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GEOTHERMAL EXPLORATION IN UGANDA

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ABSTRACT

A secure and sustainable energy mix is one of the key challenges which Government of Uganda (GoU) as a nation faces in the years ahead, as the world responds to the challenges of climate change, energy security and economic competitiveness. As a strategy to mitigate energy security and climate change, GoU decided to increase power generation in short term but also diversify its power generation sources in the long term. This was to include developing its geothermal energy resources.

The timeline for geothermal exploration in Uganda has stretched too far dating back in early 1950's when swallow wells were drilled in Buranga. There is need to apply breakthrough techniques and technology in order to fast track geothermal development in Uganda. Key elements of successful geothermal energy development include institutions, policies, reliable resource information and finance. Each of these four elements represents a factor that directly affects the outcome of the geothermal project.

Geothermal systems in Uganda are deep circulation amagmatic systems which typifies other fault-controlled Rift valley geothermal fields that are driven by deep circulation of ground meteoric waters. The heat source is ascribed to extension and thinning which resulted in high heat flow. Normally, these are deep reservoirs which can be assessed by deep penetrating measurements like magnetotelluric (MT) in combination with reflective seismic and Transient Electromagnetism. Electromagnetic (EM) and magnetotelluric (MT) methods are typically used to map resistivities at depths greater than 500 meters. Magnetotelluric (MT) measurements were tested in Kibiro and Panyimur and inversion of the data revealed a deep, sub-vertical conductor presumed to be geothermal reservoir. The interpretation of reflective seismic surveys formed a highly detailed and reliable picture of the subsurface structure, with resolution unattainable by most other geophysical methods. Exploration models have been developed for Kibiro and Panyimur geothermal sites. This will be tested by drilling deep exploration wells. Soil-gas and gas-flux measurements at Kibiro revealed active main faults presumed to control fluid flow.

The 3He/4He ratios of geothermal fluids from Buranga geothermal systems were measured to determine if a deep mantle signature was present. Results indicated elevated 3He/4He ratios. These elevated 3He/4He ratios were believed to be

evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs. The results could be used to identify extensional faults with deep permeability.

It is important to have and follow a strategy to minimize cost and maximize success in exploring for and evaluating geothermal resources. Without a good understanding of the geology of a prospect area, exploration is merely guesswork.

1. INTRODUCTION

A secure and sustainable energy mix is one of the key challenges which Government of Uganda (GoU) as a nation faces in the years ahead, as the world responds to the challenges of climate change, energy security and economic competitiveness. As a strategy to mitigate energy security and climate change, GoU decided to increase power generation in short term but also diversify its power generation sources in the long term. This was to include developing its geothermal energy resources.

Geothermal technology has the potential to provide large scale, base load power for 24 hours a day, 365 days a year. The geothermal industry in Uganda is still at a very early stage and faces a number of technical and non-technical challenges in order to achieve its potential as a contributor to Uganda's energy mix. The timeline for geothermal exploration in Uganda has stretched too far dating back in early 1950's when swallow wells were drilled in Buranga. There is need to apply breakthrough techniques and technology in order to fast track geothermal development in Uganda. Key elements of successful geothermal energy development include institutions, policies, reliable resource information and finance. Each of these four elements represents a factor that directly affects the outcome of the geothermal project.

GoU is a strong supporter of geothermal energy and since FY 2011/12, Government has committed public funds towards the development of its geothermal resources in collaboration with several development partners. GoU has so far undertaken Government-led exploration in four prospective areas to determine whether geothermal energy could generate some of its electrical-power requirements. The exploration project included geologic mapping, geophysical and geochemical surveys and developing exploration models. This will be followed by drilling thermal-gradient and deep exploration test wells in near future.

2. UGANDA'S GEOTHERMAL POTENTIAL

Geothermal resources with a moderate to high sub-surface temperatures can be found at several locations in Uganda. This is the result of the presence of tectonically active zones and young volcanic rocks. 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 extension and thinning of the crust. Crustal extension and thinning cause the mantle to become elevated. This elevated mantle results in a higher geothermal gradient within the crust. Meteoric water circulates through deep faults 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. 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 zone 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.

FIGURE 1: Distribution of geothermal sites in Uganda

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

Preliminary studies by DGSM dates way back to the 1950's when 3 shallow wells were drilled in Buranga. In early 1970s, preliminary studies were undertaken by DGSM again. Subsequent projects are outlined below.

Geothermal energy exploration programme phase 1 (1993-1994): This was the first detailed exploration project carried out on the 3 highly ranked prospects. The project was supported 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, KatweKikorongo and Buranga. The results warranted advanced exploration to up-grade and refine the exploration model.

Isotope hydrology for exploring geothermal resources phase-1 (1999-2003): IAEA together with 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): ADB funded geothermal investigations were carried out in Katwe-Kikorongo in 2003, under the "Uganda Alternative Energy Resource Assessment and Utilisation Study (UAERAUS). This was to upgrade the exploration model of Katwe-Kikorongo to pre-feasibility status.

