Presented at SDG Short Course II on Exploration and Development of Geothermal Resources,
organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya, Nov. 9-29, 2017.

GEOTHERMAL EXPLORATION IN UGANDA – STATUS REPORT

Vincent Kato
Ministry of Energy and Mineral Development
Directorate of Geological Survey and Mines
Geothermal Resources Department
Entebbe
UGANDA
kato_vicent@hotmail.com

ABSTRACT

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 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.

Geothermal exploration timeline have stretched too far dating way back in 1950's when swallow wells were drilled in Buranga. Numerous donor support projects have been undertaken to support geothermal exploration in Uganda. These have included UNDP, ICIEDA, BGR, IAEA, BGR, JICA, WB, ADB. The situation warranted breakthrough techniques and technology to fact 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. GoU established a Geothermal Resources Department with a budget and logistics (survey equipment and tools). GoU is in final stages of putting in place a geothermal policy and Bill. Since FY 2011/12, GoU has committed funds to undertake government-led geothermal studies in 4 priority areas. Conceptual models have been developed for three areaS and surveys have commenced on two more sites. There are significant accomplishments and impacts. A skilled geothermal workforce is in place but with capability gaps. There is need to reinforce by recruiting engineers, managers and technicians. It is mostly of 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 development as opposed to Eastern arm which is in mature stage. Uganda's geothermal systems are deep circulation amagmatic extensional systems that are driven by deep circulation of meteoric waters. This is attested by low Helium signatures and deep reaching boundary faults. Rift bounding faults are key exploration targets in western rift more so where they are intersected due to increased permeability and fracture density. Standard exploration methods applied include a combined MT/TDEM survey, soil gas and gas flux measurements, swallow temperature probe, reflective seismic data from oil and gas companies. Integrated models are developed. Slimhole exploration is 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 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 survey timeline in Uganda has stretched too far dating back in 1954 when 4 swallow holes were drilled in Buranga. As you see, the situation invited breakthrough techniques and technology to fast track geothermal development in Uganda. Several projects have been implemented but with no significant accomplishments.

Since Financial Year 2011/2012, GoU committed public funds towards the development of its geothermal resources. Government-led geothermal investigation surveys in Kibiro (Hoima), Panyimur (Pakwach) and Buranga (Bundibugyo) have advanced to pre-production drilling investigations (1M shallow probe surveys, temperature gradient holes, slimholes). Multiple conceptual models have been developed for these sites. These will be refined and constrained with pre-production drilling investigation 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 progress made towards geothermal development in Uganda.

2. LOCATION OF GEOTHERMAL RESOURCE AREA

Most of Uganda's geothermal resources are located in the western rift valley to which they are genetically and tectonically related. Geothermal surface features are aligned along fault scarps and fault traces (Figure 1). These resources are related to extensional tectonic intra-continental rift zones. The geological setting is extensional tectonics / fault-controlled.

3. PREVIOUS STUDIES

Geothermal studies by Department of Geological Survey and Mines (DGSM) dates way back to 1950's when 4 shallow wells were drilled in Buranga area (McConnel et al., 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 3 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 warranted advanced exploration to up-grade and refine the exploration model.

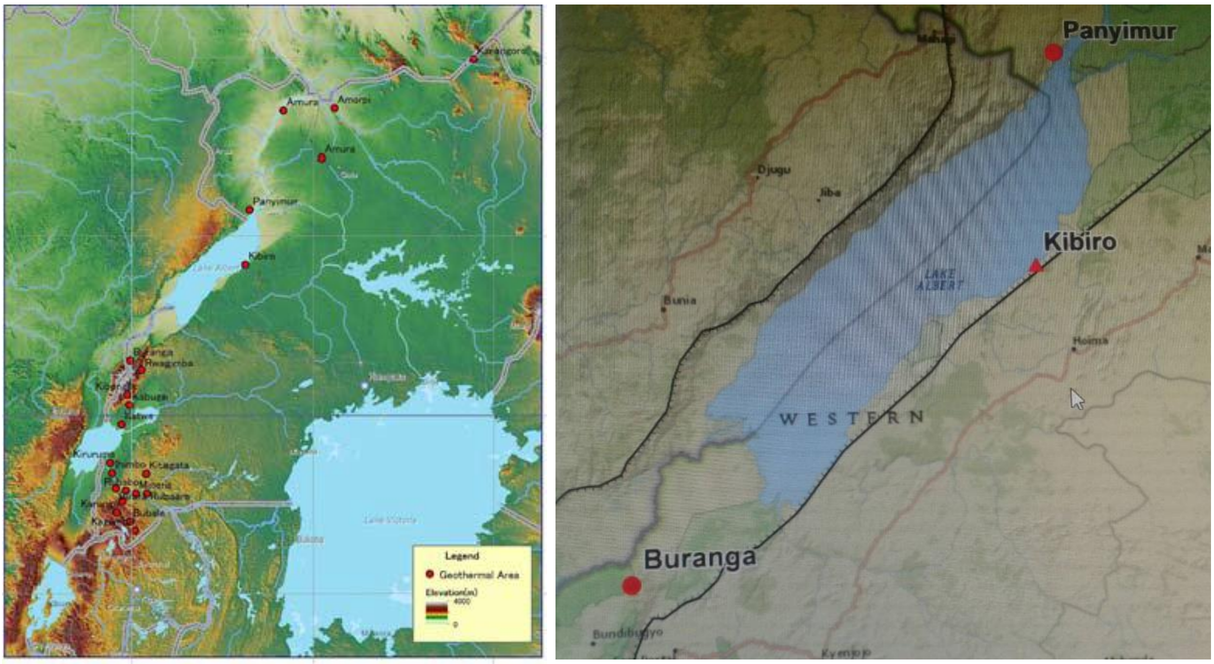


FIGURE 1: Location of Uganda's geothermal sites. On the right are areas where detailed focused studies have been undertaken.

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

Katwe-Kikorongo preliminary exploration (2003): African Development Bank (ADB) funded geothermal investigations were carried out 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.

GEOTHERM project: Germany Federal Institute for Geosciences and Natural Resources (BGR) together with MEMD conducted intermediate exploration in Buranga beginning 2003. This was under the GEOTHERM programme, which promoted the utilization of geothermal energy in developing countries. Project activities surface water sampling and analysis, isotopic studies, geophysical surveys (Gravity, TEM, and Schlumberger 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 3He/4He ratios of geothermal fluids were measured to determine if a deep mantle signature was present. These elevated 3He/4He ratios were believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs.

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

UGA/8/005 - Isotope hydrology for exploring 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. Initial exploration models were tested, supplemented, and refined by further field work. The process will continue until a hopefully reliable exploration model is achieved.

Introducing iotope 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): Data collection survey on geothermal energy development in East Africa, Final Report (Uganda): 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 eothermal resource 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 locate a prospective site 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. A conceptual model of Kibiro was developed. UNEP donated micro-seismic equipment which were installed around Kibiro to detect active tectonic fractures presumed to control geothermal activity.

4. LEGISLATION AND REGULATION

Currently, geothermal resources are regulated by the Mining Act 2003 and its regulation 2004. The existing regulatory framework allowed speculators to obtain geothermal exploration licences, thus delaying development of viable prospects. 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. Ability and capacity to undertake geothermal exploration by private investors is not there. 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. There is lack of a clear and comprehensive legal framework to regulate geothermal developers. GoU is in a process of developing a geothermal specific Legislation and regulation. GoU was technically assisted by Climate Technology Center and Network (CTCN). The Draft documents have been reviewed by EAGER hired experts and internally by an inter-Ministerial committee. Drafts are yet to be submitted to Cabinet and Parliament after undertaking a Regulatory Impact Assessment. After cabinet approval it will be transformed into a Bill which will passed into a law by Parliament. The new Bill will solve outstanding issues that are facing the geothermal industry by having legal and policy clarity.

5. GEOTHERMAL INSTITUTION

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. Originally, there was lack of legal and policy clarity with regard to geothermal resources. Staff recruitment commenced and these will be dedicated to geothermal regulation/ promotion. Core and standard geothermal investigation survey equipment have been procured. Geothermal Technology has been leveraged and benchmarked in Iceland, Japan, Kenya, New Zealand, USA and Zambia (Kalahari GeoEnergy Limited). 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.

6. CURRENT STUDIES

The geothermal investigation surveys have been mainly funded by GoU, public finance under the Uganda Geothermal Resources Development Project (1199). This project has been implemented since FY 2011/2012. The Project ended in December 2016, but was extended for another two years up to 2019 to complete the siting, drilling and testing of deep exploratory wells at the four sites. Geothermal exploration is cost intensive and risky. Few investors are willing to assume the risk in an unproven resource. GoU initiated Government-led exploration which has yielded results and major accomplishments. UNEP-ARGeo supported GoU capacity in conducting geothermal investigation surveys in Kibiro. Work culminated into developing a geothermal geological model of Kibiro. East African Geothermal Energy Facility (EAGER) funded by DFID of U.K. is extending technical support to Uganda. The EAGER hired Consultants have contributed significantly is data processing, analysis and interpretation. EAGER has supported government capacity through strengthening data management, planning and designing TGH wells (EAGER, 2016), and structural and geothermal conceptual model development at Panyimur and Buranga. EAGER has supported government capacity in developing a business model for GRD.

6.1 Western Rift Valley

Without clear understanding of the geology of a prospect area, exploration is merely guesswork. Unsuccessful attempts to explore for geothermal resources in Uganda invited a decision to first clearly understand Uganda's geothermal systems, their structural and geological setting. A working hypothesis was vital prior to undertaking any investigation surveys.

The western rift valley is approximately 100 km long normal fault systems with 1-6 km throws bounded by deeper side of asymmetric basins (border-fault segments), and the sense of basinal asymmetry commonly alternates along the length of the rift valley (Ebinger, 1989). The flanks of the rift have been uplifted 1-4 km above the surrounding Plateau, and basement lies below sea level beneath many basins.

Lithologically, it has tertiary-quaternary sediments in the graben and Precambrian basement rocks at the escarpment. The rift is seismically active both from felt and instrumental information. It is 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 active basin bounding faults. Geophysical and geological data in the Albertine Graben indicate that rifting was initiated during mid-Miocene about 17 ma (Abeinomugisha, 2010). Main bounding fault permeability increases during and after an earthquake as evidenced in flow rate of geothermal fluids.

The Western Rift 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 (Figure 2). According to Corti (2011), 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. Major bounding 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, 2011; Figure 2).

Studies of earthquake source parameter in the Western Rift show deep events down to 30-40 km (Nyblade and Langston, 1995) indicating *deep faults*. Depth to detachment estimates of 20-30km and seismicity throughout the depth range 0-30 km suggesting that planar *border faults penetrate the crust* (Ebinger and Scholz, 2012).

