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STATUS OF GEOTHERMAL EXPLORATION AND DEVELOPMENT IN UGANDA

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ABSTRACT

Exploration for geothermal energy in Uganda has been in progress since 1993. The studies have focused on three major geothermal areas namely Katwe, Buranga and Kibiro. The three areas are in advanced stages of surface exploration and will soon be subjected to exploratory drilling that will pave the way for a feasibility study. The overall objective of the study is to develop geothermal energy to complement hydro and other sources of power to meet the energy demand of rural areas in sound environment.

Recent studies have used geological, geochemical, hydrological and geophysical methods to elucidate subsurface temperatures and the spatial extent of the geothermal systems. The results indicate that the geothermal activity in the three areas is related to the volcanic and tectonic activities of the Rift Valley, which has a higher heat flow than the surrounding Precambrian crust. Subsurface temperatures of approximately 140-200˚C for Katwe, 120-150˚C for Buranga, and 200-220˚C for Kibiro have been predicted by geothermometry and mixing models. Anomalous areas have been delineated in Katwe and Kibiro prospects using geophysical methods. Drilling of shallow boreholes to a depth of 200-300m for temperature gradient measurement was carried out. The temperatures measured (30-36˚C/km) were slightly above the global average of 30˚C/km, which suggests deep reservoirs in Katwe and Kibiro or geothermal reservoirs offset from the drilled areas. Additional geophysical surveys to locate the deep reservoirs and drill sites in the two areas are recommended. The results will then be used to update the geothermal models that will be a basis for drilling of deep geothermal wells in the two areas. The Buranga area still needs detailed geophysical surveys to delineate anomalous areas that could be targets for drilling.

The fourth area, Panyimur in Nebbi district, West Nile region, has indications of a geothermal prospect following the results of the petroleum drilling programme that has encountered high temperature gradients (maximum 80˚C/km) in the vicinity of the thermal area. Preliminary investigations to promote the area for further studies are under way.

Preliminary geothermal investigations on other geothermal areas of Uganda have been done. The results indicate subsurface temperatures in the range of 100 - 160˚C suitable for electricity production and direct uses. Further geothermal investigations are recommended for these areas.

1. INTRODUCTION

1.1 The geothermal resources

Geothermal resources were estimated at about 450 MW in the Ugandan Rift System (McNitt, 1982). Most of the geothermal areas of Uganda all located in the Western Rift Valley that runs along the border of Uganda with the Democratic Republic of Congo, and is part of the western branch of the East African Rift System (Figure 1).

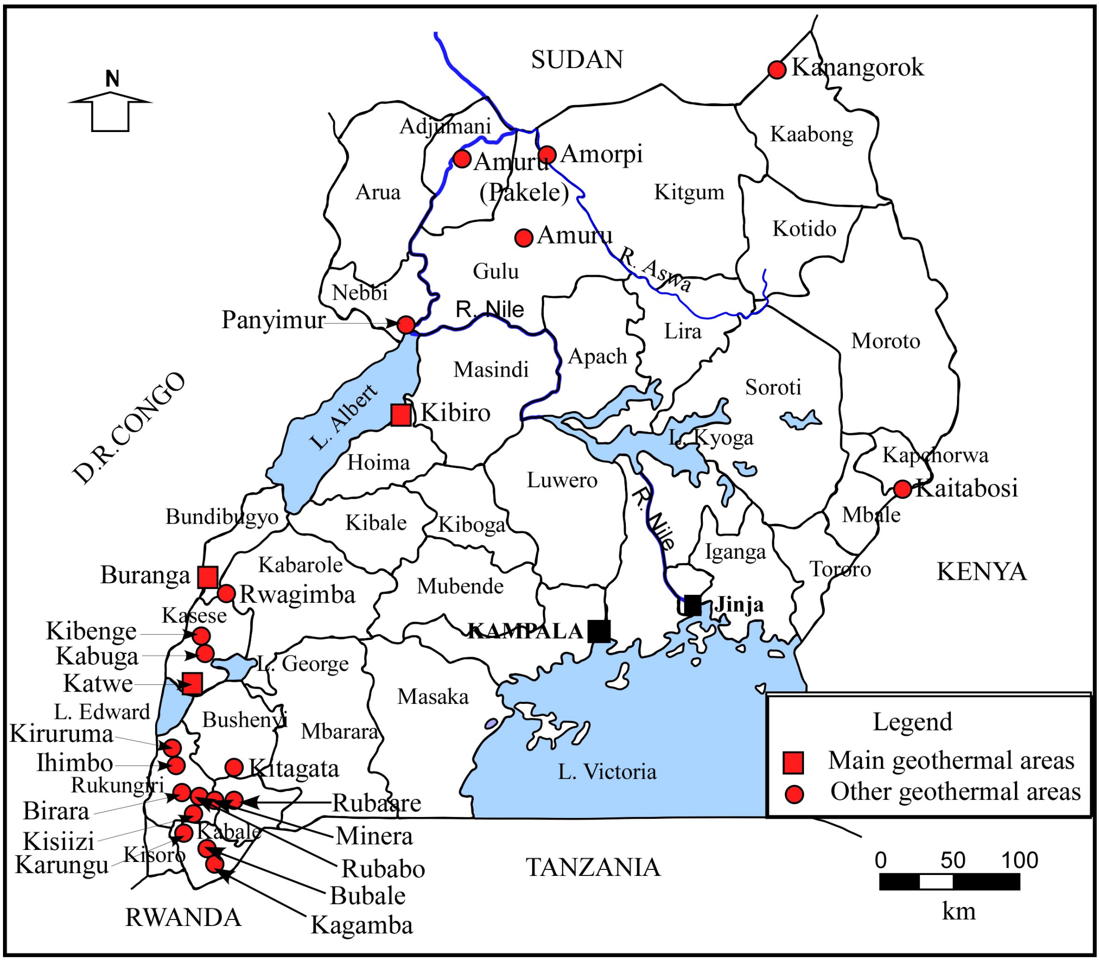

FIGURE 1: The geothermal areas of Uganda.

