Uganda) toward magma assisted-rifting during the final stages of continental break-up (Kenya, Ethiopia, Afar; Corti, 2012).

Studies of earthquake source parameter in the Western Rift show deep events down to 30-40 km (Nyblade and Langston, 1995) indicating deep faults. The western rift is bounded by high angle normal faults systems. Depth to detachment estimates of 20-30 km and seismicity throughout the depth range 0-30 km suggesting that planar border faults penetrate the crust (Ebinger, 1989).

The entire western rift valley is an area of thin crust, anomalously warm upper mantle rocks, high crustal heat flow (the geothermal gradient interpreted from well data indicates up to 67°C/km; Abeinomuigisa, 2010) and numerous geothermal systems. In addition, persistent seismicity throughout the basin attests to active crustal extension tectonics and normal faulting. Extensional / strain rates are not so high as compared to Basin and Range in the USA. But crustal extension promoted deep fracturing / faulting which aided deep circulation of meteoric water and subsequent heating to form geothermal fluids. Most of the geothermal systems in western rift valley are amagmatic geothermal systems ascribed to high

geothermal gradient caused by crustal up lift or extension which promoted deep fracturing and the circulation and heating of meteoric fluids to form hydrothermal system. These amagmatic geothermal systems occur in extensional setting, where meteoric water circulates along main boundary faults deep into the crust where it is heated. Ascending thermal water may result in hot springs and the fumaroles at the surface, generally at favorable structural settings where faults intersect thus increasing fracture density.

5.3 Local geology

Located in the western rift valley on the main RIFT fault, most geothermal systems are deep-circulation system in a tectonically active zone. These systems are believed to be fault-bounded in an amagmatic setting (non-volcanic region, high regional heat flow, and high temperature gradient). Surface features include hot springs, fumaroles and gaseous emissions. Others include travertine, calcite veins, hydrothermal alteration and silica veins. Helium ratio indicate a value of 0.2 supporting amagmatic (not related to volcanic or magmatic activity) setting. One has to note that amagmatic systems are much more wide-spread but cooler at shallow depth.

These systems are related to circulation of meteoric waters along deep (crustal scale) normal fault planes in an extensional setting. This is supported by unusually low Helium Isotope signature, low surface temperature, near neutral ph, low concentration of TDS. This is common with extensional driven (deep circulation type) as opposed to magmatic driven geothermal system. The location of these systems is related to high fracture density ascribed to intersection of several faults including the main bounding fault. Alignment of surface manifestation along the main fault (Figure 2) indicates structural permeability.

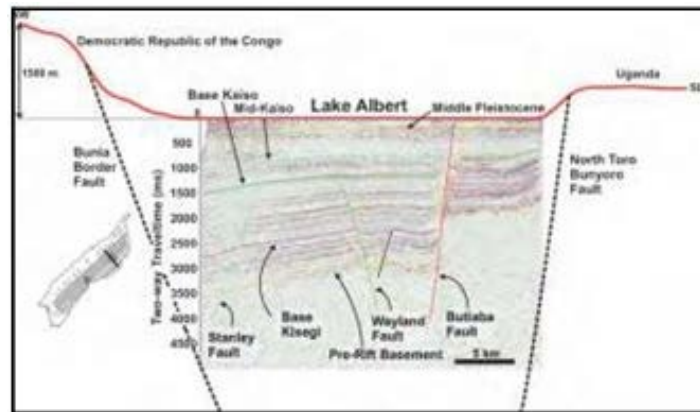


FIGURE 2: Section showing multichannel seismic line 57 from the northern part of Lake Albert (see track line inset for location). Red line at surface of profile indicates regional topography (Karp et al., 2012)

In many respects, these systems typify other fault-controlled Rift valley geothermal fields that are driven by deep circulation of ground meteoric waters (Figure 3) into high-heat-flow upper crust zone. For example, at Kibiro, fluid movement is presumed to be controlled by the main fault zone (Figure 4, Toro-Bunyoro fault) as evidenced by alignment of surface features.

Kibiro, gives a geothermometry temperature of 196°C, close to Sodium/ Potassium solute geothermometer of 205°C. Total gas content is dominated by methane due to thermal dissolution of organic rift sediments.

At Kibiro and Panyimur systems, we are looking at a deep circulation system within faulted crystalline basement rocks (Table 1; Figure 5). An exploration model can help guide decisions when designing an exploration plan and aid in interpreting the results of the collected data. A good exploration model is very important for selecting targets for test drilling. Faults have high permeability in crystalline basement rocks but fault intersection have increased permeability hence are key geothermal targets.

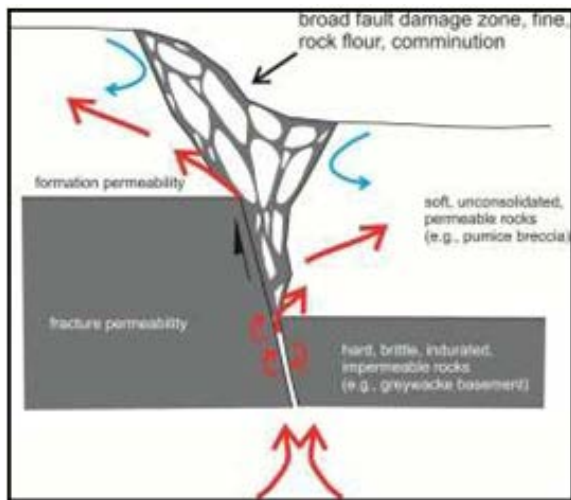


FIGURE 3: Idealized exploration model which fits Kibiro

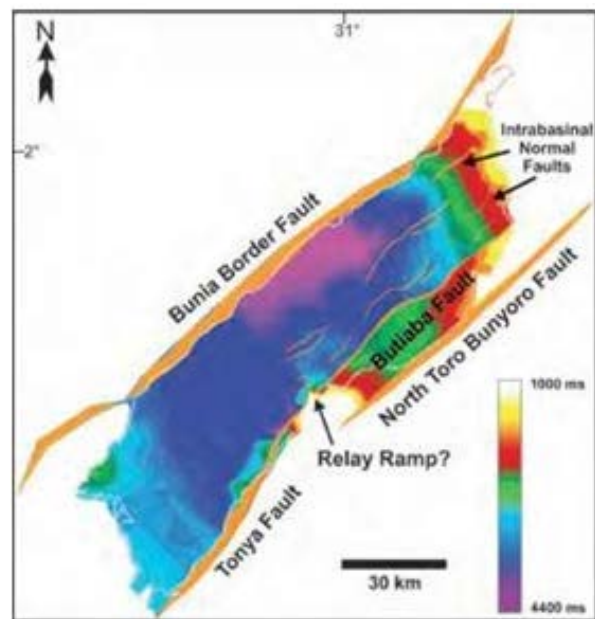


FIGURE 4: Main rift bounding fault (Karp et al., 2012)

TABLE 1: Summary of Kibiro and Panyimur geological settings

Tectonic setting	➤ Extensional tectonic regime
Controlling structures	➤ Main bounding fault ➤ Fault intersection
Controls of permeability	➤ Fracture permeability in basement – faults (secondary) ➤ Formation and fracture (primary in sediments)
Topographic feature	➤ Horst and graben
Brophy model	➤ Type E: Extensional, tectonic fault controlled geothermal resource
Moeck-Beardsman play type	➤ CV-3 extensional domain
Geological features	➤ Modern features (hot springs, fumaroles, gaseous emissions, salt precipitates) ➤ Relict features (travertine, gypsum, calcite veins, silica veins, hydrothermal alteration)
Volcanic age	➤ No volcanism (R/Ra: Kibiro 0.2 => nearly pure radiogenic He (crustal He, i.e. no volcanic heat source, no known magmatic activity, amagmatic origin)
Heat source	➤ High heat flow in areas of thinned and extending crust (extension geothermal systems). This is regionally dispersed amagmatic heat flux as opposed to focused and identifiable magmatic heat source
Horst rock age	➤ Precambrian basement metamorphic rocks, fracture dominated reservoir
Horst rock lithology	➤ Precambrian basement + sediments
Cap rock lithology	➤ Smectite rich clay

5.4 Geothermal plays

According to Corti (2012), during the initial rifting stage, widespread magmatism may encompass the rift, with volcanic activity localized along major boundary faults, transfer zones and limited portions of the rift shoulders (off-axis volcanism). This makes major rift bounding faults exploration targets. According to Corti (2012) the western rift is in stage one of boundary fault (early continental rifting) evolving to intermediate stage where by incipient internal faults begin to develop (Corti, 2012). A case is major Bunyoro-Toro fault (Main-boundary fault) and Butiaba fault (incipient internal fault).

Kibiro and Panyimur geothermal system like many geothermal systems in the western rift valley are fault-bounded extensional (horst and Graben) complexes (Brophy Type E). They occur where extension and thinning of crust occurred. As the crust pulled apart it fractured forming steeply dipping normal faults (Main boundary faults) that are perpendicular to the general direction of extension (Glassley, 2010). These high-angle main bounding normal faults can extend to considerable depth and can be focus for magma ascent into the crust or can act as fluid pathways or conduits. This created zones of high geothermal gradient and high heat flow ideal for geothermal resources. A combination of high heat flow and active extensional tectonics are ideal for forming structurally complex zones and with concentrated stress to facilitate deep circulation.

Geophysical evidence for crustal thinning across the 1,300-km-wide East African Plateau is restricted to 40- to 75-km-wide zones beneath the Western rift valleys. On the basis of seismic refraction data, crustal thinning beneath the northern part of the Western rift system is less than 25% (Ebinger, 1989). Along the length of the Western rift system, numerous small magnitude earthquakes generally with tensional focal mechanisms occur throughout the depth range 0-30 km with no apparent vertical gap in seismicity (Ebinger, 1989).

Permeability seem to be restricted to fault-controlled zones in the vicinity of the main rift faults (Glassley, 2010). The main rift faults are exploration targets according to Glassley's description of the rifting stage and fault-bounded extensional horst and graben complexes. This exploration model is the one to be tested, supplemented, and refined by field work. The process continues until a reliable model is achieved. Active crustal extension appears to enhance fracturing / dilation in normal fault system and thus favour deep fluid circulation along fault zones. The heating of deeply circulating meteoric fluids along faults is facilitated by high temperature gradient ascribed to crustal extension and thinning.