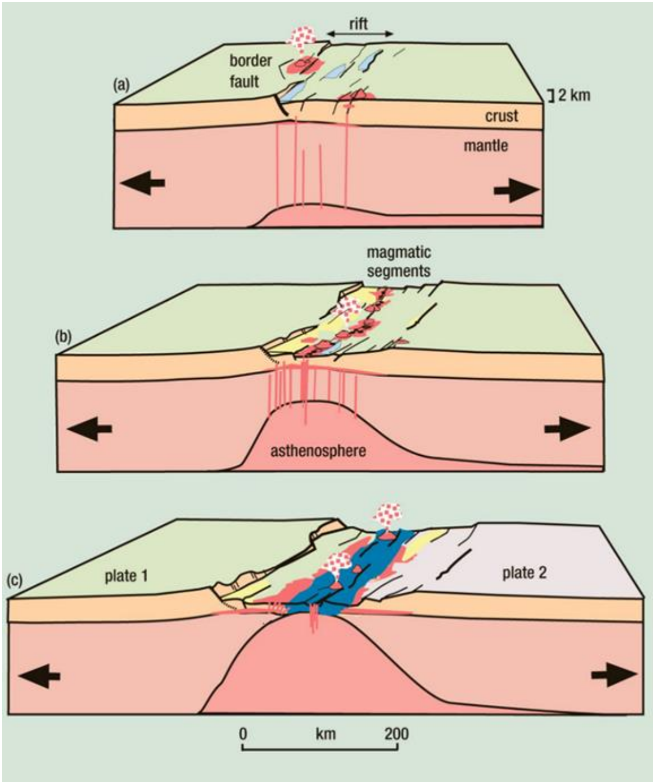


FIGURE 2: Stages of rift evolution. Western rift is presumed to be in stage a evolving to stage b (Corti, 2011)

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 indicate up to 67°C/km; Abeinomugisha,, 2010 personal comm.) and numerous geothermal systems. 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 are *fault-bounded extensional (horst and graben) systems* in non-volcanic environments which rely on deep circulation of meteoric water into the heated crust. Complexes of horsts and grabens occur in regions where there has been crustal extension and thinning. As the crust is pulled apart, it tends to fracture, forming steeply dipping faults that are perpendicular to the general direction of extension (Glassley, 2010).

Blocks of crust subside between faults forming grabens, whereas surrounding ground on opposite side of the bounding fault remain elevated forming horsts. The *high angle faults* that bound the horst and grabens can extend to considerable depth (Figure 3). Such setting are places where magma often rises in the crust, (Glassley, 2010) in response to decreased lithostatic pressure caused by crustal thinning during extension. As a result of presence of these heat, geothermal reservoir may occur. Permeability is commonly restricted to *fault-controlled zones* in the vicinity of horsts and grabens boundaries. In this case, rift bounding faults are geothermal exploration targets.

According to Inga Moeck, classification system of geothermal systems, most Uganda geothermal systems are Extensional Domain play Type CV3 (Moeck, 2013). In an extensional Domain Geothermal Play (CV3), the mantle is elevated due to crustal extension and thinning. The elevated mantle provide the principal source of heat for the geothermal system associated with this play type. According to Moeck, these are fault controlled geothermal plays in domains with extensional deformation. These non-magmatic conventional dominated geothermal plays systems are either *fault controlled* or *fault leakage controlled*.

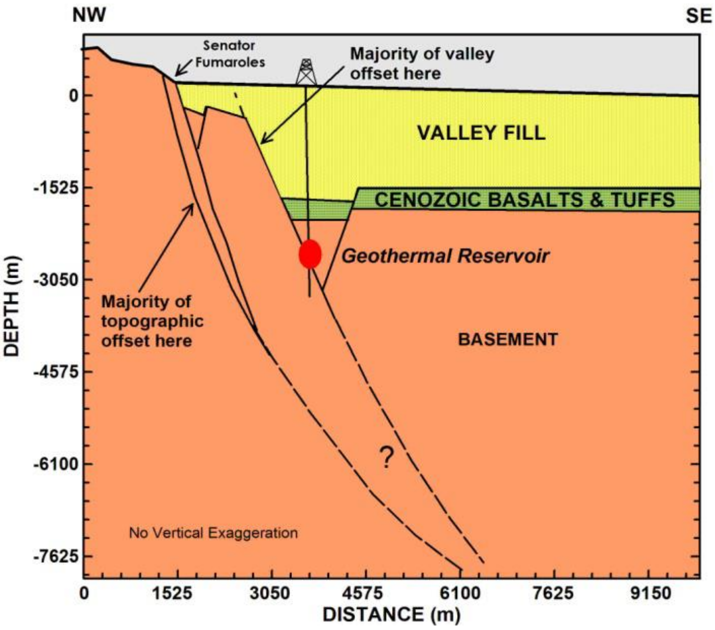


FIGURE 3: Idealized structural model of the Dixie Valley (Desert Peak) geothermal system which typifies Uganda geothermal systems

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 (Figure 4).

6.2 Kibiro Geothermal Resource Area

Surface water sampling and analysis was undertaken by Halldór Ármannsson (1994) and this data was reviewed in detail by Luigi Marini (2016a and 2016b). In collaboration with UNEP-ARGeo, GDC and GRD, a geothermal resource conceptual model was developed for Kibiro site (Figures 5, 6 and 7). Kibiro prospect is a *deep circulation (amagmatic) extensional geothermal system*. This is attested by low helium signature (BGR, 2007). The geophysical survey effectively constrained the geological setting of the Kibiro prospect, with reflection seismic, gravity and magnetics, all providing detailed constraints on the geometry, of the large scale structures affecting Kibiro area. Permeability is presumed to be structurally controlled by main rift bounding fault more so where it is intersected by cross-cutting faults (Kachuru). The main rift bounding fault provides high permeability flow-path that allows for deep circulation of meteoric waters into the thermal zone beneath the crust. TEM data has indicated a shallow reservoir at 300 m and this has been recommended for TGH.

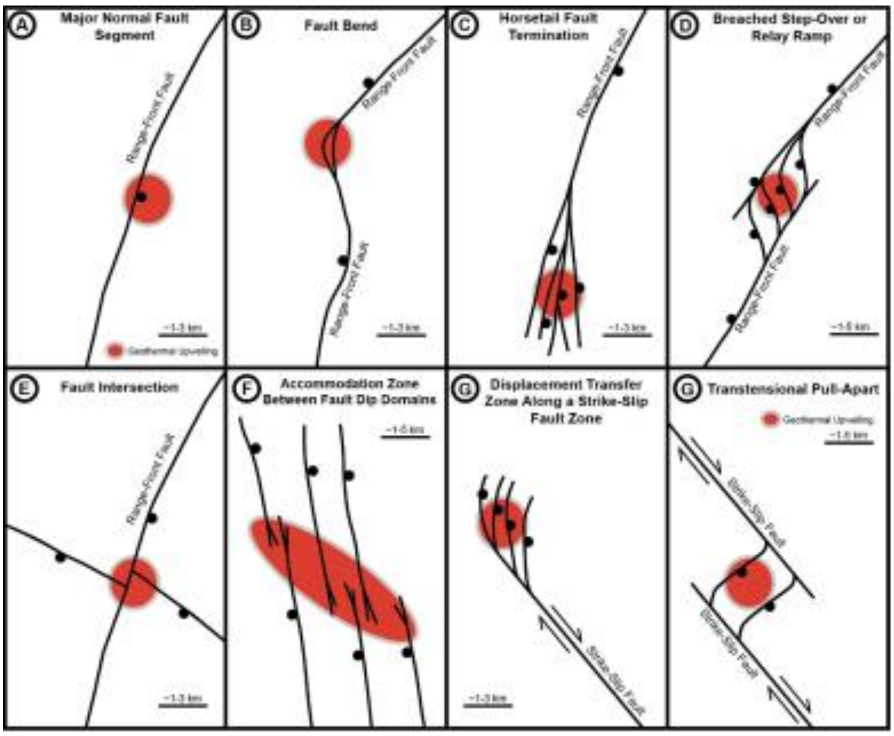


FIGURE 4: Structural setting idea for geothermal occurrence (Faulds and Hinz, 2015)

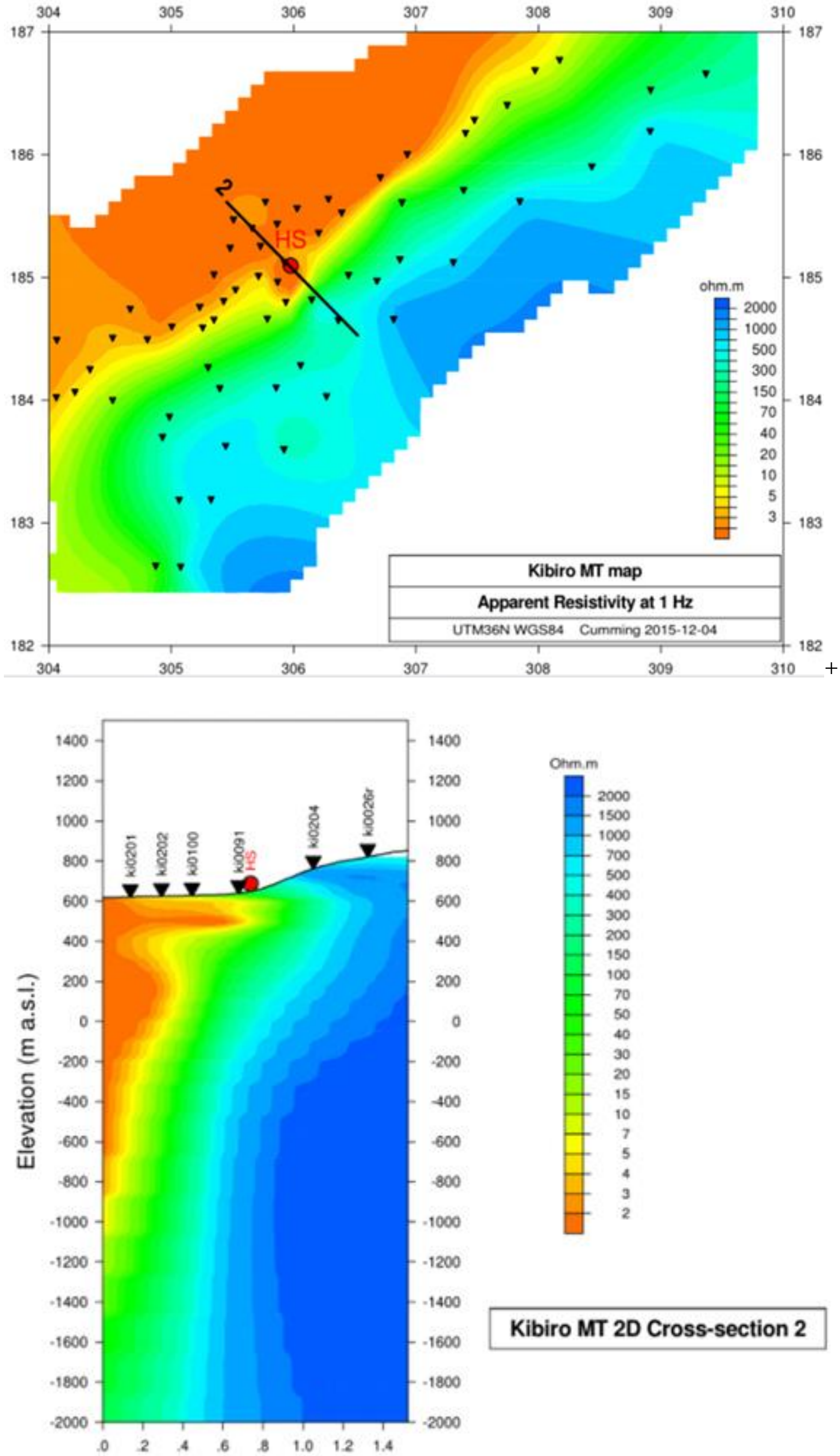


FIGURE 5: Magneto telluric section across Kibiro Prospect (Cumming, 2016). Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