The main geothermal areas are Katwe-Kikorongo (Katwe), Buranga, Kibiro and Panyimur located in Kasese, Bundibugyo, Hoima and Nebbi districts respectively. Other geothermal areas are located in the Southwest, North and Northeast Uganda.

Geothermal resources exploration in Uganda is still at the pre-feasibility phase with three most promising prospects Katwe, Buranga and Kibiro in advanced stages of surface exploration and will soon be subjected to the drilling of the first deep exploration wells and feasibility studies. Subsurface temperatures of approximately 140-200˚C for Katwe, 120-150˚C for Buranga, and 200-220˚C for Kibiro have been predicted by geothermometry and mixing models. The temperatures are suitable for electricity production and for use in industry and agriculture. Recent geological, geochemical and geophysical surveys have located geothermal anomalous areas for further investigations and location of drill sites. The temperature gradient results (30 - 36˚C/km) from shallow boreholes of 200 – 300m in Katwe and Kibiro prospects, suggest that the source of heat is either deep seated or offset from the drilled areas. There is therefore a need for additional geophysical surveys using methods which probe deeper into the subsurface to locate the heat source and its extent, in order to complete surface exploration in the three areas.

The fourth area, Panyimur in Nebbi district, West Nile region, has indications of a geothermal prospect following the results of the petroleum drilling programme that has encountered high temperature gradients (maximum 80˚C/km) in the vicinity of the surface manifestations (hot springs). This area needs to be further investigated.

Preliminary geothermal investigations on other geothermal areas of Uganda have been done. The results indicate subsurface temperatures in the range of 100 - 160˚C suitable for electricity production and direct uses.

1.2 The energy sector

The country is endowed with considerable hydropower resources with the potential estimated to be in excess of 2,500 MW. Uganda presently has a total installed capacity of electricity production of 565 MW of which 387 MW is hydropower, 160 MW is generated from thermal power plants and 18 MW from cogeneration in sugar industries. Hydropower capacity has been reduced to a mere 150 MW due to climatic fluctuations resulting in lowering of water levels in Lake Victoria, that serves as the reservoir for two major hydropower dams at Jinja; the Nalubale (formerly Owen Falls) and Kiira (Owen Falls extension) dams on the River Nile. The demand for electricity is estimated at 540 MW. To offset the demand, the Government is constructing Bujagali hydropower dam (250 MW) and in 2011 construction of Karuma (600 MW) also along the River Nile will start. In addition, other small hydros in the western part of the country are under construction. Two more dams, Ayago (600 MW) and Isimba (140 MW), also along the River Nile are at the feasibility stage. Other proposed hydropower developments on the River Nile have raised socio-economic and environmental issues and therefore a need to diversify the energy sources. Alternatives being investigated are mainly renewable sources that include geothermal, biomass, wind, peat, mini and small hydros, and solar energy.

The country's *per capita* energy consumption of 30.116 Kwh is among the lowest in the world (Energy statistics, 2006). The grid electricity access rate is very low: 12% for the whole country and about 6% for the rural areas. Electricity production is approximately 2,280 GWh per year with a demand for power growing by 8% per anuum.

1.3 Legal and institutional framework

The Ministry of Energy and Mineral Development (MEMD) implements the national energy policy with two departments i.e. Energy Resources (ERD) and Geological Survey and Mines (DGSM) involved in geothermal exploration and development. The DGSM is responsible for exploration and development of the geothermal resources while the ERD is responsible for the energy policies formulation and implementation, and administration of energy laws.

The Uganda Energy Policy was enacted in 2002 and is implemented by the Uganda Electricity Act 1999. This Act provides for an independent Electricity Regulatory Authority (ERA), private sector participation in power generation and distribution with transmission remaining a government parastatal in the medium term. The major goal of the Energy Policy 2002, is to meet the energy needs of Uganda's population for social and economic development in an environmentally sustainable manner. To achieve the above goal, there is need to tap all possible sources of energy in the country, including the new and renewable sources, to which geothermal belongs. Accordingly, one of the Energy Policy, 2002 objectives is to establish the availability, potential and demand of the various energy sources.

To further focus on the above objective, a New and Renewable Energy Policy, 2007 was enacted. The Policy aims to provide a framework to increase in significant proportions the contribution of renewable energy in the energy mix. The policy has: 1) Introduced the feed in tariffs, 2) Standardized Power Purchase Agreements, 3) Obligation of fossils fuel companies to mix products with biofuels up to 20% and 4) Tax incentives on renewable energy technologies.

Licensing for geothermal resources is currently done under the Mining Act 2003, which defines geothermal as a mineral. The above legal and institutional framework is not focused on geothermal and therefore a need for an adequate policy, law and institutional framework.

This paper presents the current status of the geothermal exploration project, and planned exploration and development activities on the geothermal systems of Uganda.

2. STUDY AREAS

The main geothermal areas are Katwe, Buranga, Kibiro and Panyimur (Figure 1). The four areas were chosen for study because of their volcanic and tectonic features that indicate heat sources and high permeability.

Other areas are located within or on the outskirts of the Rift Valley in southwest, west, north and in isolated places in northeast Uganda (Figure 1).