Kibiro prospect investigations (2004): Exploration program was carried out by ICEIDA experts and GoU counter parts with the aim of refining the pre-drilling assessment initiated by MEMD. This work included geophysical studies (TEM, gravity and magnetic survey) and geological mapping.

GEOTHERM project: Germany Federal Institute for Geosciences and Natural Resources (BGR) together with MEMD carried out intermediate exploration in Buranga beginning 2003. This was under the GEOTHERM programme, which promoted the utilization of geothermal energy in developing countries. Work included sampling of hot and cold fluids and geophysical surveys (Gravity, TEM, and Schulmberger sounding). Micro-Seismometers were installed in areas surrounding Buranga to map active geological structures. Micro-Seismic 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 from faultbounded Buranga geothermal systems 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-WB project: ICEIDA together with MEMD undertook exploration in Kibiro and Katwe Kikorongo. Work involved drilling Gradient Holes and was supported under WB Power IV program. 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 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. 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 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.

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 (1921, 1922) 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 midMiocene about 17 ma (Abeinomugihsa, 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 (Maasha, 1975; Shudofsky, 1985; Wagner and Langston, 1988; Nyblade and Langston, 1995) indicating deep faults. The western rift is bounded by high angle normal faults systems. 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, 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 indicate up to 67°C/km, Abeinomugihsa, 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 amagamatic 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 swallow 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.

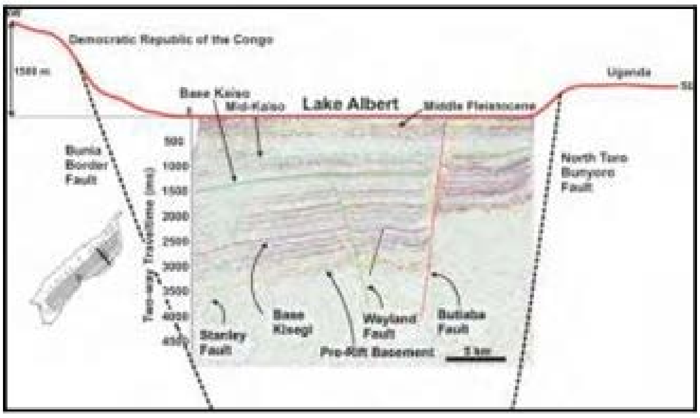

FIGURE 2: Multichannel seismic line 57 from the northern part of Lake Albert (see track line inset for location). Red line at surface of profile indicates regional topography (Karp et al, 2012)

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.

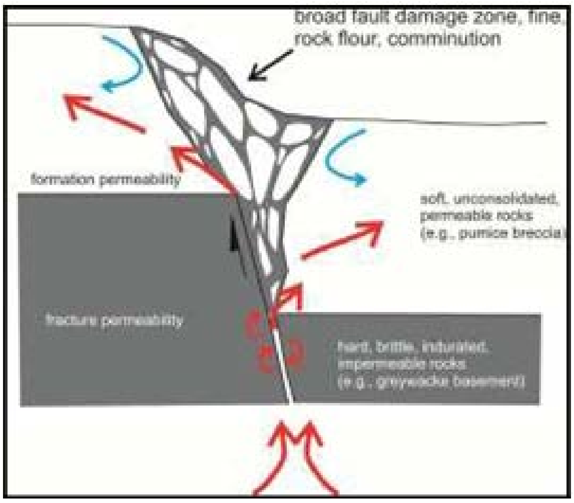

FIGURE 3: Idealized exploration model which fits Kibiro (Rae, 2014)

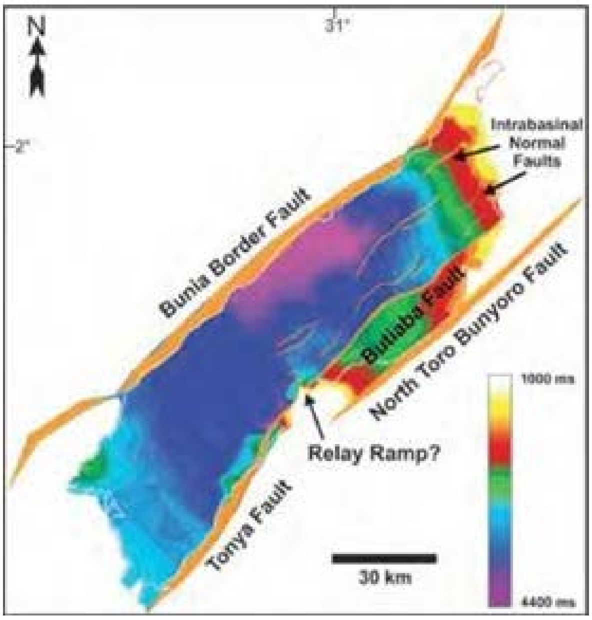

FIGURE 4: Main rift bounding fault (Karpl et al, 2012)

TABLE 1: Summary of Kibiro and Panyimur geological settings

Tectonic setting	• Extensional tectonics
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: Externsional, 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).

