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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 an advanced stage 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. The methodology of the study has focused on geology, geochemistry, hydrology and geophysics with the aim of elucidating 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, 120-150°C and 200-220°C for Katwe, Buranga and Kibiro respectively have been predicted by geothermometry. Anomalous areas have been delineated in Katwe and Kibiro prospects using geological, hydrological and geophysical methods. Drilling of shallow boreholes to a depth of 200-300m for temperature gradient measurement has been completed and the temperatures measured. The results will be used to update the geothermal model that will be a basis for the drilling of deep exploration wells. Other geothermal areas are at preliminary level of investigation and the results will soon be available that will be a basis for their prioritisation for future development.

1. INTRODUCTION

The exploration for geothermal resources in Uganda is still at the reconnaissance and exploration stage. Reconnaissance surveys on Ugandan hot springs started in 1921 by the Geological Survey of Uganda and the first results were published by Wayland (1935). In 1973, as a result of the oil crisis, an attempt was made to initiate a geothermal project with United Nations support, but this did not materialise due to the political turmoil in the country. Geothermal resources were estimated at about 450 MW in the Ugandan Rift System and three areas Katwe-Kikorongo (Katwe), Buranga and Kibiro identified as promising areas for geothermal exploration (McNitt, 1982).

Various surface exploration methods have been used with the aim to establish the subsurface temperature of the geothermal systems, the source of heat, the flow characteristics of the geothermal fluids and the spatial extent of the geothermal reservoirs. Three areas Katwe, Buranga and Kibiro are in advanced stages of surface exploration and will soon be subjected to the drilling of the first deep exploration wells. The rest of the geothermal areas of Uganda are at a preliminary level of investigation and results will soon be available that will be a basis for their prioritisation for detailed surface exploration.

This paper summarises the current status of the exploration for geothermal resources in Uganda as at July 2008.

2. STUDY AREAS

The main geothermal areas are Katwe-Kikorongo (Katwe), Buranga and Kibiro. They are all located in the Albertine graben that runs along the border of Uganda with the Democratic Republic of Congo (Figure 1). The Albertine graben is part of the western branch of the East African Rift System in Uganda, commonly known as the Western Rift Valley.

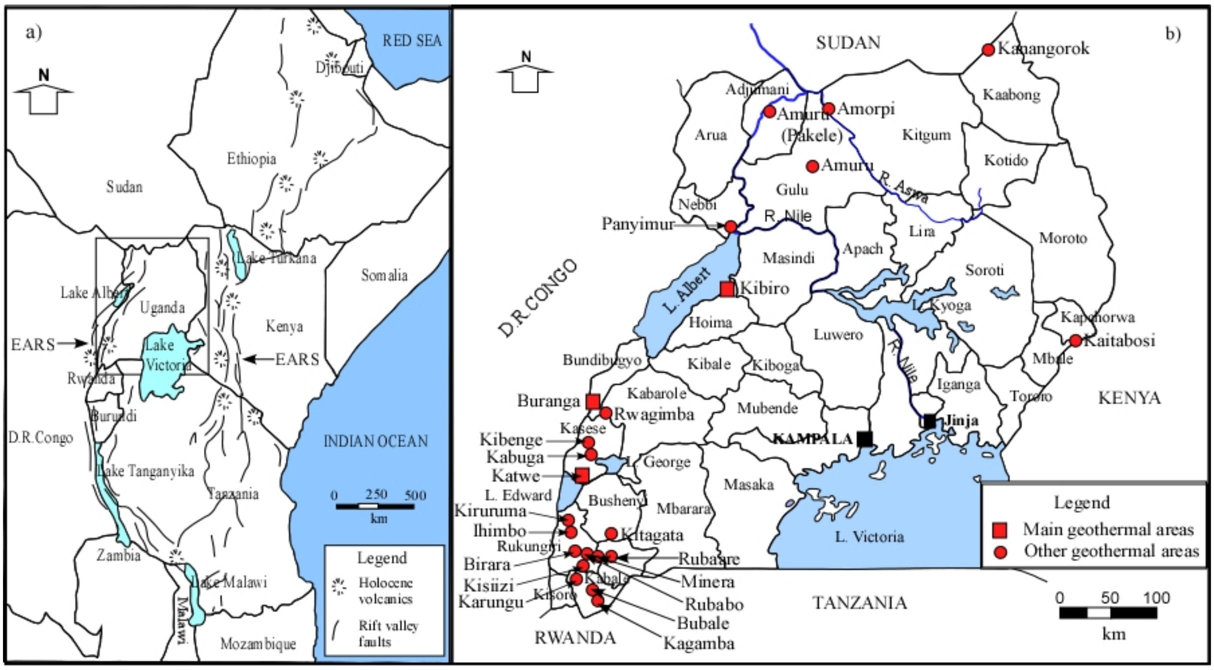

FIGURE 1: a) East African Rift System (EARS), b) Locations of the geothermal areas of Uganda

The three 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, and north and in isolated places in east and northeast Uganda (Figure 1).

