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TECHNICAL REVIEW OF GEOTHERMAL POTENTIAL OF KIBIRO GEOTHERMAL PROSPECT, UGANDA

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1. INTRODUCTION

This paper presents the executive summary of the recently-completed geothermal resource assessment report for the Kibiro hot springs geothermal prospect in western Uganda (Alexander et al., 2016). This report was prepared for the United Nations Environment Programme (UNEP). As part of their initiative to promote geothermal resource development and utilization in East Africa, UNEP has implemented the GEF-funded African Rift Geothermal Development Facility Project (ARGeo). One of ARGeo’s primary components is to provide technical and financial assistance for surface exploration studies for the ARGeo member countries (Burundi, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, and Uganda).

In 2014, the Uganda Ministry of Energy and Mineral Development, Department of Geological Survey and Mines (DGSM) submitted a request for technical assistance to UNEP for surface exploration studies at the Kibiro geothermal prospect (DGSM, 2014). In its proposal, DGSM requested provision of scientific equipment and high-level experts in areas of geology, geochemistry, and geophysics. UNEP chose this proposal as one of the projects for technical assistance for surface exploration studies.

The Geothermal Development Company of Kenya (GDC) was nominated to provide technical advice and equipment for the surface exploration studies at Kibiro. Three technical consultants were selected by UNEP to provide advisory services and hands on training: Kenneth B. (Keg) Alexander, geologist; William Cumming, geophysicist; and Luigi Marini, geochemist. This report was prepared by the UNEP technical consultants.

Preexisting and new geological, geochemical, and geophysical data have been compiled and evaluated to form separate, integrated resource conceptual models of Kibiro. The conceptual models illustrate the various components of a geothermal system: heat source, reservoir, cap rock, temperature distribution, and fluid pathways. Alternative conceptual models representative of the uncertainty in the data and interpretation are used for exploration well targeting and resource capacity assessment.

2. KIBIRO

The Kibiro geothermal prospect is located in the Hoima District, western Uganda, about 210 km NW of Kampala (Figure 1). The prospect area is at an elevation from about 620 to 1000 m asl on the SE shore of Lake Albert within the western branch of the East African Rift System (EARS). The only thermal manifestation of the prospect is represented by the Kibiro hot springs, which are situated on a fan delta of about 1.3 km x 0.6 km, limited by the lake shore and the foot of the ~300-400 m high escarpment forming the southeastern side of the rift.

Figure 1. Simplified geologic map of the Albertine Rift showing rift sediments and basement. The nearest volcanic deposits to Kibiro are located >150 km to the SW near the Rwenzori Mountains (Ring, 2008)

There are three hot spring areas at Kibiro (Figure 2). The main area, Mukabiga (Figure 3), is located at the base of the main fault escarpment, where the temperature range is 57-86 °C and the flow is 4 L/s. A second group of hot springs are found downstream, in an area of salt gardens called Mwibanda, where the temperature range is 33-72 °C and the flow rate is 2.5 L/s. Other springs are within the nearby Muntere salt gardens, where the highest recorded temperature is 45 °C. Taking a total natural discharge of 6.5 kg/s and an average temperature of 68 °C, the total heat transfer is on the order of 1.9 MW thermal (MWt). Based on rules of thumb for estimating MW electrical (MWe) from MWt, and allowing for reduced efficiency at lower temperature, this would suggest a minimum potential power capacity of about 0.1 MWe. All of the hot springs have relatively similar chemistry due to limited mixing with brackish shallow groundwater. Their chemical composition is Na-Cl, with average TDS of 4500 mg/kg. Gas chemistry is dominated by methane (CH_4).