According to Moeck: Classification of geothermal plays according to geological habitats, Kibiro and Panyimur Geothermal System can be classified as Extensional Domain play type - CV3. In an Extensional Domain play type - CV3 the mantle is elevated due to crustal extensional and thinning (Moeck, 2013). The elevated mantle provides the principal source of heat for geothermal systems associated with this Play Type (Moeck, 2013). The resulting high thermal gradients facilitate the heating of meteoric water circulating through deep faults or permeable formations. This explain the heat source for these systems ascribed to crustal extension and thinning. Moeck (2013) gives a generic model of a

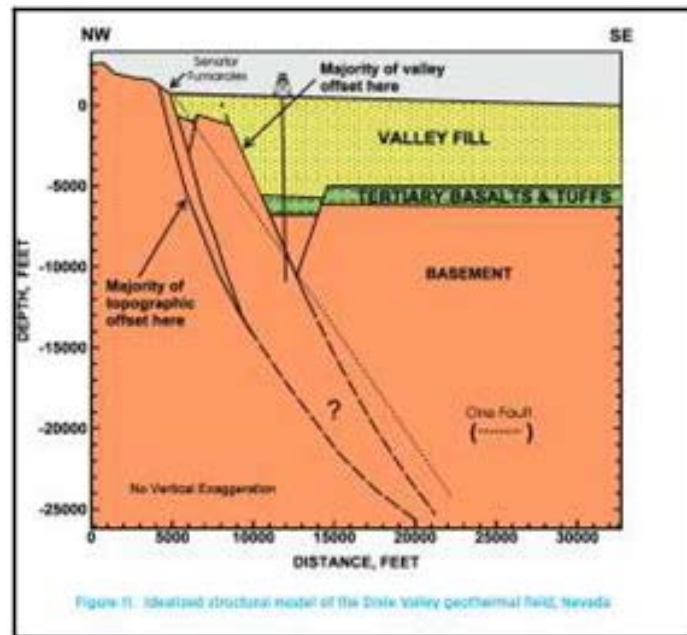


FIGURE 5: Idealized structural model of the Dixie Valley geothermal field, Nevada, which typifies Kibiro and Panyimur (DoE, 2006)

fault controlled extensional domain play with elevated mantle due to active crustal extension (Moeck, in press).

Heat source is ascribed to thinned crust, elevated heat flow and recent extensional domain. The majority of geothermal systems in western rift are amagmatic, relying on high regional heat flow throughout the rift valley. These systems employ discrete fault intersection and interaction areas as conduits for geothermal circulation. In geothermal exploration we look for normal faults as they provide open pathways for large quantities of fluids to move through rocks.

5.5 Geothermal exploration targets

Amagmatic geothermal systems in the western rift valley are controlled by a variety of fault intersection and fault interaction areas (favorable structural setting). Here we have high heat flow and active faulting in extensional geothermal systems. These geothermal system are believed to be a deep convecting / circulation geothermal system, occurring in the relatively permeable pathways along the main fault zones where it intersects multiple fault zones (high fracture density). In tectonically active regions like in Kibiro, fault zones are commonly the most important exploration targets as they can channel geothermal fluids from deep levels in the crust to relatively shallow reservoirs thus providing more accessible and more economical resource. However, it is critical to determine which type of structures and which of the faults are most favorable for providing fluid conduits. Such structures must be fully characterized to guide exploration. Major rift faults exploration targets are shown in Figure 6.

During rifting, as the crust pulled apart it fractured forming steeply dipping normal faults that are perpendicular to the general direction of extension (Glassley, 2010). These high-angle faults can extend to considerable depth and can be focus for magma ascent into the crust or can act as fluid pathways if active and permeable. This created zones of high geothermal gradient and high heat flow ideal for geothermal resources. Permeability tend to be restricted to faultcontrolled zones in the vicinity of the main faults (Glassley, 2010). Escarpment ranges nearby allow meteoric waters to infiltrate to deep hot regions and these represent favorable exploration targets in fault-controlled non-magmatic systems.

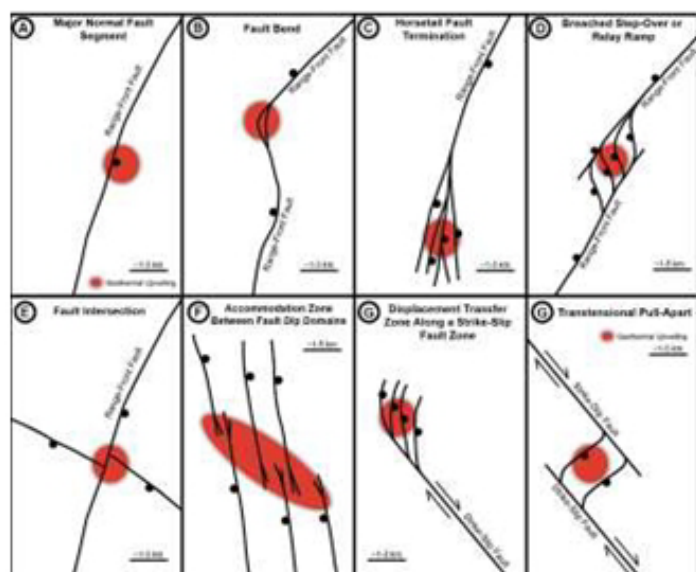


FIGURE 6: Favorable structural setting for geothermal systems in the Great Basin region (Faulds and Hinz, 2015)

5.6 Type of exploration method

According to Glassley, geothermal resources in fault-bounded extensional systems tend to be relatively deep. This calls for deep penetrating measurements to detect deep permeability. The MT survey is one of the recommended method (Figure 7) in combination with TDEM. This would permit assessment of which fault segment or stratigraphic horizon that accommodate geothermal fluid. Seismic reflection data would indicate location of major faults and areas of structural complexity such as fault intersections, where fracture density would likely be greatest.

5.7 Kibiro exploration results

5.7.1 Geophysical results

MT/TDEM measurements were run across Kibiro geothermal field. Inversion of the data revealed a deep, sub-vertical conductor (structural controlled permeability) coinciding with main rift fault (Figure 8). The sub-vertical conduit is presumed to be a highly fractured rocks along main fault zone oriented perpendicular to the least principal stress direction.

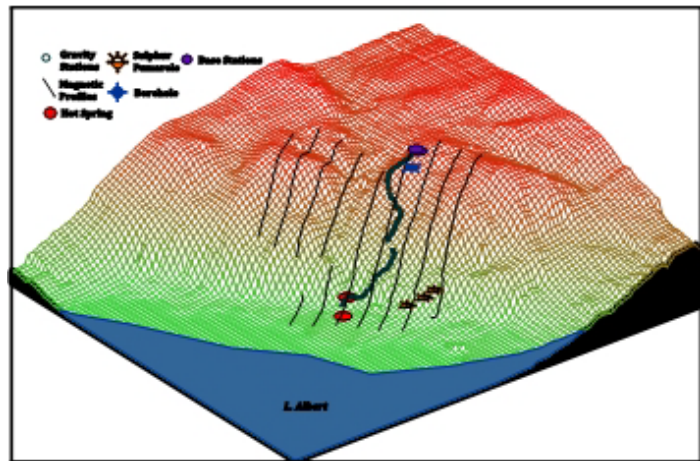


FIGURE 7: MT/TDEM planned profile lines targeting main rift fault at Kibiro

The interpretation of seismic surveys formed a highly detailed and reliable picture of the subsurface structure, with resolution unattainable by most other geophysical methods. Such a picture is highly desirable in geothermal exploration to guide drilling. The seismic section reveals active faults (deep seated structural discontinuity; Figure 9) that function as conduits for subsurface fluids. These faults allow deep crustal scale fluid circulation and represent prospective “Play” for geothermal exploration. Systems with connectivity to deep crustal heat supply are favorable for sustained geothermal production.

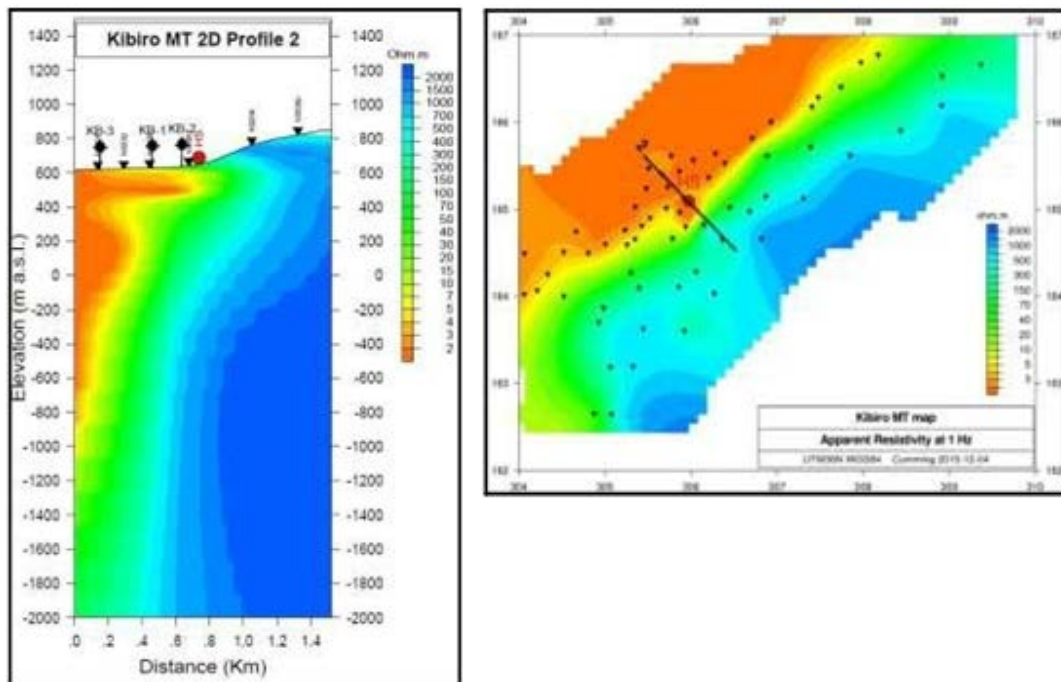


FIGURE 8: a) MT sounding revealed a sub-vertical conduit, which is interpreted as main rift bounding fault; b) Apparent resistivity map of Kibiro showing resistive basement rocks and conductive basin fill

TEM data has indicated a shallow reservoir at 300m and this has been recommended for TGH (Figure 9).

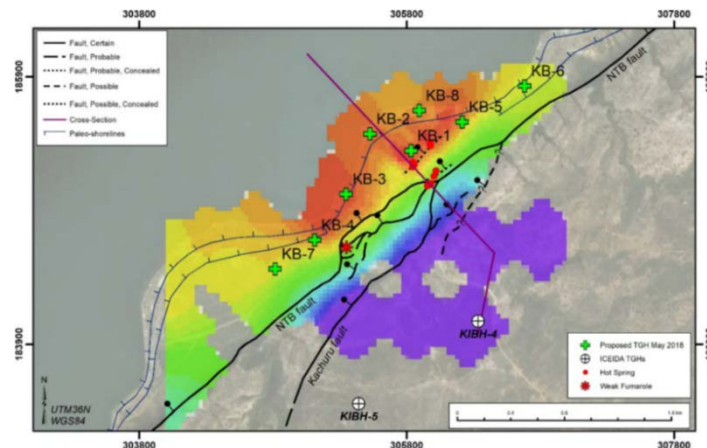


FIGURE 9: Map showing resistivity values around Kibiro. Note locations of recommended TGH Preliminary conceptual model (Figure 9, 10 and 11) has been developed for Kibiro by integrating all data sets. This is going to be constrained by TGH data (see figure 9 for TGH locations).