The tectonic structural features of the Albertine graben indicate that the three study areas coincide with the accommodation zones (or transfer zones) (Figure 2). The accommodations zones form structural traps which are a potential for geothermal reservoirs.

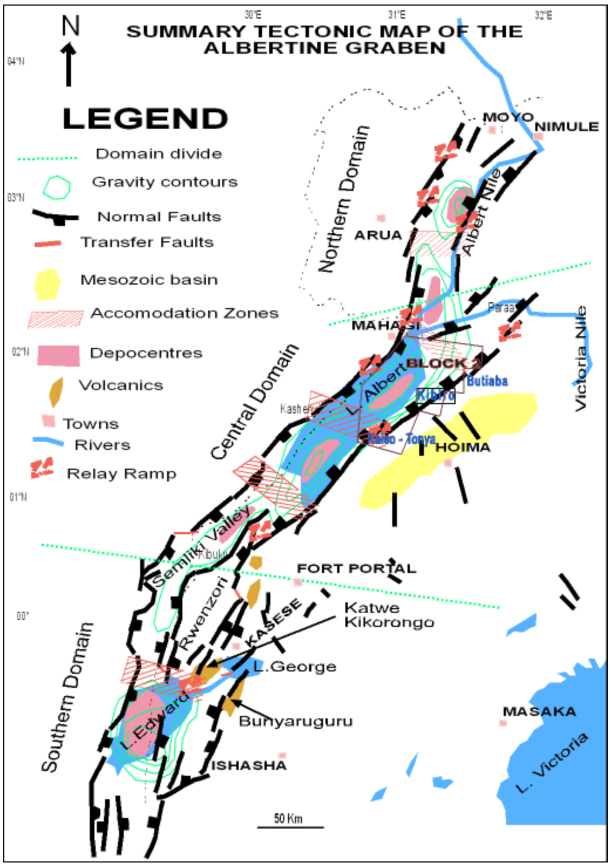

FIGURE 2: Tectonic map of the Albertine rift where the Uganda geothermal areas are located

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 (Figure 3) dominate the area. 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 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 characterised 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 3). The maximum surface temperatures in the hot springs in

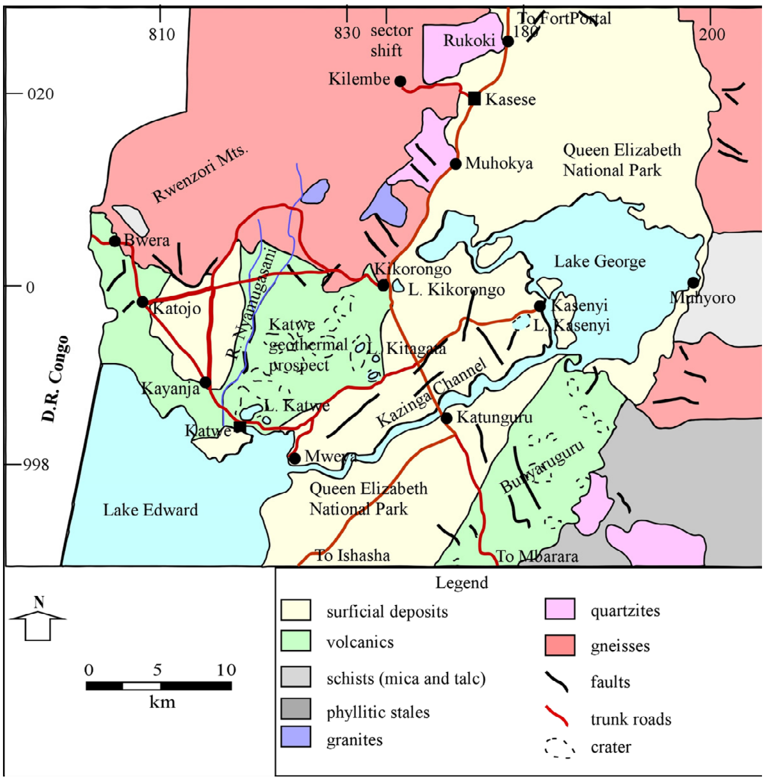

FIGURE 3: The geology of the Katwe-Kikorongo volcanic field and surroundings

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 contents and salinity of 19,000 to 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 (Ármannsson, 1994). The thermal fluids from Lake Kitagata and Lake Katwe craters are characterised 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 a possibly of hot spring water not mixing with cold groundwater. The isotope composition of sulphur and oxygen in sulphates 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 and ultramafic xenolith. The major source of salinity is rock dissolution, but some magmatic input is suggested (Bahati, et al., 2005).