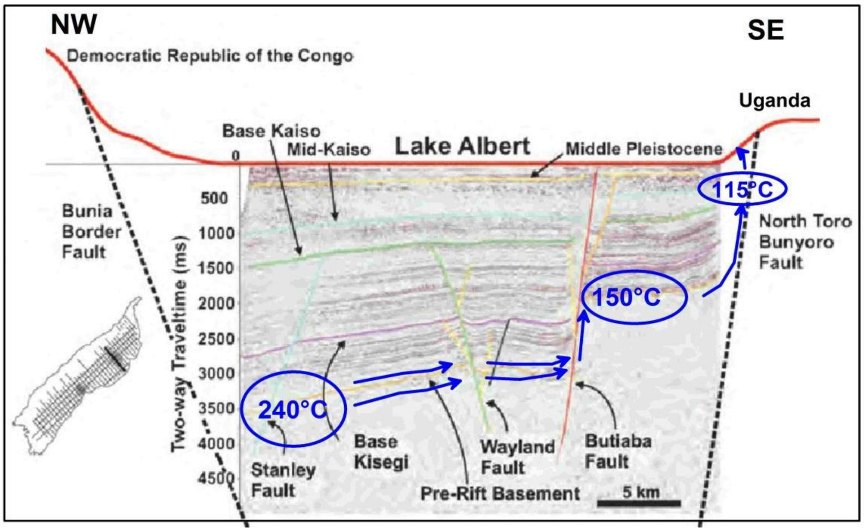


FIGURE 6: Multiple conceptual models were developed using geochemical data (Luigi Marini, 2016a and 2016b)

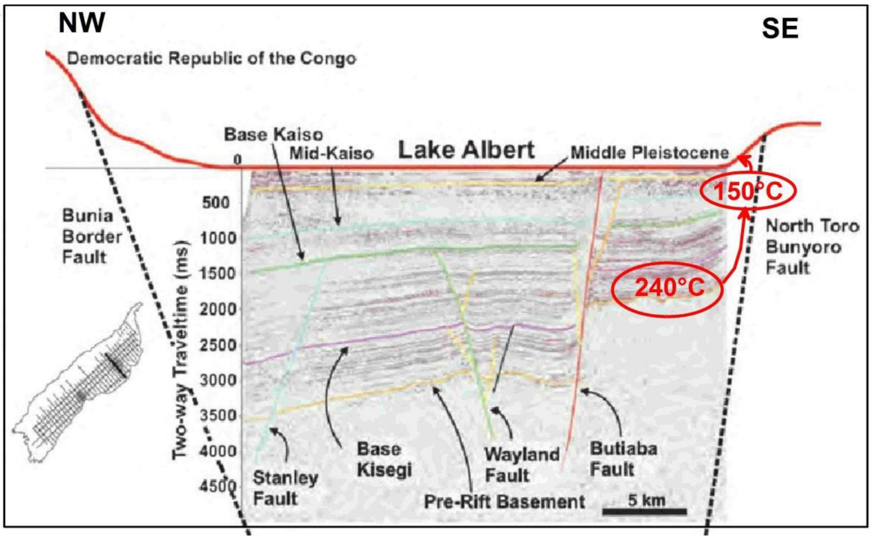


FIGURE 7: Multiple conceptual models were developed using geochemical data (Luigi Marini, 2016a and 2016b). Soil gas and gas flux measurements were undertaken in Kibiro by GDC personnel to aid in mapping active permeable fractures. This data was complimented by swallow temperature surveys to map thermal anomalies.

Gas flux measurements (Figure 8) indicate high anomalies along main rift bounding fault (Figure 9) complimenting soil gas data and shallow temperature probe survey data. The main rift bounding fault is seismically active according to preliminary micro-earthquake survey being undertaken in Kibiro (Figure 10).

6.3 Panyimur Geothermal Resource Area

Government-led geothermal investigation surveys have been undertaken at Panyimur area by GRD, technically supported by EAGER hired experts. Work included a combined MT/TDEM survey (Figures 11 and 12) supplemented by detailed structural mapping (structural model develoment) together with EAGER hired structural geologist (EAGER, 2017) Figure 13. Geothermal conceptual models have been developed (Figures 14-17) and these are being updated and refined as new data emerge.

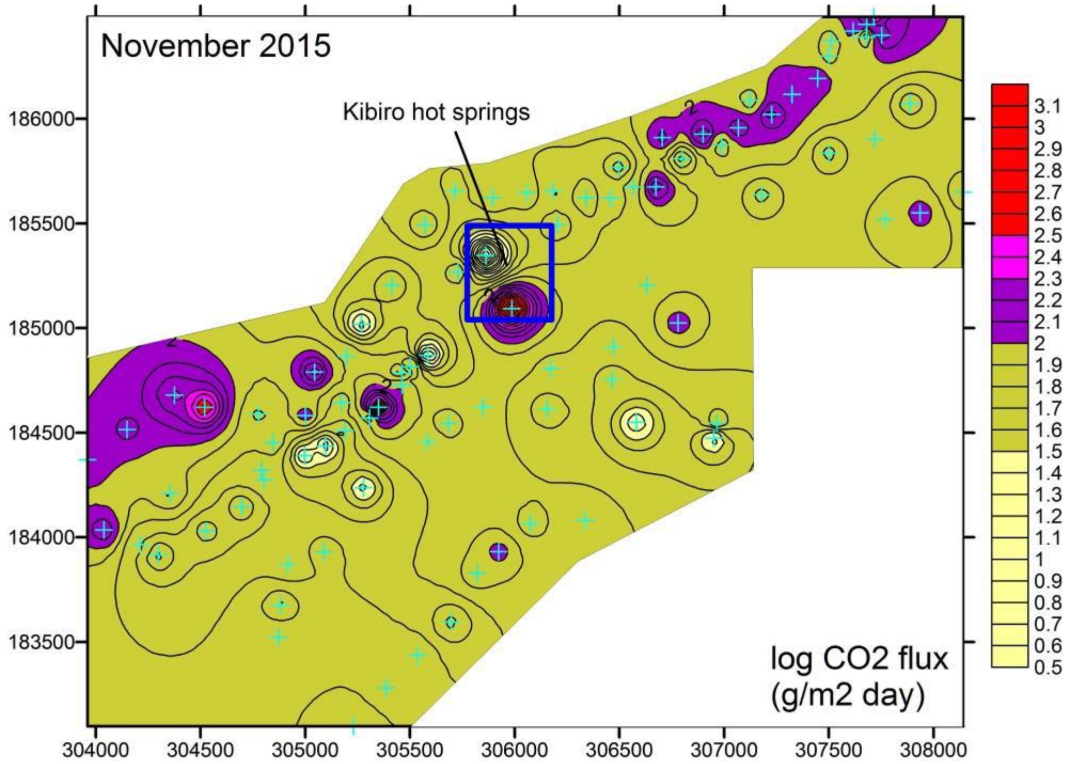


FIGURE 8: Gas flux measurements at Kibiro by GDC

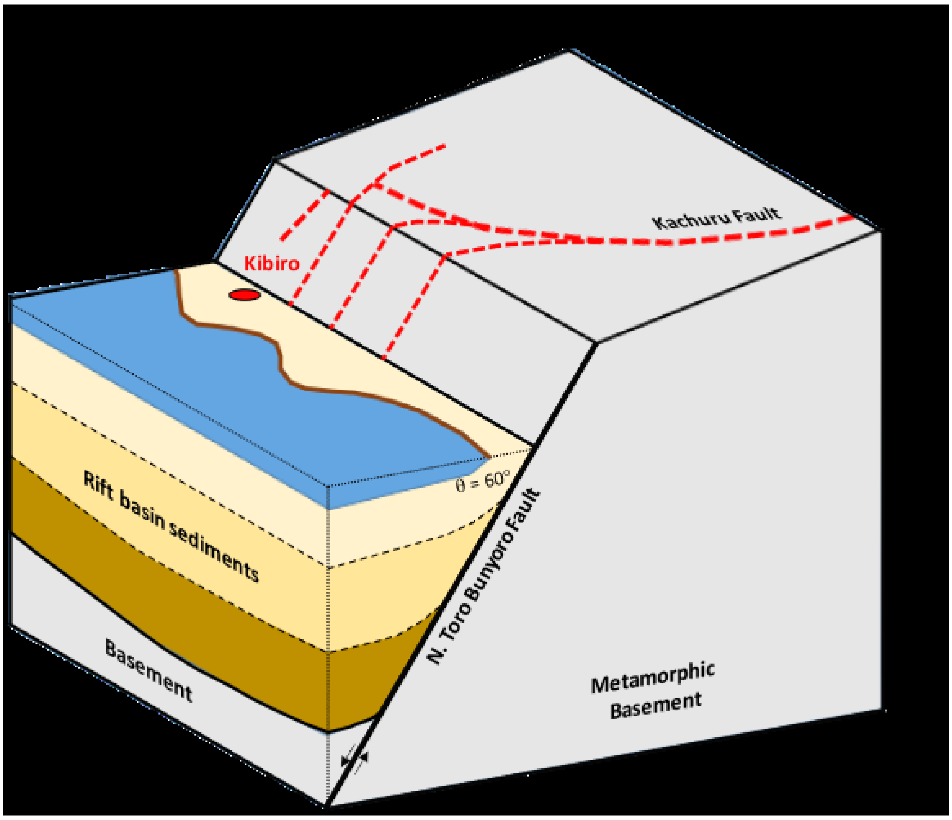


FIGURE 9: Schematic block diagram for Kibiro (Alexander, 2016)

FIGURE 10: Installing micro-seismic equipment donated by UNEP-ARGeo around Kibiro area

