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GEOTHERMAL EXPLORATION IN UGANDA STATUS REPORT

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ABSTRACT

Uganda is endowed with geothermal energy resources due to its geological setting in an intra-continental rift setting. Geothermal energy remains a largely undeveloped energy resource in Uganda despite the enormous potential. In the current climate change and energy security environment, geothermal energy is a suitable energy option. Historically efforts have been undertaken by various players to develop geothermal energy in Uganda but with no success. These have included Government-led exploration, ICEIDA-ISOR, BGR, JICA, UNDP, IAEA, AfDB, and World Bank.

In response to the government's national goal of developing alternate energy sources to mitigate energy scarcity, Government of Uganda has committed public funds and personnel towards development of its geothermal resources under the Uganda Geothermal Resources Development Project (1199). The Project is being implemented by Geothermal Resources Department under the Ministry of Energy and Mineral Development. Nationwide preliminary surveys have been conducted to stock take all known Uganda geothermal resources and prepare them for future detailed surveys in future. Much of these geothermal resources are presumed to have a heat source ascribed to elevated mantle related to extension and crustal thinning.

Detailed geothermal exploration has been undertaken at Katwe-Kikorongo, Kibiro, Buranga and Kibiro. These geothermal resources are located in an intra-continental rift system which is still in its initial stage of evolution. The extensional tectonic setting is charcaterised by main bounding faults which are deeply penetrating. These are pathways for meteoric waters which penetrates deep into the heated crust and form geothermal resources. Permeability is restricted to main boundary fault zones which are also conduits for magma ascent to shallow levels of the crust. Alignment of surface indicators of geothermal activity along main boundary rift faults indicates structural control of these hydrothermal conduits (faults).

The Western rift, the western branch of the East African rift system, is bordered by high angle normal fault systems bounding one side of spoon-shaped basins (Ebinger, 2015). Depth-to-detachment estimates of 20-30 km, the rollover geometry of asymmetric basins, and seismicity throughout the depth range 0-30 km suggest that planar border faults along one side of rift basins penetrate the crust (Ebinger, 2015).

According to the description by Glassley (2014) of Fault-bounded extensional (Horst and Graben) complexes (Brophy Type E), the EARS fits into this description. Complexes of horst and graben occur where there has been extension and thinning of the crust (Glassley, 2011). As the crust is pulled apart, it tends to fracture forming steeply dipping faults that are perpendicular to the general direction of extension (Glassley, 2011). Blocks of crust subside between these faults forming grabens, where as the surrounding ground on the opposite side of the bounding faults remain elevated forming horst (Glassley, 2011). The high angle faults bounding the horst and graben can extend to considerable depth. Such setting are places where magma often rises to the crustin response to decrease in lithospheric pressure caused by crustal thinning during extension. As a result of presence of heat sources numerous geothermal resources can be present (Glassley, 2011). Geothermal resources in such setting tend to be relatively deep and permeability is restricted fault-controlled zones in the vicinity of horst and graben boundaries (Glassley, 2011). According to the above literature, fault-bounding faults are considered exploration targets in the western rift valley.

These geothermal system are deep-circulation system and in many respects typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. At all the four studied prospects, fluid movement is controlled by the fault zone that bounds rift valley. The 3He/4He ratios of geothermal fluids Buranga were measured to determine if a deep mantle signature was present (BGR, 2004 Noble gas sampling). Findings revealed elevated 3He/4He ratios which were believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs. Soil gas surveys at Kibiro indicated the main boundary fault as surface traces of active hydrothermal conduits.

Magnetotelluric (MT) measurements are planned to be run across all four fields together with TDEM along the NE-SW striking structural feature. Inversion of the data is expected to reveal a deep, sub-vertical conductor associated with a rift bounding fault.

1. BACKGROUND

Uganda is endowed with geothermal potential due to its geological setting in the intra-continental rift system. Continental rift system are conduits of heat hence this presents potential for geothermal resources. Geothermal energy in Uganda remains a largely untapped energy resources with enormous potential.

Uganda would like to add to and diversify the energy mix in order to address its unmet power demands. In the current climate change and energy security environment, geothermal presents itself as an attractive energy option. To utilize these geothermal resources to generate electricity, the Government must overcome several obstacles that are unique among the renewable energy technologies. One significant barrier in geothermal project development is the high investment risk during the resource exploration phase, which can make financing a geothermal project difficult as compared to other renewable energy sources, including wind and solar.

Several geothermal exploration programmes have been undertaken in Uganda by different players who have faced exploration challenges and hence without a breakthrough. Timeline has stretched too far hence the need for breakthrough techniques and technology. These have included Government-led exploration programs by Geological Surveys of Uganda, ICEIDA-ISOR, IAEA, UNDP, JICA, World Bank, BGR and AfDB

Since 2011/12 Government led-exploration has been undertaken at four prospects, Kibiro, Buranga, Katwe-Kikorongo and Panyimur. Studies have indicated that these prospects are located in extensional tectonic setting domain in the rift valley. Continental crust extensional and thinning resulted into mantle being elevated near the surface in the crust. The elevated mantle is presumed to be the source of heat for these geothermal systems in the rift system. Intrusion of magma into the thinned crust brings up great quantities of heat. As the crust was pulled apart it fractured forming steeply dipping normal faults. According to seismic studies, these high angle faults extend to a considerable depth allowing deep circulation of meteoric waters to be heated and form geothermal resources. These geothermal resources related to deep circulation of meteoric water along faults and fractures.

Permeability is restricted to fault controlled zones and these form exploration targets. Rift bounding faults have high permeability but when intersected by transverse faults they have increased permeability. All the four prospects are presumed to be fault-bounded extensional systems. In case of Katwe, the magma made it to surface along the main rift deeply penetrating fault running in NE-SW direction. Located in the rift valley these geothermal system are presumed to deep-circulation system and they typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. Fluid movement is presumed to be controlled by the main rift-bounding fault zone.

2. LOCATION OF GEOTHERMAL RESOURCES SITES IN UGANDA

Most of the geothermal resource sites are located in the western rift valley and are genetically related to it. The map below (Figure 1) shows currently known geothermal sites in Uganda and it is not in any way exhaustive or a comprehensive inventory as more and more geothermal sites are discovered. Some geothermal resources in the basement rocks are related to tectonic activity as well as radiogenic heat (27, 28).

The geothermal resources are located in extensional tectonic rift valley setting. This is an area which experience *crustal extension* and *thinning*. This results into magma ascent into the thinned crust and high heat flows. Crustal extension resulted into high angle rift bounding normal faults deeply penetrating the crust. These are favorable conduits for deep water circulation into the heated crust. Intra-continental rift setting are conduits of heat and the associated geothermal resources. The controlling structures are rift bounding faults in a horst and graben setting.

3. PRE-DRILLING FEASIBILITY ASSESSMENT

3.1 Western Rift System

Literature was reviewed on the Western Rift System in order to come out with an appropriate exploration strategy. According to literature available**, t**he western arm of the East African Rift System (EARS) is still in its initial stage of evolution or early continental rifting stage. In the initial rift evolution 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 (Corti, 2011). Deeply penetrating major boundary faults offer preferential pathways for magma ascent and hence are potential geothermal resources targets. The western rift system of the EARS is at the initiation stage of rift formation which is classified as stage 1 Boundary faults. The next stage is called intermediate stage and the final is internal fault stage in order on increasing maturity. The Eastern rift is at internal stage characterized by internal faults in the rift basin. This evolution is indicative of a progressive transition from *fault-dominated rift morphology in the early stages of extension* toward magma assisted-rifting during the final stages of continental break-up (Corti, 2011).

The geothermal systems in the western rift valley fall under fault-controlled extensional domain geothermal play type CV3. In an Extensional Domain Geothermal Play (CV3) the mantle is elevated due to crustal extension and thinning (Moeck, 2013). 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 (Moeck, 2013).