3. CURRENT STATUS

3.1 Katwe geothermal prospect

3.1.1 Geology

The results of geological surveys in the Katwe prospect indicate that explosion craters, ejected pyroclastics, tuffs with abundant granite and gneissic rocks from the basement dominate the area (Figure 2). The volcanic rocks, mainly composed of pyroclastics and ultramafic xenoliths, are deposited on the extensive Pleistocene lacustrine and fluvial Kaiso beds and in some places directly on Precambrian rocks. Minor occurrences of lava are found in the Lake Kitagata and Kyemengo craters. The age of the volcanic activity has been estimated as Pleistocene to Holocene (Musisi, 1991). The deposit is greyish, generally coarse to fine-grained, calcareous and mixed with sand and silt of Pleistocene sediments. Travertine deposits have been found in Lake Katwe, Lake Nyamunuka, Lake Kasenyi, and Lake Kikorongo (Groves, 1930) and in the vicinity of

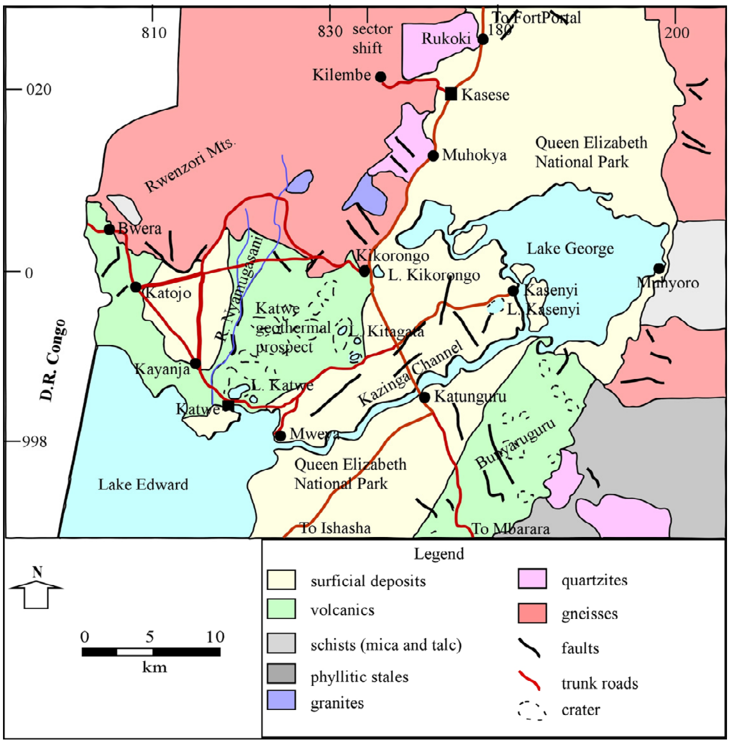

FIGURE 2: The geology of the Katwe-Kikorongo volcanic field and surroundings

Lake Kikorongo at Kikorongo junction (Kato, 2003). The lava flows, craters and extinct hydrothermal deposits give an indication of a heat source for the geothermal activity. The prospect stretches from Lake Katwe to Lake Kikorongo and occupies an area of approximately 150 km^2. Outside the crater area, the geology is characterized by surficial deposits to the east and the west, and to the north lie the Rwenzori Mountains whose geology is dominated by gneisses, granites, granulites, amphibolites, schists and in some places quartzites.

3.1.2 Geothermal manifestations

The geothermal surface manifestations in the Katwe prospect are hot springs located in the Lake Kitagata crater, and warm springs and travertine deposits that have built up tufas in the Lake Katwe crater, which is located 12 km southwest of Lake Kitagata (Figure 2). The maximum surface temperature in the hot springs in Lake Kitagata crater is 70°C, while in Lake Katwe Crater it is 32ºC.

3.1 3 Geochemistry

The geothermal fluids are characterized by high carbonate and sulphate, and salinity of 19,000 - 28,000 mg/kg total dissolved solids. High carbonate and sulphate in the geothermal water tend to invalidate solute geothermometer results in Katwe. Subsurface temperatures are estimated at 140-200˚C using plausible solute geothermometers (Armannsson, 1994). The thermal fluids from Lake Kitagata and Lake Katwe craters are characterized by the presence of high levels of hydrogen sulphide of about 30-40 ppm which suggests the source of the geothermal water to be volcanic and hydrothermal (Bahati, 2003).

3.1.4 Isotope hydrology

A number of water samples from hot springs, cold springs, rivers and lakes as well as rock samples were collected and analyzed for isotopic compositions. The objective was to provide hydrological information essential to the exploration for geothermal resources using isotopes. Isotopes analyzed for included those of hydrogen (δ^2H_{H2O}, $^3H_{H2O}$), oxygen ($\delta^{18}O_{H2O}$, $^{18}O_{SO4}$), sulphur ($\delta^{34}S_{SO4}$), and strontium ($^{87/86}Sr_{H2O}$, $^{87/86}Sr_{Rock}$).
The results indicate that the Katwe geothermal system is most likely recharged from high ground in the Rwenzori Mountains. The tritium concentration in the thermal waters from the Katwe area is minimal suggesting that the hot spring water is not mixed with cold groundwater. The isotopic composition of sulphur ($\delta^{34}S$), and oxygen ($\delta^{18}O$) in sulphate suggests a magmatic and hydrothermal source for the geothermal water. Strontium isotopes in water and rock ($^{87/86}Sr_{H2O}$, $^{87/86}Sr_{Rock}$) indicate an interaction between the rocks sampled and the geothermal fluids. The rocks interacting with the fluids, i.e the reservoir rock types, in Katwe are basalt. The major source of salinity is rock dissolution, but some magmatic input is suggested (Bahati, et. al., 2005).

