APPLICATION OF MAGNETOTELLURICS AND TRANSIENT ELECTROMAGNETIC IN KIBIRO GEOTHERMAL PROSPECT-WESTERN UGANDA.

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ABSTRACT

Geophysics is an extremely important tool in geothermal exploration. Magnetotellurics (MT) and Transient electromagnetic (TEM) techniques were some of the used geophysical exploration surveys in Kibiro Geothermal prospect in Western Uganda. Between 2004 and 2016, a total of 157 TEM and 64 MT stations were acquired using DGSM Geonics Protem 57, Phoenix, and Zonge GDP32-12 systems. A central loop system receiver for TEM survey was used and frequency range for MT survey was between 0.5 and >200 Hz. The MT and TEM surveys imaged low resistivity clay-rich lake beds that cap a higher resistivity and potentially permeable clastic reservoir below 150 m depth. The unusually very low resistivity zone on top of the clay rich sediments inferred a hydrothermally altered sedimentary clay zone; and therefore a hot permeable aquifer exists below 150km depth. MT data imply that the North Tooro-Bunyoro (NTB) Fault dips steeply beneath sediments to the northwest.

Keywords: Geophysics, exploration, hydrothermally, resistivity, Clay, frequency, survey

INTRODUCTION

With an increase in population and industrialisation, Uganda is set to meet high demands for electricity and therefore, a need to diversify to geothermal energy to boost its hydropower energy supply. Kibiro is one of the potential geothermal prospects for electricity generation, located in Hoima District, western Uganda, about 210 km NW of Kampala (*figure 1*). The prospected area is located in the Lake Albert basin (5km thick sediments) 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.

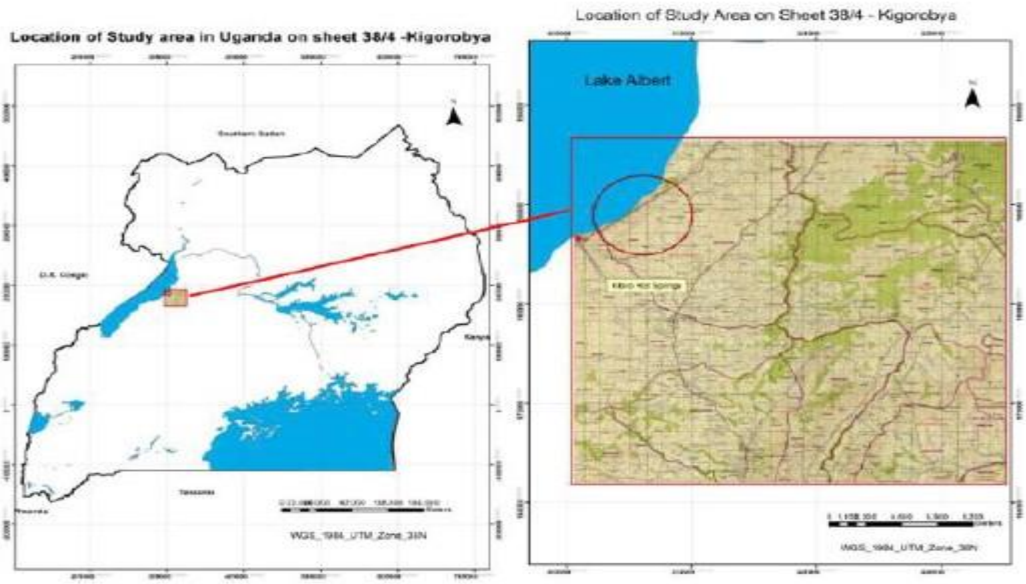

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Figure 1: Location of Kibiro in Uganda and on topographic map sheet 38/4 (Mawejje et al., 2013)

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Minimum Potential power capacity is about 0.1 MWe. Kibiro geothermal system is a fault-hosted type involving deep circulation of meteoric waters along tectonic structures. Since Kibiro is located in a non-volcanic zone, there is no specific heat source. Heat is gained by meteoric waters through rock-to-water conductive heat transfer at considerable depth. Reservoir rock is within the Precambrian metamorphic basement with estimated temperature of 200 ^{o}C or higher.