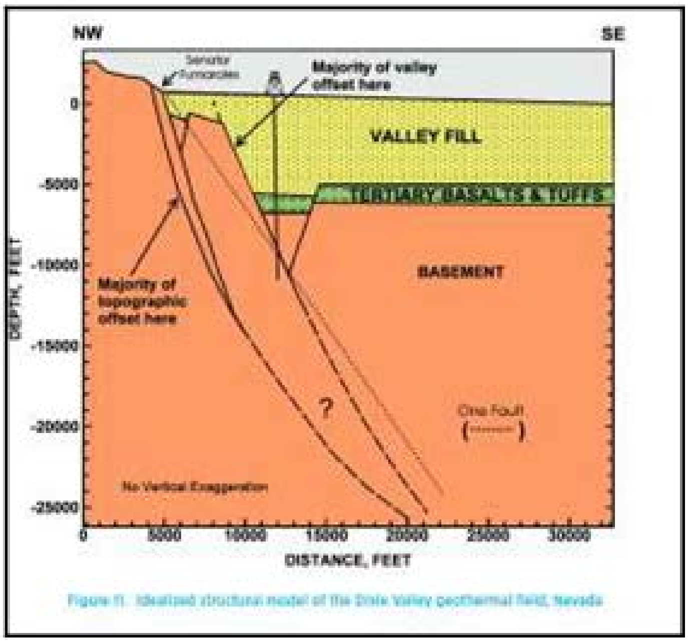

FIGURE 5: Idealized structural model of the Dixie Valley geothermal field, Nevada, which typifies Kibiro and Panyimur (DoE, 2006)

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 (Rykounov and others, 1972; Bram and Schmeling, 1975; Maguire and Long, 1976; Hebert and Langston, 1985; KRISP, 1987). 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 fault controlled extensional domain play with elevated mantle due to active crustal extension (from 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 swallow 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.

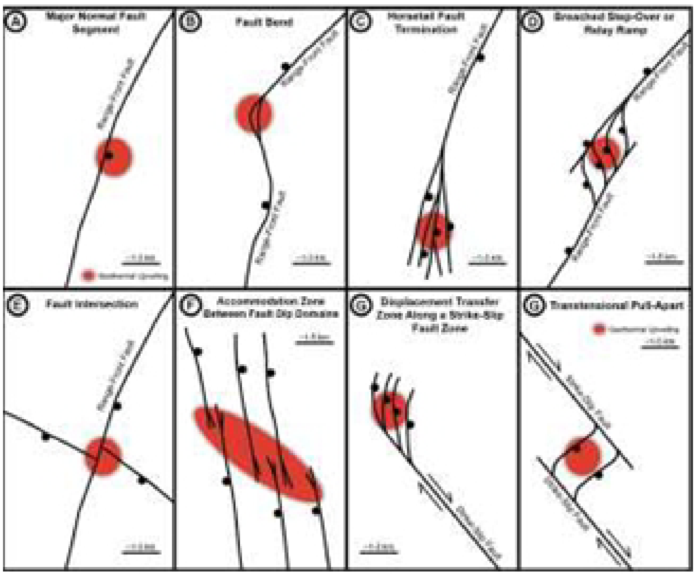

FIGURE 6: Favorable structural setting for geothermal systems in the Great Basin region (Faulds and Hinz, 2015)

5.6 Type of exploration method

According to Glassley, (2013), 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.

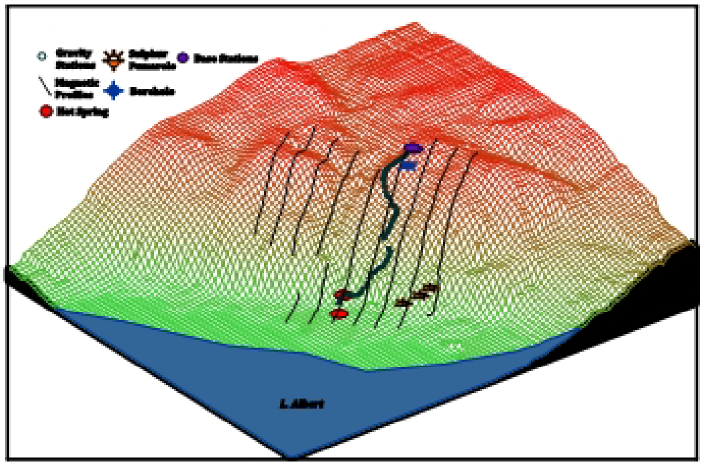

FIGURE 7: MT/TDEM planned profile lines targeting main rift fault at Kibiro

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.

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.