A temperature of 140 - 150°C was obtained for the sulphate-water ($S^{18}O_4$-$H_2{}^{18}O$) isotope geothermometer (Bahati, et. al., 2005) which compares reasonably well with that from solute geothermometers.

3.1.5 Geophysics

Geophysical surveys; Transient Electromagnetic (TEM) and Gravity were conducted in the Katwe geothermal prospect (Gislason, et. al., 2005). The results indicate the existence of two low resistivity anomalous areas (Figure 3). The first one is located around Lake Katwe and the second stretches from Lake Kitagata to Lake Kikorongo. The gravity data agrees with the TEM resistivity data and indicates that the two low resistivity anomalous areas are controlled by a N-S fault east of Lake Katwe and a NNE-SSW fault in the Lake Kitagata – Lake Kikorongo area (Figure 3).

3.1.6 Temperature gradient drilling

The drilling of six thermal gradient wells up to a maximum of 300m depth in the volcanics did not show any indication of Olivine-Biotite-Pyroxene (OBP) series. This confirms that the depth to the intrusive source of heat is greater than 300m to which the wells were drilled (Gislason et.al., 2008).
The results from the temperature gradient measurements give almost linear profiles indicating conductive heat transfer (Gislason et.al., 2008). However, the values between 30 and 36˚C/km are slightly above the global average of 30˚C/km suggesting that the geothermal reservoir is either deep-seated or offset from the drilled sites.

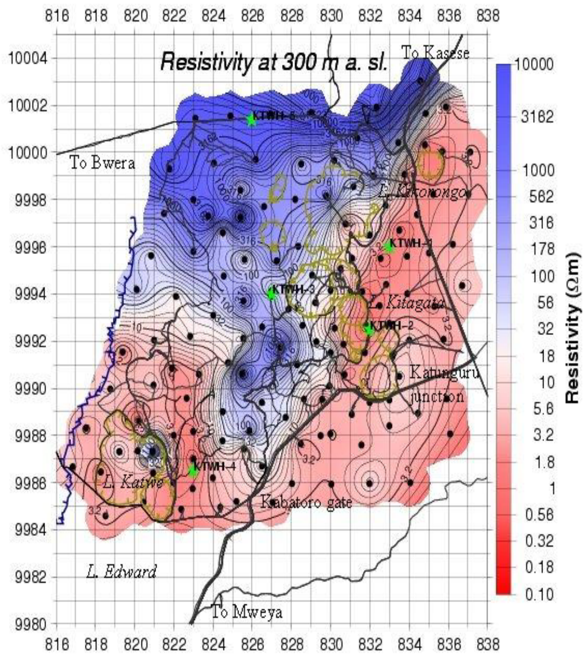

FIGURE 3: Katwe. Resisitivity at 300 m a.s.l., (from Gislason et. al., 2005)

3.2 Kibiro geothermal prospect

3.2.1 Geology

The Kibiro geothermal prospect is divided into two entirely different geological environments by the escarpment, which cuts through the field from SW to NE (Figure 4).

To the east of the escarpment, the geology is dominated by Precambrian crystalline basement, characterized by granites and granitic gneisses that are mylonitic in the fault controlled valleys. To the west lies an accumulation of thick sequences of Rift Valley arenaceous Kaiso and argillaceous Kisegi sediments of at least 5.5 km thickness, but without any volcanic rocks on the surface. The faults of the escarpment that strike N50^{0}E constitute the main structures in the tectonic environment. The forces causing the rifting of the Archaean plate have put stress on the granitic rocks resulting in block faults with two main directions, N20^{0}E and N90^{0}E.

Crosscutting joints striking mainly E-W and N20^{0}E with vertical dips are found in all the rock types. A less common joint set of N130^{0}E also occurs (Gislason et.al., 2004) (Figure 4).

Some joints are open while others are filled with secondary minerals commonly quartz or siliceous material and rarely by calcite. The faulting and jointing in the crystalline basement constitute high yielding aquifers as evidenced by the shallow thermal gradient wells drilled in the area.

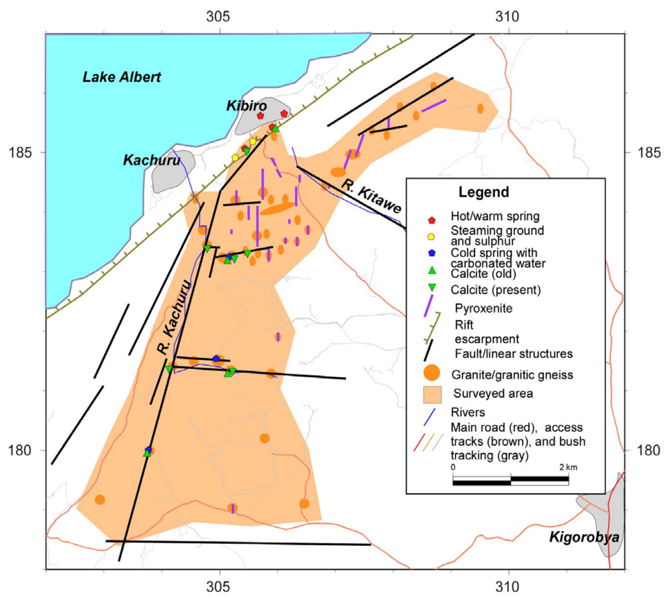

FIGURE 4: Kibiro. Geology and geothermal surface manifestations (from Gislason, et. al., 2004)

Recent geological and geophysical studies show anomalous areas that can be traced along faults in the block faulted granites to the east and away from the Rift escarpment (Gislason, et. al., 2004).