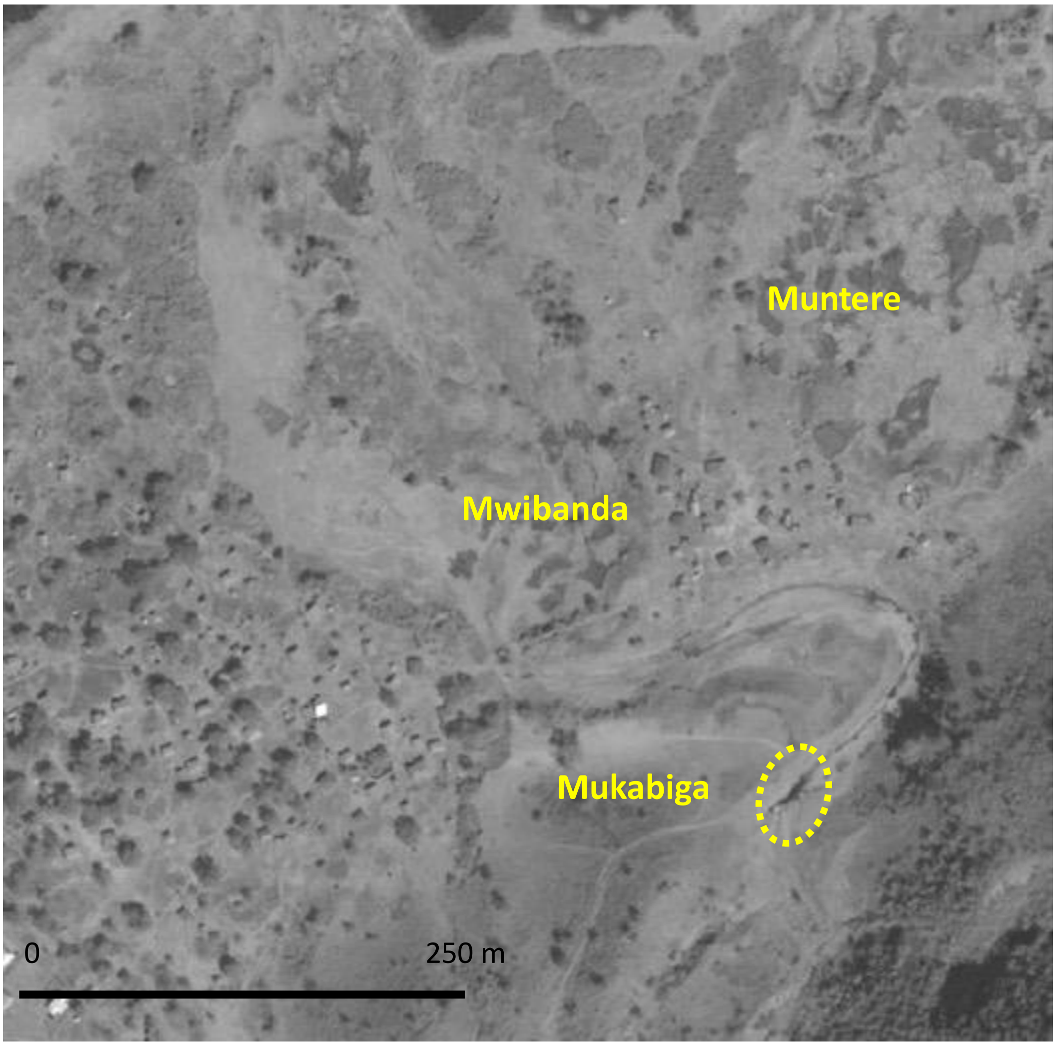

Figure 2. DigitalGlobe grayscale imagery showing the three primary discharge areas of Kibiro hot springs. Mukabiga springs (circled in yellow) are the main Kibiro springs. The field verified location of Mukabiga springs is WGS84 UTM Zone 36N 305966.05 mE, 185094.81 mN. Mwibanda and Muntere are salt gardens.

The elevation of Kibiro hot springs is about 20 m higher than the level of Lake Albert (about 620 m asl) indicating that they are not hydrologically connected. However, lake water elevation has decreased about 100 m over the past ~2000 years, affecting the regional water level as well as the location and flow of thermal water discharges at the surface. Based on available data, the discharge of Kibiro springs has declined over time from 13 L/s in 1967, to 6.7 L/s in 1969, and 4.0 L/s in 2015.

Figure 3. Main hot springs at Kibiro (Mukabiga) looking toward the SW. The springs discharge from a fault breccia outcrop on the western side of the ravine (Natakunda, 2015).