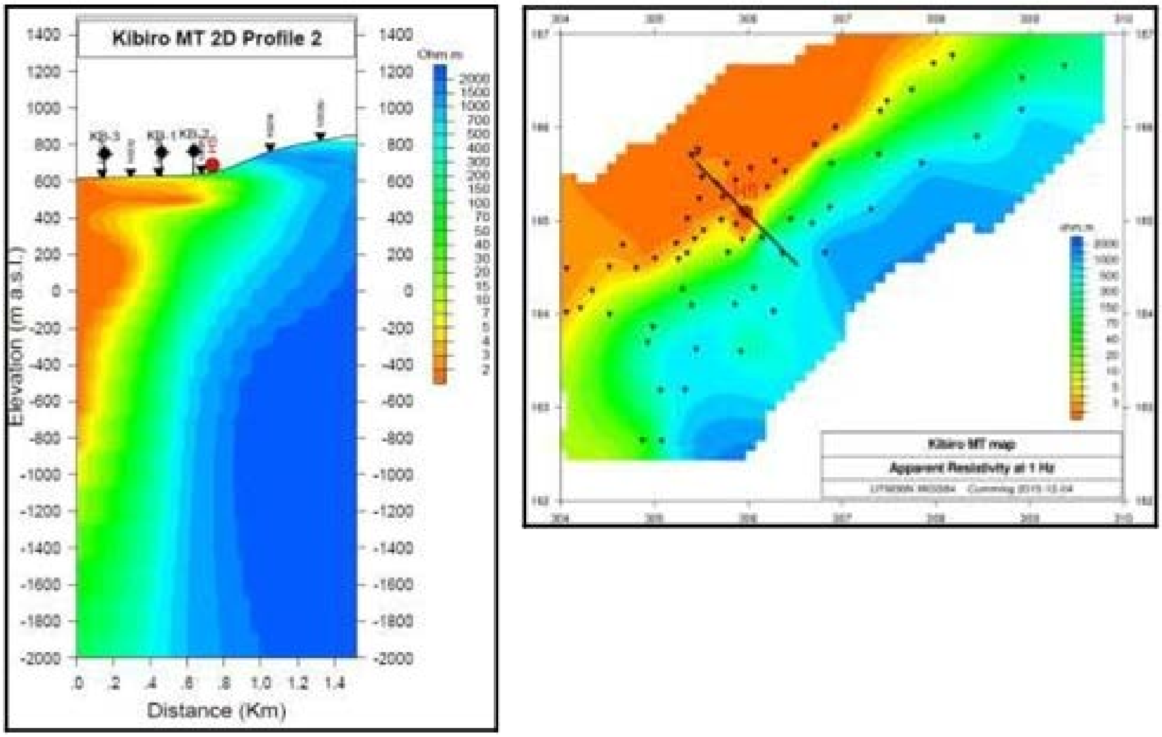

FIGURE 8: a) MT sounding revealed a sub-vertical conduit, which is interpreted as main rift bounding fault; b) Apparent resistivity map of Kibiro showing resistive basement rocks and conductive basin fill

5.7.2 Geochemical survey

Carbon dioxide (CO_2) and radon (Rn) were also measured at Kibiro active geothermal system during the study. Elevated gas concentrations coincide with the main active rift normal fault (Figure 10). The 3He/4He ratios of geothermal fluids from Kibiro system were measured to determine if a deep mantle signature was present. These ratios were not elevated and are believed to be crustal sources. Kibiro system is non-magmatic based on Helium ratios.

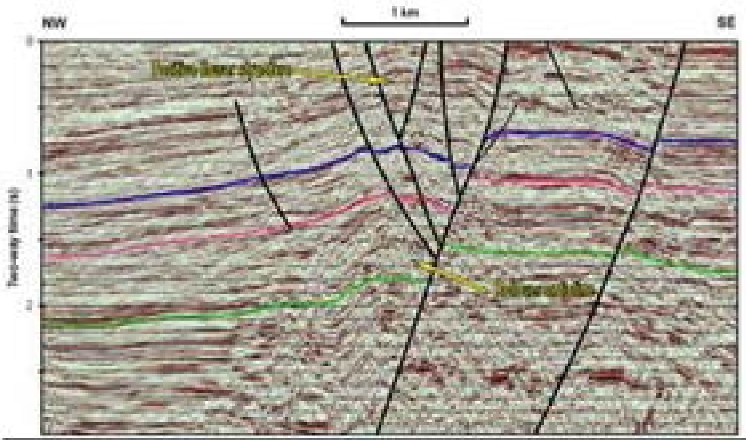

FIGURE 9: Seismic section revealing high angle deep penetrating boundary normal faults near Kibiro (Karp1 et al, 2012)

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.