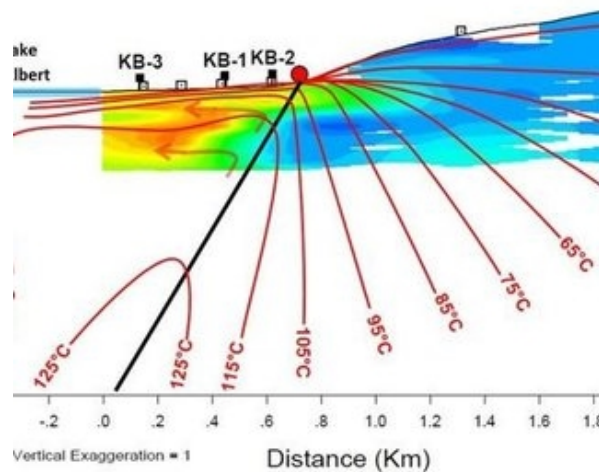


FIGURE 10: Section showing a preliminary conceptual model of Kibiro

TEM data acquired by ISOR has been re-interpreted using a geophysical software (*Geotools*) to refine and up-date the preliminary model of Kibiro. The project plans to drill TGH to reduce the geological uncertainty and risk prior to drill deep full diameter exploration wells. Siting of locations of TGH holes has been conducted and drilling is expected early 2019. Prefeasibility studies of direct use application have been conducted by EAGER recommending salt drying, spa, heating oil pipeline, fish drying and aquaculture.

5.7.3 Geological mapping

Obvious magmatic heat sources are lacking. Younger structures were targets like recent faults (normal) and fractures. The main rift fault (deep penetrating) was targeted particularly in areas of fault intersection (increased fracture density). Permeability controls were found to be main rift bounding faults (fracture permeability) as evidenced by alignment of modern and relict surface features (Figure 11). Enhanced dilation here facilitates deep circulation of hydrothermal fluids. One cannot rule out formation permeability from Tertiary - Quaternary sediments. Faults intersections were targeted and Kibiro geothermal system is located at fault intersection an area of increased fracture density. EAGER Consultants produced a structural and thermal anomaly map which aided in siting TGH (Figure 12).

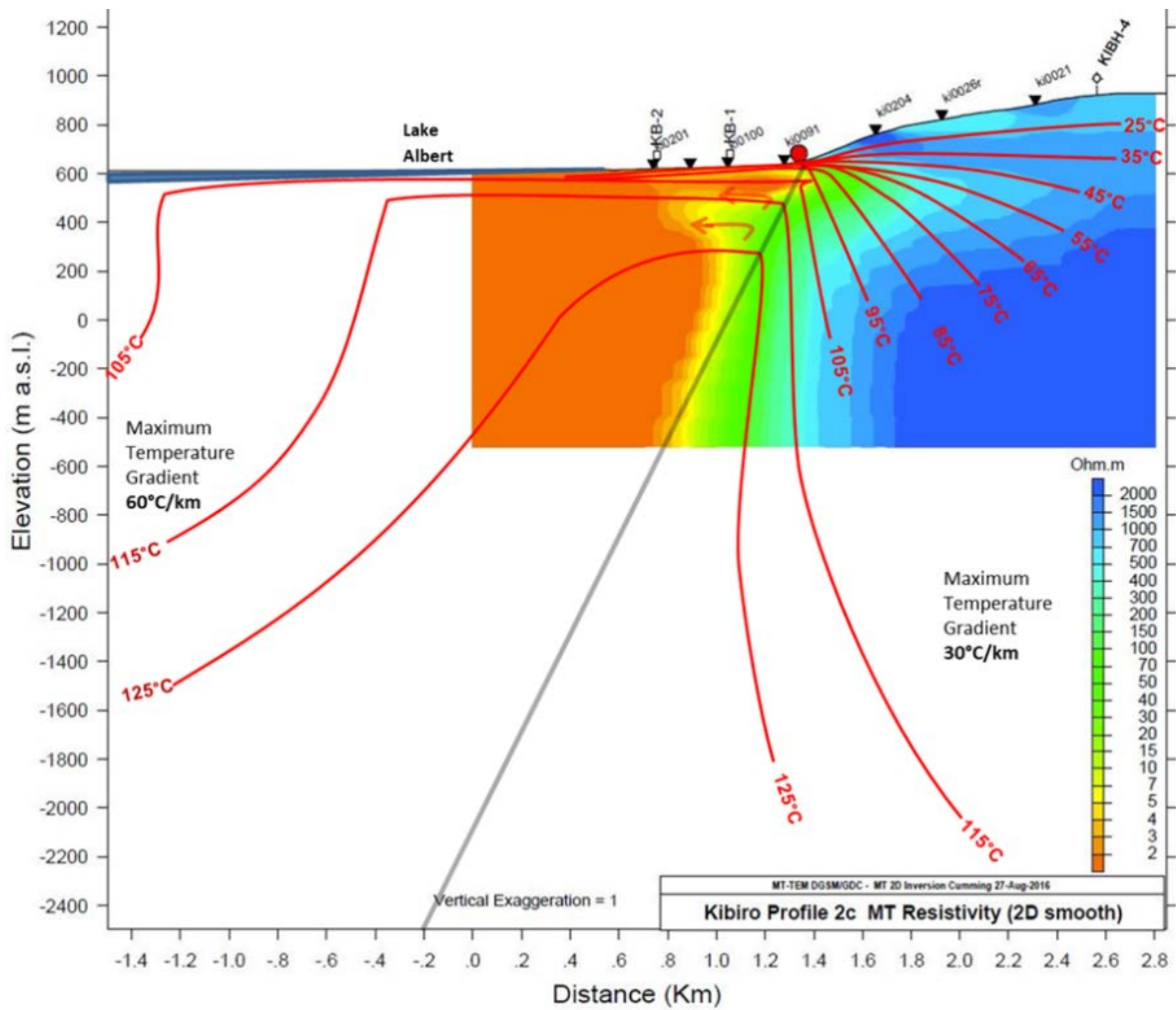


FIGURE 11: Section showing a preliminary conceptual model of Kibiro

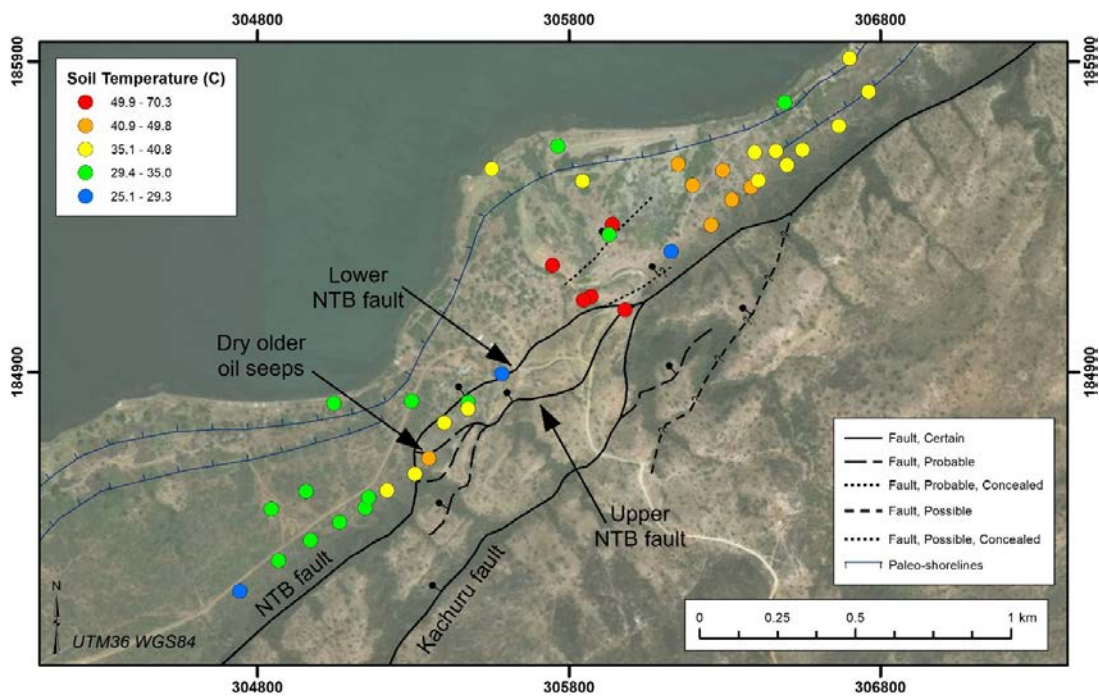


FIGURE 12: Map showing structures and surface temperatures around Kibiro (EAGER, 2018)

5.8 Panyimur exploration results

Government-led geothermal investigation surveys have been undertaken at Panyimur area by GRD, technically supported by EAGER hired experts. Preliminary geothermal conceptual models have been developed and these are being updated and refined as new data emerge. Work included detailed structural mapping (Figure 13) combined with an MT/TDEM survey (Figure 14, 15, 16 and 17), carried out together with EAGER hired structural geologist (EAGER, 2017a).

Like, Kibiro, Panyimur prospect is a *deep-circulation amagmatic extension system* and in many respects, typifies other *fault-controlled geothermal systems* that are driven by deep circulation of ground waters. At Panyimur, fluid movement is controlled by the main rift bounding fault zone that bounds the west side of the rift valley. Data gap closure is planned at Panyimur to include TEM survey, shallow temperature probe surveys, soil gas and gas flux measurements.