3.2.2 Geothermal manifestations

The geothermal surface manifestations in the Kibiro geothermal prospect are mainly concentrated at Kibiro, west of the escarpment, on the shores of Lake Albert. They comprise hot and warm springs (Figure 4). There are fresh and continuous depositions sulphur and petroleum in the Kachuru area and along the escarpment for approximately 1.5 km from the Kibiro hot springs towards the Kachuru fault. The deposits are cold and preliminary interpretation indicates that they could be related to petroleum than geothermal as previously thought. Calcite deposits are observed in cracks and fissures in many locations along the escarpment, Kachuru fault, Kitawe fault and in the crystalline rocks located south-southeast of Kibiro, indicating extinct thermal fluid discharges (Figure 4).

The hot springs at Kibiro are located along the Kitawe fault that strikes NW - SE and east of the main fault, the Tooro - Bunyoro fault, and not controlled by the intersection of a secondary oblique fault and the Tooro – Bonyoro fault as previously thought (Getahun et al, 2011). The total flow measured from the hot springs is approximately 7 l/s and the maximum surface temperature is 86.4˚C (Gislason et. al., 1994).

3.2.3 Geochemistry

The fluids are characterized by a neutral pH, and salinity of 4,000 - 5,000 mg/kg total dissolved solids. A subsurface temperature of 200 - 220°C is inferred by geothermometry and mixing models (Armannsson, 1994).

3.2.4 Isotope hydrology

Stable isotope results show that two groups of waters located east and south of Kibiro represent the groundwater that could be the source of recharge for the Kibiro hot springs (Figure 5). A massive flow of groundwater from a higher elevation than all the cold-water sampling points is also suggested. This high ground is represented by the Mukhihani-Waisembe Ridge in Kitoba subcounty, located 20 km southeast of Kibiro.

The tritium concentration of the Kibiro hot spring water is 1.25 TU similar to that of the groundwaters (0 - 3.5 TU), and indicates that the hot spring water has cold groundwater contribution as suggested by geochemical modelling and is therefore a mixture of a hot water component and cooler water (Ármannsson, 1994). However, it should be

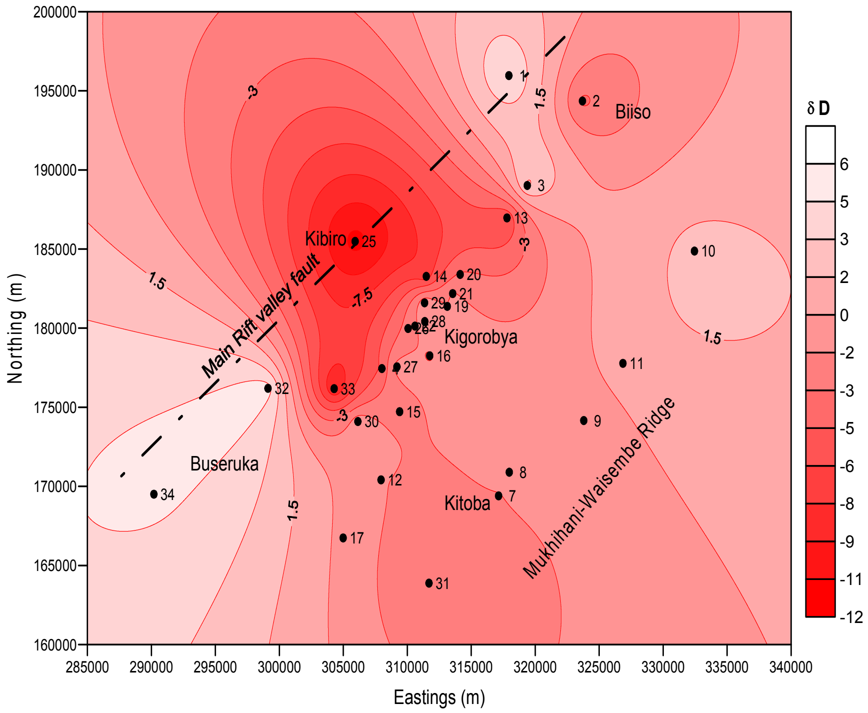

FIGURE 5: Kibiro. Deuterium variation in surface and groundwaters, dots represent sampling points

noted that the tritium background in precipitation for the area is rather low, up to a few tritium units only, and indications of mixing may not always be clear.
The isotope composition of sulphur and oxygen in sulphates expressed in $\delta^{34}S$ (SO_4) and $\delta^{18}O$ (SO_4) suggest a magmatic contribution. Strontium isotopes in water and rock ($^{87/86}Sr_{H2O}$, $^{87/86}Sr_{Rock}$) indicate an interaction between the granitic gneisses and the geothermal fluids. The reservoir rock types in Kibiro are, therefore, granitic gneisses (Bahati, et. al., 2005).

3.2.5 Geophysics

The results of the geophysical surveys indicate the existence of anomalous areas in the Kibiro prospect (Gislason et. al., 2004). A low resistivity anomaly trench was traced into the crystalline basement, following the fault lines of the block-faulted granites, first to the SSW away from Kibiro and then following W-E fault lines toward Kigorobya Town (Figure 6).

The gravity data does not show any distinct density variations, except for the large density contrast between the sediments in the Rift Valley and the granites east of the escarpment. There is, however, an indication of a higher gravity field in an area roughly coinciding with the W-E low-resistivity anomalous area (Figure 6). This might indicate a deep higher density intrusive acting as a heat source for the geothermal activity producing the low-resistivity anomaly.