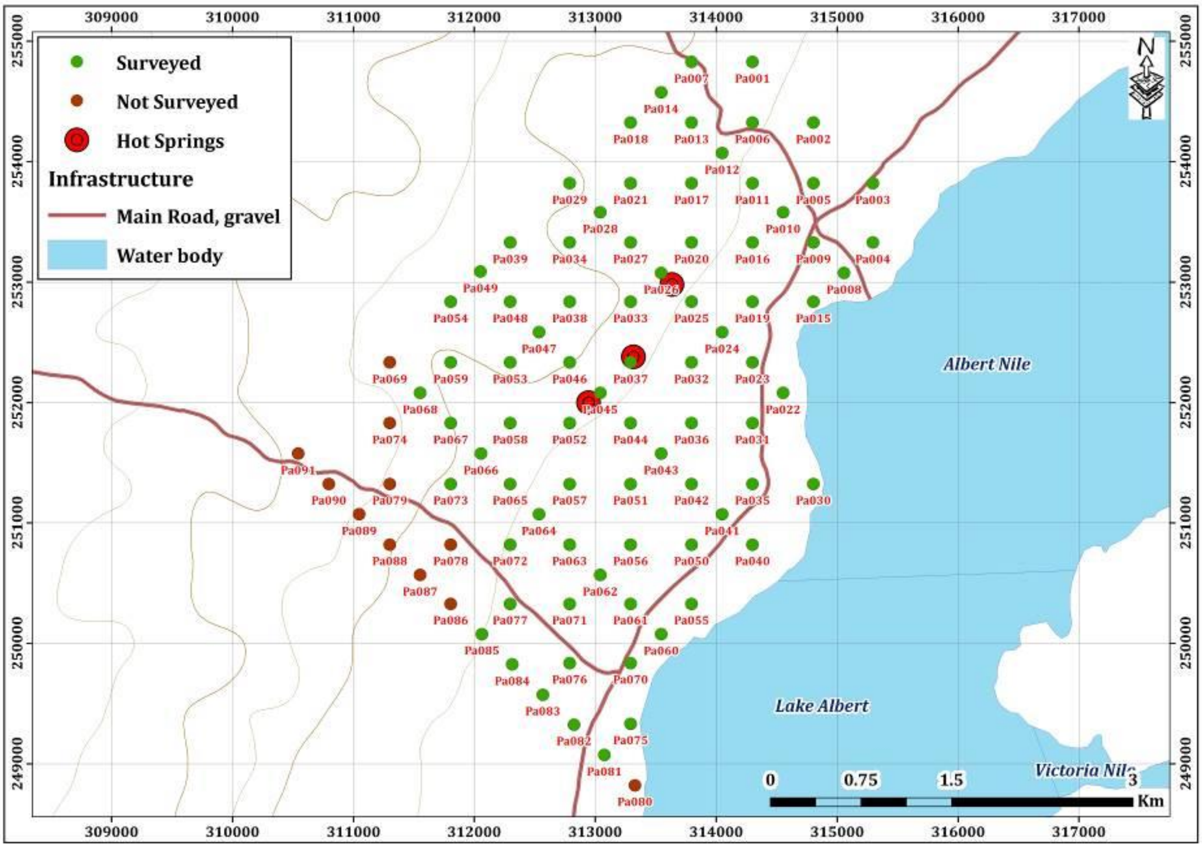


FIGURE 11: MT/TDEM Survey points in Panyimur area

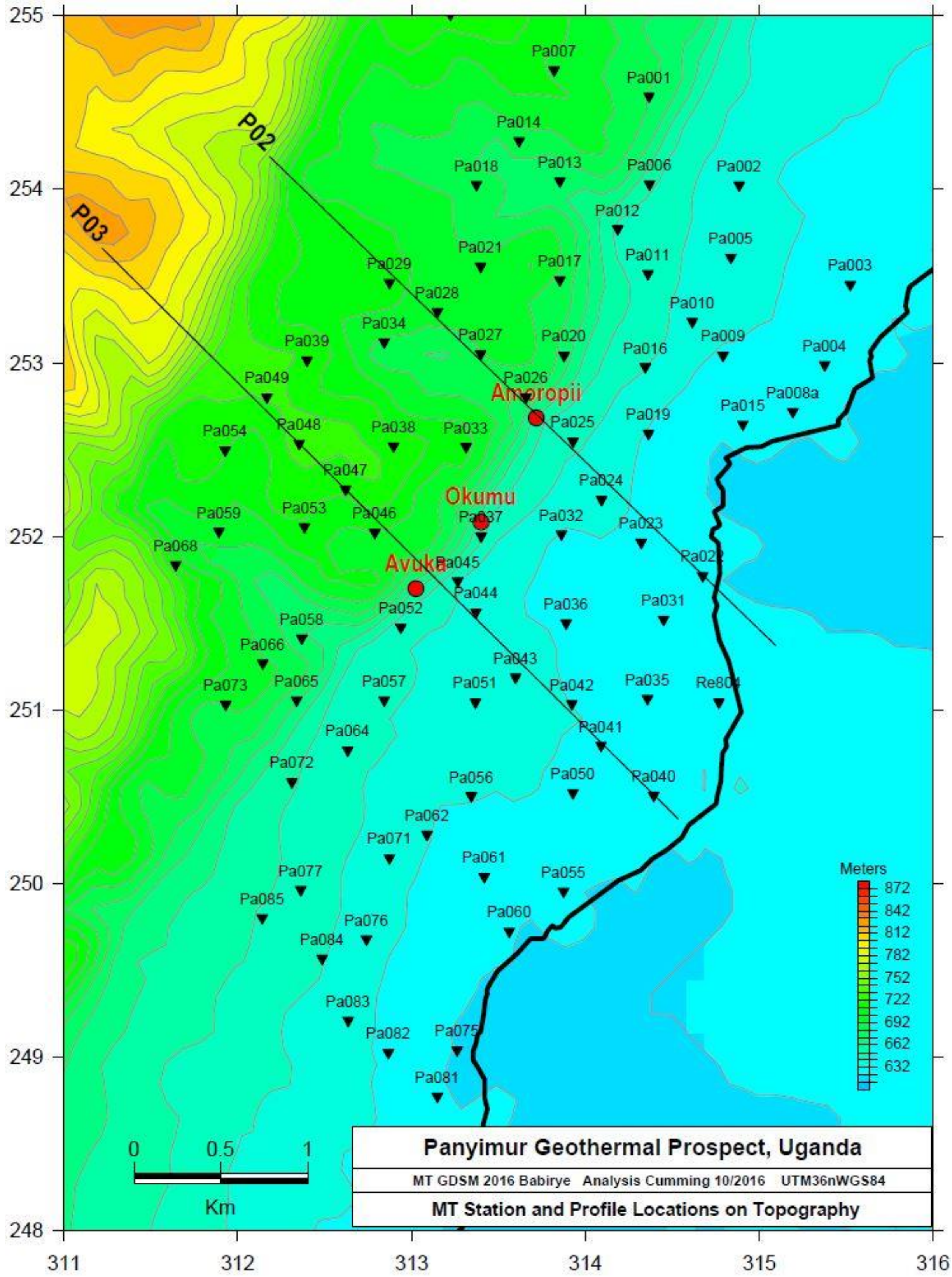


FIGURE 12: Panyimur Map MT station on topography map with hot springs (Cumming, 2016)

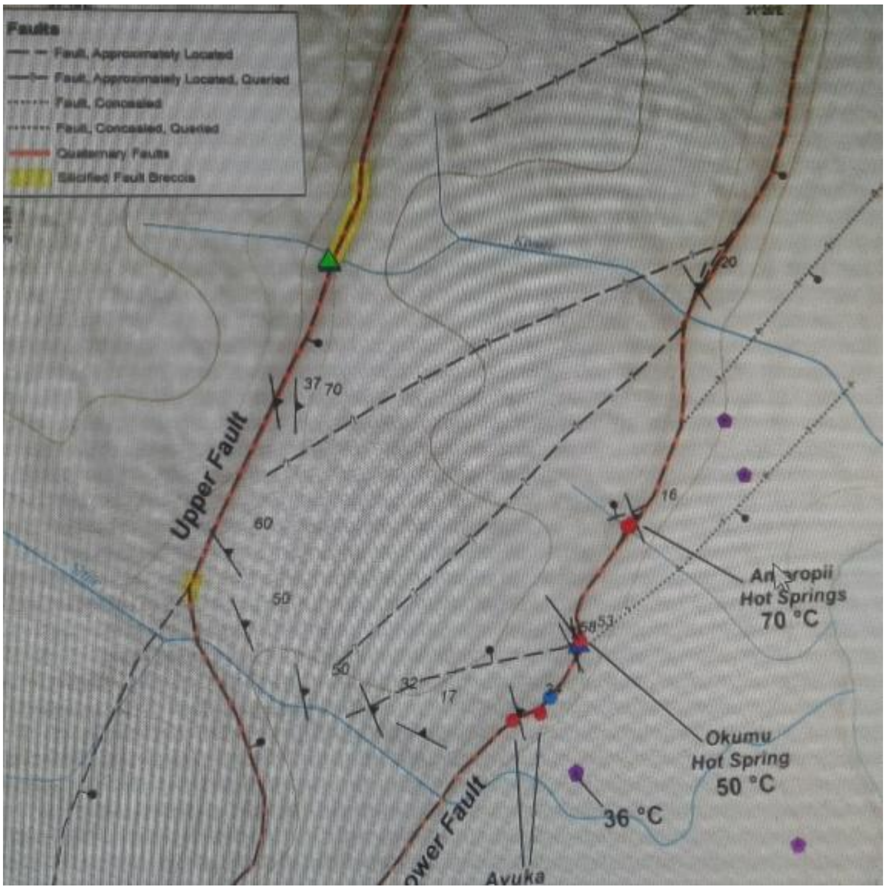


FIGURE 13: Structural mapping of Panyimur (EAGER, 2017)

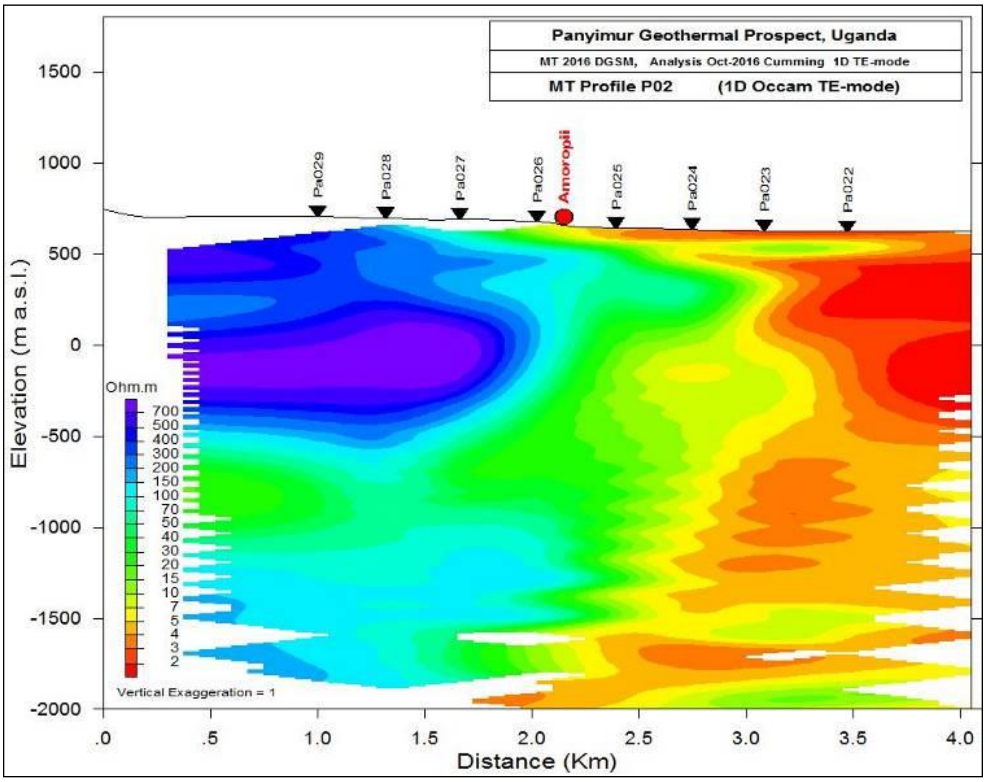


FIGURE 14: Panyimur profile P02-ID MT Resistivity (Cumming, 2016). Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