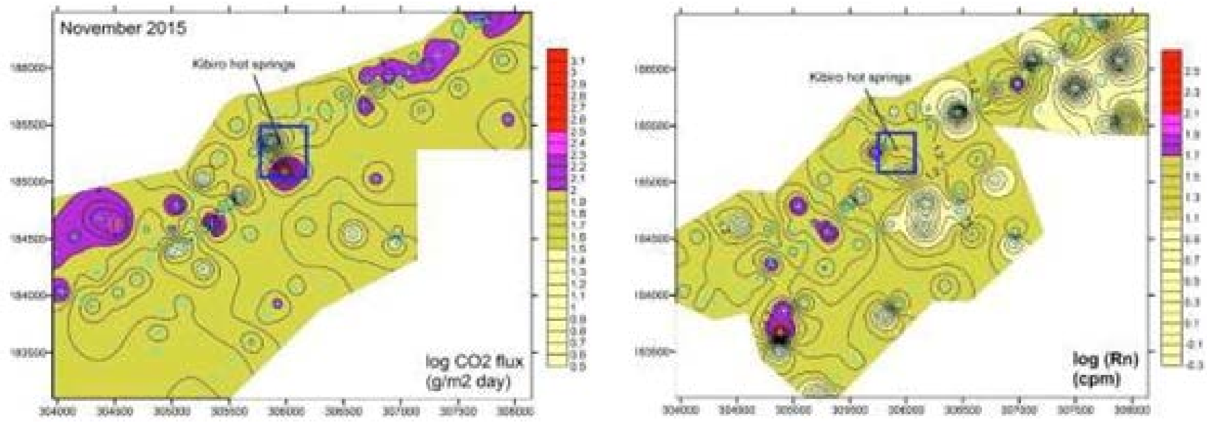

FIGURE 10: Contour map showing the geographical distribution of the five component populations of the 222Rn activity in soil gases for the Kibiro dataset of November 2015

5.8 Panyimur exploration results

A combined MT/TDEM survey was undertaken at Panyimur. Inversion of the data revealed a deep, sub-vertical conductor presumed to be fault controlled geothermal reservoir (Figure 12 a and b). Once again MT results reveal a resistive basement rocks and conductive basin fill. Processing of MT/TDEM data is on-going to develop an exploration model of this prospect.

Reflective seismic indicate deep seated faults presumed to control fluid movement in this area (Figure 12c).

5.9 Katwe- Kikorongo exploration results

An exploration design has been developed targeting main NE-SW trending deep seated fault (Figure 13). This will be traversed by MT/TDEM profiles to map the presumed deep seated faults.

Soil-gas and gas-flux measurements will be carried out in this area. Analyzing radon gas at Katwe is expected to locate active faults that communicate with the reservoir. This technique will help in tracing permeable concealed structures in this area.

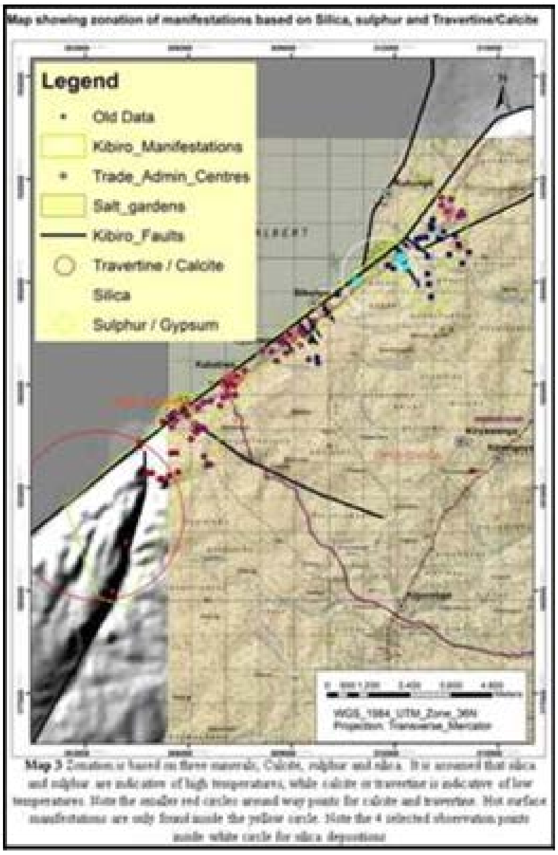

FIGURE 11: Kibiro map

5.10 Buranga exploration results

Combined MT/TDEM survey has been carried out in this area. Data gap closure is on-going with assistance from EAGER/DFID (Figure 14).

Soil-gas and gas-flux measurements will be carried out in Buranga. Analyzing radon gas is expected to locate concealed faults that communicate with the reservoir. This technique will help in tracing permeable concealed structures in this area. The 3He/4He ratios from Buranga site were measured to determine if a deep mantle signature was present. Results indicated elevated ratios. This was believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs.