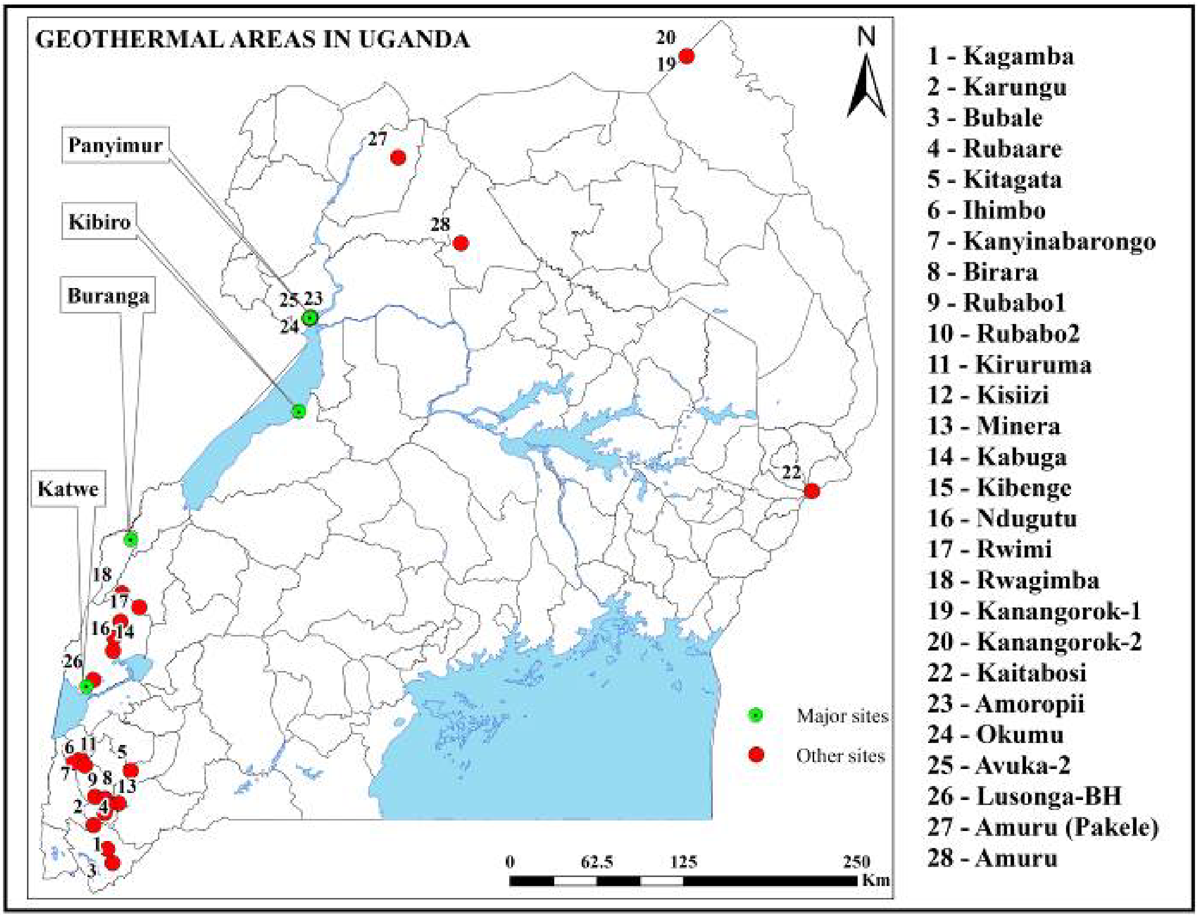

FIGURE 1: Map showing geothermal sites in Uganda

The Western rift, the western branch of the East African rift system, is bordered by high angle normal fault systems bounding one side of spoon-shaped basins (Ebinger, 2015). Depth-to-detachment estimates of 20-30 km, the rollover geometry of asymmetric basins, and seismicity throughout the depth range 0-30 km suggest that planar border faults along one side of rift basins penetrate the crust (Ebinger, 2015).

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 and Kenya rift valleys (Rykounov et al, 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). 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 (Wohlenberg, 1968; Rodrigues, 1970; Zana and Hamaguchi, 1978; Brown and Girdler, 1980; Fairhead and Stuart, 1982; Shudofsky, 1985). Western rift is known to be seismically active both from felt and instrumental information. Report on the Uganda Earthquake of 20 March 1966 reveals depth of between 12 to 36km.

According to the description by Glassley (2014) of *Fault-bounded extensional* (Horst and Graben) complexes (Brophy Type E), the EARS fits into this description. Complexes of horst and graben occur where there has been *extension and thinning* of the crust (Glassley, 2011). As the crust is pulled apart, it tends to fracture forming steeply dipping faults that are perpendicular to the general direction of extension (Glassley, 2011). Blocks of crust subside between these faults forming grabens, where as the surrounding ground on the opposite side of the bounding faults remain elevated forming horst (Glassley, 2011). The high angle faults bounding the horst and graben can extend to considerable depth. Such setting are places where magma often rises to the crustin response to decrease in lithospheric pressure caused by crustal thinning during extension. As a result of presence of heat sources numerous geothermal resources can be present (Glassley, 2011). Geothermal resources in such setting tend to be relatively deep and permeability is restricted fault-controlled zones in the vicinity of horst and graben boundaries ((Glassley, 2011). According to the above literature, fault-bounding faults are considered exploration targets in the western rift valley.

4. WELL LOG AND FLOW TEST DATA

Oil companies drill deep wells and measure temperature during wire-line logging and well flow tests. Temperature data was acquired for wells Mputa, Nzizi and Waragi between Kibiro and Kaiso-Tonya, Turaco in Ntoroko; Ngaji in Katwe-Kikorongo. One well encountered almost carbon dioxide which is believed of mantle voltiles. These data has revealed elevated heat flow along the rift valley ascribed to crustal extension and thinning which resulted into magma ascent into the crust.

4.1 Seismic sections

Seismic sections from oil companies were acquired for Kibiro, Buranga, Katwe and Pakwach. Seismic sections have revealed deep seated rift bounding fault which are presumed to be controlling the permeability of the geothermal systems (Figures 2-4).

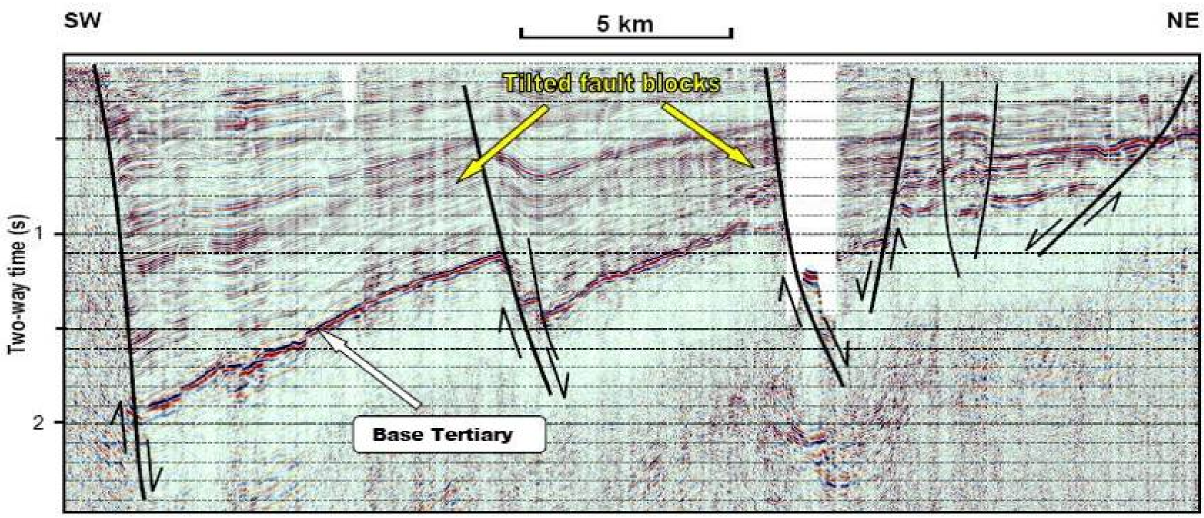

FIGURE 2: Seismic section at Pakwach showing deep seated rift bounding faults (well targets), tilted blocks, and domino style faulting with development of antithetic faults (PEPD)