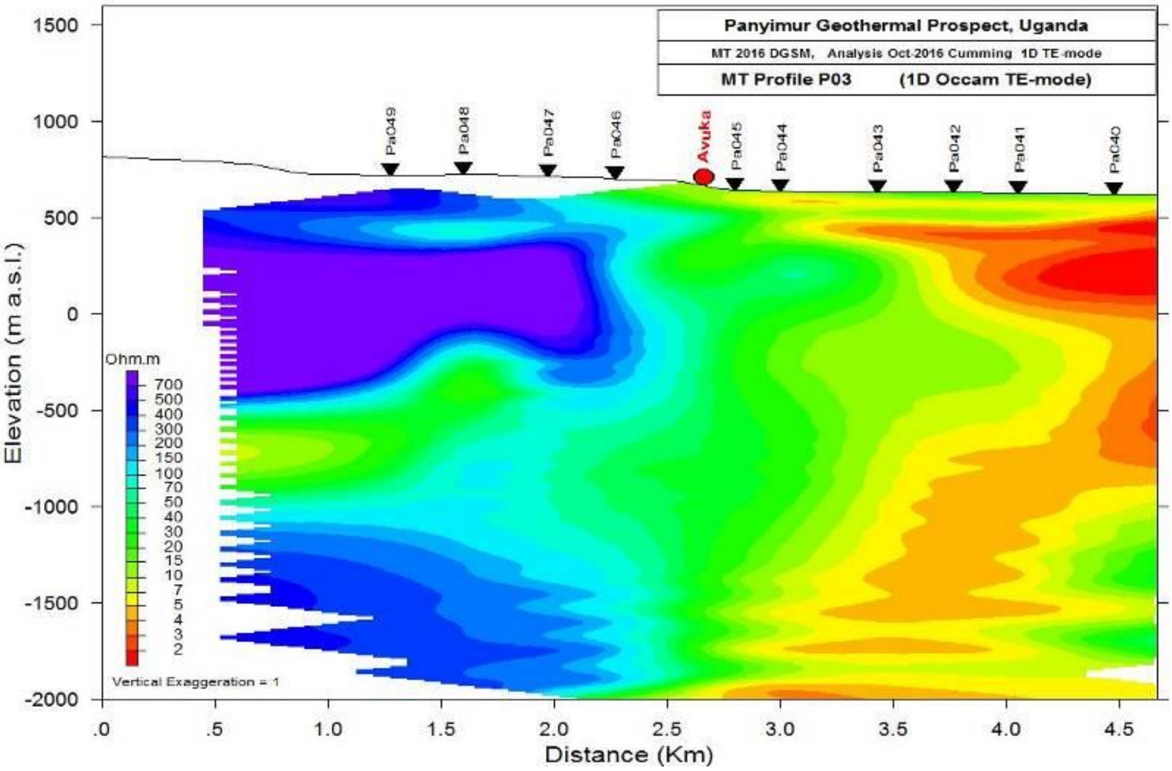
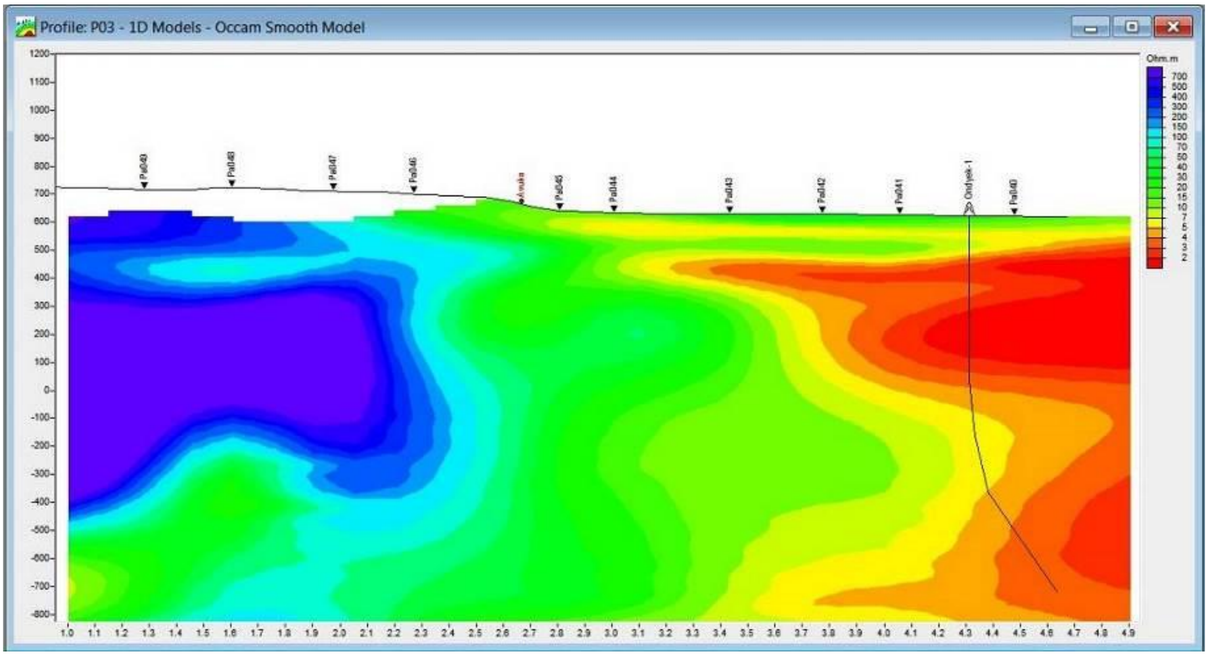


FIGURE 15: Panyimur profile P03-ID MT Resistivity (Cumming, 2016). Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.



FFIGURE 16: MT profile along Panyimur. Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

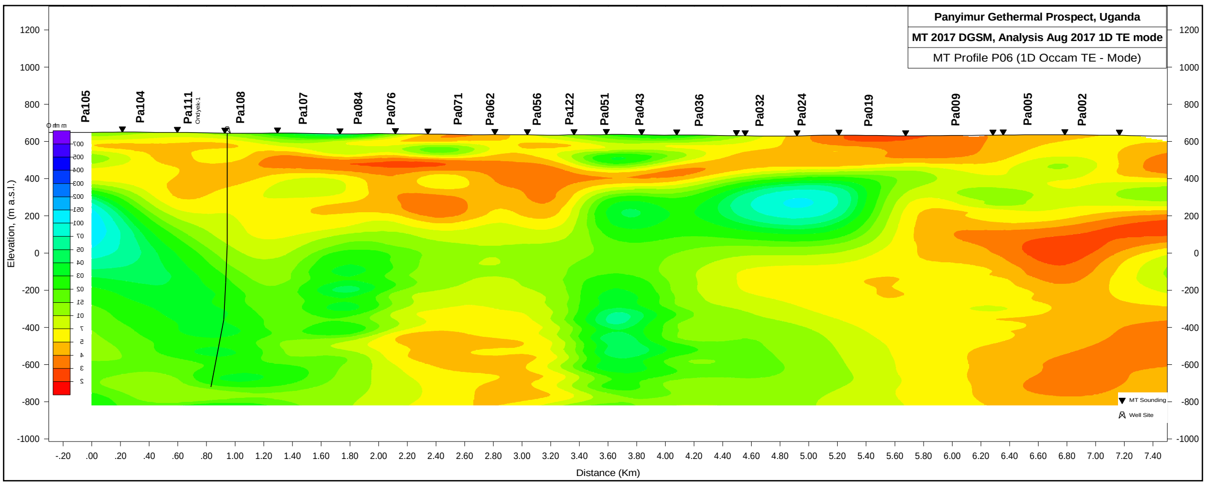


FIGURE 17: MT profile P10-1D models – Occam Smooth Model along Panyimur. Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

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.

The Dutch consortium of TNO, IF Technology and MET-support funded by the Netherlands Government is undertaking Panyimur data inventory and review of this data to build a conceptual model of this prospect. The consortium will provide support on the following four subjects; time-depth conversion, alignment of MT models with the seismic interpretation, a geothermal update of the seismic interpretation and workshop on how to build GIS-like earth science database. Geothermal investigation surveys in this area is leveraging on oil and gas data accumulated by oil companies.

6.4 Buranga Geotheral Resource Area

Geothermal Investigation surveys have been undertaken in Buranga by M/s Gids Consult Ltd supported by Geothermal Development Company (GDC) of Kenya (Figure 18). Further work has been undertaken by GRD technically assisted by EAGER hired expert. EAGER hired expert are involved in geothermal and structural model development (Figure 19). The area has been structurally mapped by GRD supported by EAGER experts. Review of MT data acquired by GDC revealed key data gaps which warranted data gap closure. In October 2017, GRD undertook focused MT in-fill surveys around the hot spring areas. Data is being processed.

Originally MT measurements were regionally conducted covering an area of more than 10 km, and sampling was not systematic possibly because of inaccessibility (Figure 20). Modelling such data proved difficult and anomalies indicated were questionable. These could be related to interpolation of dispersed data. More systematic measurements were warranted. GRD planned this survey and in October 2017, it was undertaken (Figure 21).

EAGER hired experts are planning drone aided thermal anomaly mapping in inaccessible areas of Buranga. Clearance of drone equipment is being finalised by relevant GoU institutionals like Ministry of Defence, Civial Aviation Authority and Ministry of Internal Affairs.