Existing and new geological, geochemical, and geophysical data have been compiled and analyzed to develop an integrated resource conceptual model of Kibiro. The conceptual model illustrates the various components of a geothermal system: heat source, reservoir, cap rock, temperature distribution, and fluid pathways. A range of conceptual models representative of the uncertainty in the data and interpretation are used for exploration well targeting.

In the preferred conceptual model, the Kibiro geothermal system is a fault-hosted type involving deep circulation of meteoric waters along tectonic structures.

The ascending branch of the Kibiro thermal circuit is controlled by the intersection of (i) the NE-SW trending North Toro Bunyoro (NTB) normal fault, the dominant structural and topographic feature in the area with a dip of 60-65° NW towards the rift, and (ii) the N20°E-trending Kachuru Fault and its minor fault splays (Figure 3). The intersection of these faults is expected to determine conditions of high vertical permeability favoring the upflow of the thermal waters towards the surface.

The descending branch of the Kibiro thermal circuit likely occurs mainly in fractured zones of the igneous-metamorphic basement rocks to the SE. Since Kibiro is located in a non-volcanic zone of the western branch of the EARS, there is no specific heat source. Heat is gained by meteoric waters through rock-to-water conductive heat transfer at considerable depth, that is at the base of the thermal water circuit. The maximum depth to which the meteoric water descends is constrained by the reservoir temperature and the local geothermal gradient.

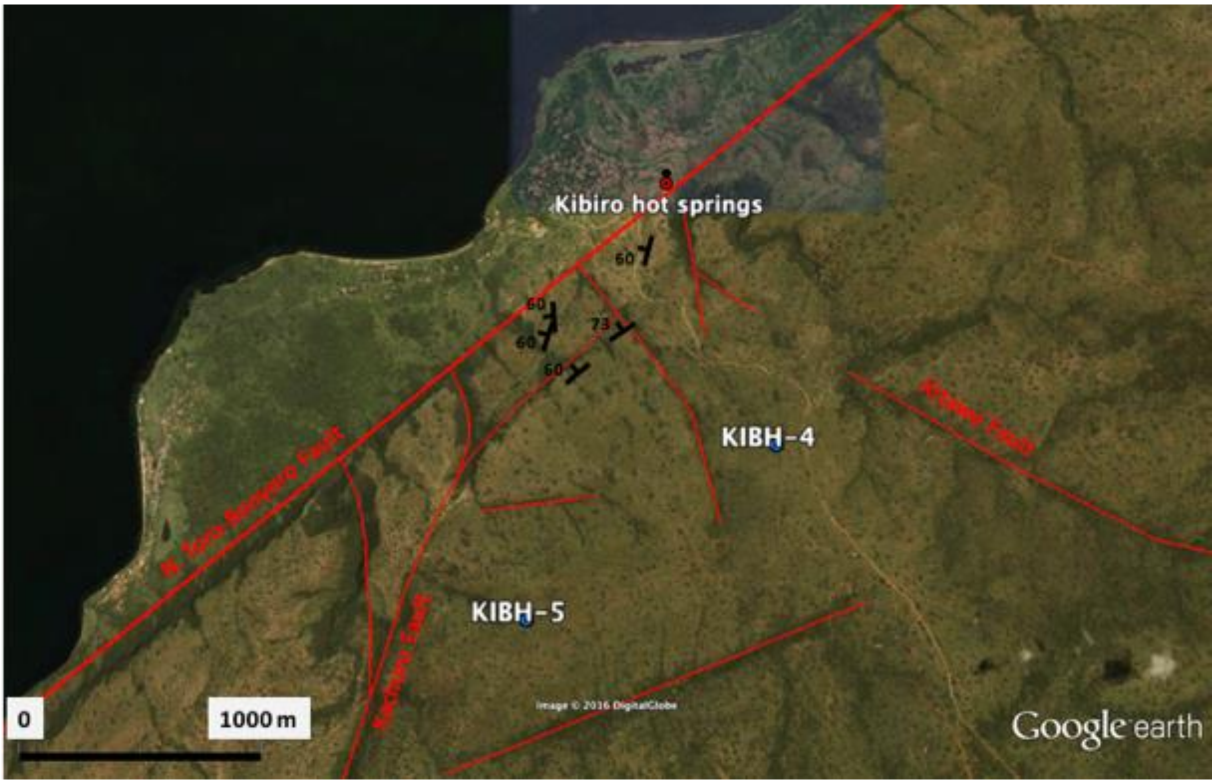

Figure 3. Google Earth image showing results of structural observations made in the field by DGSM. Field verified fault locations in red. Strike and dip measurements in black.