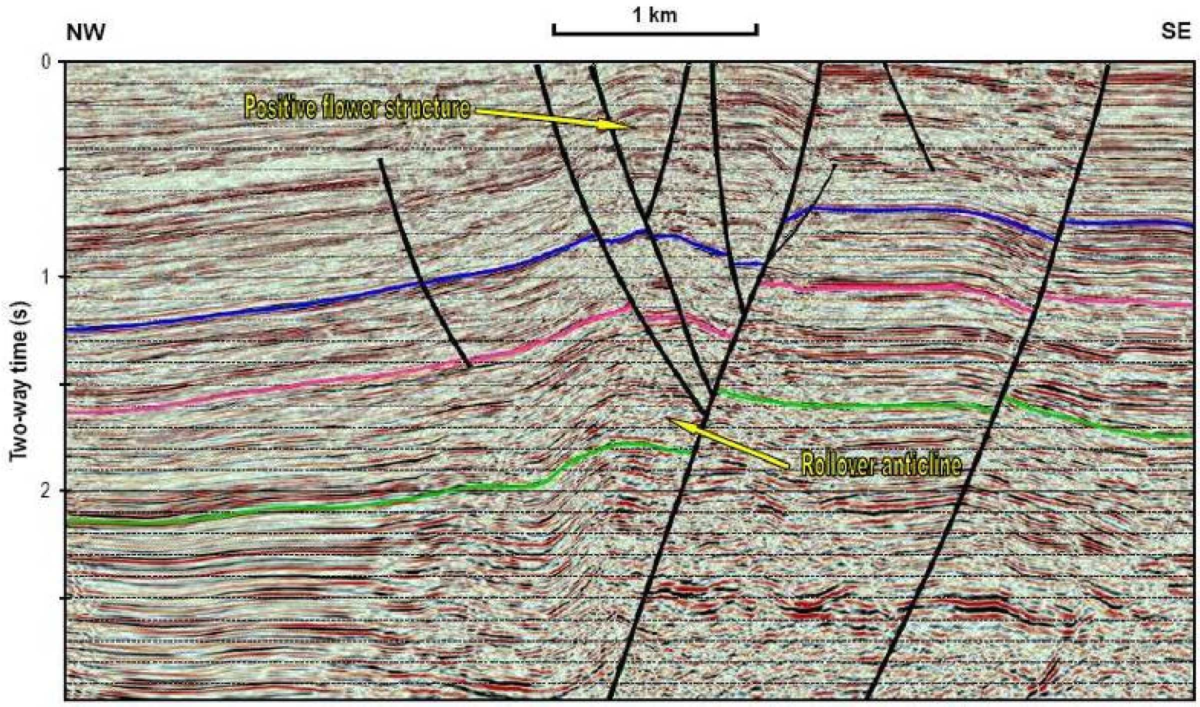

FIGURE 3: Seismic section at Lake Albert showing deep seated rift bounding faults (well targets), tilted blocks, flower structure development (PEPD)

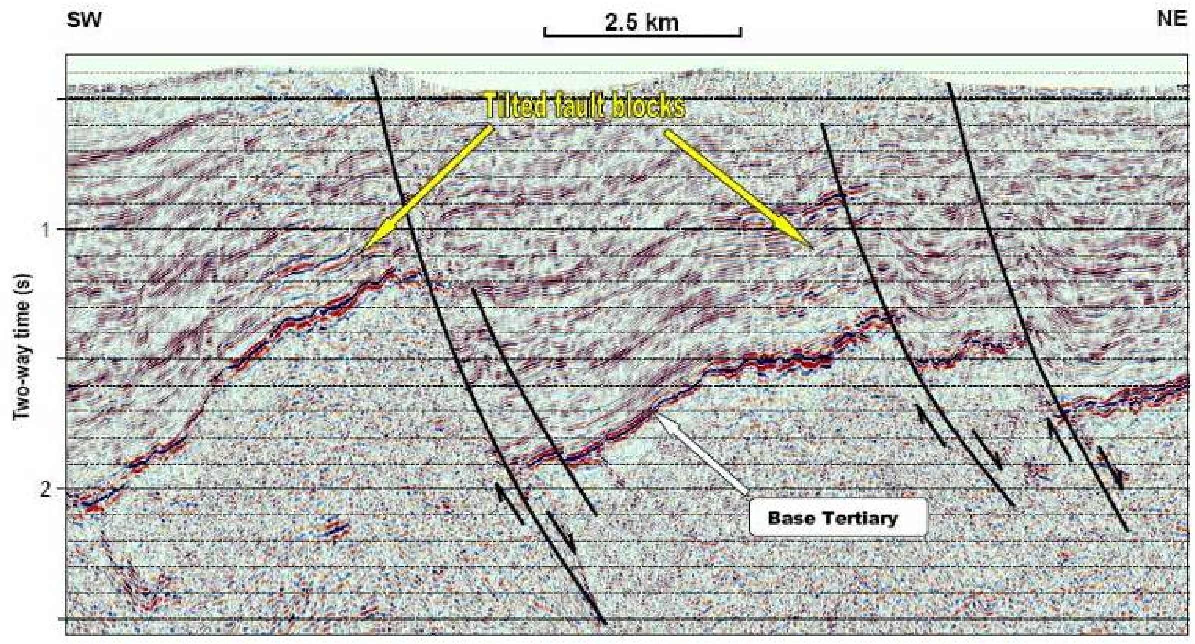

FIGURE 4: Seismic section at Lake-Edward Basin showing half grabens, deep seated faults, rotated fault blocks, slightly listric faults (PEPD)-

5. PRELIMINARY SURVEYS

Aeromagnetic data: Regional aeromagnetic survey data is available for rift valley areas (SMMRP and PEPD). Obtained at high elevations and wide flight-line spacing, however, the data is not suitable for interpreting geologic features important to geothermal exploration at the prospect level. But it revealed an anomalies at Kibiro which was confirmed related to geothermal activity (Figure 5).

Hydrothermally altered rocks were encountered coinciding with low magnetic anomaly zone north east of Kibiro.