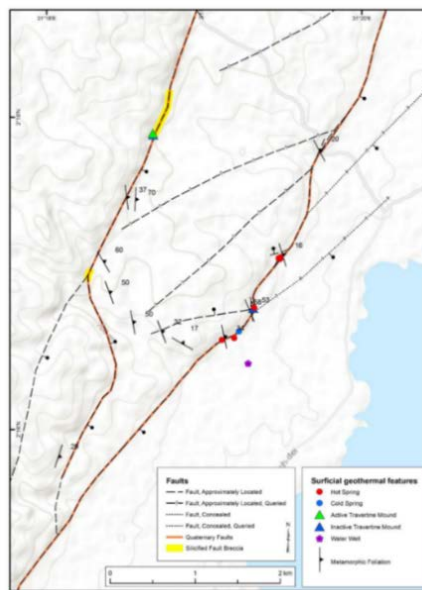


FIGURE 13: Map showing Structural mapping results of Panyimur, (EAGER 2018)

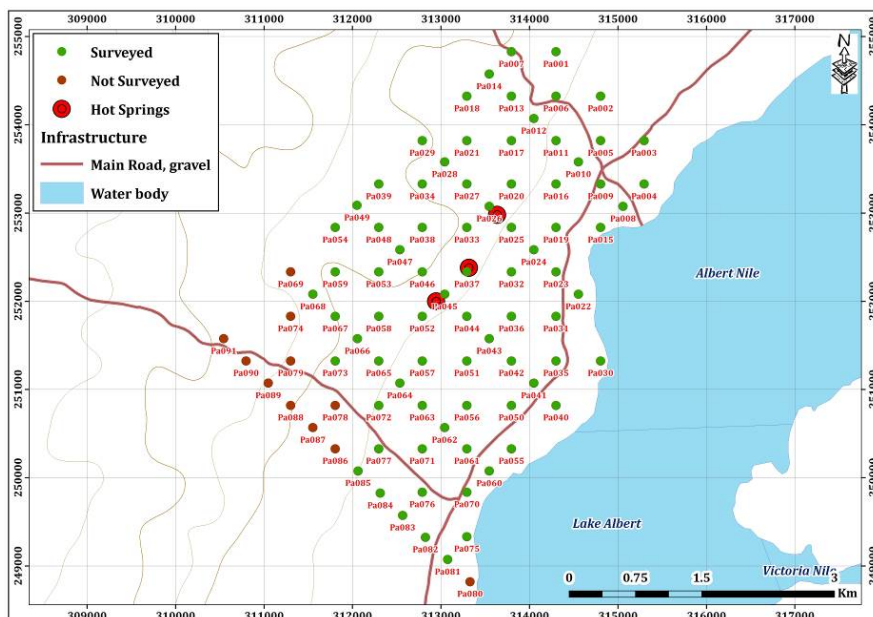


FIGURE 14: Map showing MT/TDEM Survey points in Panyimur area

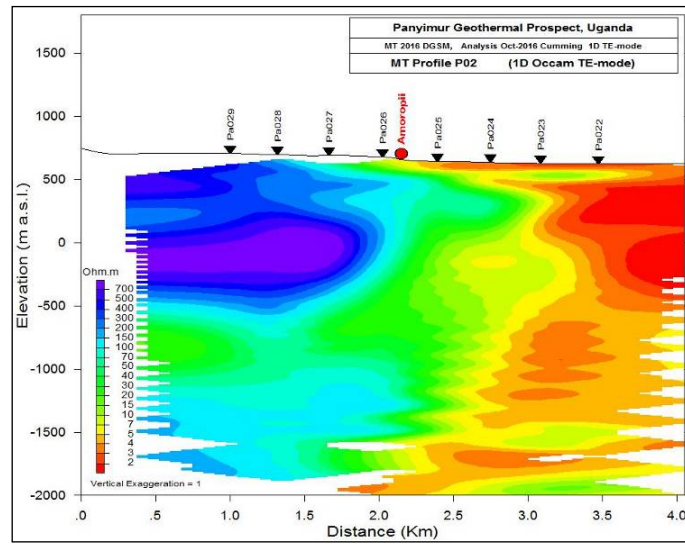


FIGURE 15: Section showing Panyimur profile P02-ID MT Resistivity (Cumming, 2016). Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

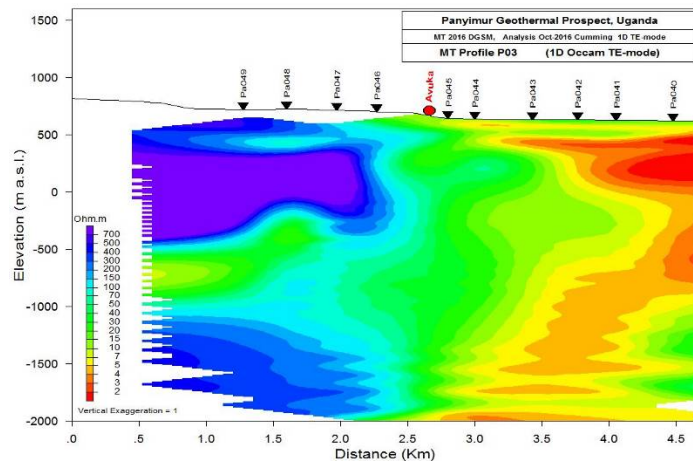


FIGURE 16: Section showing Panyimur profile P03-ID MT Resistivity (Cumming, 2016). Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

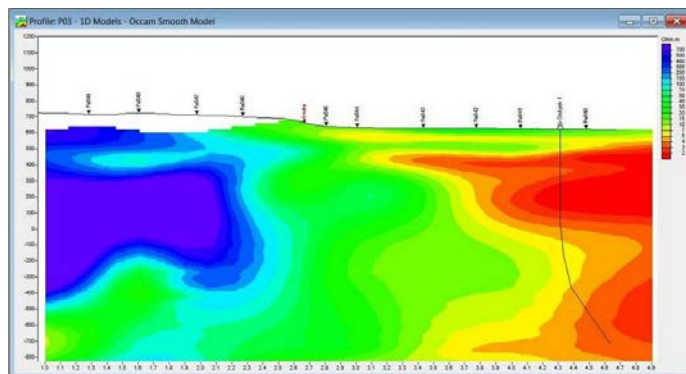


FIGURE 17: Section showing MT Profile along Panyimur. Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

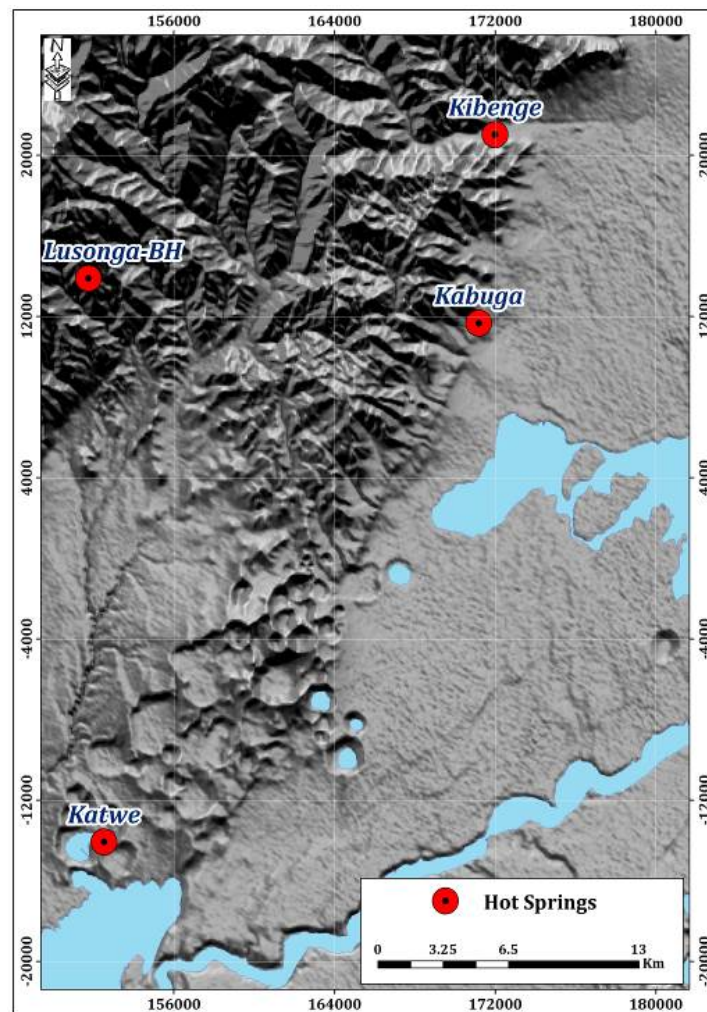


FIGURE 19: Map showing NE-SW principal rift bounding fault zone which is presumed to control geothermal activity

MT field survey was conducted to image the sub-surface structures presumed to control geothermal activity and results are presented in Figures 20, 21 and 22.