A temperature of 130-140°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

Transient electromagnetic (TEM) and gravity surveys were conducted in Katwe geothermal prospect. The results of the geophysical surveys (Gislason, et al., 2005) indicate the existence of two low resistivity anomalies (Figure 4). 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 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 4).

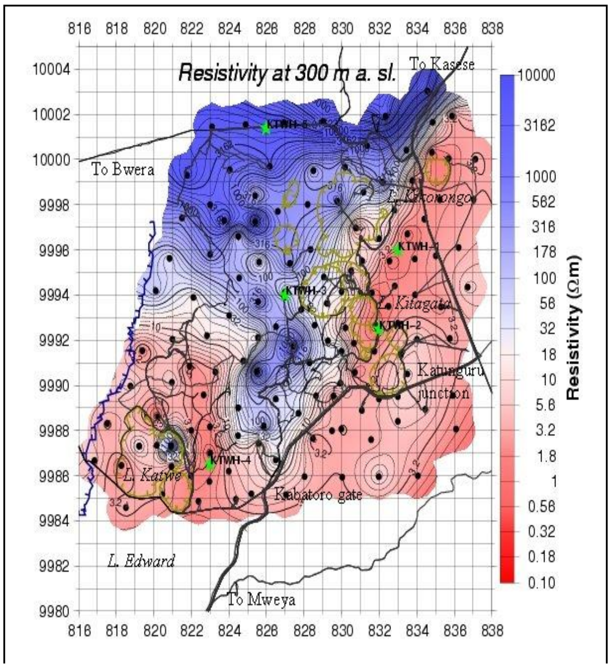

FIGURE 4: Katwe, resistivity at 300 m a.s.l. (from Gislason, et al., 2005)

3.1.6 Temperature gradient drilling

The drilling of six thermal gradient wells up to 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 300 m 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 are low suggesting a very deep-seated geothermal reservoir.

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. 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°E constitute the main structures in the tectonic environment. The forces causing the rifting of the Archaean plate have put stress on the on the granitic rocks resulting in the in block faults with two main directions, N20°E and N90°E. Crosscutting joints striking mainly E-Wand N20°E with vertical dips are found in all the rock types. A less common joint set of N130°E also occurs (Gislason et al., 2004) (Figure 5).

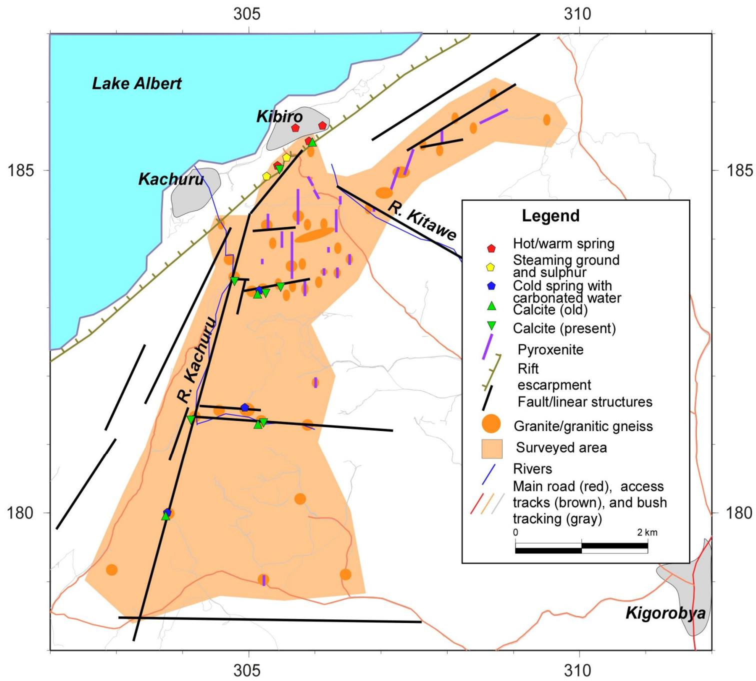

FIGURE 5: Kibiro, geology and geothermal surface manifestations (from Gislason, et al., 2004)

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.