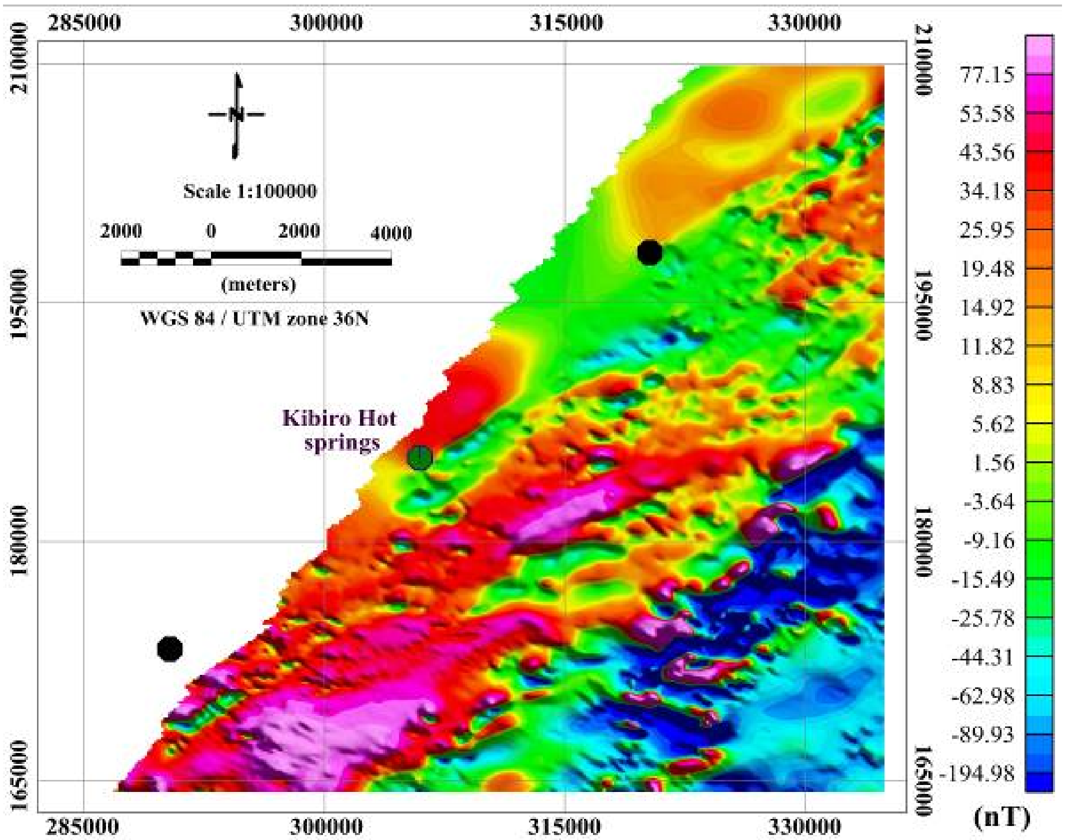

FIGURE 5: Airborne magnetic map of Kibiro

JICA-GOU: Experts from West Jec Japan funded by JICA together with the Ministry Staff undertook geothermal reconnaissance survey of south west and western Uganda. Seventeen (17) geothermal sites investigated. Work included geochemical water sampling, analysis and interpretation. This was aided by remote sensing to aid in mapping structures which control permeability and hydrology.

UGRDP: Geothermal investigations were conducted at seven (7) geothermal sites in north and north eastern Uganda. Most of these are deep-circulation systems and they typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters (Figures 6 and 7). At these prospects, fluid movement is controlled by deep fault / fracture zone. The reservoir is developed in basement rocks except at Suam (Figure 8) which is a caldera rim type system.

As a result of this activity, the inventory of known geothermal occurrences in Uganda was vastly expanded, resulting in a more comprehensive view of the total geothermal resource base in Uganda. In parts of the Aswa Shear Zone, Pre-Cambrian metamorphic rocks indicate a radiometric anomaly which is presumed to be principal heat source.

Detailed surface mapping, structural analysis of faults using DEM maps, interpretation of satellite images, analysis and evaluation of mineral distributions, and many other techniques have been applied at these sites.

Field mapping was undertaken along transfer zones (Butiaba-Wanseko, Kaiso-Tonya, Pakwach, Katwe-Kikorongo), off-axis volcanism (Fort Portal) and along major rift boundary faults. Surface indicators of geothermal activity were discovered. It appears generally the rift system is associated with geothermal activity (thermal zone underneath the crust) but only differing in permeability controls.