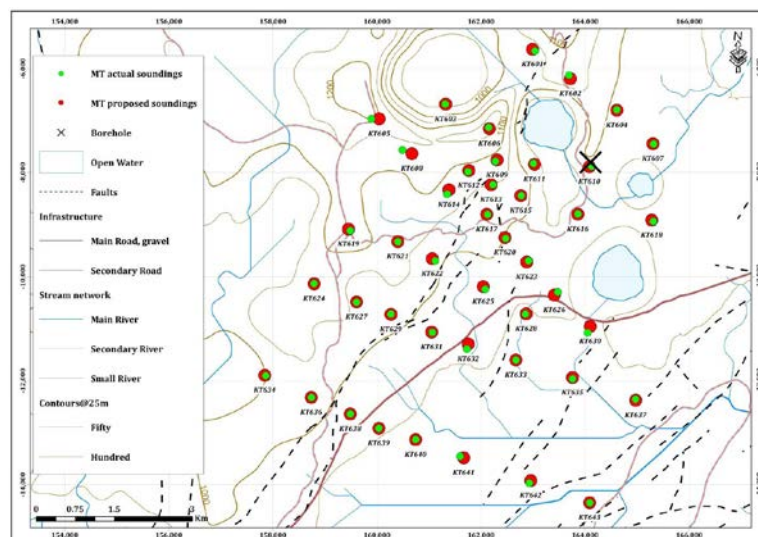


FIGURE 20: Map showing MT station locations

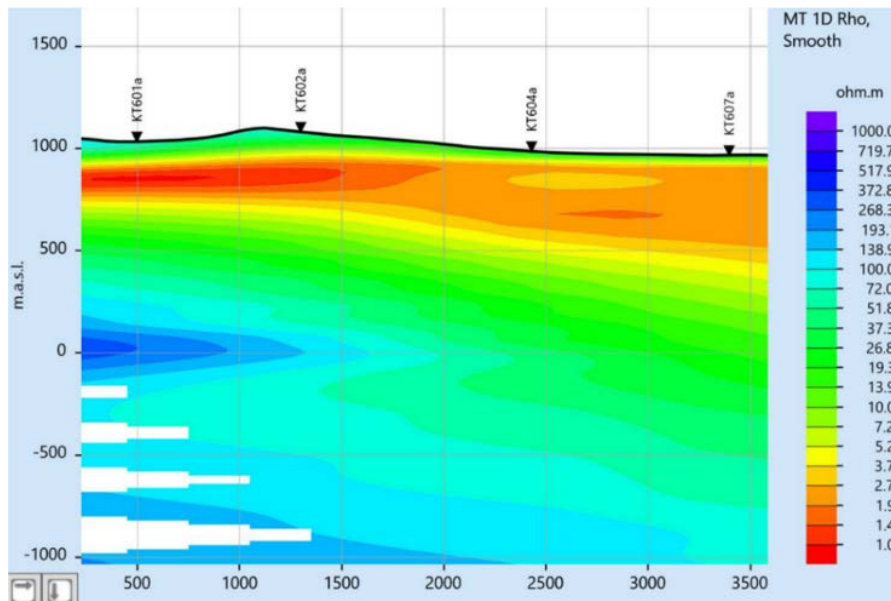


FIGURE 21: Katwe MT slice line resistivity cross-section - Profile 00a

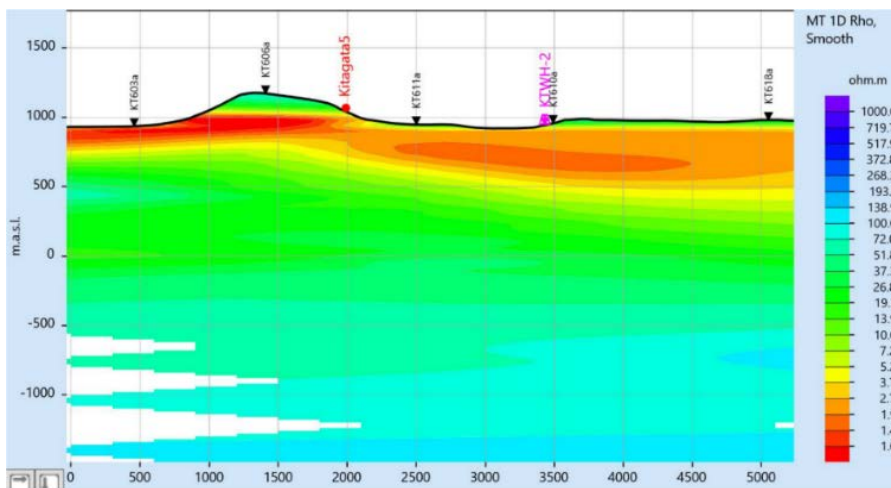


FIGURE 22: Katwe MT slice line resistivity cross-section - Profile 00

Results are still being interpreted and more processing is expected with EMpower geophysical data processing software to develop a 3D conceptual model. One has to note that this a volcano-tectonic regime which should be taken into account when interpreting data.

5.10 Buranga exploration results

Geothermal investigation surveys have been undertaken in Buranga by GRD technically assisted by EAGER hired expert. EAGER undertook structural analysis and thermal anomaly mapping (Figure 23).

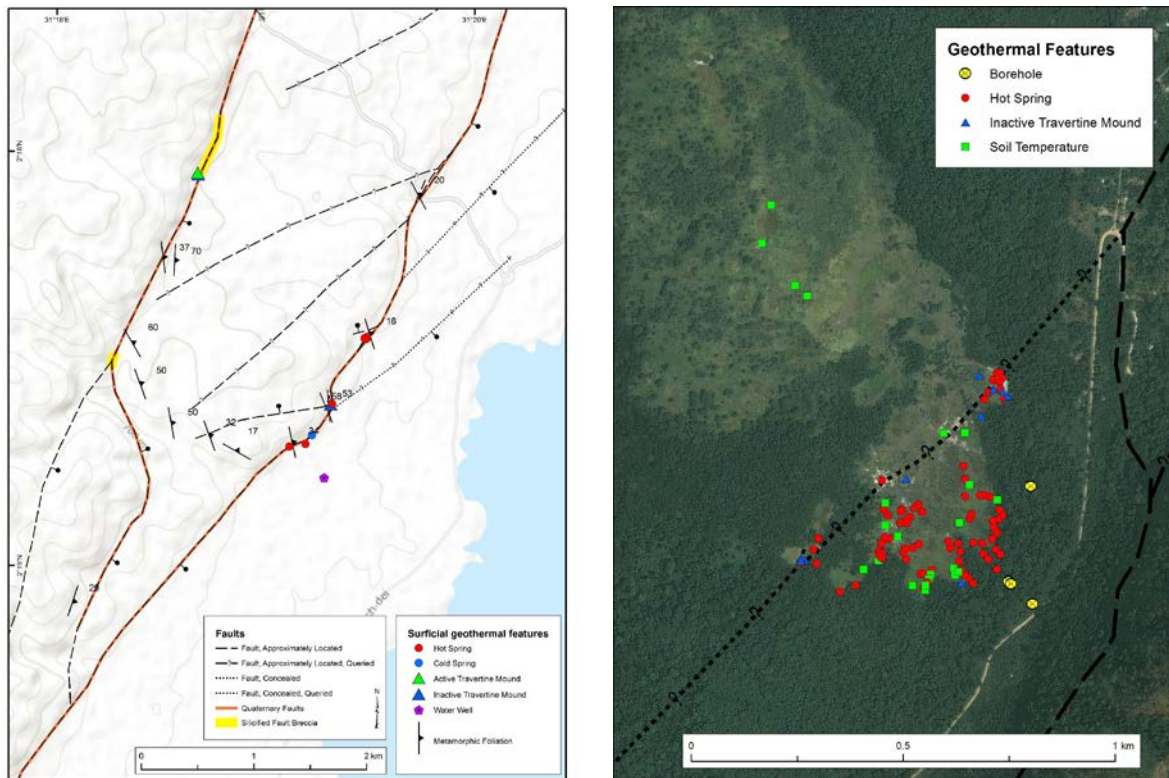


FIGURE 23: Structural map of Buranga on left and thermal anomaly map (EAGER, 2017a)

EAGER hired experts conducted drone aided thermal anomaly mapping in inaccessible areas of Buranga. A thermal anomaly map was produced (Figure 24).

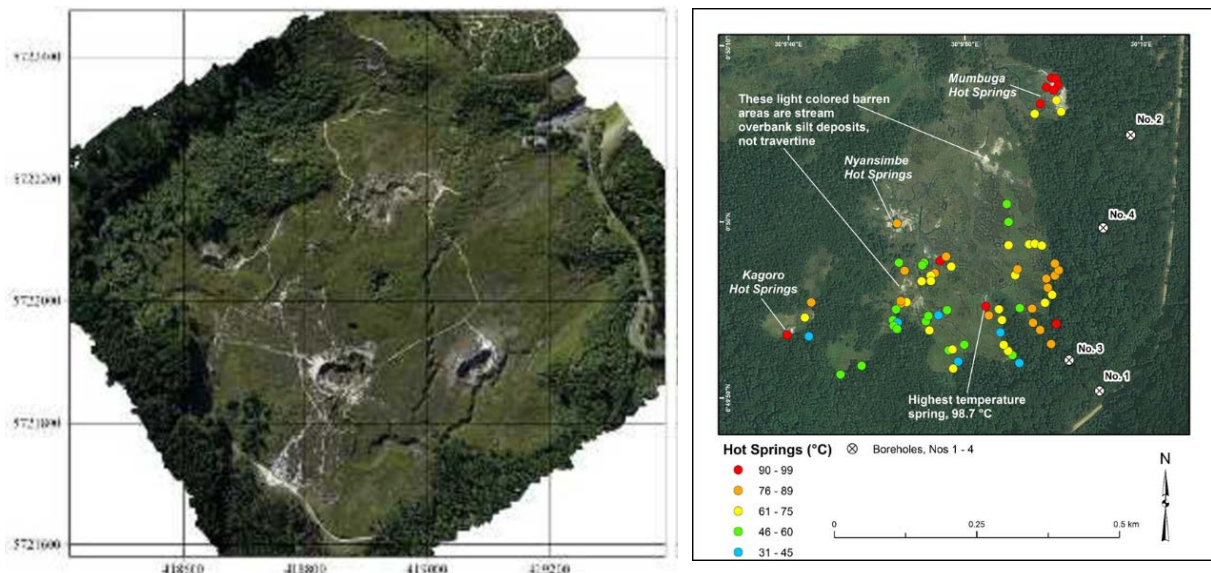


FIGURE 24: Map showing a thermal anomaly map of Buranga

Soil gas surveys have been conducted in Buranga and reveal a NE-SW trend presumed to indicate a structural control (Figure 25).

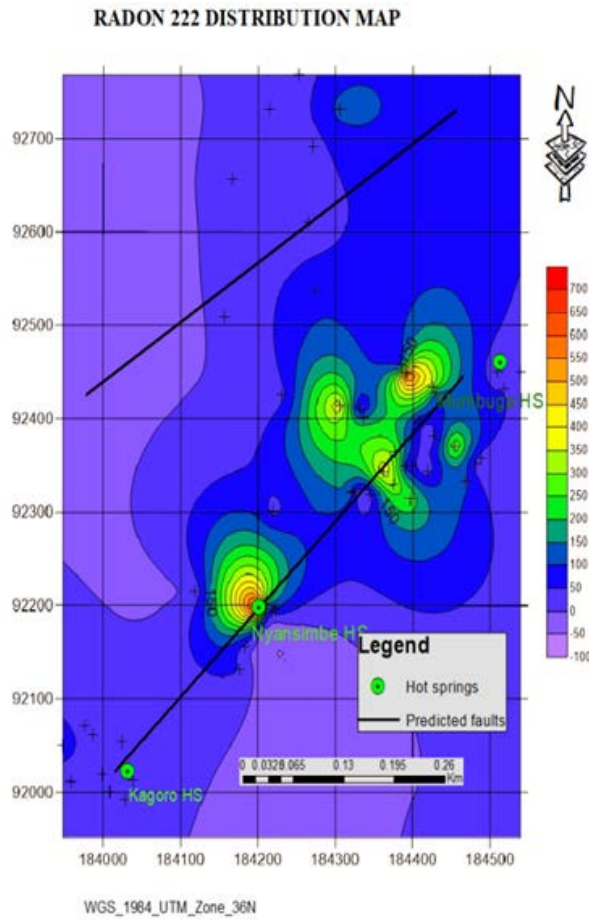


FIGURE 25: Map showing Radon distribution

A preliminary conceptual model (Figure 26) has been developed which will be refined and up-dated with TGH data.

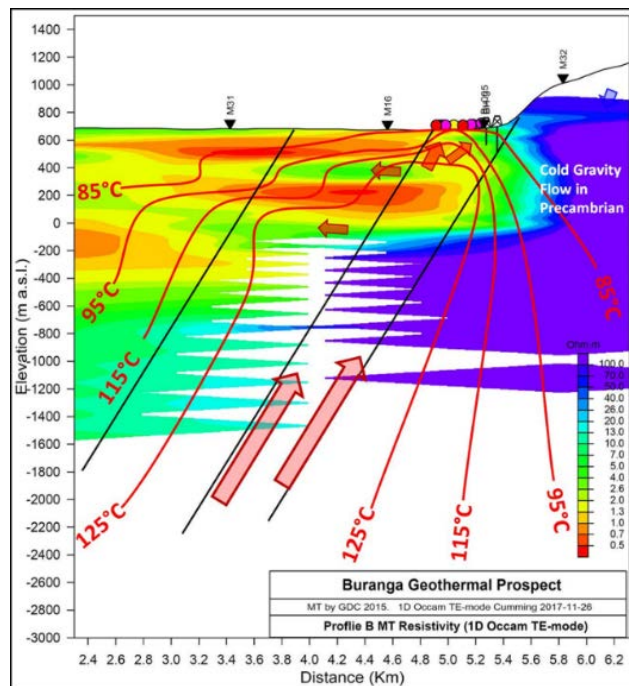


FIGURE 26: Section showing a preliminary geothermal conceptual model of Buranga (EAGER, 2017a)

5.11 Ihimbo Geothermal Area

Geothermal studies have been conducted in Ihimbo (Figure 27) and surface manifestations include hot springs, travertine domes, vegetation kill areas, warm springs and gaseous emissions. Ihimbo prospect is an extensional deep-circulation non-magmatic system. In many respects, the Ihimbo geothermal system typifies other fault-controlled geothermal fields that are driven by deep circulation of ground meteoric waters. At Ihimbo, fluid movement is controlled by the Ihimbo fault zone (an internal fault) trending NE-SW. The main rift bounding fault is characterized by travertine dome and cones an indication of past geothermal activity.