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 and Kachuru, west of the escarpment, on the shores of Lake Albert. They comprise hot and warm springs at Kibiro, and deposits of sulphur and indication of fumarolic activity at Kachuru (Figure 5). The fumarolic activity is heavily pronounced in the Kachuru area in a stretch of an altered belt that spans along the escarpment for approximately 1.5 km from the intersection of the Kachuru fault and the main escarpment to the Kibiro hot springs. 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.

The hot springs at Kibiro are apparently related to a secondary fault, oblique to the main Rift fault, and most likely controlled by the intersection of the two (Figure 5). 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 characterised by a neutral pH, and salinity of up to 4,000 - 5,000 mg/kg total dissolved solids. A subsurface temperature of 200 - 220°C is inferred by geothermometry (Armannsson, 1994).

3.2.4 Isotope hydrology

Stable isotope results show that two groups of waters located east and south of Kibiro (Figure 6) represent the groundwater that could be the source of recharge for the Kibiro hot springs. A massive flow of groundwater from a higher elevation than all the cold-water sampling points is suggested in Figure 6. This high ground is represented by the Mukihani-Waisembe Ridge in Kitoba subcounty, located 20 km southeast of Kibiro.

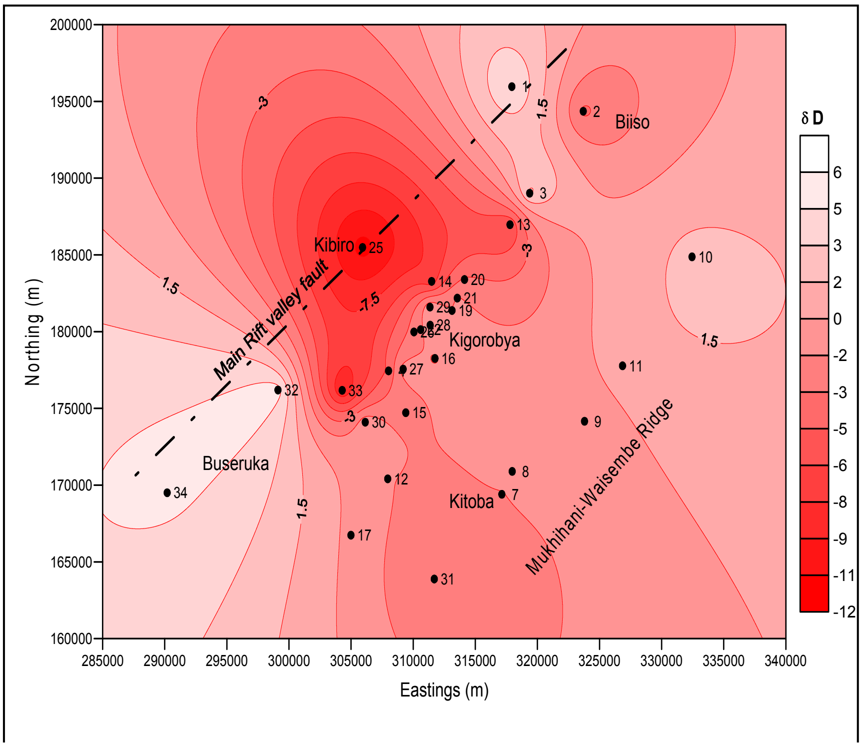

FIGURE 6: Kibiro, deuterium variation in surface and ground waters. Numbered dots represent sampling points

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 had been suggested by geochemical modelling (Ármannsson, 1994) and is therefore a mixture of a hot water component and cooler water. However, it should be 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 indicated 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 7).

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 anomaly (Figure 7). This might indicate a deep higher density intrusive acting as a heat source for the geothermal activity producing the low-resistivity anomaly.

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.

3.1.6 Temperature gradient drilling

Six thermal gradient wells drilled up to 300m were sunk in the geophysical anomalies in the crystalline basement. The lithological analysis and the temperature gradient results indicate that the wells were too shallow to intercept a geothermal reservoir.

The results from the oil exploration drilling done by the petroleum exploration companies in the Butiaba – Wanseko area a few kilometres northeast of Kibiro geothermal field indicated a geothermal gradient of 60°C – 70°C. This fairly high geothermal gradient may be associated with either Kibiro or Panymur geothermal systems.