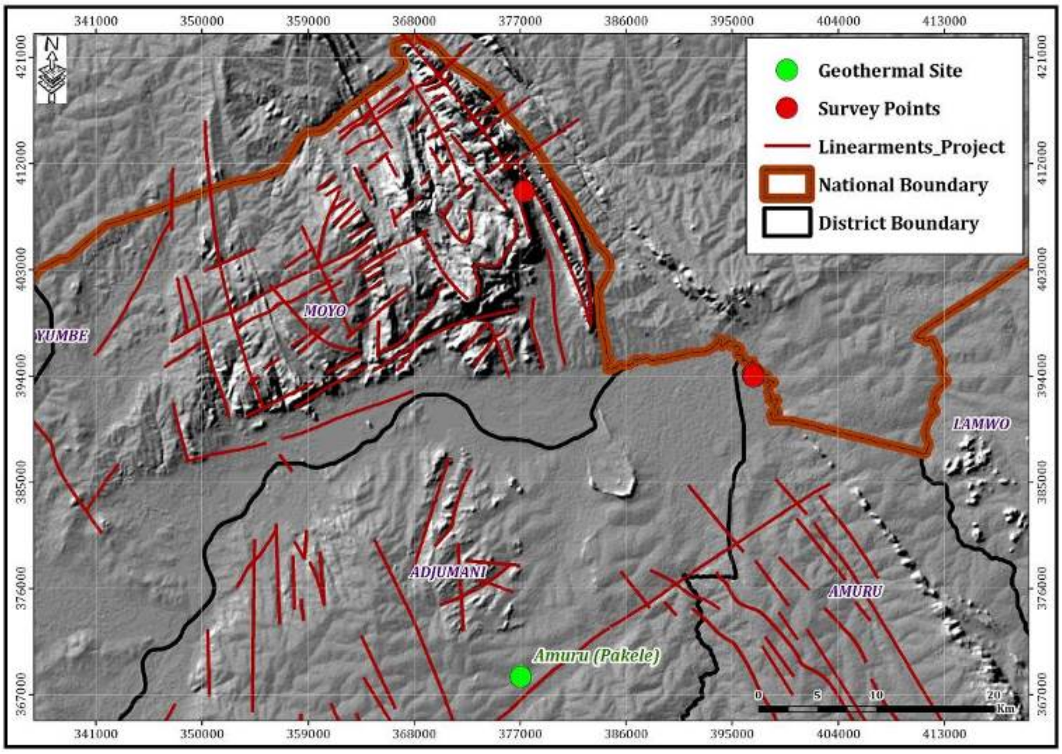

FIGURE 6: Map showing prospects in Northern Uganda

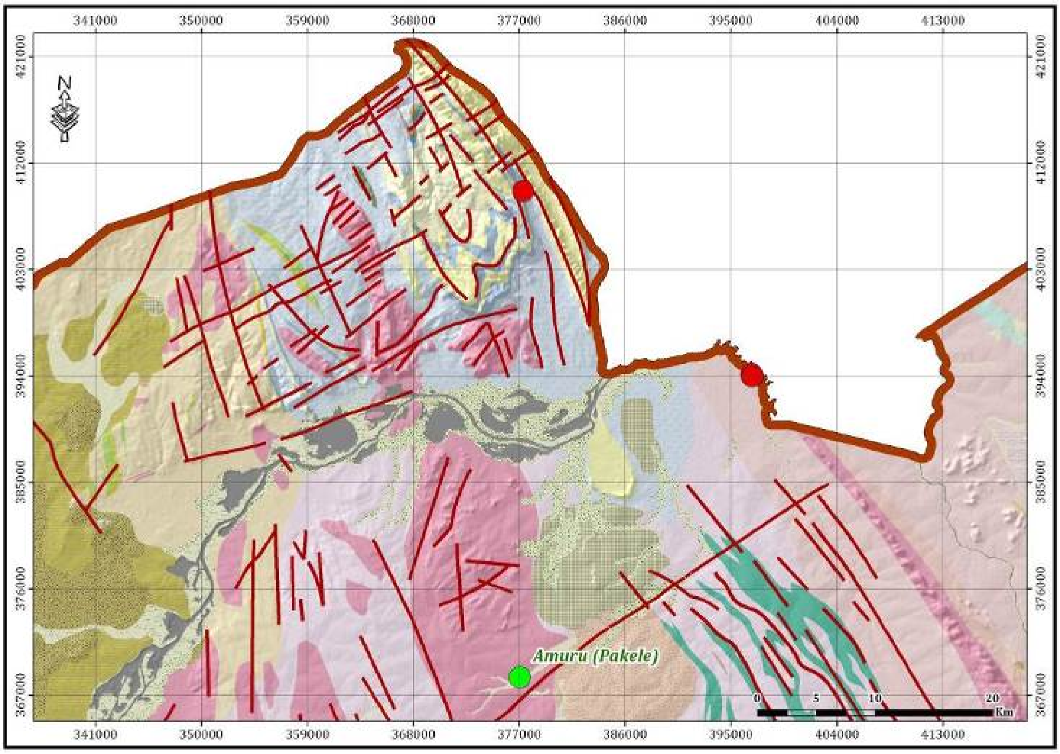

FIGURE 7: Map showing regional geology in Northern Uganda

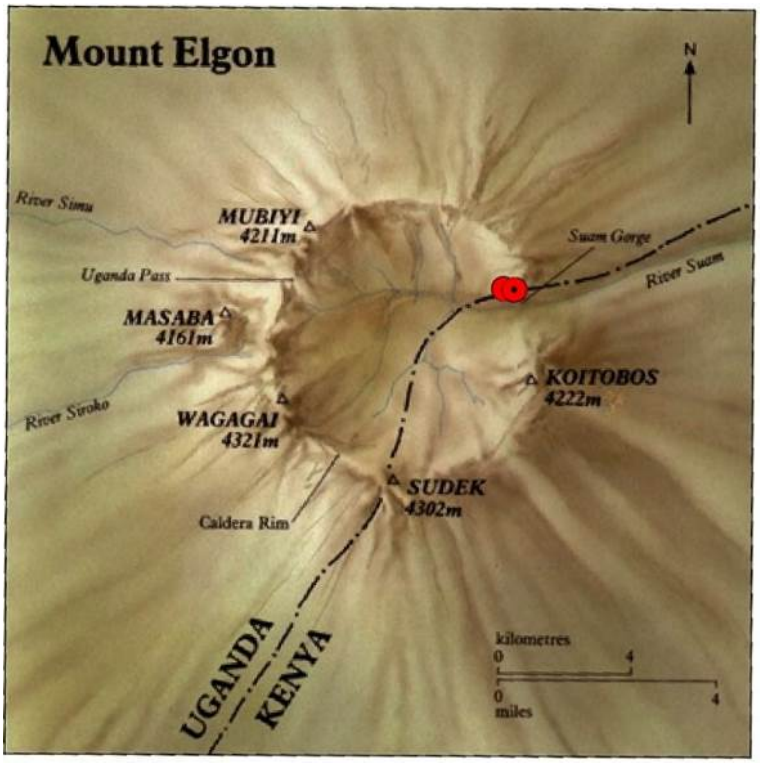

FIGURE 8: Suam Hot spring (Caldera rim type of geothermal)

6. DETAILED GEOTHERMAL EXPLORATION SURVEYS

6.1 Kibiro

Kibiro geothermal system is located in an extensional tectonic domain where crustal extensional and thinning resulted in magma ascent into crust and associated high heat flow. Surface manifestations include native sulfur deposits, altered ground, hot springs, warm springs, warm seeps, gypsum flakes, and gas seeps along main boundary fault—features (structural controls) typical of conventional geothermal resources. Gravity, aeromagnetic, magnetics, and reflection-seismic surveys have been run over the Kibiro system. Of these, gravity and magnetic data were the most useful and cost effective in defining the structural setting and fault locations. The utility of the gravity data was due to the large displacement between the rift escarpment range and the low-density rift valley fill.

Located in the rift valley (extensional tectonics), the Kibiro geothermal system is a deep-circulation system and typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. The reservoir is developed in basement rocks exposed along the escarpment. Fluid flow within Kibiro geothermal systems is presumed to be controlled by rift main bounding fault as evidenced by alignment of thermal features. Kibiro is a fault-bounded geothermal system.

The 3He/4He ratios of geothermal fluids Kibiro were measured to determine if a deep mantle signature was present (BGR, 2004 Noble gas sampling). Findings revealed elevated 3He/4He ratios in Kibiro which were believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs.

The heat source for the Kibiro Geothermal Area is ascribed to elevated mantle into the crust. Meteoric water circulates deep into the heated crust. Soil gas sampling has been undertaken at Kibiro. Preliminary results indicate elevated concentrations of both Rn-222 and CO_2 along the main bounding fault.

Magnetotelluric (MT) measurements have been undertaken across Kibiro geothermal field together with TDEM. A total of 66 MT sounding and 26 TEM sounding have been undertaken (Figure 9). Inversion of the data is expected to reveal a deep, sub-vertical conductor associated with a rift bounding fault.