The key components of a geothermal system relative to the geological conceptual model are summarized below and illustrated in Figure 4.

Heat Source

The Lake Albert rift basin is located in a region of passive rifting, where the deep seated mantle plume drives crustal extension, and is associated with the occurrence of hydrothermal features, such as Kibiro hot springs, which are due to heating of meteoric water by circulation in the upper crust.

Kibiro is located in a non-volcanic zone of the western branch of the EARS. The high temperature Kibiro hot springs are associated with faulting on the southeastern border and shoulder of the Lake Albert rift. The heat source is rock-to-water conductive heat transfer at considerable depths in the amagmatic Lake Albert rift basin.

Reservoir Rocks

Available geological data suggest that the deep geothermal reservoir is probably hosted in the sedimentary rocks above the pre-rift basement beneath Lake Albert. A review of the stratigraphy near shore (based on well Waki-B1) shows that the base of the Kisegi unit is a thick (~15 m) conglomerate unit. Possible reservoir rocks are present in the Lower Kisegi at a depth of approximately 800 to 1000 m. The sandstone bed thickness encountered in the Waki-B1 well reaches a maximum of 30 m about 885 m beneath the surface.

Cap Rocks

The deep cap rock is probably constituted by low permeability shale beds in the Lower Kisegi beneath Lake Albert. Above a depth of about 800 m, sandstone beds become less prevalent in favor of moderately thick sequences composed of many stacked shale beds. A shallow, flat-lying clay zone with a base shallower than 300 m appears to extend from the lakeshore to the Kibiro hot springs, potentially capping a shallow thermal outflow aquifer.

Fluid Flow

Based on strictly the geological data review, fluid flow in the reservoir rocks and cap rock described above is one of the possible models. Alternatively, the ascending branch of the thermal circuit could be the zone of intersection between the NTB Fault and the Kachuru fault, whereas the descending branch of the thermal circuit, that is the descending pathways for the meteoric waters recharging the Kibiro geothermal system, could be fractures and faults dissecting the basement to the SE of Kibiro.