The objective of this paper is to assess the relevance of MT and TEM surveys in delineating the geothermal reservoir and the cap-rock, provide more information about the subsurface structures of the prospect.

RESEARCH METHOD

Transient electromagnetic (TEM) method

This method follows Faraday's law of electromagnetic Induction (1).

$$E = -N \frac{d\Phi}{dt} \quad \text{.............. (1)}$$

where E is the induved voltage, $d\Phi$ is the magnetic flux change, dt is change in time and N is the number of loops. The negative sign (-) represents Lenz's law

Eddy currents are induced in the subsurface due to primary magnetic field generated by the strong current flow in the surface rectangular loop. According to Kaufman and Keller (1983), the intensity of these eddy currents at a certain time and depth depends on ground resistivity (conductivity, size, and shape of subsurface conductor).

A typical Central Loop System that was used in Kibiro is shown in *figure 2*.

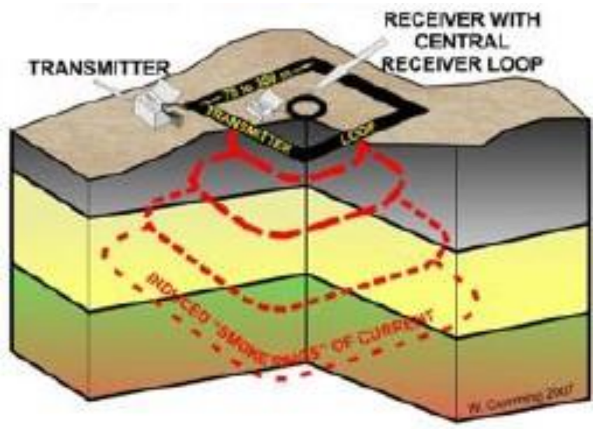

Figure 2: TEM measurement layout (Kenneth et al, 2016)

Magnetotelluric(MT) method

MT method is a technique for Passive surface measurement of the Earth's natural electric (E) and magnetic (H) fields and it assumes planar horizontal magnetic source field. This is a diffusive process whose physics depends on Maxwell's equations of electromagnetic induction MT Measure time changes of E and H, at arrays of sites with a frequency range 10 KHz to .0001 Hz (0.0001 s to 10000 s).

Impedance tensor (Z)

Two orthogonal components of electric field (E) and two orthogonal components of magnetic field (B) (usually north, x and east, y) are measured, apparent resistivity is determined from their ratios and it is described as impedance tensor. Equation (2) defines the magnetotelluric impedance tensor is defined as:

$$\begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} B_x \\ B_y \end{pmatrix} = \begin{pmatrix} E_x \\ E_y \end{pmatrix} \quad \text{.................. (2)}$$

MT Equipment

MT equipment is made up of the electrodes(Ex, Ey), coils (Hx, Hy, Hz), Recording unit and battery. *Fig 3* shows how they are laid out in the field during survey.

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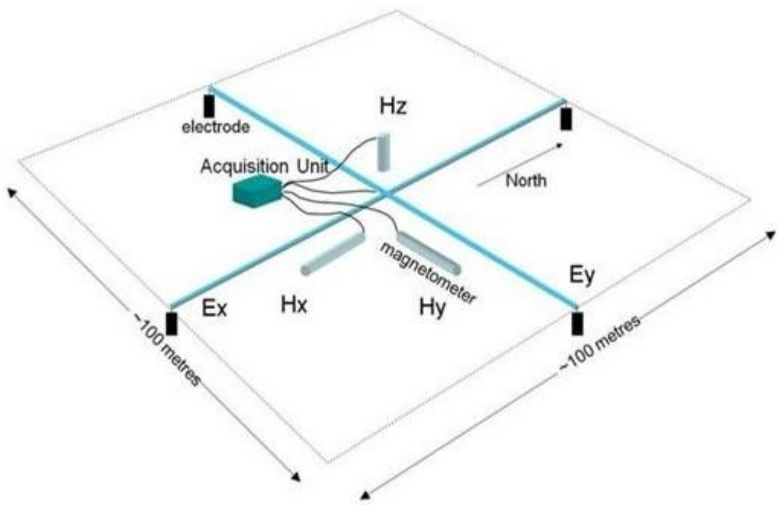

Figure 3: Schematic diagram out of MT equipment field lay out (https://openei.org/wiki/Magnetotellurics)

Data acquisition.