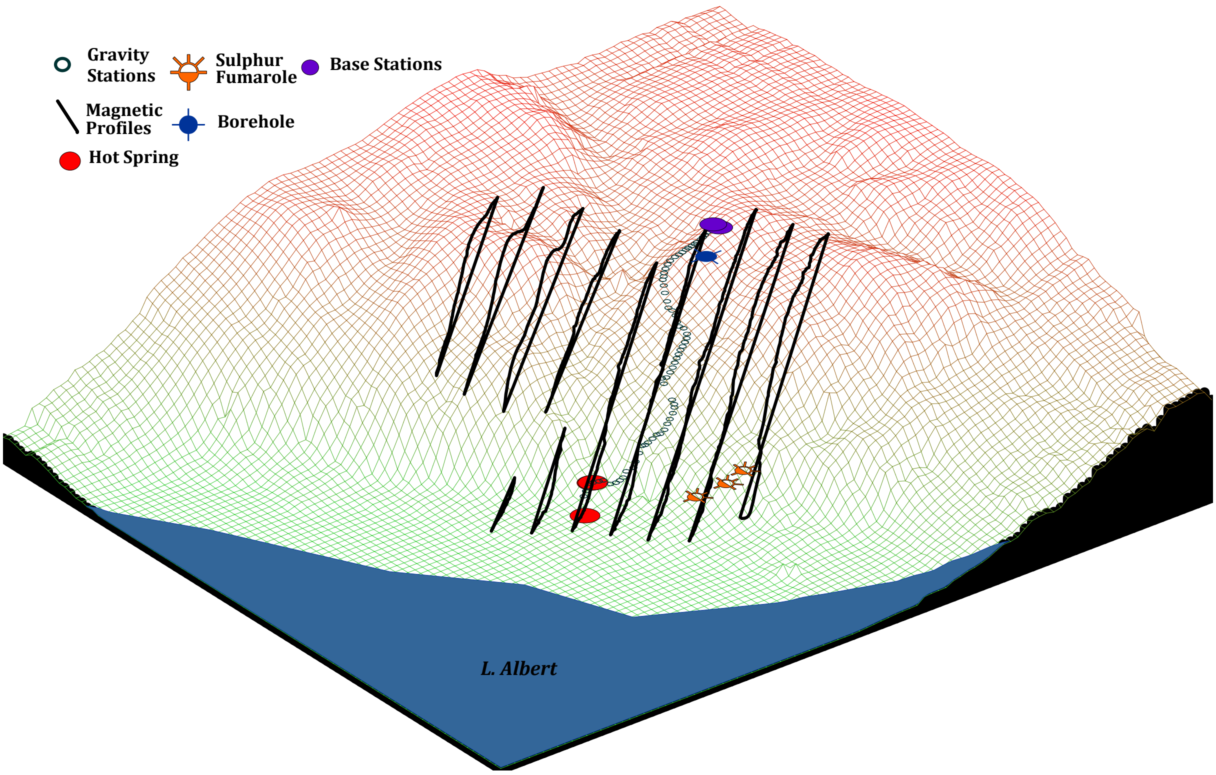

FIGURE 9: Tight grid survey lines

FIGURE 10: Geophysical survey team at Kibiro

FIGURE 11: Soil gas sampling

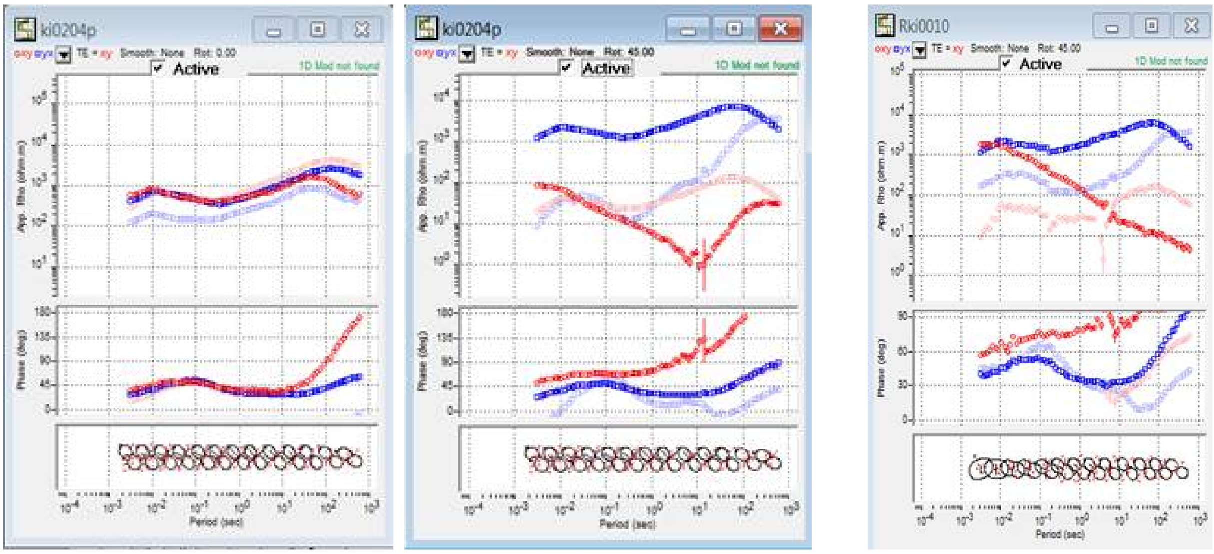

FIGURE 12: Some of the collected resistivity data still being processed

6.2 Panyimur

Located in the rift (extensional tectonics), like Kibiro, the Panyimur system is presumed to be a deep-circulation system and typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. At Panyimur, fluid movement is presumed to be controlled by the main bounding fault that bounds the west side of the rift valley. The reservoir is developed in basement rocks exposed along the escarpment. Fluid flow within Panyimur geothermal systems is STRUCTURALLY controlled by the main rift bounding faults as evidenced by alignment of thermal features.

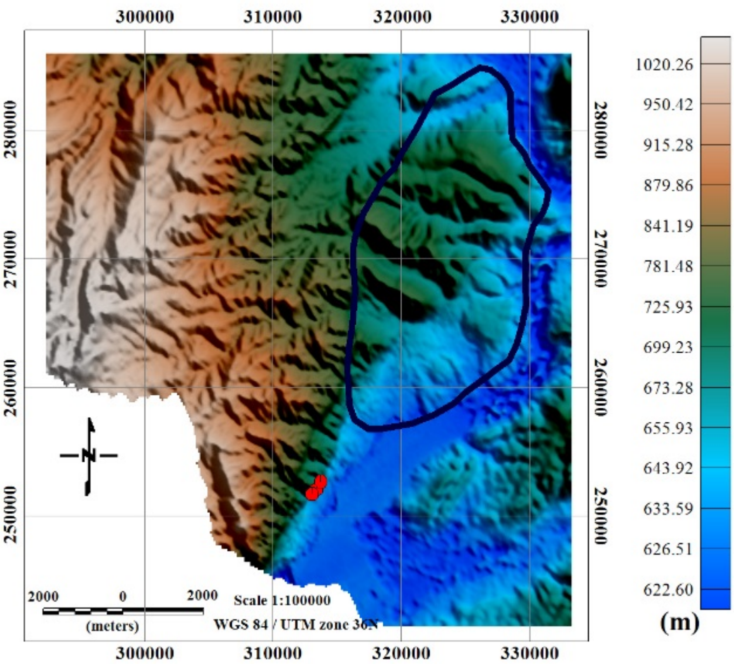

FIGURE 13: Panyimur

The heat source for the Panyimur Geothermal Area is believed to be *elevated mantle* in the thinned crust. Deep reaching rift bounding faults act as meteoric pathways to the thermal zone underneath the thinned crust. Reflection seismic surveys revealed this high angle rift bounding fault.

Magnetotelluric (MT) measurements are planned to be run across Panyimur geothermal field together with TDEM along the NE-SW striking structural feature. Inversion of the data is expected to reveal a deep, sub-vertical conductor associated with a rift bounding fault (Panyimur Fault) geothermal reservoir.

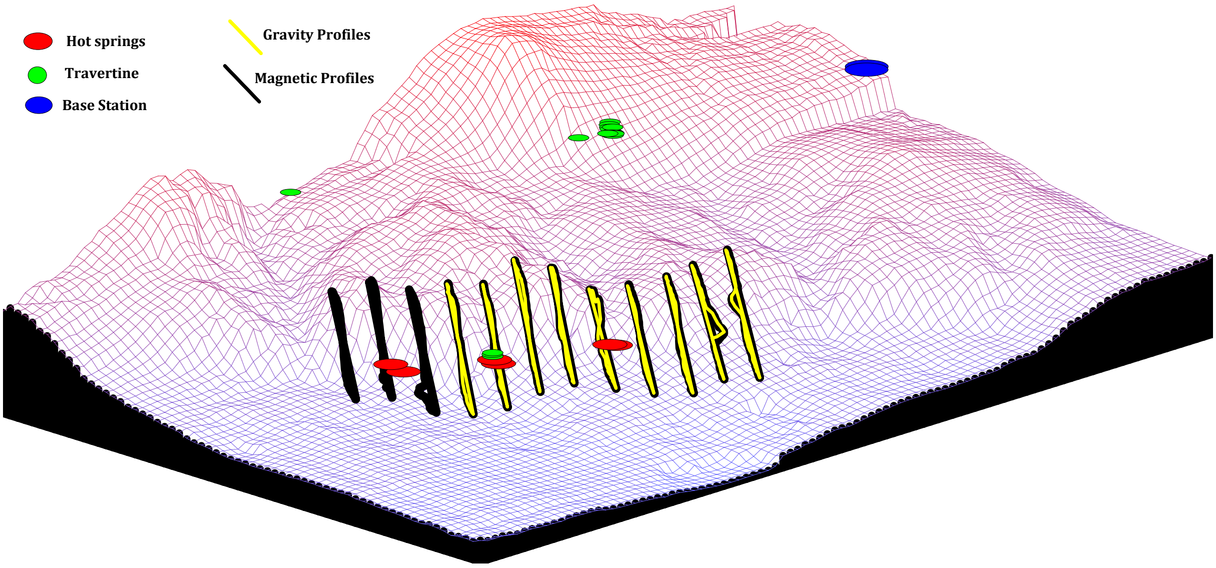

FIGURE 14: Magnetic and gravity profiles at Panyimur

6.3 Buranga

Gravity, aeromagnetic, magnetics, MT/TEM and reflection-seismic surveys have been run over the Buranga system. Located in the rift valley (extensional tectonics), the Buranga geothermal system is a deep-circulation system and typifies other fault-controlled geothermal fields that are driven by deep circulation of ground waters. At Buranga, fluid movement is controlled by the rift bounding fault zone (Bwamba fault) that bounds Rwenzori Mt on the west. The 3He/4He ratios of geothermal fluids Buranga geothermal systems were measured to determine if a deep mantle signature was present (BGR, 2004 Noble gas sampling). Investigation documented elevated 3He/4He ratios in Buranga which were believed to be evidence of deep permeability and possibly deeper, higher-temperature fluid reservoirs. Helium isotopes suggest that Buranga geothermal systems may have fluid circulation from deep depths (Figure 15).