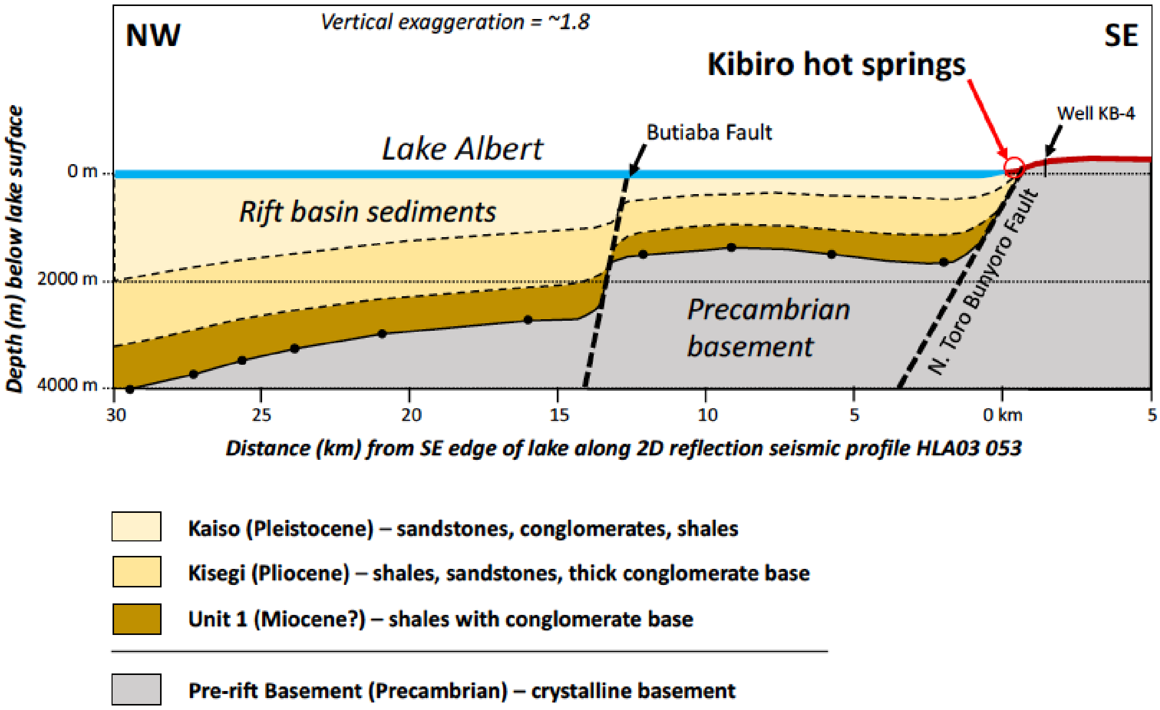

Figure 4: Geological cross section NW-SE through Kibiro. Black dots are measured depths to basement from the 2D reflection seismic survey along Profile Line HLA03 053 (Uganda PEPD, 2004). Stratigraphic interpretation based on seismic reflection data presented in Karp et al. (2012). The Eastern Platform is between the Butiaba and NTB Faults.

The geochemistry analyses conducted in conjunction with the geologic structure, stratigraphy, and reflection seismic information conclude that the Kibiro hot springs are most likely associated with a 115 to 150 °C fault-hosted upflow with no direct magmatic heating.

The geophysical surveys very effectively constrain the geological setting of the Kibiro prospect, with reflection seismic, gravity, and magnetic data all providing detailed constraints on the geometry of the large-scale structures affecting the Kibiro area. However, the seismic coverage stops offshore and none of the remaining surveys have sufficient resolution to resolve the upflow zone that supplies the hot springs, likely to occur at the intersection of the NTB Fault with the obliquely-striking Kachuru Fault.

The transient electromagnetic (TEM) resistivity data have been the most important geophysical data set for targeting temperature gradient holes (TGHs) at Kibiro. A shallow secondary reservoir (or a thermal outflow aquifer) is probably present at depths <300 m below the Kibiro fan delta, from the lakeshore to the Kibiro hot springs, as consistently indicated by the TEM data (Figure 5). The sedimentary clay aquicludes capping these relatively resistive aquifers are particularly low in resistivity in comparison to the sediments of adjacent deltas, most likely indicative of hydrothermal alteration. The most likely high-permeability zone would be gravels and conglomerates washed down the fault scarp during floods when the lake water is low (making clay and silt content lower).

The NTB Fault itself might be permeable if a well intersects it close to an intersection with another fault or a prominent irregularity in the surface of the Precambrian. However, the resistive zone below 150 m depth is a much easier target and the proposed TGHs will demonstrate whether it corresponds to a 115 to 150 °C resource.

The integrated conceptual model is presented in Figure 6.