For TEM resistivity survey, DGSM Geonics Protem 57 system was used and included 75 soundings spaced about 1 km apart in 6 profiles mainly on the Precambrian rocks SE of the NTB Fault. More 25 TEM stations were acquired in 2016 on the sediments using Zonge GDP32-12 system with a ZT30 battery powered transmitter and TEM transmitter loop sizes of 200-m diameter.

64 MT stations were acquired using Phoenix systems in Kibiro, frequency range 0.5 to > 100Hz and it targeted the sedimentary margins of lake albert.

The TEM Resistivity and MT data I am analyzing in this paper were collected by Department of Geological Survey and Mines, Uganda, and its partners between 2004 and 2016.

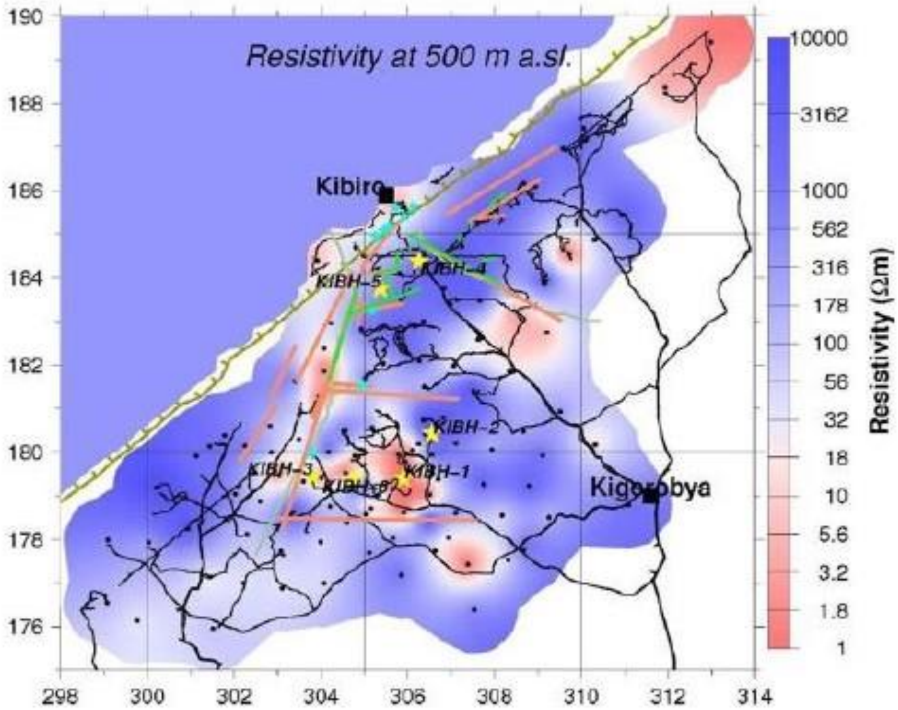

Figure 4: Image of Resistivity at 500 m above sea level with, inferred faults and fractures (pink lines), gullies (light green lines) and calcite and sulphur deposits indicating hydrothermal activity (light blue stars). (From Árnason & Gíslason, 2009)

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RESULTS AND DISCUSSIONS

TEM Survey 2004-2005

As a result of the survey, imaged zones of <10 ohm-m resistivity within the, or else, very resistive >1000 ohm-m Precambrian rocks were produced (*Figure 4*). The low resistivity zones were often apparently less than 500 m wide with a significant vertical extent of 800 m or more, as illustrated in the cross-section shown in *Figure 5*, however there was no conclusion on the implication of such low embedded resistivity zones.