Stable-isotope analyses indicated that the thermal waters are meteoric origin. BGR documented elevated helium-3 to helium-4 (3He/4He) ratios. While the ratios were higher than expected for a purely crustal source (0.2 Ra), they were much lower than those found in geothermal systems driven by mid- to upper-level crustal magma chambers. It was concluded that that the helium must be derived from deep within the crust and the crust-mantle boundary. The high permeabilities implied of deep through-going fault zone will be imaged by the magnetotelluric (MT) data.

The heat source for the Buranga Geothermal Area is ascribed to the elevated mantle due to extension and crustal thinning. Numerous hot springs are found along the escarpment, and hanging valleys and sediment terraces attest to Holocene faulting within the Semliki basin (Davies, 1951). This implies that the escarpment fault is a controlling structure. Magnetotelluric (MT) sounding have been undertaken across Buranga geothermal field together with TDEM. Data processing and interpretation is on-going.

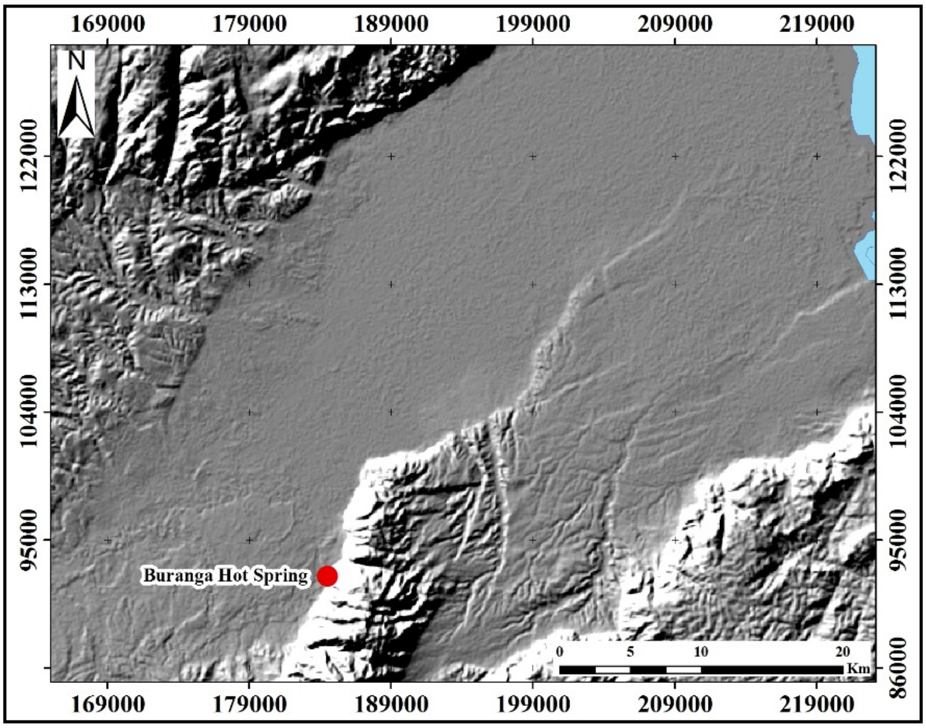

FIGURE 15: Map showing main Bwamba fault (NE-SW striking structural feature) with hot spring, a main controlling structure

6.4 Katwe

Gravity, aeromagnetic, magnetics, and reflection-seismic surveys have been run over the Katwe system. Thermal Gradient Holes were also drilled in this area. Distribution and trends of surface features provide valuable clues to the nature and structural control of geothermal reservoir. High angle deep penetrating faults are targeted here since they are believed to offer structural control geothermal fluid flow and are potential migration pathways for magma ascent. The heat source for the Katwe is believed to be deeply buried magma body since it is in a volcanic (6.89 – 8ka Boven et al 1998) terrain. The presence of young volcanic rocks (< 1 my in age) is among the best diagnostic criteria for locating potential geothermal resources. While none of the magma bodies have been discovered, there is little doubt that extensive heat sources underlie the Katwe field, as proven by the active volcanism. Here the exploration target is the NE-SW rift bounding fault (Figures 16 and 17).

Magnetotelluric (MT) measurements are planned to be run across Katwe geothermal field together with TDEM targeting high angle deeply penetrating faults.

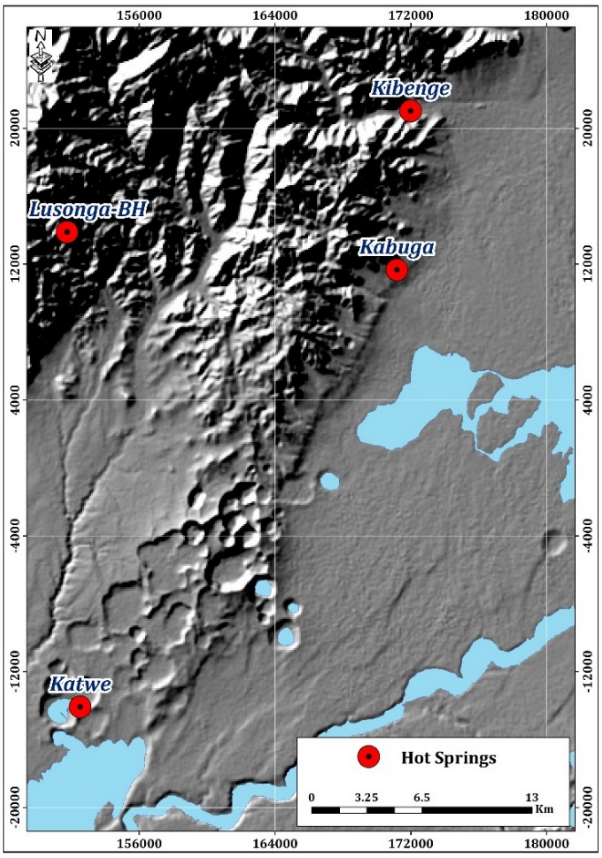

FIGURE 16: Showing major NE-SW rift bounding fault presumed to offer structural control geothermal activity in Katwe