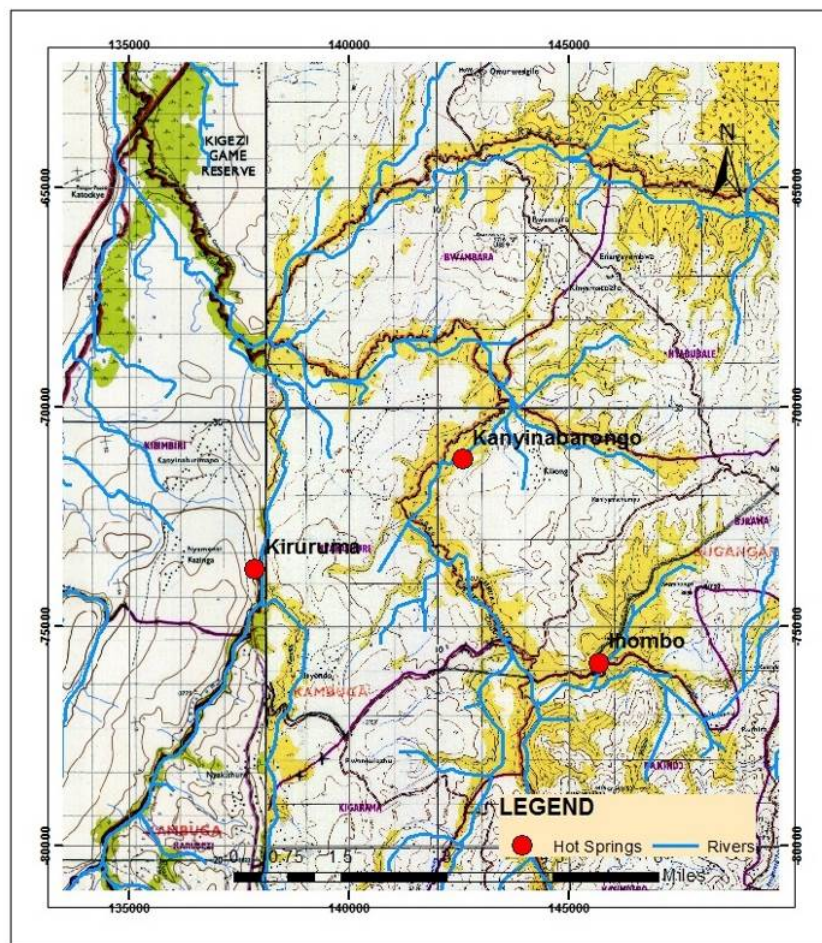


FIGURE 27: Topographic map of Ihimbo Area

Geochemical surveys have involved surface water sampling and analysis (JICA 2014), soil gas (R_n) and gas flux measurements. Shallow temperature measurements were also undertaken during the soil gas and gas flux measurements. Gas flux data and soil gas data (R_n) were processed (Figure 28 and 29). Anomalous gas concentrations are presumed to locate active fault zones presumed to control geothermal activity. High flux is presumed to be indicative of anomalous flux associated with geothermal activity.

Magnetotelluric survey (40 MT soundings) were conducted (Figure 30 and 31) around the geothermal area. TDEM survey is planned in this area to correct for static shift in MT data. Focused structural mapping will aid in developing a geothermal resource model of this site. The field crew will leverage on the oil and gas data which was collected in this area more so reflective seismic data and gravity data.

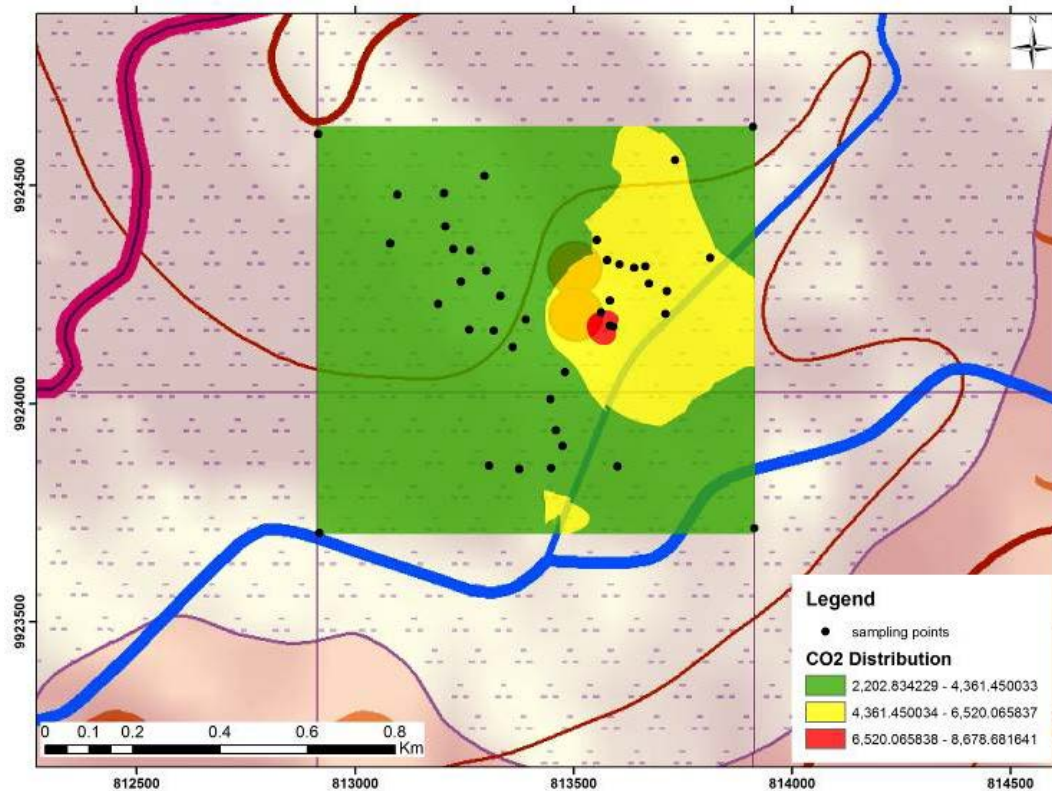


FIGURE 28: Spatial distribution of CO₂ flux measurements in Ihimbo area. Anomolous gas flux are presumed to indicate geothermal activity (permeable conduits).

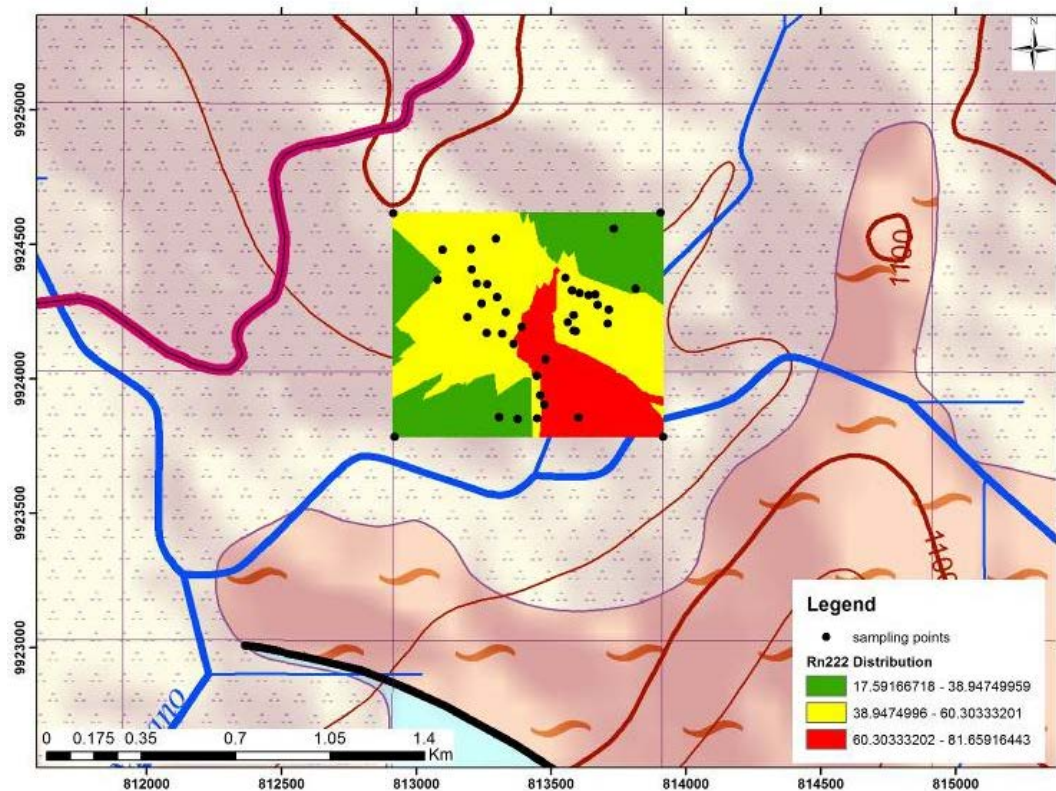


FIGURE 29: Distribution of activity of ²²²Rn diffusively degassed from the soil in Ihimbo geothermal prospect. Anomolous concentrations are presumed to indicate concealed faults that act as conduits for geothermal fluids.