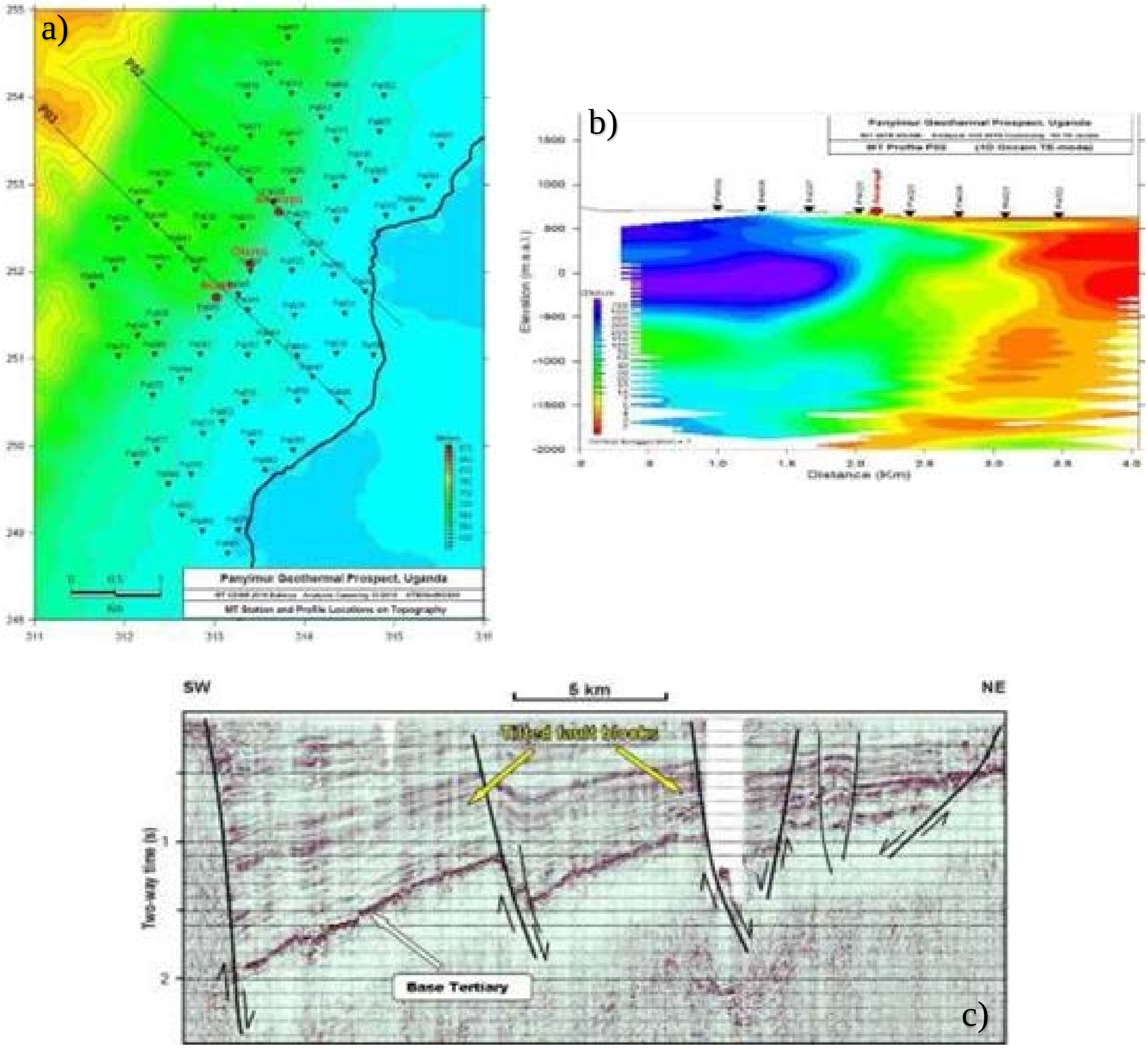

FIGURE 12: a) Resistivity map of Panyimur area; b) Resistivity cross-section of Panyimur area; c) Deep reaching faults. Panyimur geothermal system typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. At Panyimur, fluid movement is controlled by main rift fault zone (Karp et al., 2012).

5.11 Exploration strategy

The project 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.

- **Reflection-seismic survey** to map deep penetrating faults. 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.