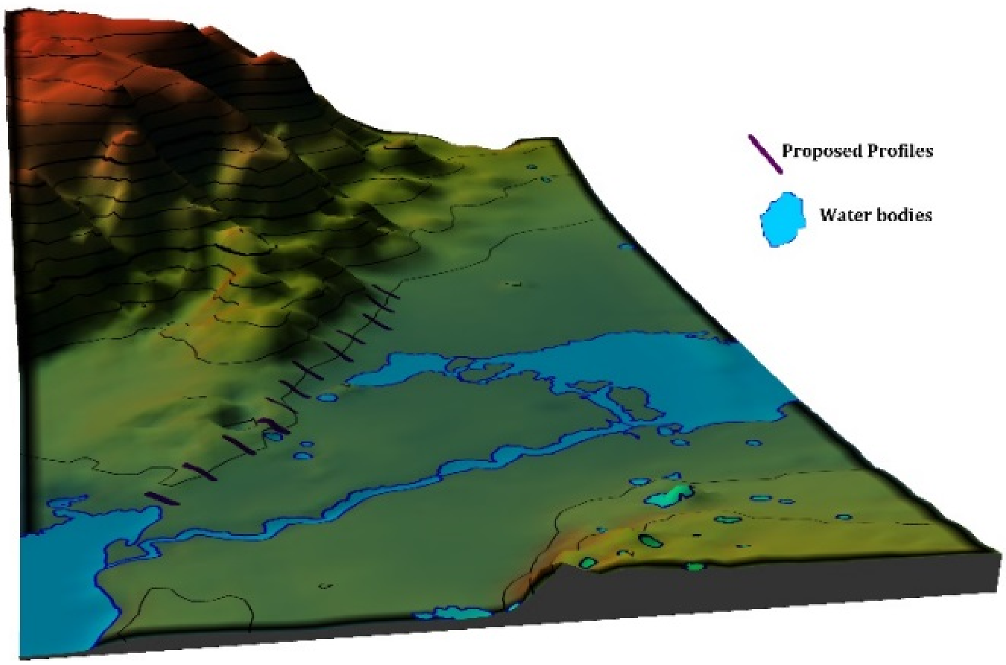

FIGURE 17: Showing main rift bounding fault, NE-SW striking structure and proposed MT/TEM profile lines

7. GEOLOGICAL MODELS

The studied geothermal systems are located in intra-continental rift setting. The rift system is still in initial evolution stage where by rift bounding faults are preferential pathways for magma ascent into the crust. These are extensional tectonic domain where by crustal extension and thinning resulted into magma ascent into the thinned crust. This resulted into heated crust (thermal zone) and high heat flow the principal source of heat for these systems. This geological models need to be tested and refined until a hopefully more reliable model is got to guide drilling. As of now the author believe these are fracture controlled system, involving deep circulation into the heated crust. These typifies other fault controlled geothermal fields driven by deep circulation of groundwater. Fault/fracture permeability is favored instead formation permeability at Kibiro, Panyimur, Buranga and Katwe.

8. NATIONAL GEOTHERMAL DATABASE

The Geothermal Resources Department is organizing existing data on geothermal resources in Uganda. A National Geothermal Database will enable the location, sharing, and reuse of data, and reduces the redundancy of data. This is intended to reduce costs in terms of time and money (Figure 18).

9. HUMAN CAPITAL DEVELOPMENT

The Ministry has a small base of experienced professionals and equipment. The Government has an objective of developing a geothermal industry workforce with skills and capacity to enable the rapid development of the industry. Government is working international geothermal centers of excellence and education organization to build capacity (Figure 19). These include United Nations University-Geothermal Training Programme in Iceland, short courses (UNU-GTP, KenGen, GDC) in Kenya, West Jec Inc in Japan, ARGeo-UNEP. In house training is also undertaken (Figure 20).

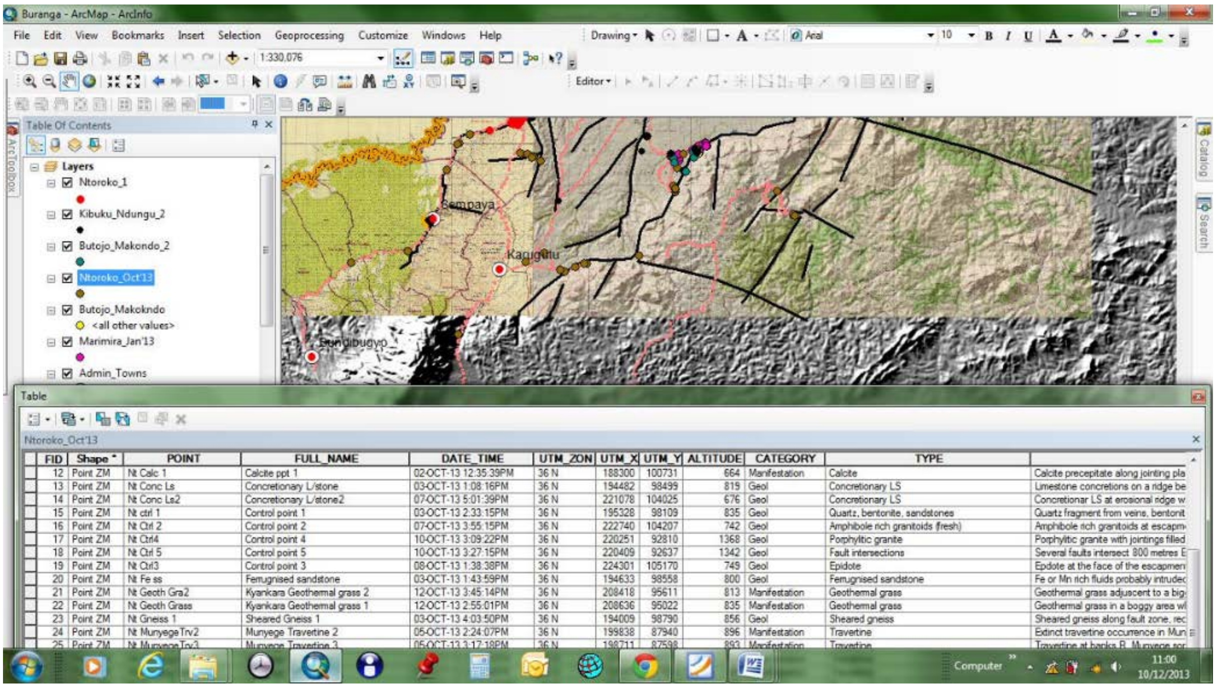

FIGURE 18: National geothermal database

FIGURE 19: GDC Consultants in Kibiro Uganda (Nov 2015)

FIGURE 20: Training in field mapping in Uganda

10. GEOTHERMAL RESOURCES DEPARTMENT

The Government has restructured the Ministry of Energy and Mineral Development and has established a Geothermal Resources Department. Procurement of mapping equipment, geological software, office equipment and accessories commenced and is on-going. This Department will steer and spearhead geothermal development in Uganda.

11. POLICY FORMULATION

Government is working with Climate Technology Center and Network (CTCN) to put in place a geothermal energy policy, Act and Regulation.

11.1 On-going and up-coming projects

- **UNEP-ARGeo**: Geophysical Surveys (MT/TEM) has begun in Kibiro Geothermal Area. Work was conducted by GDC of Kenya and Local counter parts. Also undertaken was geochemical surveys which included soil gas sampling and surface water sampling.
- **Energy for Rural Transformation (ERTIII)**: Under this World Bank funded project, geothermal has a component for equipment and capacity building.
- **SREP**: Uganda has been earmarked for SREP funds to at least drill two sites with 3 wells at each site.

12. CONCLUSION

- Uganda is endowed with geothermal resources ascribed to its geological setting and as evidenced with surface indicators of geothermal activity.
- Western rift is in initial evolution stage where by bounding faults are preferential pathways for magma ascent into the thinned crust. This presents geothermal resources potential.
- The heat source of geothermal systems is related to elevated mantle into the crust and high heat flow.
- These geothermal systems are fault-bounded extension tectonics systems whereby permeability is controlled by main bounding faults. This is evidenced by alignment surface geothermal indicators.
- Main bounding faults offer high permeability but intersections of faults present increased permeability. They are also preferential pathways for magma upwelling.
- Soil gas survey has revealed active hydrothermal conduits (faults).
- Elevated 3He/4He ratios in Buranga which were believed to be evidence of deep permeability, hydrothermal conduits (faults) and possibly deeper, higher-temperature fluid reservoirs.
- Soil gas sampling has revealed elevated levels along the main bounding fault at Kibiro.
- Main bounding faults are exploration targets. MT/TEM soundings are planned across these targets to detect high permeability zones.
- Establishment of a National Geothermal Database will enable the location, sharing, and reuse of data, and reduces the redundancy of data

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