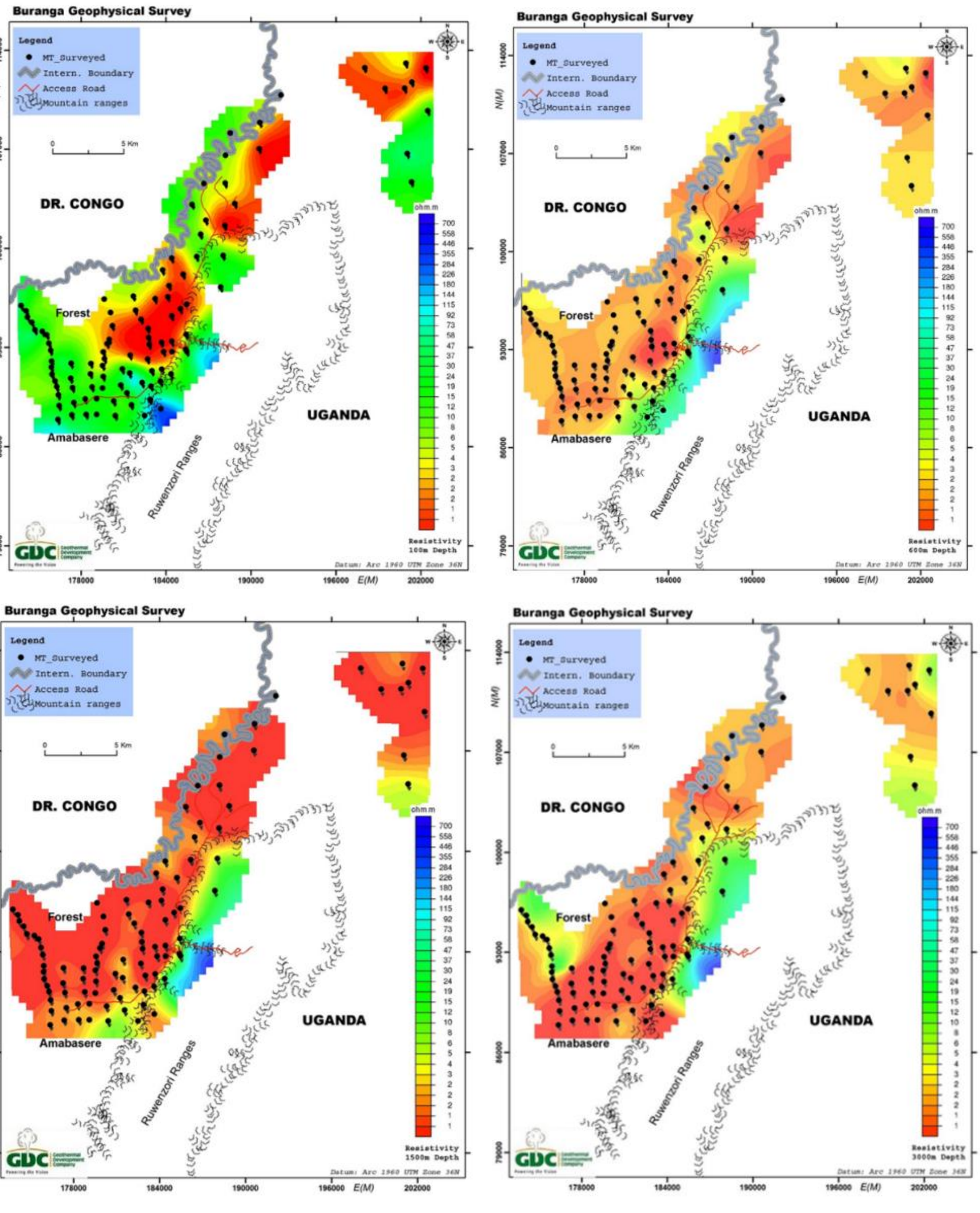


FIGURE 18: MT/TDEM data by GDC

6.5 Ihimbo Geothermal Resource Area

Geothermal Resource investigations have been conducted in this area including geological mapping. Surface manifestations include hot springs, travertine domes, vegetation kill areas, warms springs and gaseous emissions. Located in Ihimbo Forest Reserve in Rukungiri District (Figure 22) Ihimbo prospect is an extensional deep-circulation amagmatic 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.

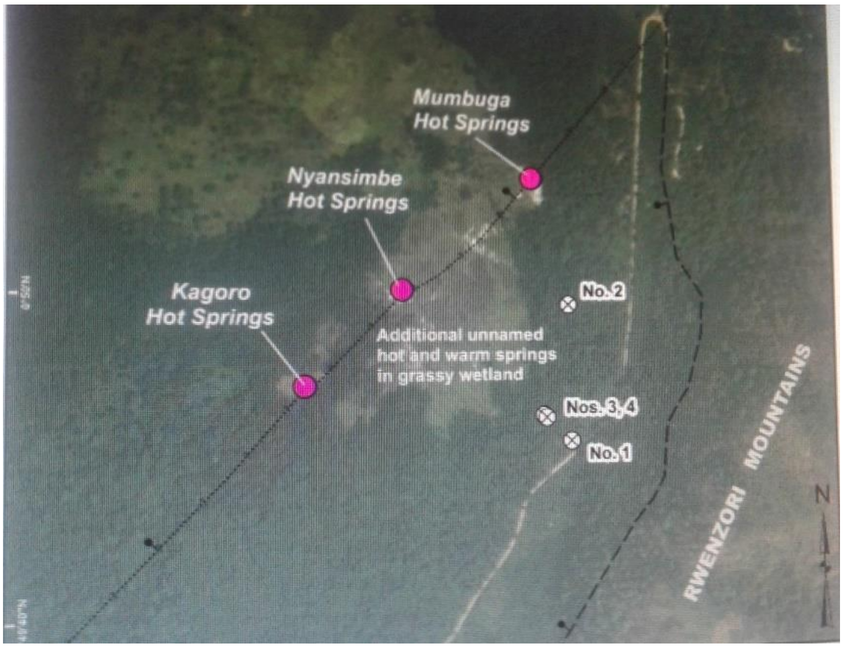


FIGURE 19: Structural map of Buranga (EAGER, 2017)

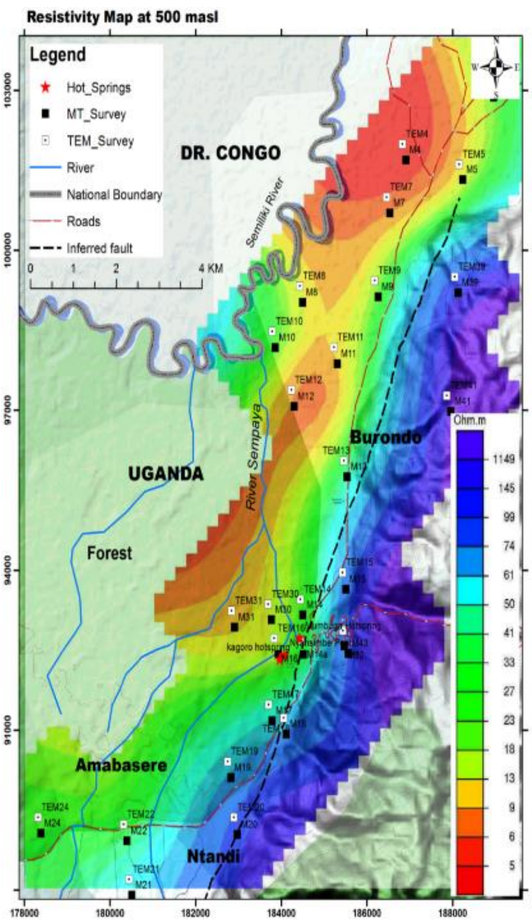


FIGURE 20: Resistivity survey (MT/TEM) at Buranga: Warm colors (red) indicate areas of low resistivity and cool colors (green and blue) indicate areas of high resistivity.

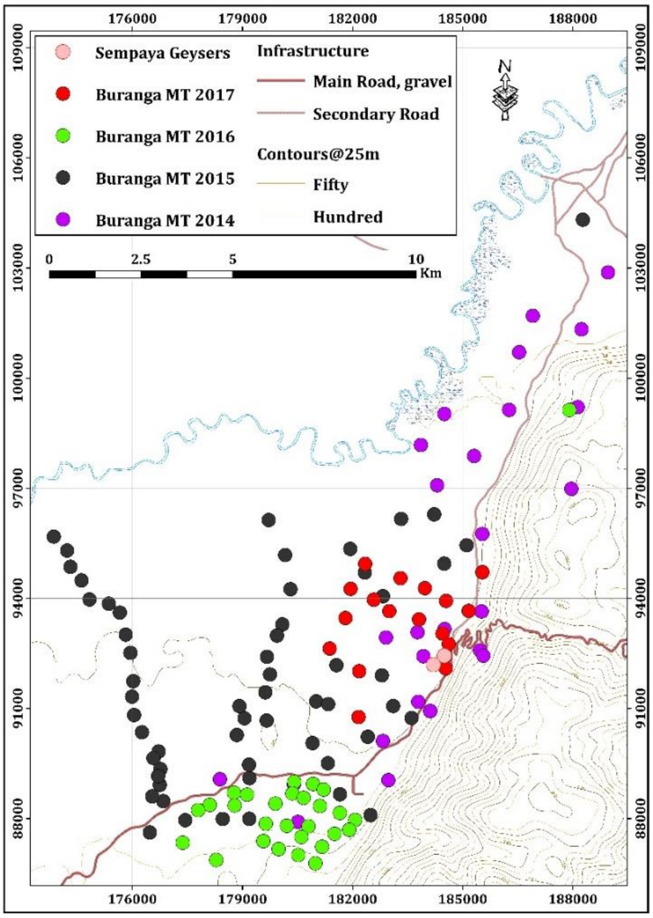


FIGURE 21: Red dots indicate focused MT measurements conducted in October 2017 by GRD

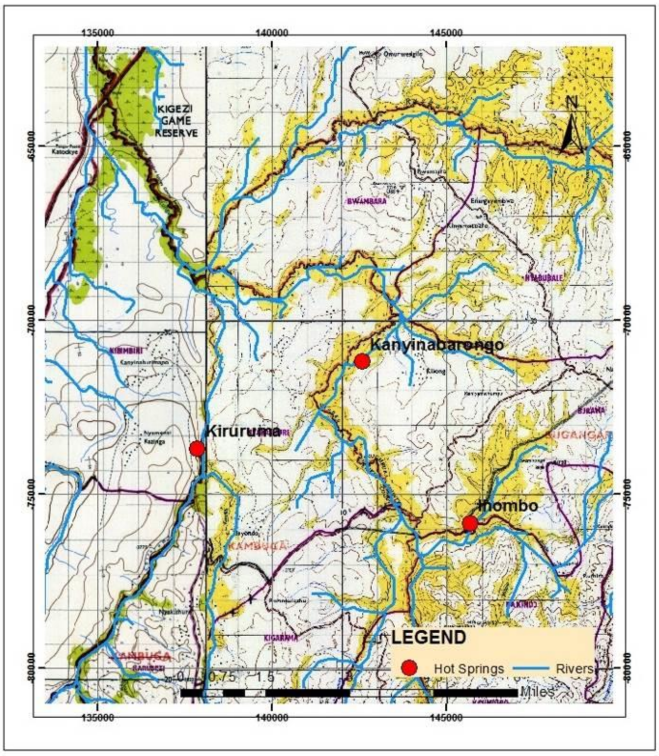


FIGURE 22: Topographic map of Ihimbo Area

Geochemical surveys have involved surface water sampling and analysis (JICA, 2014; Ármannsson et al., 2008), soil gas (Rn) and gas flux measurements. Swallow temperature measurements were also undertaken during the soil gas and gas flux measurements. Gas flux data and soil gas data (Rn) were processed (Figures 23 and 24). Anomalous gas concentrations are presumed to locate active fault zones presumed to control geothermal activity. High flux are presumed to be indicative of anomalous flux associated with geothermal activity.