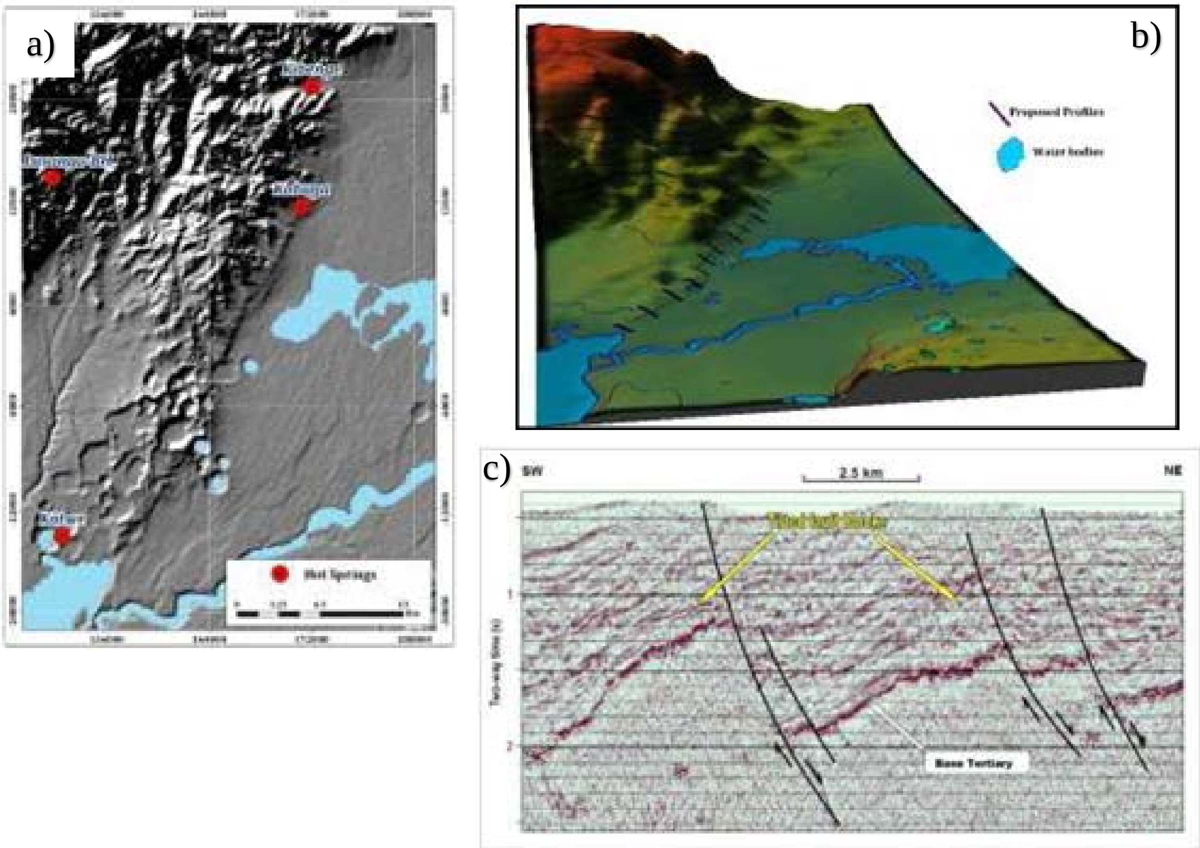

FIGURE 13: a) NE-SW trending fault bounding Rwenzori mountain and characterised by surface manifestations; b) Planned MT/TDEM profiles along the main NE-SW fault; c) Deep faults presumed to control geothermal fluid movement at Katwe (Karp et al., 2012)

- **MT mesurements** to delineate presumed deep, sub-vertical fault conduits and develop 3D images of sub-surface. MT method is preferred to be used to map resistivity at depths greater than 500 meters. The resistivity profile with depth as given in an MT sounding can assist in detecting 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.

- **Geological mapping:** Detailed surface and structural analysis of faults.

- **Data integration:** All data sets will be integrated to build an exploration 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

The GoU restructured the Ministry of Energy and Mineral Development(MEMD) and established a Geothermal Resources Department (GRD) under the Directorate of Geological Survey and Mines (DGSM). GRD is mandated to spearhead the development of Uganda's geothermal resources. For geothermal to contribute to Uganda's energy mix and to reach its full capacity in climate change mitigation, it is necessary to address technical and non-technical barriers through policy intervention.