Conversely, the stations positioned on a more resistive rock were disrupted by induced polarization (IP) effects that are usually encountered in using central loop TEM soundings on very resistive rocks with embedded conductive material like pyrite (Christensen et al., 2006). Additionally, given the rapid lateral variation in resistivity, a dipping plane model might have been more realistic than the 1D layered inversions applied.

2016 TEM survey

Figure 6 indicates that the clay in the Kibiro area is unusually low in resistivity, for example, as compared to the delta located 1.5 km to the SE. In the framework of sediment-hosted geothermal reservoirs worldwide, this pattern usually indicates the extent of sediments affected by hydrothermal alteration, with low resistivity associated with more alteration. Because there is more than one clay layer, the low resistivity is more likely to be associated with alteration from an outflow rather than from an up-flow, except closer to the NTB Fault. S1 TEM resistivity profile passed near proposed TGHs KB-2, KB-4, and KB-6. close to the NTB Fault and oriented along strike. Therefore, it is consistent with the flat dip of the low resistivity clay-rich sediments. S2 TEM resistivity profile passes near proposed TGHs KB-5, KB-1, and KB-4; about300 m northwest of the surface expression of the NTB Fault; and oriented along strike. the consistency implies that the low resistivity clay-rich sediments have little dip. S3 TEM resistivity profile passes near proposed TGHs KB-5, and KB-3. As a profile oriented sub-parallel to strike, the consistency in the layering implies that the clay-rich sediments have little dip.

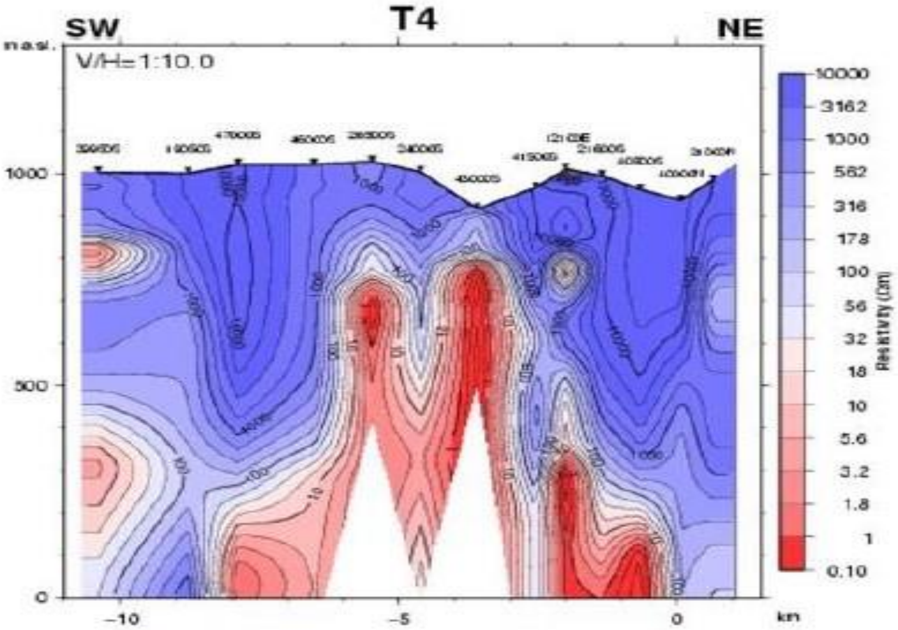

Figure 5: TEM resistivity cross-section showing vertically oriented low resistivity zones (Gíslason et al. (2005)