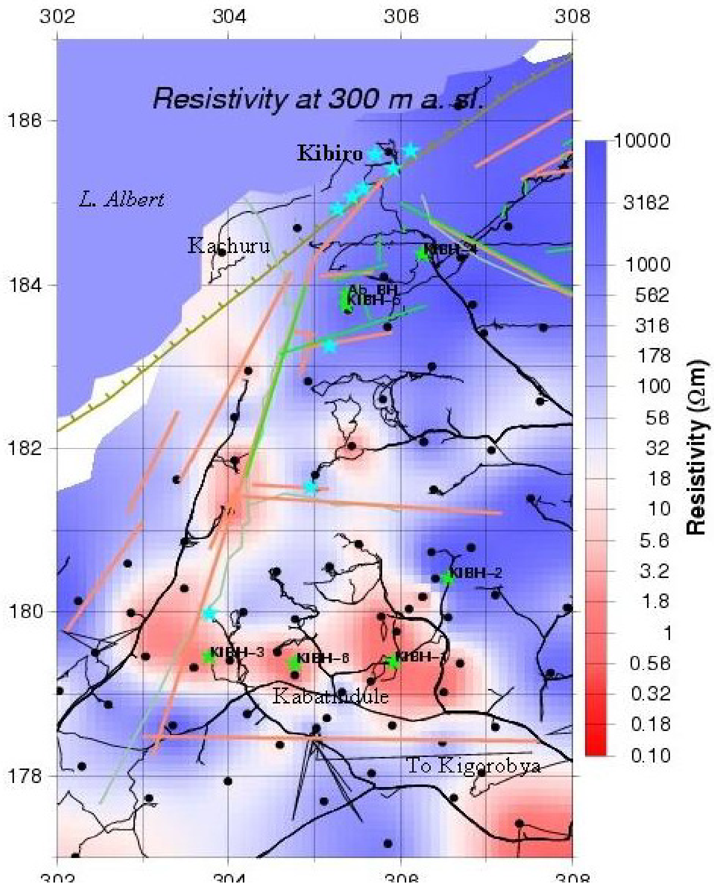

FIGURE 6: Kibiro. Resisitivity at 300 m a.s.l., faults and fractures, geothermal surface manifestations (stars) (from Gislason et. al., 2005)

The cause of these low-resistivity anomalies can, at the moment, not be stated with certainty, but the most likely explanation is conductive alteration minerals in fractures in the otherwise resistive base-rock. Saline water in fractures could also be a possible candidate, but the relatively low salinity of the water discharges from hot springs at Kibiro and other cold springs in the area makes this rather unlikely.

3.2.6 Temperature gradient drilling

Six thermal gradient wells were drilled up to 300 m in the geophysical anomalous areas in the crystalline basement. The lithological analysis and the temperature gradient results indicate absence of a geothermal gradient east of the escarpment (16˚C/km) but slightly elevated towards the escarpment (31˚C/km). The results indicate that the anomalous area in the crystalline basement east of the escarpment is not caused by a geothermal activity or represents an old geothermal system that has cooled down.

3.3 Buranga geothermal prospect

3.3.1 Geology

Buranga is located at the foot of the Rwenzori massif near the base of Bwamba escarpment and localized by the major Rift Valley faults (Figure 7). Buranga has no evidence of volcanism but is highly tectonically active.

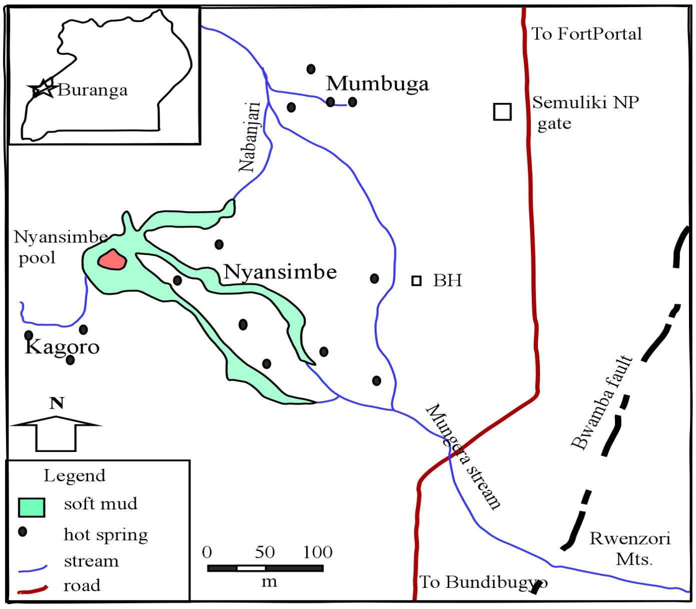

FIGURE 7: Buranga geothermal area

The hot springs emerge through sediments of Kaiso beds and peneplain gravels. The Kaiso beds and peneplain gravels consists of variable sands and gravels with irregularly distributed boulders containing sub-angular fragments.

The Kaiso sediments are underlain by fine to medium-grained, poorly consolidated sands and clays; some coated with calcareous material. Precambrian rocks of the main rift fault, which strikes N45°E and dips N60-65°E, underlie the sediments. The rocks form the northern half of Rwenzori massif and consists mainly of migmitites, gneisses and amphibolites. They strike N10-30°E and have complex joint systems. The hot springs seem to lie on a fracture/fault line striking N40°E parallel to main rift fault.