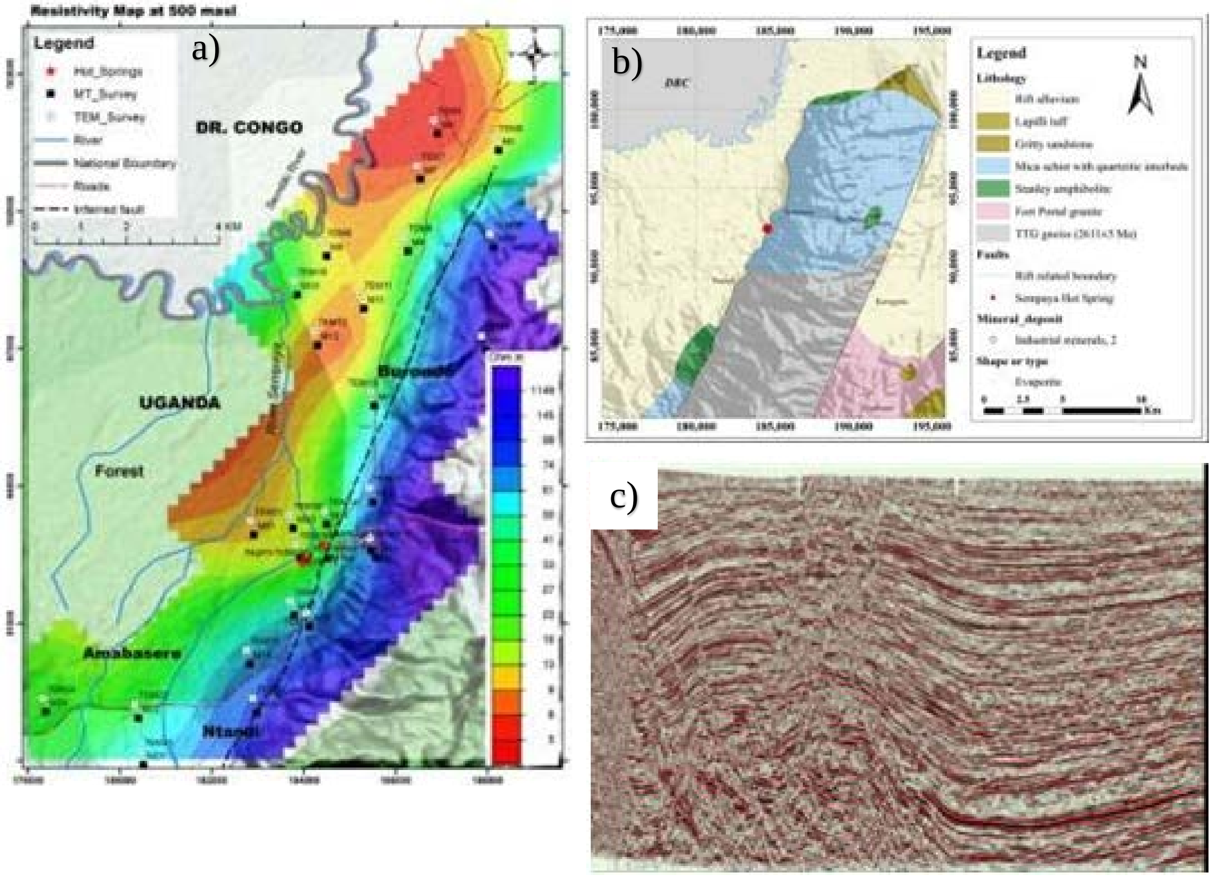

FIGURE 14: a) MT results around Buranga; b) Main Rwenzori fault presumed to control geothermal fluid flows; c) Reflective seismic section showing deep seated Rwenzori bounding fault (left) presumed to control geothermal fluids flow (Karp et al., 2012)

In collaboration with Climate Technology Center and Network (CTCN), MEMD has developed specific geothermal energy policy, Act and Regulations. These are yet to be tabled before Cabinet and Parliament. Lack of specific laws governing geothermal resources is one of the main institutional barriers to geothermal development in many countries. Experience has shown that the relative success of geothermal development in many countries is closely linked to government policies, regulations, incentives and initiatives. MEMD has undertaken several actions to enhance governmental and public knowledge about geothermal energy and its uses to mitigate information and awareness barriers. Government has undertaken capacity building to address the issue of small base of experienced professionals. This training has also involved on-the-job training / hands-on training at GDC in Kenya as well as in-house trainings.

7. ON-GOING GEOTHERMAL PROJECTS

- **World Bank ERT-3:** Within this programme, Energy for Rural Transformation (ERT-3) there is a geothermal component which will soon be implemented. It involves procuring geochemical equipment and pre-drilling studies in prospective areas.

- **EAGER:** This a DFID funded project and is being implemented. It involves pre-drilling studies at Panyimur and Buranga as well as developing a geothermal database.

- **UNEP-ARGeo:** This on-going with data gap closure using micro-seismic data at Kibiro.
- **BGR:** BGR has started a project with GRD under the GEOTHERM-3 Programme.

8. CONCLUSION

The western rift, the western branch of the East African Rift System, is bounded by high angle normal faults systems. Depth to detachment estimates of 20-30km and seismicity throughout the depth range 0-30 km (Ebinger, 1989).

Most geothermal sites in Uganda are fault-bounded system related to high crustal heat flow, high temperature gradients and active extensional tectonics. Recent faulting due to crustal extension and thinning resulted in deep penetrating faults which permit deep circulation and heating of meteoric waters in regions of high heat flow.

These systems area in zones of high fracture density due to fault intersection between main bounding fault and cross cutting faults. Any exploration effort should be focused on mapping high angle rift faults, presumed to be deep at crustal scale to allow deep circulation. A combination of geophysical, geochemical and geological methods will map fractures presumed to control fluid migration. MT/TDEM measurements across these geothermal sites are expected to reveal deep, sub-vertical geothermal reservoirs. These systems typifies other fault-controlled systems that are driven by deep circulation of waters. Fluid movement is presumed to be controlled by the main rift fault zones.

Finally, it is important to follow a strategy to reduce cost and maximize success in exploring for and evaluating geothermal resources.

9. RECOMMENDATIONS

- Data closure should be undertaken in Panyimur and Buranga to complete pre-drilling studies.
- A combined MT/TDEM survey should be undertaken at Katwe to map the presumed geothermal reservoirs and develop an exploration model.
- Analyses of soil-gases and measurements of gas-fluxes at Buranga and Katwe geothermal sites should be undertaken. Analyzing radon gas should help locate mapped faults that communicated with the reservoir.
- The 3He/4He 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.

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