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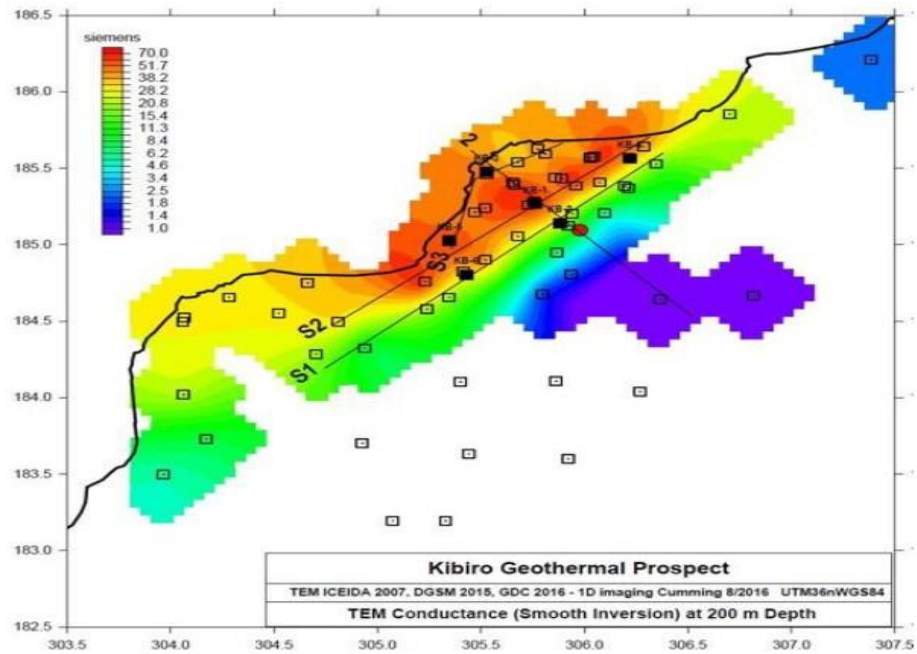

Figure 6: Map of TEM conductance (total low resistivity smectite clay) to 200 m depth, four profiles are shown by thin black lines S1, S2, S3 (Kenneth et al, 2016)

Fig 7 represents the actual clay distribution even though it is reduced by lateral interference for stations that are closer to the NTB Fault near the hot spring. The red-yellow zone (low resistivity clay) 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.