3.3.2 Geothermal manifestations

Buranga has the most impressive surface geothermal manifestations with a wide areal coverage in the whole of the western branch of the East African Rift System. They include hot springs that are close to boiling and calcareous tufa. The surface temperature is close to 98˚C and the flow is approximately 10-15 litres/second, an indication of high permeability.

3.3.3 Geochemistry

The fluids are neutral with a pH of 7-8 and salinity of 14,000 – 17,000 mg/kg total dissolved solids. In the earlier study by Ármannsson (1994) a good agreement was obtained for all plausible solute geothermometers tested for several hot springs and pools in Buranga and it was concluded that the subsurface temperature was 120 - 150°C. This temperature is in agreement with the results of gas analysis which show absence of hydrogen, suggesting that the subsurface temperature is less than 200°C.

3.3.4 Isotope hydrology

The results from stable isotopes suggest that the geothermal water is from high ground in the Rwenzori Mountains like in Katwe (Figure 8).

There is no tritium in the thermal water from Buranga which implies that it is not mixed with cold groundwater. The strontium ratios in rocks indicate that the geothermal water, most likely, interacts with granitic gneisses. The source of sulphate is minerals or rock (terrestrial evaporates) with a possible magmatic contribution (Bahati et. al., 2005). Studies by the Federal Institute for Geosciences and Natural Resources (BGR) of Germany and the Government of Uganda using helium isotopic ratio ($^3He/^4He$) in gaseous discharges from hot springs also suggest a magmatic source of solutes for Buranga (BGR-MEMD, 2007).

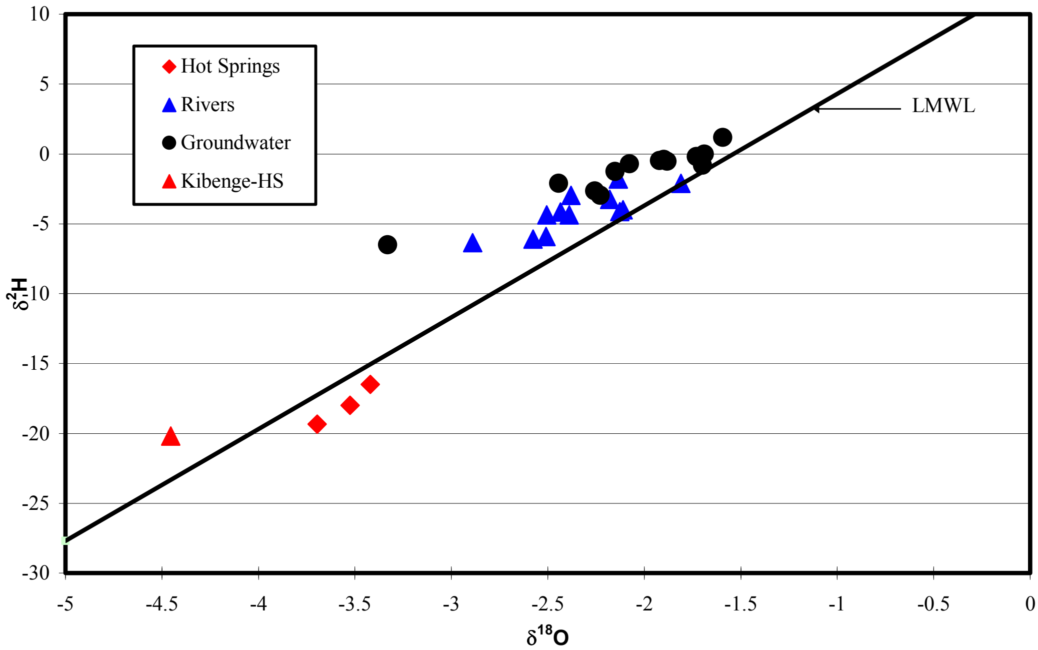

FIGURE 8: Buranga. Stable isotopic composition of hot and cold water samples

3.4 Panyimur geothermal prospect

3.4.1 Geology

Panyimur hot springs are located on escarpment front just near the shores of Lake Albert, in Panyimur subcounty, Nebbi district (Figure 1).

The area is characterized by fractured crystalline basement rocks such as coarse hornblende gneisses, coarse hornblende garnet rocks, talcose rocks and pegmatitic veins in a gorge that dips into the escarpment from the hot springs. A foliation/basement schistose trends NNE-SSW. Others schistose trend almost NE, parallel to the local major faults.

Rocks in the area include crystalline basement rocks (coarse jointed granitic-gneiss outcrops to the west) and Pleistocene sediments to the east of the Rift fault boundary.

3.4.2 Surface manifestations

The thermal area can be divided into three groups of hot springs namely; Amoropii, Okumu and Avuka, all along the faults that mark the western escarpment of the Rift Valley. The hot springs are aligned in a northeast direction and possibly controlled by the intersection of the traverse faults and the main rift fault. The hot springs stretch for a length of approximately 1.5 km along the main rift fault with Amoropii further northeast and Avuka further southwest. Other surface manifestations reported include deposits of travertine, sulphurous algae and smell of hydrogen sulphide characteristic of a high temperature area. The surface temperature ranges from 35˚C to 58˚C. The maximum surface temperatures at Avuka is 55˚C, at Okumu is 47˚C and 58˚C at Amoropii.

The Okumu hot spring is tapped through a protected spring which is surrounded by inactive travertine mounds (old spring deposits). All the discharges are characterized by gas bubbling.