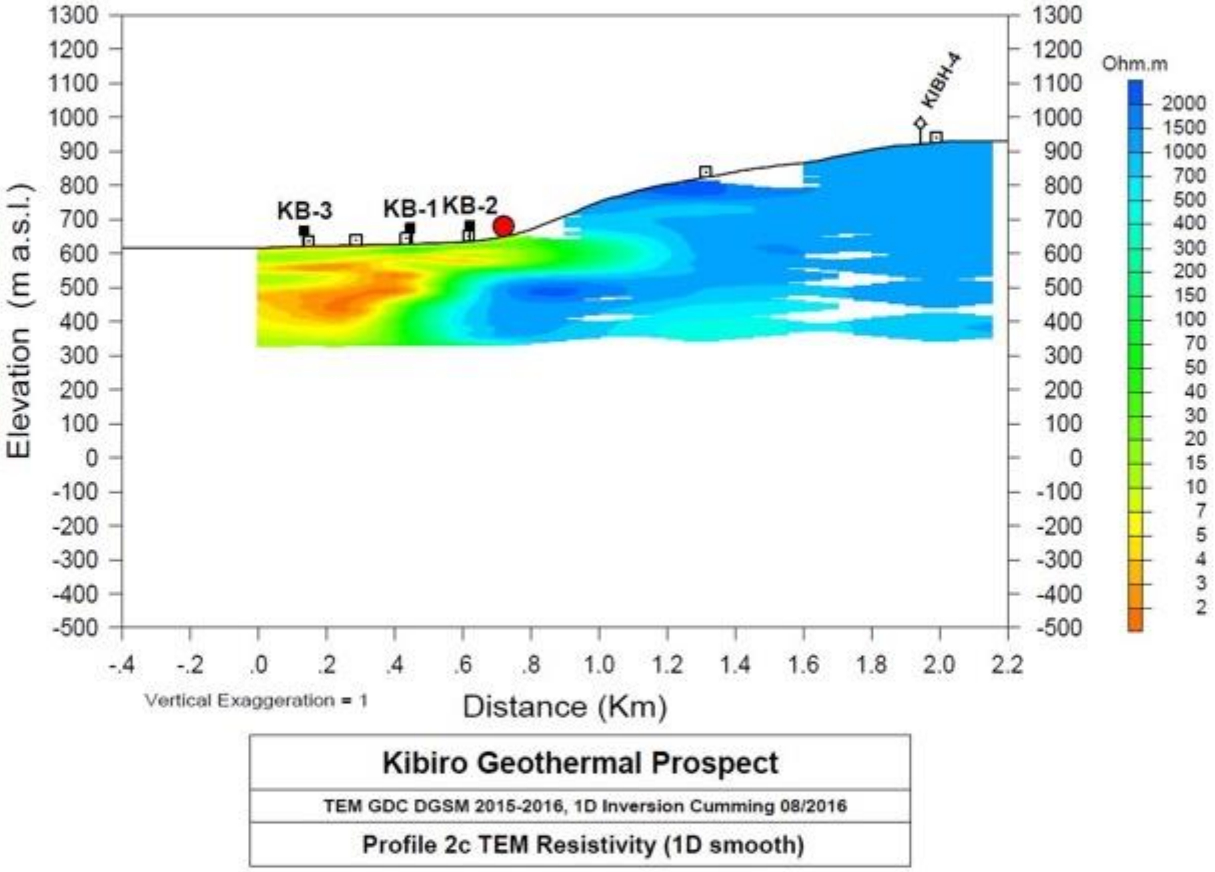

Figure 5: Profile 2 TEM resistivity cross-section. This section crosses the proposed TGHs KB-1, KB-2, and KB-3, and the existing KIBH-4 well. The low resistivity (red-yellow) clay zone is interpreted as capping a more resistive and therefore possibly permeable hot aquifer. The geometry of the transition to the very resistive metamorphic rocks southeast of the hot spring is not well constrained by these stations.