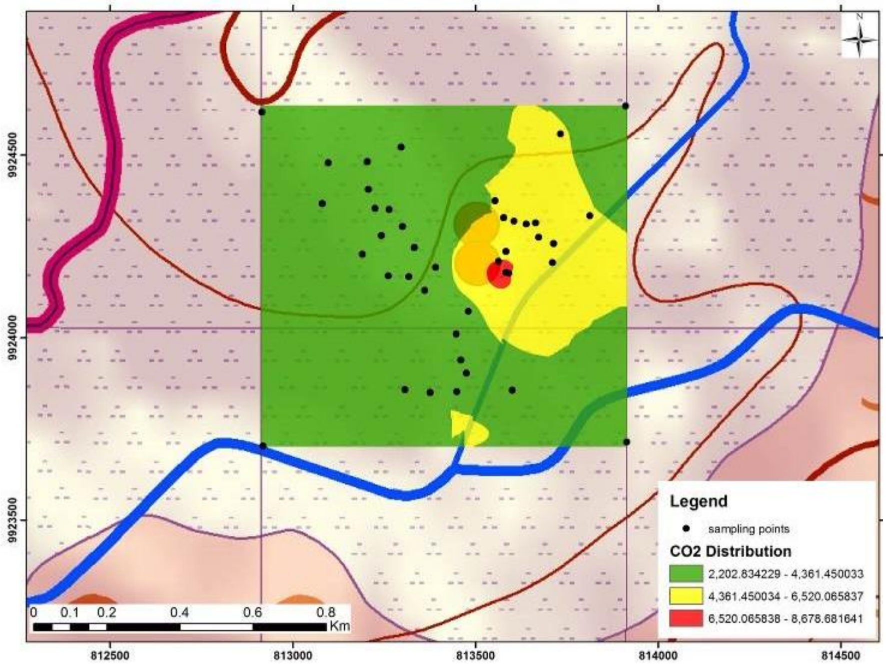


FIGURE 23: Spatial distribution of CO_2 flux measurements in Ihimbo area. Anomolous gas flux is presumed to indicate geothermal activity (permeable conduits).

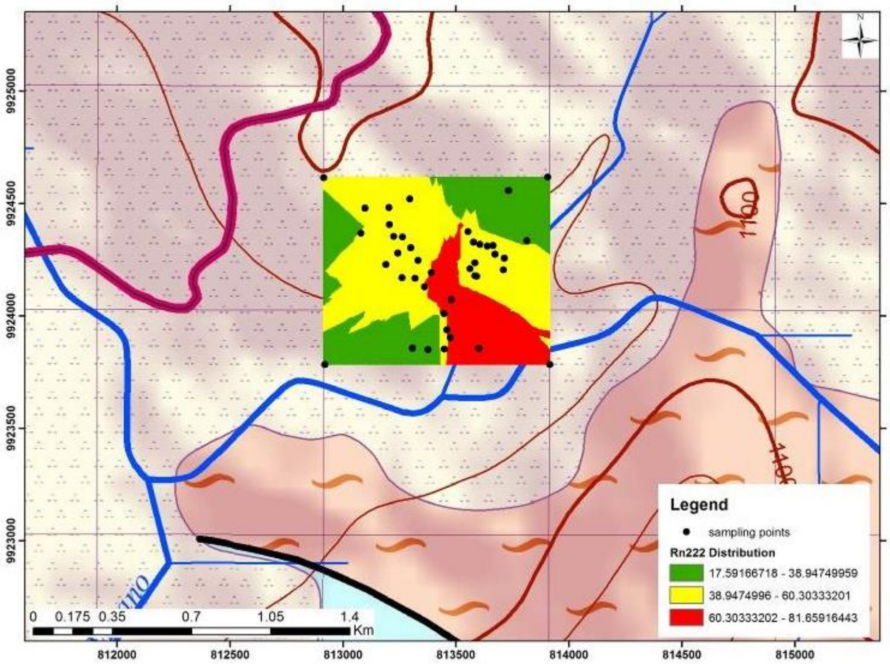


FIGURE 24: Distribution of activity of 222Rn diffusively degassed from the soil in Ihimbo geothermal prospect. Anomolous concentrations are presumed to indicate concelaed faults that act as conduits for geothermal fluids.

Magnetotelluric measurements (40 MT soundings) have been conducted (Figure 25) around the geothermal area. Key gaps in data will be identified for subsequent data gap closure. 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.

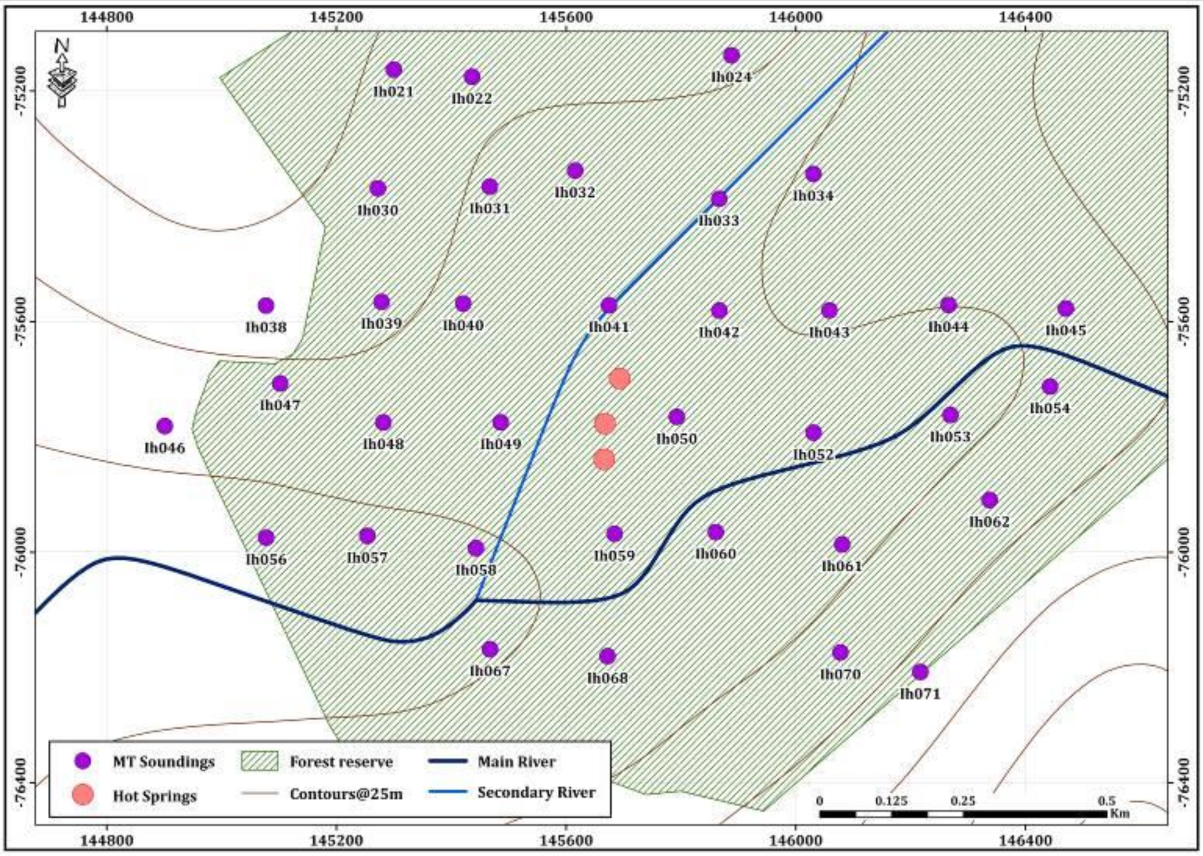


FIGURE 25: Stations for MT sounding at Ihimbo Geothermal Resource Area

6.6 Katwe Geothermal Resource Area

Kawe-Kikorongo geothermal prospect lies in a rift valley. It is also presumed to be a *deep circulation extension system*. This system is presumed to be *fault-bounded extensional (horst and graben) complex (Brophy Type E)*. The system is structurally controlled by the prominent NE-SW trending rift bounding fault (Figure 26). The deep penetrating crustal faults are indicated by reflective seismic section from oil and gas survey. The faults are seismically active and aligned with numerous geothermal surface manifestations including tufa towers.

Unlike other fault-bounded systems in Uganda, the *deep crustal fractures extended to a considerable depth* giving way to magma escaping culminating into Katwe-Kikorongo quaternary volcanic field. These volcanic materials are characterised by SIO_2 under saturation, low Al, moderately high K but extremely high Ca content (Tappe et al., 2003). Pyroclastics dominate over lavas (Holmes and Harwood, 1932) due to the *extremely volatile rich explosive nature of the volcanism*. Magmatism was active in upper Pleistocene and continued intermittently until recent times (Holmes, 1950; Lloyd et al., 1985). These are *less viscous* and all the material is likely to have been ejected with minimal chances of forming *shallow magma chambers* (intrusion of young magmas). Silicic magma are viscous and in most cases get lodged in swallow high level magma storage chambers producing heat needed by geothermal systems unlike basaltic magmas which are less viscous and extremely volatile.

Geothermal investigation surveys will involve reviewing oil and gas data more so gravity, and reflective seismic. This will be followed by focused structural mapping, combined MT/TDEM survey (Figure 27), soil gas and gas flux measurements. There after pre-drilling investigations (swallow temp probe surveys, TGH and slimhole) will be conducted. Data will be integrated a geothermal conceptual model developed.

7. FUTURE PLANNED ACTIVITY

a) **Katwe-Kikorongo:** Field personnel will conduct a combined MT/TDEM survey, soil gas and gas flux measurements, shallow temperature probe survey, detailed structural mapping, reviewing oil and gas data and develop multiple conceptual models. Finally we plan to undertake slimhole exploration prior to deep well drilling.

b) **Kibiro**: Drilling six (6) TGH/ Slim wells to confirm reservoir prior to drilling deep wells. Additional structural mapping with EAGER hired expert is planned to refine the model.