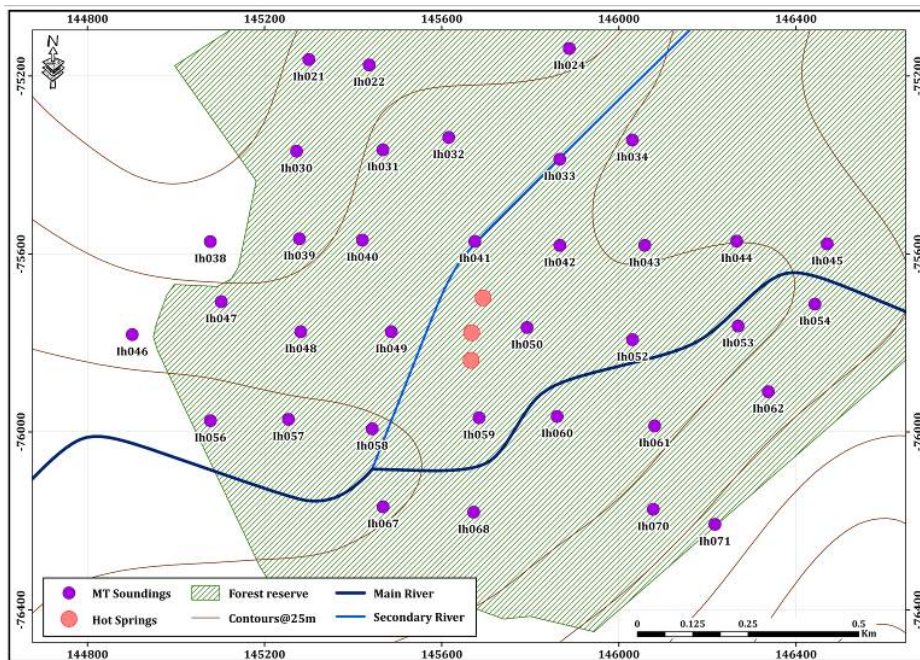


FIGURE 30: Map showing stations for MT Sounding at Ihimbo Geothermal Resource Area

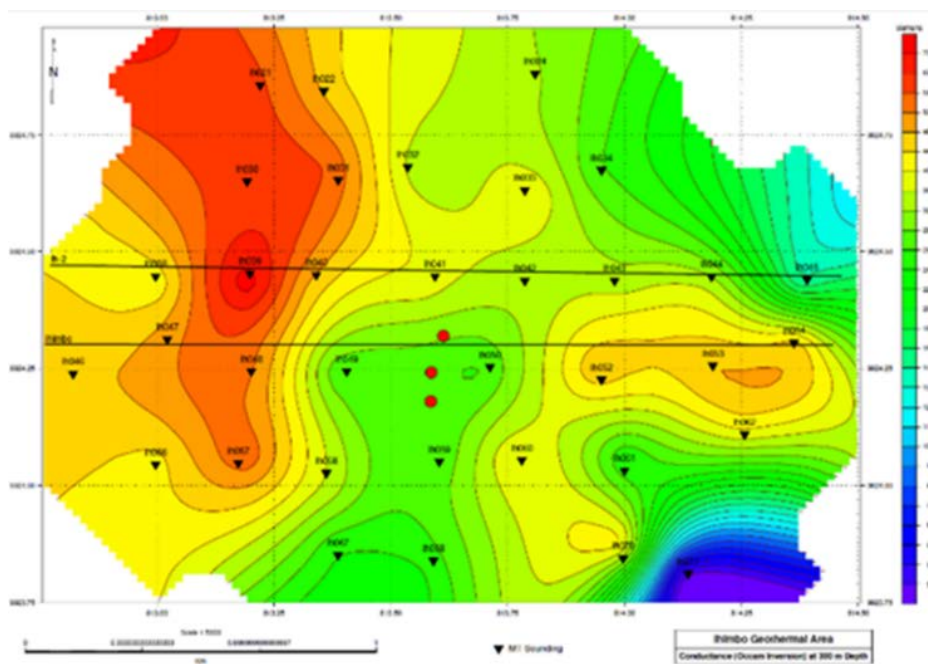


FIGURE 31: Map showing resistivity results around Ihimbo. Note the open anomaly in NW.

5.12 Other areas

Preliminary geothermal investigation surveys have been conducted around other areas after geothermal play fairway analysis. These included:

Nyamwamba Fault Site: This principal normal fault NE-SW trending fault dipping SE (Figure 32) characterized by thermal manifestations. It is seismically active and deep seated according to seismic information. It is an ideal geothermal exploration target which is presumed to allow deep circulation of water to be heated by heated crust.

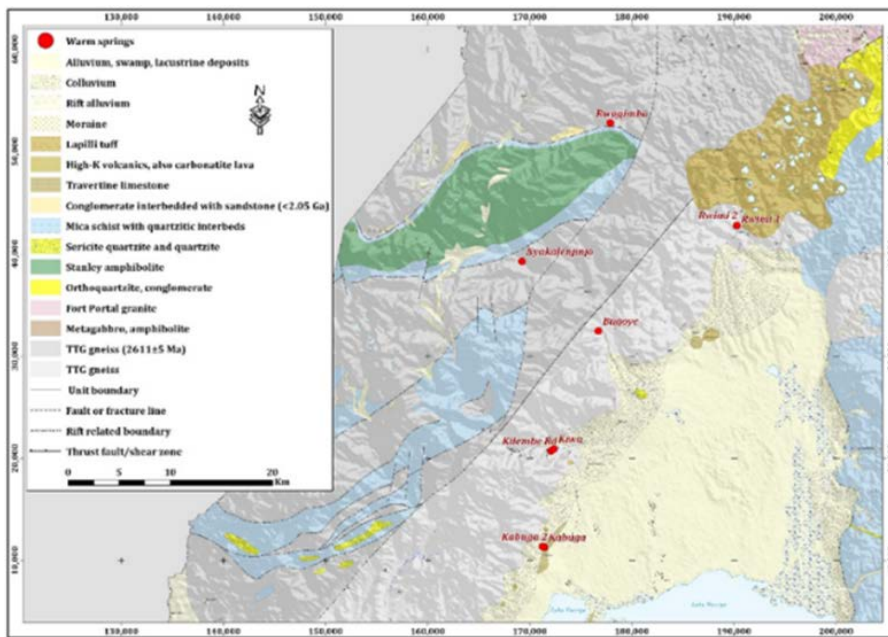


FIGURE 32: Map showing geology around Nyamwamba normal fault and thermal manifestations

Geothermal exploration should focus basin ward where the faults are dipping starting with low cost methods. LiDAR imagery will be used to bring out details of topographic features that are previously unavailable revealing structural patterns.

George Fault Site: This site is located in rift extensional regime (Figure 33) and has surface manifestations which include travertines, gaseous emissions and warm springs (Dwenkorebe spring). It is seismically active (Figure 34). It is recommended to conduct soil gas surveys and shallow temperature measurements *basin ward* prior to deploying cost intensive MT/TDEM surveys.

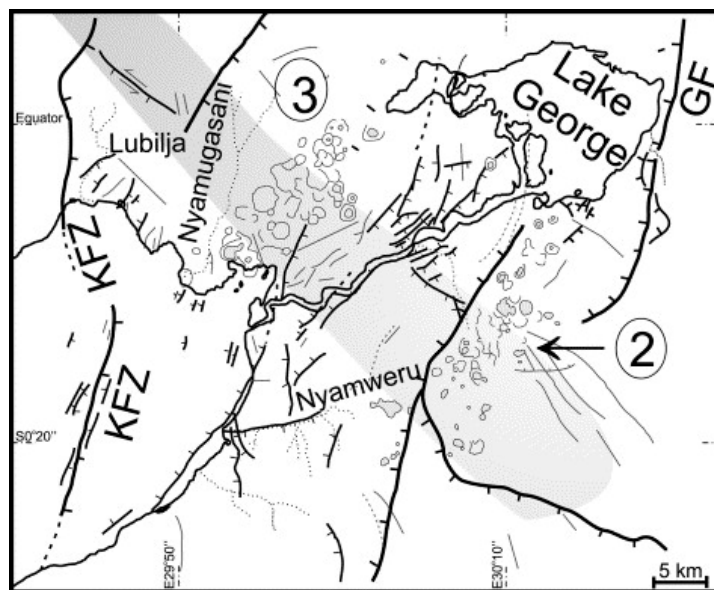


FIGURE 33: Map showing George normal Fault (GF) on eastern side of Lake George dipping westward

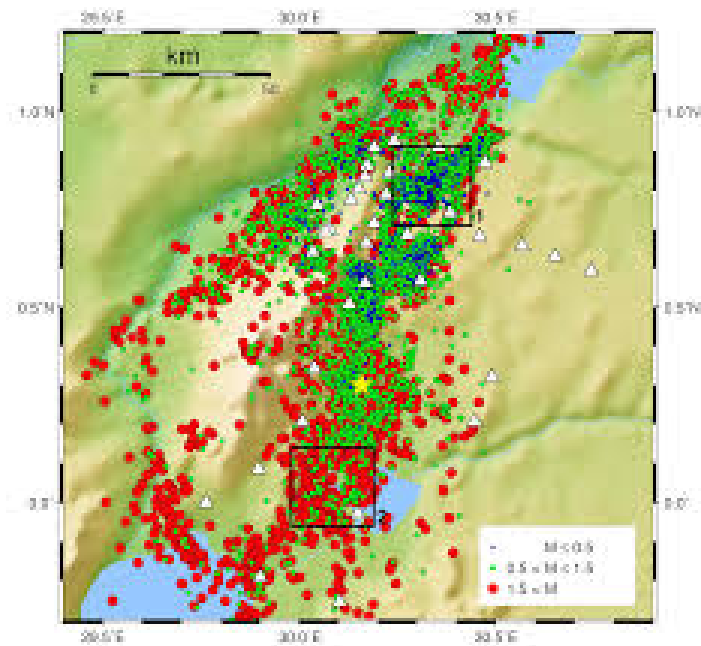


FIGURE 34: Map showing seismicity of the area.

LiDAR data is recommended to help map subtle linear faults in this area obscured by volcanic debris. LiDAR data will be acquired primarily to delineate the traces of faults.

Rwimi-WASA fault: This is on the eastern side of Rwenzori. It is steeply dipping and seismically active (Figure 35). It is almost similar in setting to Bwamba fault which hosts the Buranga hot springs.