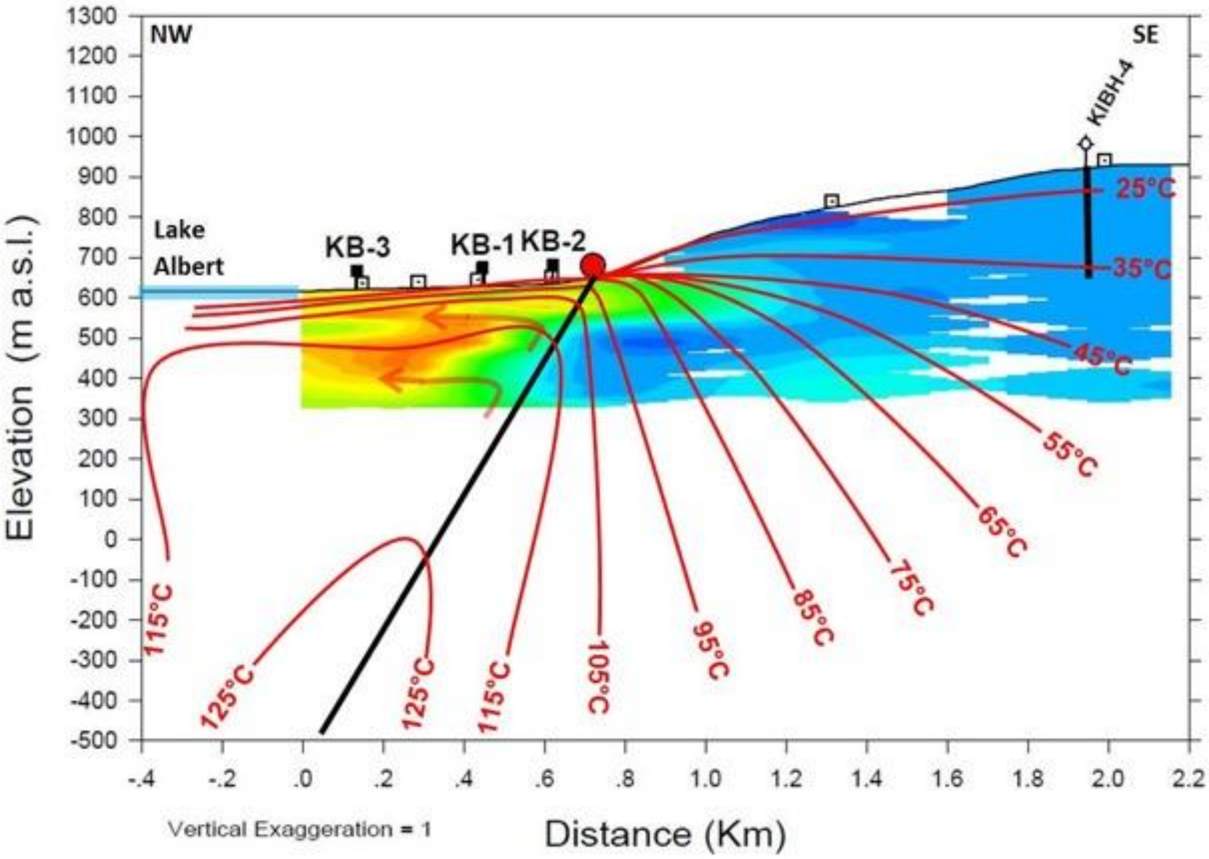

Figure 6: Conceptual model cross-section along Profile 2 with isotherms illustrating the relationship of the proposed upflow along the NTB Fault to the Mutabiga Hot Spring and the interpreted outflow at 105 °C below 50 m depth and outflow at 115 °C below 150 m depth interpreted from the TEM resistivity, with low resistivity (red) indicating a low permeability sedimentary clay cap. The water table is shown as slightly elevated above Lake Albert because the hot spring pressure is artesian relative to the lake level. The well KIBH-4 is included to illustrate how the area near it is conductively heated by the Kibiro upflow. The 10 °C contour interval is not extended below 85 °C to the northwest of Mutabiga Hot Spring because of contour crowding. For similar reasons, thermal convection in the hydrologically isolated fracture zone intersected by KIBH-4 is not represented because it would require a contour interval of 1 °C. Such local fracture zones in the Precambrian will be heated conductively and, if permeability is sufficiently high over a large enough vertical distance, convection will alter the isotherm pattern contoured at 1 °C, but at a range of temperature at or below what would be expected from conductive heating by the Kibiro upflow.

Based primarily on the TEM resistivity but also considering access, houses, and the demonstration of the size of any shallow sedimentary reservoir, six sites have been proposed to drill four TGHs, with TGHs after the first one decided based on earlier drilling. The relatively resistive rocks at about 150 m depth below the base of a flat-lying sedimentary clay zone will be the primary target for TGHs farther than 300 m from the surface trace of the NTB Fault, whereas TGHs closer than 200 m from the fault trace will primarily target the NTB Fault itself.

The temperature measurements and cuttings logs from the TGHs will be the primary data used to update the geophysical interpretations following drilling. However, if a water sample without drilling fluid contamination could be obtained, perhaps in a TGH/slim hole well that could be stimulated to flow at a small rate, then earlier expectations for a higher temperature reservoir could be more reliably assessed based on the geochemistry of a deeper aquifer.

Proposed TGH locations must be field verified for accessibility, logistics (equipment and water storage), available space, and geotechnical stability prior to mobilizing any drilling rig.

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