3.4.3 Geochemistry

The fluids are slightly above neutral with a pH of 7-9 and low salinity of 300 – 900 mg/kg total dissolved solids (Armannsson et. al., 2007). Presence of hydrogen sulphide in Okumu (2.48 ppm) and Amoropii (5.61 ppm) hot spring waters indicates that the source of heat is could be volcanic and, therefore, the possibility of a high subsurface temperature in the area. But the Quartz and NaK predicted geothermometer temperatures of 100-115°C and 100-140°C for Panyimur are low suggesting that the sampled waters may not be in equilibrium and most likely contaminated with surface cold waters. A repeat of the sampling is needed to get more representative samples which could assist in delineating the subsurface temperature of the area.

3.5 Other geothermal areas

The rest of the geothermal areas of Uganda are at a preliminary level of investigation. The current results predict subsurface temperatures of 100 - 160˚C suitable for electricity production and direct uses. Four areas have been selected for detailed surface exploration and they include Rubaare in Ntungamo district, Kitagata in Bushenyi district, Ihimbo in Rukungiri district, and Kanangorok in Kabong district.

4. ON-GOING PROGRAMMES

The RAF/8/047 project, *"Introducing isotope hydrology for exploration and management of geothermal resources in the African Rift System"* is a technical cooperation project between the IAEA and the five ARGeo Countries namely; Eritrea, Ethiopia, Kenya Tanzania and Uganda. The project started in 2009 and is ending this year 2011. The project is a component of the ARGeo project. It uses isotope techniques to delineate flow of the geothermal fluids from the surface to the subsurface and back to the surface. In Uganda it would address some of the gaps in knowledge in selected Ugandan geothermal prospects by determining the source of recharge, residence time and sub-surface temperature of potential geothermal prospects. It was also designed as a tool for management of geothermal fields in production. This project did not realize its objectives and a new project proposal by ARGeo is needed for continued support from the IAEA for the cycle 2012 – 2014.

5. PRIVATE SECTOR PARTICIPATION

Two companies; (i) Cozumel Energy Ltd., and (ii) GIDS Consult Ltd., were licensed in 2011 to carryout geothermal exploration and development in Katwe and Buranga geothermal prospects respectively.

6. CONCLUSIONS

Subsurface temperatures of 140-200°C, 120-150°C and 200-220°C are inferred by geothermometry for Katwe, Buranga and Kibiro respectively. These temperatures, if confirmed, are good for electricity production and for direct use in industry and agriculture.

Anomalous areas have been partially mapped by geological and geophysical studies in Katwe and Kibiro prospects.

Temperature gradient measurements (30 - 36°C/km) suggest geothermal reservoirs in Katwe and Kibiro that are either deep seated or offset from current drilled positions.

Isotope hydrology results indicate the source of the geothermal fluids to be from high ground in the Rwenzori Mountains for Katwe and Buranga, and from the Mikihani-Waisembe ridge for Kibiro. Reservoir rock types are most likely basalt in Katwe, and granitic gneisses in Buranga and Kibiro. Three areas, Katwe, Buranga and Kibiro, have reached advanced stages of surface exploration. The fourth area, Panyimur, has indications of a geothermal prospect following the results of the petroleum drilling programme that has encountered high temperature gradients (maximum 80˚C/km) in the vicinity of the thermal area. Presence of H_2S in the thermal waters is an indication of a volcanic source of heat and a high temperature area but predicted sub surface temperatures are as low as 100-140 ˚C.

In other areas, the current study has identified other potential geothermal areas with subsurface temperatures of 100-160˚C good for further exploration and development.

7. RECOMMENDATIONS

7.1 Katwe and Buranga

Before the feasibility study is undertaken, the following need to be done: 1) Carry out additional geophysical surveys using the Magnetotellurics (MT) and Transient Electomagnetics (TEM) methods to delineate the boundaries of the low resistivity anomalous areas, probe in the deeper layers of the crust and delineate the heat source, 2) Structural geological and hydrological mapping focused on locating drill sites, 3) Updating of the geothermal models and location of drill sites.

7.2 Kibiro

Before the feasibility study, the following need to be done: 1) A package of geoscientific studies aimed at determining the area and target features for geophysical exploration; and at estimating underground conditions as accurately as possible. 2) Geophysical surveys to identify subsurface features of possible geothermal association: ie reservoir type features and deep fault planes; to propose alternative exploration drilling sites.

7.3 Panyimur

This area is still at the reconnaissance stage of investigation. The following activities need to be done before the area is recommended for the feasibility study: 1) Carryout detailed geological, geochemical and geophysical (MT, TEM and Gravity) surveys at Panyimur to delineate geothermal anomalous areas, identify the source of heat and targets for deep drilling, 2) Carryout hydrological and hydrogeological surveys to study in detail the structures that control the fluid flow mechanisms, 3) Updating of the geothermal model and location of drill sites.

7.4 Feasibility study

Drilling of 2-3 wells to discover a reservoir in the most promising prospect(s); Katwe, Buranga, Kibiro and Panyimur. The objective of the feasibility study is to drill at selected sites; prepare technical and financial/investment plans for the installation of an appropriately sized power plant and feasibility of direct use in industry and agriculture.

7.5 Other areas

The rest of the geothermal areas should be investigated in detail for the possibility of producing electricity and direct heat for industry and agriculture.

7.6 Geothermal Strategy

The current institutional model for geothermal activities is inadequate since the activities are divided between two departments making the execution of geothermal projects difficult. There is therefore a need for a single independent institution that should take the resposibility for geothermal exploration and development. Licensing for geothermal resources is currently done under the Mining Act 2003, which defines geothermal as a mineral.

However, the above legal and institutional framework is not focused on geothermal and therefore a need for a geothermal strategy. The strategy will put in place an adequate Policy, Institutional and Regulatory frameworks for geothermal energy development.

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