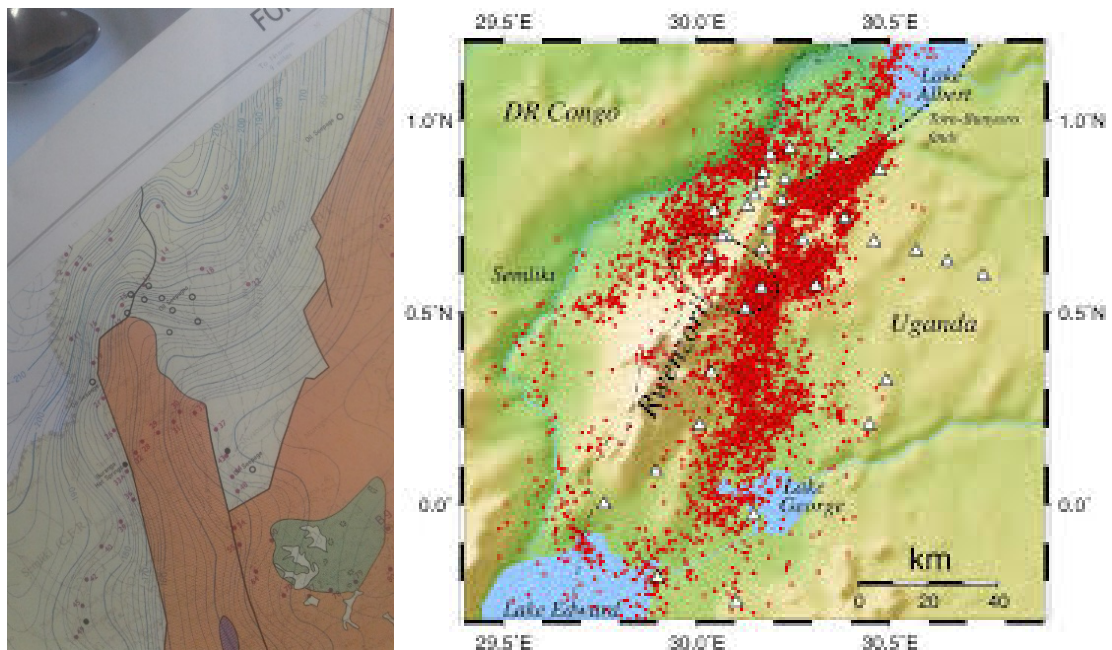


FIGURE 35: Map showing Rwimi-Wasa fault on eastern edge of Rwenzori almost parallel to Bwamba fault. On the right is a seismicity map of the area.

It is recommended to conduct soil gas surveys and shallow temperature measurements prior to deploying cost intensive MT/TDEM surveys.

Kichwamba Fault: This is ideal in that it is STEP-OVER or relay ramp (Figure 36) and is a main bounding fault which is tectonically active. Mapping has revealed fossil surface indicators of geothermal activity.

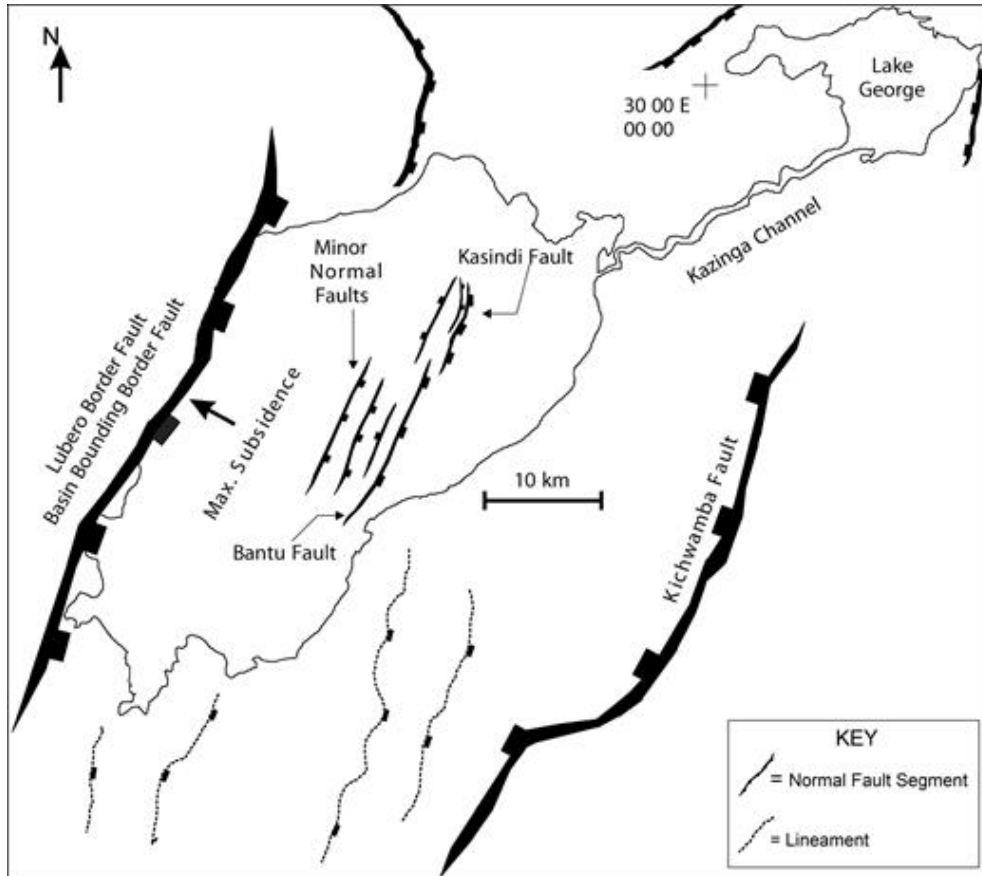


FIGURE 36: Map showing Kichwamba fault dipping NW

It is recommended to conduct soil gas surveys and shallow temperature measurements basin ward prior to deploying cost intensive MT/TDEM surveys.

Kaiso-Tonya Site: A large relay of step over (Figure 37 and 38) was mapped by oil companies and surface indicators of geothermal activity were mapped. The area has favourable characteristics for geothermal activity.



FIGURE 37: Map showing Kaiso-Tonya main normal faults and displacements

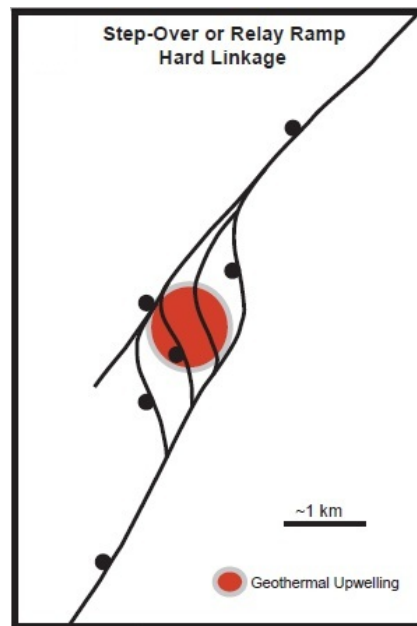


FIGURE 38: Diagrammatic representation of relay ramp (Faulds and Hinz, 2015)

It is recommended to conduct soil gas surveys and shallow temperature measurements basin ward prior to deploying cost and labor-intensive MT/TDEM surveys.

5.32 Exploration strategy

The projects now follow an exploration strategy to reduce cost and maximize success in exploring for geothermal resources. It was important to learn from past failures and determine which of the techniques used for geothermal exploration did not identify a geothermal system. DGSM assessed both failed and successful techniques.

- **Seismic reflection analysis** to map deeply penetrating fault zones. The interpretation of seismic surveys form a highly detailed and reliable picture of the subsurface structure, with resolution unattainable by most other geophysical methods. Such a picture is highly desirable in geothermal exploration to guide drilling.
- **MT/TDEM survey** to delineate and detect the geometry and depth of the clay cap, and also in determining the boundary between the alteration zone and the geothermal reservoir. Static shifting techniques have been applied utilizing TDEM surveys.
- **Soil gas and gas flux measurements** to delineate permeable deep penetrating faults.
- **Shallow temperature surveys** to map shallow thermal anomalies associated with geothermal activity
- **Geological mapping:** Detailed surface and structural analysis of faults to involve LiDAR mapping.
- **Thermal Gradient Holes** drilling to map and delineate the shallow thermal anomaly.
- **Data integration:** All data sets will be integrated to build conceptual model.

No geophysical “silver bullet” currently exists for the geothermal industry. Rather, we will employ various studies from a suite of geophysical exploration methods to better understand a geothermal reservoir prior to drilling.

6. INSTITUTIONAL FRAMEWORK

MEMD was restructured and a Directorate of Geological Survey and Mines (DGSM) was established. Under DGSM is a Geothermal Resources Department (GRD) which oversees, promote and manages geothermal exploration and development in Uganda. Core geothermal survey equipment have been procured. Much as the institution has been established there are still some capability gaps (technical, management, engineering and scientific). More effort is needed to put in place a skilled geothermal workforce to spearhead geothermal development.

Currently, geothermal resources are regulated by the *Mining Act 2003* and its regulation 2004. The *Mining Act 2003*, gives potential geothermal investors inadequate legal security. There is legal and regulatory gaps and the Mining Act 2003 is being reviewed. Geothermal energy has a peculiar nature (it has an element of mineral and water) that it needed a specific law taking into consideration its uniqueness. GoU was technically assisted by Climate Technology Center and Network (CTCN) to draft geothermal policy and regulation. The Draft documents have been reviewed by EAGER experts and internally by an inter-Ministerial committee. Drafts are yet to be submitted to Cabinet and Parliament for further management.

7. ON-GOING GEOTHERMAL PROJECTS

- **Uganda Geothermal Energy Resources Development project** (1199) is government funded project ending in June 2019 with a promise of funding another project.
- **World Bank ERT-3:** Within this programme, Energy for Rural Transformation (ERT-3) there is a geothermal component which is being implemented.
- **EAGER:** This a DFID funded project and is being implemented. It involves pre-drilling studies at Kibiro, Panyimur, Katwe and Buranga. Preliminary conceptual models have been developed for Kibiro and Panyimur and TGH locations sited. This programme ends in November 2018.

8. CONCLUSION

Uganda has made a substantial progress towards exploring its geothermal resources as well as putting in place the necessary institutions and policies. Human capital development has been addressed as well. An exploration strategy has been developed.

Uganda geothermal systems are *fault-hosted extensional (non-magmatic) systems* which rely on deep circulation of meteoric waters. They are presumed not to be derived from active or recently active magmatic activity. They are a result of thinned crust, elevated heat flow in recent extensional domains. Preliminary conceptual models of Kibiro, Panyimur and Buranga have been developed, and plans are in advanced stages to drill TGH.

MT survey was conducted in Katwe following structural mapping by EAGER experts and local staff. Preliminary conceptual model is being developed.

Further analysis in Ihimbo will include resistivity surveys (TEM), structural mapping, LiDAR mapping, leveraging oil and gas data and finally developing a geothermal conceptual model. TGH exploration is recommended prior to deep drilling.

Work has commenced in other selected areas with favourable characteristics (structural and tectonic controls) of geothermal prospectivity. We shall down-select two (2) sites of the most promising sites for Detailed Study.

9. RECOMMENDATIONS

- Data closure should be undertaken in Katwe and Buranga to complete pre-drilling studies.
- Analyses of soil-gases and measurements of gas-fluxes at Buranga and Katwe geothermal sites should be undertaken. Analysing radon gas should help locate mapped faults that communicated with the reservoir.
- The $3\text{He}/4\text{He}$ ratios of geothermal fluids from fault-bounded geothermal systems should be measured to determine if a deep mantle signature was present.
- Most of these geothermal systems are deep circulation systems and typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. Here, fluid movement is controlled by the main fault zone (structure controlled permeability) that bounds the rift and hence should be key exploration target.
- LiDAR data should be acquired to map subtle fractures and faults in the areas investigated due to their high resolution and enhanced elevation data (70cm).
- Completely independent subject matter experts should review the geologic conceptual models prior to drilling.

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