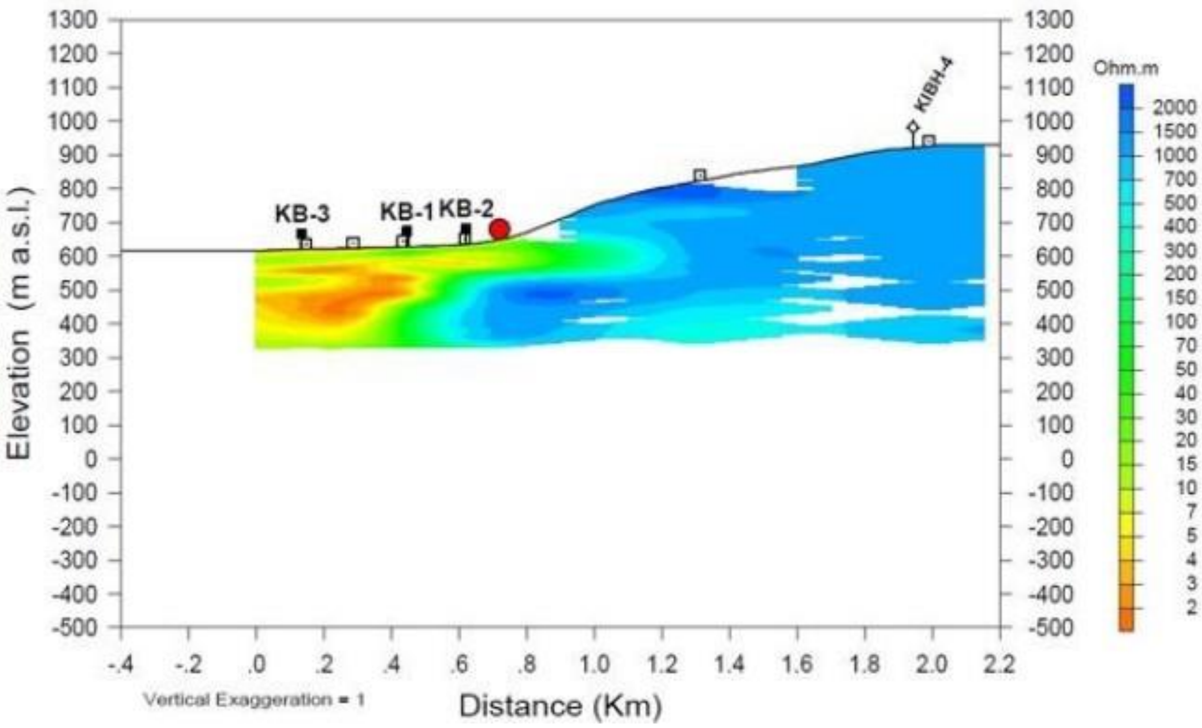

Figure 7: Profile 2 TEM resistivity cross-section. This section crosses the proposed TGHs KB-1, KB-2, and KB-3, and the existing KIBH-4 well (Kenneth et al, 2016).

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MT interpretation

Eight MT cross-sections were generated for this analysis. A single map slice in *Figure 8* is used to illustrate overall map patterns – all MT maps at Kibiro look very similar, with the strike having fewer deviations at some depths. However, the interpretation is mainly done using resistivity cross-sections. However, because the lake prevents the extension of the survey over the dipping NTB Fault, coverage will be too incomplete to support reliable imaging of the most interesting targets

In addition, the map in *Figure 8* also shows the resistivity at 450 masl (about 180 m depth), highlighting the geometry of the NTB Fault and the great contrast in resistivity across the fault. In this case, the 2D strike of the NTB Fault is very uniform and so its resistivity contrast is resolved by profiles perpendicular to the fault. The alignment with the fault is dominant, although profiles more oblique to the fault produce a resistivity pattern with a relatively conductive zone extending to the southeast of the NTB Fault. The MT shows relatively high resistivity corresponding to a potential aquifer at 180 m depth for all TGH locations except KB-3 *(figure 8).*

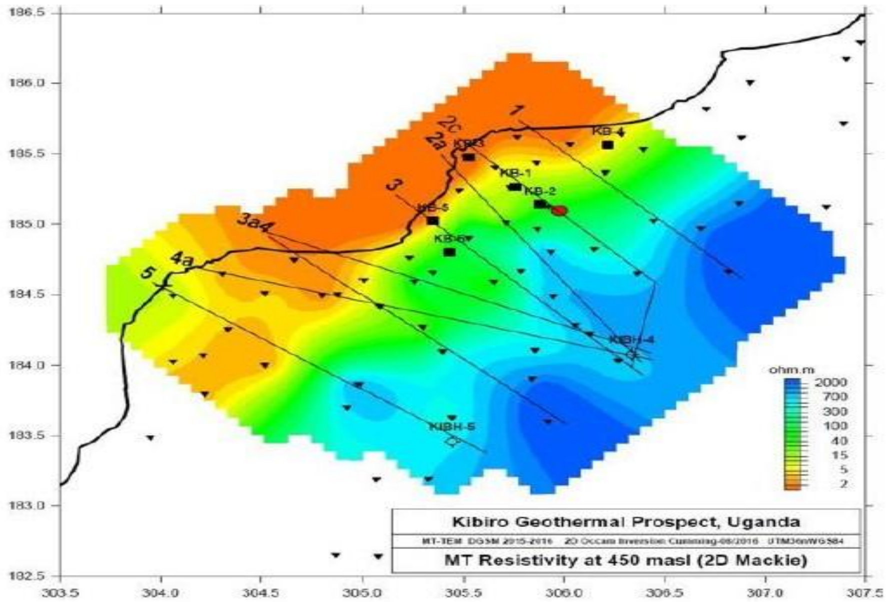

Figure 8: Map of MT resistivity at 450 m a.s.l (roughly 180 m depth) showing resistivity pattern just below the shallowest conductor. MT stations are black triangle, red dot is the main Kibiro hot springs, the locations of the proposed TGHs are black squares (Kenneth et al, 2016).