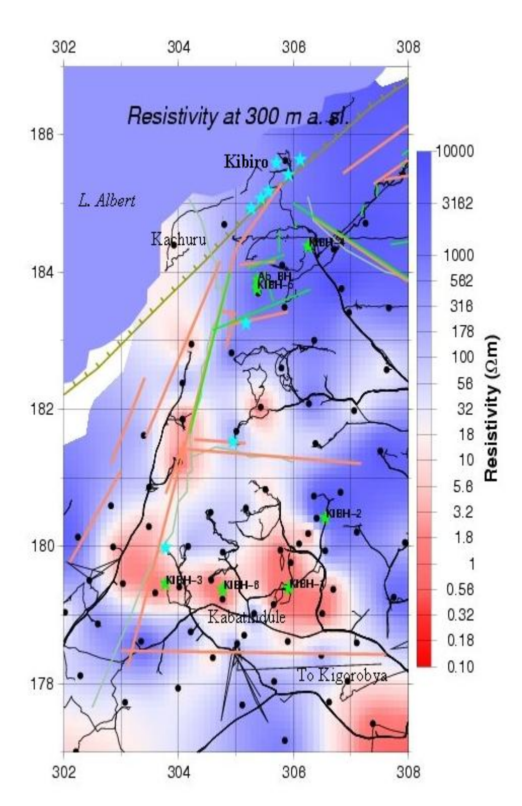

FIGURE 7: Kibiro. Resistivity at 300 m a.s.l., faults and fractures, geothermal surface manifestations (stars) (from Gislason, et al., 2005)

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. Buranga has no evidence of volcanism but is highly tectonically active. 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 (Kisegi sedts). Precambrian rocks of main rift fault, which strikes N45°E and dips N60-65°E, underlie the sediments. The rocks form northern half of Rwenzori massif and consists of mainly migmitites, gneisses and amphibolites. They strike N10-30°E and have complex joint systems. The hot springs 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 (hot springs) with a wide areal coverage in the whole of the western branch of the East African Rift System. They include hot springs, calcareous tufa and recent surveys have reported small-scale fumaroles at Mumbuga spring area. 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 solute geothermometers tested for several hot springs and pools in Buranga and it was concluded that the subsurface temperature was 120-130°C with a possible maximum of 150°C.

3.3.4 Isotope hydrology

The results from stable isotopes suggest that the geothermal water is from high up in the Rwenzori Mountains like in Katwe. 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).

4. ON-GOING PROGRAMS

Drilling of shallow wells of 200-300 m for temperature gradient measurement in Katwe and Kibiro to confirm the low resisitivity anomalies. This activity has been completed and the results of the temperature gradient measurements will be used to upgrade the geothermal model that will be used as a basis for locating deep exploration wells.

Preliminary geothermal investigations in other areas across the country. The aim is to rank the geothermal areas of Uganda in terms of their geothermal potential for more detailed surface analysis and development.

The RAF/8/047 project, "Introducing isotope hydrology for exploration and management of geothermal resources in the African Rift System" is currently on-going. This is part of IAEA contribution towards the ARGeo regional project. In this project, isotope techniques will be used to address some of the knowledge gaps in selected ARGeo sites and will add knowledge on the source of recharge, dating and sub-surface temperature determination of potential geothermal prospects. This will result in better characterisation of potential geothermal fields of Uganda.

5. CONCLUSIONS

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

Anomalous areas have been delineated by geology and geophysical studies in Katwe and Kibiro prospects.
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 and ultramafic xenolith in Katwe, and granitic gneisses in Buranga and Kibiro.

Three areas, Katwe, Buranga and Kibiro, have reached advanced stages of surface exploration and so have their geothermal models.

6. RECOMMENDATIONS

Katwe: Before the feasibility study is undertaken, the following need to be done: 1) Carry out additional geophysical surveys using the magnetotellurics (MT) method to probe in the deeper layers of the crust and identify 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.

Kibiro: Before the feasibility study, the following need to be done: 1) Carry out additional geophysical surveys using MT method to delineate the geothermal anomalous area from the current large anomalous area, 2) Structural geological and hydrological mapping focused on locating drill sites, and 3) Updating of the geothermal model and location of drill sites.

Buranga: This prospect has not reached advanced stages in surface exploration like Katwe and Kibiro. The following activities need to be done before the area is recommended for the feasibility study: 1) Carry out detailed geophysical surveys using MT, Transient Electomagnetics (TEM), gravity methods, and seismic studies to delineate geothermal anomalous areas and 2) Updating of the geothermal model and location of drill sites.

Butiaba - Wanseko area: The relatively high geothermal gradient observed in oil wells around this area should be investigated to determine its relationship with either Kibiro or Panymur geothermal systems.

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

The rest of the geothermal areas should be investigated in detail for the possibility of installing binary geothermal power plants. The most promising areas from the current results include Rubaare in Ntungamo district, Panyimur in Nebbi district, Kitagata in Bushenyi district, Ihimbo in Rukungiri district, and Kanangorok in Kabong district.

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