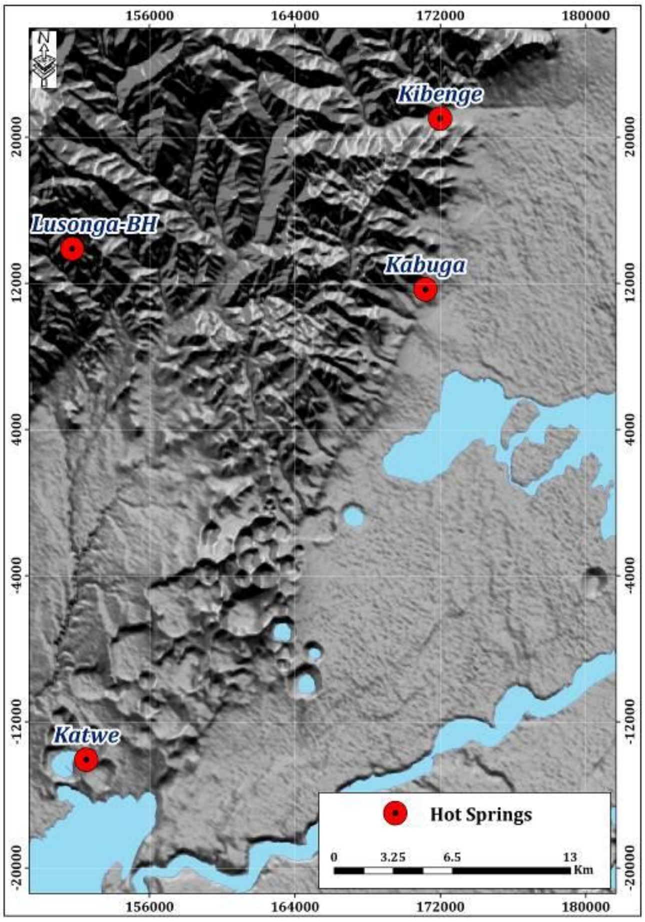


FIGURE 26: Note NE-SW principal rift bounding fault

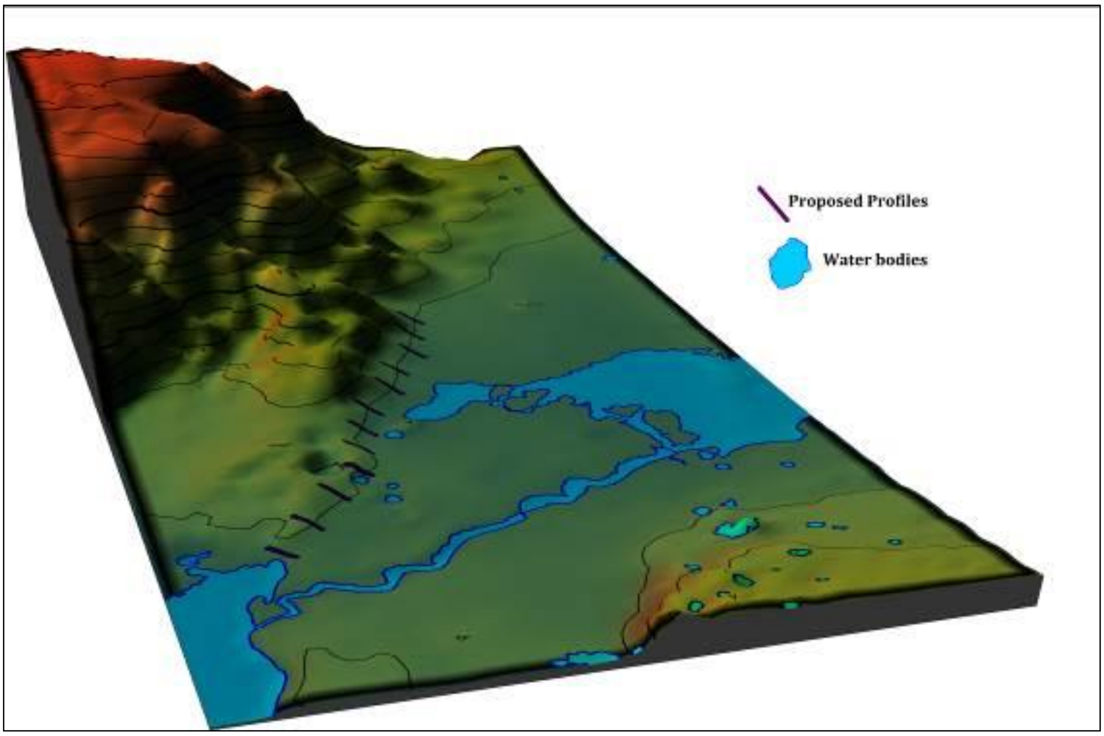


FIGURE 27: Planned MT/TDEM profiles perpendicular to principal strike of the rift bounding fault

c) **Panyimur**: Field personnel will conduct soil gas and gas flux measurements, shallow temperature surveys, TDEM survey for MT static correction using recommended Geonics Equipment. Additional structural mapping with EAGER hired expert is planned. GRD plans to drill six (6) TGH/Slim holes prior to deep drilling.
d) **Ihimbo**: Field crew plan to conduct additional MT infill, TDEM survey, detailed structural mapping, review oil and gas data (down hole temperature data, reflective seismic data), integrate data and develop multiple conceptual models. GRD plans to drill six (6) TGH/Slim holes prior to committing deep exploration wells.
e) **Buranga**: GRD is processing infill MT data, planning to acquire TDEM using recommended Geonics, undertake soil gas and gas flux measurements, shallow temperature surveys, drone aided thermal anomaly mapping, drill six (6) TGH/Slim holes. Slimhole exploration is planned prior to committing deep exploration.

8. FUNDING OPPORTUNITIES

The World Bank (WB) Energy for Rural Transformation (ERT-3) has committed funds USD 700,000 towards geothermal development. This will be applied towards geothermal development studies and equipment for pre-drilling investigations.

Uganda has submitted request for GRMF to undertake slimhole exploration in at least two prospects.

9. 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 amagmatic 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.

The conceptual models of Kibiro was developed, and plans are in advanced stages to drill six (6) TGH/Slim holes in Kibiro. GRD is technically assisted by EAGER hired experts. The conceptual model is based on available geologic, geophysical, geochemical and hydrologic data. This model is not unique but can be considered a first approximation, established within existing constraints. As additional data are generated, more specific models will be developed.

Data gap closure is going in Panyimur technically assisted by EAGER hired experts which include TDEM survey, soil gas and gas flux measurements, shallow temperature surveys and detailed structural mapping. Data will be integrated and conceptual model developed. Slimhole exploration is recommended.

Data gap closure is going in Buranga technically assisted by EAGER hired experts. Work will involve TDEM survey, Drone aided thermal anomaly mapping, soil gas and gas flux measurements, shallow temperature probe survey. Slimhole exploration is recommended.

MT/TDEM is planned in Katwe following structural mapping by EAGER experts and local staff. This will be followed by soil gas and gas flux measurements, shallow temperature measurements. The data will be supplemented by oil and gas data to include reflective seismic, gravity and oil well temperatures. Slimhole exploration is recommended.

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

In all the investigated prospects slimhole exploration is planned prior to committing cost intensive and risky deep exploration. It is better to drill a cheap dry well than an expensive dry well.

REFERENCES

Abeinomugisha, D., 2010: Development of a petroleum system in a young rift basin prior to continental break up: The albertine graben, of the East African Eift System. AAPG, Search and Discovery Article #10284. *Website: http://www.searchanddiscovery.com/documents/2010/10284abeinomugisha/*

Alexander, K., 2016: *Draft geothermal geology report. Kibiro Geothermal Prospect, Uganda*. UNEP-ARGeo, GDC, GRD.

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

Ármannsson, H., Bahati, G., and Kato, V., 2008: Preliminary investigations of geothermal areas in Uganda, other than Katwe-Kikorongo, Buranga and Kibiro. *Papers presented at Second African Rift Geothermal Conference (ARGeo-C2),* Entebbe, Uganda, 19 pp.

BGR, 2007: Detailed surface analysis of the Buranga geothermal prospect, West Uganda. Final report, 168 pp.

Corti, G., 2011: Evolution and characteristics of continental rifting: Analog modeling-inspired view and comparison with examples from the East African Rift System. *Tectonophysics, 522-523,* 1-33.

Cumming, W., 2016: *Kibiro geophysics*. Presentation.

EAGER, 2016: *Specification for drilling temperature gradient holes*. East Africa Geothermal Energy Facility, report U-14-D01.

EAGER, 2017: *Structural geology at Panyimur and Buranga*. East Africa Geothermal Energy Facility, report U-23-D02.

Ebinger, C.J., 1989: Tectonic development of the western branch of the East African rift system. *Geological Society of America Bulletin, 101-7*, 885-903.

Ebinger, C.J. and Scholz, C.A., 2012: Continental rift basins: The East African perspective. In: Busby, C. and Azor, A. (eds.), *Tectonics of Sedimentary Basins: Recent Advances* (1st ed.). Blackwell Publishing, Chisester, United Kingdom, 664 pp.

Faulds, J.E. and Hinz, N.H., 2015: Favorable tectonic and structural settings of geothermal systems in the Great Basin Region, Western USA: Proxies for discovering blind geothermal systems. *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, 6 pp.

Glassley, W.E., 2010: *Geothermal energy. Renewable energy and the environment*. CRC Press, Boca Raton, Florida, United States, 320 pp.

Holmes, A., 1950: Petrogenesis of Katungite and its associates. *Amer. Miner., 35*, 772-792.

Holmes, A. and Harwood, H.F., 1932: Petrology of the volcanic fields east and south-east of Rwenzori, Uganda. *Quart. J. Geol. Soc. Lond.*, *88*, 370-439.

JICA, 2014: *Data collection survey on geothermal energy development in East Africa. Final report (Uganda).* Japan International Cooperation Agency, West Japan Engineering Consultants Inc., and Mitsubishi Materials Techno Corporation, 148 pp.

Lloyd, F.E., Arima, M., and Edgar, A.D., 1985: Partial melting of phologpite-clinopyroxenite nodule from south-west Uganda: An experimental study bearing on the origin of highly potassic continental rift volcanics. *Contributions to Mineralogy and Petrology*, *91*, 321-329.

Marini, L, 2016a: *Geochemical model of Kibiro*. Second UNEP-ARGeo Technical Review Meeting, Dar es Salaam, Tanzania.

Marini, L., 2016b: *Geochemistry report. Kibiro Geothermal Prospect, Uganda. Draft Report for UNEP-ARGeo.*

McConnell, R.B. and Brown, J.M., 1954: Drilling for geothermal power at Buranga hot springs, Toro. Geological Survey of Uganda, unpublished report R.B.M/16.

Moeck, 2013: Geothermal plays in geologic settings. *IGA workshop on developing best practice for geothermal exploration and resource*.

Ochmann, N., Lindenfeld, M., Barbirye, P., and Stadtler, C. 2007: Microearthquake survey at the Buranga geothermal prospect, Western Uganda. *Proceedings of the Thirty-Second Workshop on Geothermal Reservoir Engineering, Stanford University*, Stanford, United States, 8 pp.

Tappe, S., Foley, S.F., and Pearsons, D.G., 2003: The Kamafugites of Uganda: A mineralogical and geochemical comparison with their Italian and Brazilian analogues. *Periodico di Mineralogia, 72*, 51-77.