Figure 9 illustrates the relationship of the proposed TGH locations to the resistivity pattern; the red (low resistivity clay) zone below the proposed TGH locations is deduced as capping a more resistive formation and therefore perhaps permeable hot aquifer. All of the cross-sections illustrate the clay alteration deepening towards the lake but vary to the extent that they indicate a clay apron that might overlie a thermal aquifer. Because most of the Kibiro peninsula hosts such a clay alteration zone, the area of the peninsula was made P50 in the resource assessment. The little decreased 300 to 1000 ohm-m zone in the Precambrian crystalline rocks southeast of the NTB Fault is plausible, perhaps due to the penetration of cooled thermal water in isolated fractures.

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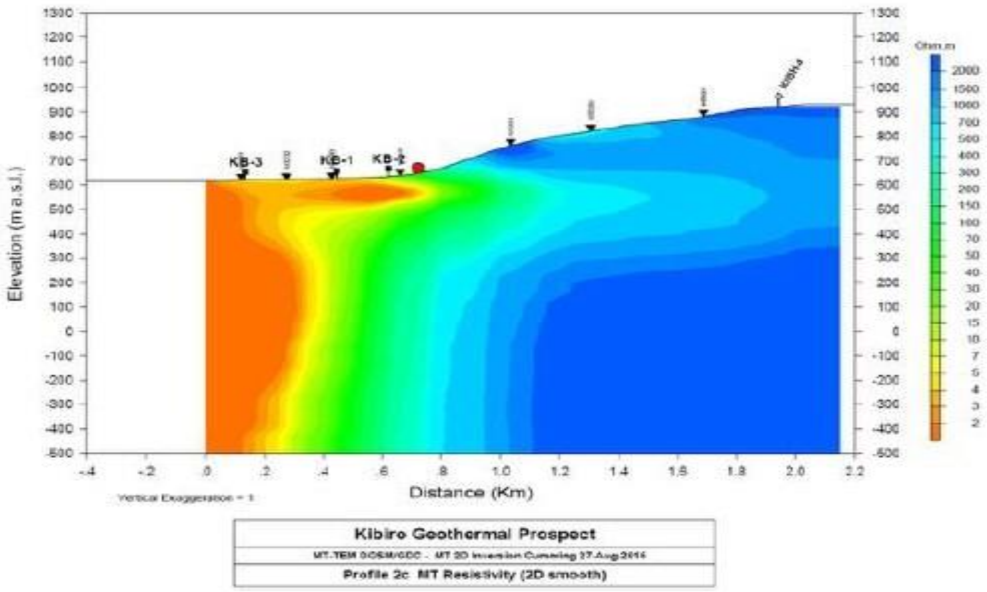

Figure 9: Image shows Profile of MT 2D resistivity cross-section crossing the proposed TGHs KB-1, KB-2, and KB-3, the Mukabiga hot springs, and the existing well KIBH-4(Kenneth et al, 2016).

CONCLUSIONS

There is consistency with MT and TEM although the TEM provides greater resolution of two shallow very low resistivity zones likely corresponding to hydrothermally altered sedimentary clays. Most likely, flat-lying clay-rich lake sediments cap a thermal aquifer at 150 m depth. The high resistivity zone at 150 m depth gives a clue of this aquifer existence, determined by the 4 TEM cross-sections, assuming it's the permeable hot aquifer, responsible for hydrothermal alteration of the over-lying clay-rich sediments, thus low resistivity.

The clay-rich formations and the likely aquifers on-lap the NTB Fault as provided for by TEM data. The formations appear to be relatively undisturbed by faulting, reducing the chance of encountering fracture permeability at shallow depth but increasing the chance that an up-flow associated with an intersection of the NTB Fault with a fault in the Precambrian metamorphics will not be sealed by fault gouge and so can outflow into an adjacent aquifer. Aside from the NTB Fault itself, a relatively resistive aquifer with a top near 150 m depth is a principal target of the proposed TGH drilling program.

Owing to the MT resistivity, a shallow aquifer probably lies beneath a clay zone over much of the Kibiro cape. Its thickness is not well constrained by the MT but its base is about 100 to 150 m deep. The MT implies that the NTB Fault dips steeply beneath sediments to the northwest. The MT resistivity is generally consistent with the structural model for the dipping fault extending below the lake but, because of the lake, resolution is unlikely to improve enough to identify a specific well target.

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